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Pros and Cons of 'Backing Winners' in Innovation Policy

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Abstract

In the economics profession there is a fierce debate whether industrial and innovation policy should be targeted to specific sectors or firms. This paper discusses the welfare effects of such targeted policies in a third-market international trade model under imperfect competition. A theoretical case for picking winners through a preferential innovation policy is discussed, which is shown to hold without evoking retaliation from foreign competitors. However, in practice information uncertainties remain a concern. The question whether in this case 'backing winners' is a wise policy option depends on the characteristics of the information asymmetries and on the extent the government is able to design selection procedures in a way to minimize the transaction costs that may be caused from the market participants' opportunistic behavior.

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1. INTRODUCTION

Both in theoretical economic analyses and in the policy arena, there is a debate about whether innovation and industrial policies favouring certain industries or firms are welfare enhancing or not. For example, the "innovation platform", a think tank organised by the Dutch government with the prime minister as chairman, has selected a number of economic sectors which are believed to have a key role in the knowledge economy of the Netherlands. These sectors will have some priority in obtaining support through government funding. This policy of selecting and consequently 'backing winners' was inspired by an advice by the Advisory Council on Science and Technology (AWT (2003)). Yet much criticism was raised against the selection procedure and the presumption that the government is able to predict which sectors or firms would be winners in innovation. For instance, Jacobs and Theeuwes (2005) asserted that it would be better to back 'challengers' instead of winners; however, without indicating how the government would be able to decide about these challengers. The Scientific Council for Government Policy, in a report on innovation policy, criticized the procedure of selecting key innovative sectors by arguing that backing winners may lead to protection of existing structures, institutions and interests (WRR (2008)). The procedure excludes innovative outsiders indeed, which do not yet have the strength and size to qualify as winner. Moreover it is unclear why winners need government support anyhow.

This paper discusses the options for a targeted industrial and innovation policy from the perspective of a strategic game among firms or sectors, where welfare effects of such targeted policy may stem from a cost reduction and industry-wide profit creation. Government support may take various forms and the usual debate around the benefits and the scepticisms of industrial/public/trade policies will all matter one way or another. For a small open economy, in that most of the modern industries are exposed to the international competition, most of the government intervention will naturally take the international trade policy feature. While the conventional wisdom of laisser-faire is valid, in large part, under the idealized world of perfect competition, it has been identified that a strategic incentive to intervene with international trade under imperfectly competitive market structures may exist (e.g. Brander and Spencer (1983, 1985)). Such shift in the theoretical stance was made from recognition of the interactive feature among the firms and governments, which is contrasted to the conventional economic reasoning based on the terms-of-trade advantage. The arguments received criticisms as well, which were mainly clustered upon the 'beggar-thy-neighbour' feature and the possibility of a mutually destructive trade war. A unilaterally optimal policy may lead to distortion of international competition and retaliating responses may follow, in which case the policy has a negative, instead of the warranted positive effect on national welfare.

While the conventional discussions have been made around the structure of uniform – all the beneficiary firms are treated equally - policy, a non-uniform policy may further strengthen the strategic trade intervention incentives: the industry-wise aggregate profits can be newly created without affecting the other trading partners and therefore without the usual retaliatory concern. This new feature is particularly strengthened when a public policy aims to encourage the R&D activities by the firms. Domestic firms can be unequally treated to create an asymmetric structure of the firms' effective marginal costs. The restructured cost conditions among the firms then sets a new game rule for the firms to rationalize their output decisions, which may serve to save upon market-wise production costs for the benefit of the policy-imposing country's profit improvement (Jo (2009a)). This profit creation can be sustained even for a technology without economy of scale, which is distinguished from the conventional profit creating argument in the literature which is valid only when economy of scale prevails in the production technology. Also, since this new profit creation aspect of strategic R&D subsidy remains valid without affecting the other trade-involved countries, it is robust to the usual trade war concern. Also, it can be shown that such strategic benefits of a non-uniform R&D policy can enhance domestic profits even when the free trade is initially optimal. While the theoretical aspects of the new argument can be well-grounded, however, the practical choice of the policy details still remains questionable. For example, firms may take extra actions to be given a favour by the policy authority. It may create unhealthy transaction costs from the social welfare perspective without a visible countervailing benefit, whereas firms may take it as an incentive to economize upon their pre-policy cost conditions so that they can be picked as a winner group. In this respect, it will be critical to sort out the important factors for the success of an industrial policy while, at the same time, staying alert for the possibilities that the undesired negative effects may be caused.

This paper aims to provide a theoretical and qualitative assessment of the pro and con sides of industrial policy so that it can give a hint under which circumstances and ways of organizing a targeted innovation policy of the government can be welfare enhancing. In the perspective of the policy discussions on whether and, if so, how to back winners – or challengers - the paper focuses on the dynamic game perspectives of an industrial policy which naturally exploits the own rationalizing behaviour of the private sector. Together with the potential rationale of backing winners, the paper also presents the issues for which a policy authority has to be alert for a successful implementation of such a targeted policy. In this respect, our analysis sheds a meaningful light on the on-going efforts by the government to bring about efficiency gains and a welfare improvement.

The remainder of the paper is organized as follows: section 2 illustrates the above-mentioned 'aggregate-profit creation' effect of a non-uniform R&D policy and the theoretical justification of an unequal treatment of the domestic firms. This strategic effect is shown to be greater as the domestic firms are treated more discriminatorily. Section 3 then discusses the practical implications. The robustness and benefits of the idea of backing winners is highlighted and the issue of how to rationalize upon the cost-saving effects of an innovation policy is also discussed. Other benefits and concerns related with the incomplete information and the proper policy design are also addressed. Section 4 touches upon the distinction between the corrective and strategic objectives of a policy. It also indicates how a redistribution scheme may matter from a political economic concern. Section 5 contains concluding remarks.

2. THE MODEL FOR THE BASIC RATIONALE

This section presents a two-county two-sector third-market international trade model to illustrate that a country has a strategic incentive to introduce non-uniform R&D policies to create industry-wise profits without affecting the trade-related countries. This potential rationale will be used as the benchmark model to sort out the factors that may matter for a successful implementation of an innovation policy. The conventional case with the initially uniform R&D policy is reviewed first so as to emphasize its beggar-thy-neighbour feature, and then the aggregate-profit creation effect of a non-uniform industrial policy is discussed. The analysis leads to the main policy guideline, that 'backing' the right targets – both present and potential – should be the more important rationale than simply picking the winners when an industrial innovation policy is considered.

The simplifying assumptions of the basic model are as follows. Each of the two countries, domestic and foreign, is endowed with a single factor of production, referred to as labor and denoted by L and L^*, respectively, using which the firms produce a numeraire good and a homogenous oligopoly good. Consumers in the two countries consume only the numeraire good, which is produced under competitive conditions with constant returns to scale. The oligopoly sector in each country has n and n^* Cournot firms and produces under constant marginal costs only to export to the third-market.[2] The trade is assumed to be balanced by implicitly assuming that the numeraire good is imported from the third-market in exchange for the export of the oligopoly good. The number of firms in the oligopoly sector is assumed to be fixed due to the existence of some form of entry and exit barriers. In this third-market framework, there would be no scope for an import-protective device. Rather, a government may

[2] Domestic consumption of the oligopoly good and various returns to scale can be easily incorporated without affecting the main results.

seek to intervene with trade by promoting exports in one form or another. While this strategic aspect of an export promoting trade policy may be best presented through export subsidies, R&D policies will be considered here since the aggregate profit-creation effect to be demonstrated in the main sections below does not occur under export subsidies[3], let alone the GATT Codes limiting the practice of the latter. Initially, only the domestic government imposes an R&D subsidy and it is assumed to be applied uniformly to all domestic firms. The case to be considered here is a two-stage game in which government decides upon a uniform R&D subsidy in the first stage, and the firms compete in quantities under the Cournot conjecture in the second stage possibly over more-than-one finite periods.[4] The time structure of the game here is different from a typical one-shot game or a conventional dynamic extension of it in that the cost-reducing benefit of an R&D policy is realized over time. The Cournot conjecture is only for demonstrational convenience and the main argument can be extended to a wide range of conjectural variations.

2.1. *Criticisms against the Conventional Uniform Policy*

Let x_i and y_j denote exports to the third oligopoly market by domestic firm i (=1,2,..,n) and foreign firm j (=1,2,..,n^*) which add up to the total industry output Q. c_i and c_j^* denote each domestic and foreign firm's marginal cost and π_i and π_j^* denote each firm's profit from their third-market sales. Assuming the intra-country symmetric costs for the initial state, we have $c_i=c$, $c_j^*=c^*$, $x_i=x$, $y_j=y$, $Q=nx+n^*y$, $\pi_i=\pi$ and $\pi_j^*=\pi^*$ for all i and j. Let s denote the uniform R&D subsidy to each domestic firm. Then, the after-subsidy marginal cost for a domestic firm can be defined as

$$k = c - \alpha(S - s) - \beta s = c - ((n-1)\alpha + \beta)s \tag{1}$$

where $S = ns$ is the total R&D expenditure by the domestic government. α (>0) represents the external cost-reducing effect spilled over from the R&D subsidy to all the other domestic firms and β (>0) represents the cost-reducing effect of the R&D subsidy to a firm on its own marginal cost. The spillover effect is assumed to work within the national border only, which can be easily extended to the case of an international spillover. Let $P(Q)$ be the inverse demand for the oligopoly good in the third market. Then the firms' profits are defined by

$$\pi(x, y; s) = P(Q)x - cx + ((n-1)\alpha + \beta)sx\,;\ \pi^*(x, y; s) = P(Q)y - c^* y \tag{2}$$

[3] For a non-uniform export subsidy, aggregate profit creation is cancelled out by the increased subsidy expenditure (Jo (2009b)).

[4] For a more general three-stage game in which firms decide upon private R&D investments as well as the Cournot exports, see section 3.1.1. (iii).

and, considering that the cost-reducing benefit of the R&D subsidy is realized over time, say T periods, the relevant domestic welfare would be the following T-period discounted value of domestic labor income (L) plus domestic firms' profits from the third-market ($n\pi$) net of one shot government subsidy expenditures (ns) with δ being the discount factor:

$$W(T)=\sum_{t=1}^{T}\delta^{t-1}(L+n\pi)-ns\,. \tag{3}$$

The subgame perfect Nash equilibrium of the game is defined by the optimal subsidy s satisfying the optimization condition

$$dW(T)/ds=n(\sum_{t=1}^{T}\delta^{t-1}\,d\pi/ds-1)=0 \tag{4}$$

and the T-repetition of one-shot Cournot-Nash equilibrium in the second stage as follows:

$$\pi_x=P+xP'-c+((n-1)\alpha+\beta)s=0\,;\quad \pi_y^*=P+yP'-c^*=0, \tag{5}$$

Assuming that the usual regularity conditions hold globally,[5] the global uniqueness of the Cournot equilibrium can be implied and a comparative statics reveals the followings: (i) $x_s > 0$, $y_s < 0$, (ii) $P_s < 0$, $Q_s > 0$ and (iii) $\pi_s > 0$, $\pi^*_s < 0$. We can further show that the positive optimal R&D subsidy which maximizes the national welfare W^T exists for large T and δ.[6] This unilateral incentive to offer a strategic R&D subsidy is consistent with the conventional findings: an R&D subsidy imposed in the first stage alters the firms' strategic interaction in the second stage of the game and thereby makes domestic firms' aggressive behavior credible in the market share rivalry, enhancing domestic national welfare even net of subsidy expenditure. This national incentive however is not confined to one country but reciprocal. It can be easily shown by considering the T^*-period foreign welfare

$$W^*(T^*)=\sum_{t=1}^{T^*}\left(\delta^*\right)^{t-1}(L^*+n^*\pi^*)-n^*s^*\,, \tag{6}$$

with $\pi^* = Px - c^*y + ((n-1)\alpha^* + \beta^*)s^*y$ and s^*, α^*, β^*, δ^*, T^* defined analogously. The foreign government's unilateral incentive for an R&D subsidy is implied as well, and we can readily construct further details to conclude that the mutual R&D subsidies by both governments turns

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[5] The regularity conditions are: (i) $P'' < 0$ or not too much if positive, (ii) second order conditions for the firms ($\pi_{xx}=xP''+2P'<0$, $\pi^*_{yy}=yP''+2P'<0$), (iii) x and y are strategic substitutes ($\pi_{xy}=xP''+P'<0$; $\pi^*_{yx}=yP''+P'<0$) and (iv) each firm is exporting a positive amount in equilibrium.

[6] As is well known through the other literature, the signs depend jointly on the relative sizes of n, n^* and the sign of P'', while the linear demand case is independent of these parameters. A large n, in particular, induces over-competition among the domestic firms and may lead to a negative s. For detailed proofs, see Jo (2009a) for the R&D policy case and Leahy and Montana (1998) for the export subsidy case: the working mechanisms of the policies are similar.

out to be jointly sub-optimal.[7] The skepticism of the prisoners' dilemma phenomenon is reinforced and the trade war remains concern.

2.2. *Superiority of Preferential Innovation Policy to Uniform Policy*

The conventional discussion as reviewed above assumed a uniform subsidy. When an R&D policy takes a *non-uniform* structure, however, a new strategic feature can be drawn by which national policy authorities may be further motivated to intervene: an asymmetric treatment of the domestic firms through a non-uniform system of R&D policy may successfully manipulate the firms' decisions and improve the national welfare, without affecting other countries, more than uniform policy accomplishes. In this section we illustrate this superiority of non-uniform policy to uniform structure.

Suppose that the firms in each country have the same technology and thus share the same marginal costs. Assuming that all firms export positive quantities to the third-market, the uniform R&D subsidies s (≥0) and s^* (≥0) with the first order conditions (5) will constitute an initial equilibrium. Summing the first order conditions (5) across all the firms in the oligopoly yields

$$(n+n^*)P(Q)+QP'(Q)-(nk+n^*k^*)=0\,. \tag{7}$$

When the demand $P(Q)$ is non-convex or not-too-convex as assumed in the basic model, the implicit function theorem guarantees a unique Q. It is obvious then that the industry output Q, the price P and therefore the industry-wide revenue PQ all depend only on the sum of the marginal costs $nk + n^*k^*$ but not on their distribution across the firms.[8] This independence implies that a rearrangement of the initially uniform subsidies into a non-uniform way preserving the total subsidy expenditure does not affect the industry output and price, while the composition of the equilibrium output of each firm changes. To prove, suppose that the domestic government redesigns the initially uniform R&D subsidy $\{s\!: ns = S\}$ to $\{s_i\!: \sum_{i=1}^{n} s_i = ns = S\}$ in a discriminatory way while the total R&D subsidy expenditure S is preserved and the new equilibrium still remains interior, where s_i denotes the R&D subsidy to domestic firm i (if positive). For simplicity, the foreign subsidy is assumed to remain uniform. Then the domestic firm i's marginal cost after the redesign becomes $k_i \equiv (c-\alpha(S-s_i)-\beta s_i)$ whereas

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[7] Given the joint global welfare $\overline{W}(\tau) \equiv W(\tau)+W^*(\tau)$ defined at the equilibrium (s, s^*) over τ periods, the implicit function theorem implies $d\overline{W}(\tau)/ds<0$ and $d\overline{W}(\tau)/ds^*<0$. Reducing the equilibrium subsidies improves the joint welfare.

[8] The observation that industry output and price in a Cournot industry are independent of the distribution of marginal costs has been noted and used several times in the literature. For example, see Bergstrom and Varian (1985), Salant and Shaffer (1999) or Bandyopadhyay et al (2004).

foreign firms' marginal cost remains the same at k^*. The first order conditions after the domestic subsidy redesign change to

$$\pi^i_{x_i} = P(Q) + x_i P'(Q) - k_i = 0, \quad \pi^*_y = P(Q) + yP'(Q) - k^* = 0 . \tag{8}$$

Since $\{s_i\}$ is such that $\sum_{i=1}^n s_i = ns \equiv S$ and the equilibrium is interior, the sum of marginal costs $\sum_{i=1}^n k_i + \sum_{j=1}^{n*} k^* = nc - ((n-1)\alpha + \beta)S + n^* k^*$ does not change. Then we have the following observation:

Observation 1: *$\Delta P = \Delta Q = \Delta(PQ) = 0$, where Δ denotes the changes caused by the domestic subsidy redesign.*

Now we will see how domestic firms rationalize upon their choices when the structure of the subsidy is modified. Denoting the initial outputs of the domestic and foreign firms by x and y, the following first order conditions need to be satisfied:

$$P(Q) + (x + \Delta x_i)P'(Q) - (k + \Delta k_i) = 0, i = 1,2,...,n , \tag{9}$$

$$P(Q) + (y + \Delta y_j)P'(Q) - (k^* + \Delta k_j^*) = 0, j = 1,2,...,n^* . \tag{10}$$

Since Q remains the same and $\Delta k_j^* = 0$, (8) implies that the above conditions (9) and (10) are reduced to

$$\Delta x_i P'(Q) - \Delta k_i = 0$$

Since $P' < 0$, it follows that Δx_i and Δk_i take the opposite sign from each other and the following observation is implied.

Observation 2: *The output of a firm experiencing a subsidy decrease will contract and the output of a firm experiencing a subsidy increase will expand while there will be no change in the output of a firm – either domestic or foreign - whose subsidy unchanged.*

Now we are ready to discuss the main feature of the arguments. $\Delta P = \Delta Q = \Delta y_j = 0$ implies that the foreign and the third countries are not affected, allowing us to focus on the domestic welfare only. Since it also implies that the domestic firms' aggregate revenue will not change, the industry-wide aggregate profit of the domestic firms will increase if and only if the domestic firms' aggregate cost of production decreases. This aggregate profit gain to the domestic firms therefore will improve the national welfare. In the discussions below, we highlight this new feature of '*aggregate profit creation*' of strategic non-uniform R&D policies, which comes through an asymmetric treatment of the domestic firms and its aggregate cost saving effect. This cost saving effect will turn out to be greater as the subsidies are redesigned in a more discriminatory way.[9] From the first order conditions (8), the equilibrium output of the domestic firm *i* is given by $x_i = (k_i - P)/P'$ and the aggregate production cost for the domestic firms will be defined by

$$\sum_{i=1}^{n} k_i x_i = \sum_{i=1}^{n} k_i \frac{k_i - P}{P'} = \frac{1}{P'}\sum_{i=1}^{n} k_i^2 - \frac{P}{P'}\sum_{i=1}^{n} k_i \tag{11}$$

Using the standard variance identity for $\{k_i\}$, we can rewrite the above aggregate cost to

$$\sum_{i=1}^{n} k_i x_i = \frac{1}{P'}\left(n\sigma_k^2 - \frac{\left(\sum_{i=1}^{n} k_i\right)^2}{n^2} \right) - \frac{P}{P'}\sum_{i=1}^{n} k_i \ , \tag{12}$$

where σ_k^2 is the variance of $\{k_i\}$. Since $P' < 0$ and $\sum_{i=1}^{n} k_i$ remains unchanged, the aggregate cost $\sum_{i=1}^{n} k_i x_i$ decreases when the variance σ_k^2 increases. Noting $\sigma_k^2 = ((n-1)\alpha + \beta)^2 \sigma_s^2$ in which σ_s^2 denotes the variance of $\{s_i\}$, we can conclude that the aggregate production cost of the domestic firms becomes lower as the variance of the subsidies becomes greater. Domestic aggregate profit increases accordingly and thus domestic welfare improves, which effects are greater as the domestic firms are treated more discriminatorily. The following corollary summarizes the discussion.

Corollary 3: *Suppose that the uniformly optimal R&D subsidy s prevailed and domestic government redesigns it in a non-uniform way so that* $\sum_{i=1}^{n} s_i = ns = S$ *and the new Nash equilibrium remains interior. Then, the domestic national welfare improves – more with a greater degree of non-uniformity of the subsidies – while the foreign and the third importing countries remain unaffected.*

The above discussions imply that a country may be attracted to heavily subsidize a few firms while accommodating the loss to the firms receiving lower subsidies through an appropriate national redistribution scheme. It is noteworthy here that the incentive for an unequal treatment of the domestic firms remains valid even when free trade was initially optimal and no ex-ante R&D policy was presumed. A detailed discussion is skipped but the necessary action will have to combine both R&D subsidies and taxes so that no new public expenditure is to be financed. The R&D expenditure and revenue can be cancelled out while the rationalizing behavior among the firms can create aggregate profits. Or subsidizing a few (or all) firms through a newly financed fund may be considered as well if the expected welfare gain is big enough to cancel

[9] The intuition behind can be clearly highlighted when the initially-uniform subsidies are redesigned only across the two firms as illustrated in the Appendix.

out this subsidy expenditure. As an additional remark, the main argument can be extended in many directions including an explicit introduction of ex-ante private R&D investments as well as heterogeneous costs and non-Cournot competition modes, the details of which are discussed in the next section.

3. PRACTICAL IMPLICATIONS OF BACKING WINNERS

The analysis of section 2 shows that a non-uniform structure of R&D subsidies is superior to the usual uniform one. Whether the unilaterally optimal R&D policy was imposed or free trade prevailed as the initial state, it is asserted that a redesign of the initially-uniform R&D policy in a non-uniform way or a new imposition of non-uniform R&D policy leads the firms to rationalize their behavior in a way to create industry-wise profits. Since this welfare enhancement effect is strengthened as the degree of the non-uniformity of the firm-specific policy increases, this provides a country with an incentive to further strategically stimulate private sector decisions through an asymmetric system of the R&D policy.

The main question, however, is about the practical implementation. The theoretical model assumes that the initial marginal costs (c) and the cost-reducing parameters (α, β) are the same for all firms. In case c, α and β are equal for each firm or sector, or when the government is unable to discriminate between firms or sectors with respect to these parameters, the policy of picking winners according to the analysis of the previous section boils down to throwing a dice to select the winners, who will obtain higher subsidies, whereas the others will lose. Obviously such policy is not feasible. First it will be legally not viable to select recipients of subsidies by a purely random selection mechanism. In reality, however, the parameters c, α and β will indeed differ amongst firms and sectors. In that case it seems reasonable to select those firms or sectors which have the lowest value of c and the highest values of α and β so that subsidizing these firms or sectors is most efficient. Then, the next questions are: how does the government assess differences in c, α and β in selecting winners to be backed and how do the firms or sectors react when the government is uncertain about the true values of these parameters?

From that perspective of practical policy implementation, the remainder of this section focuses on how to realize the benefits of the non-uniform policy prescription and it looks at what loopholes and caveats the policy prescription contains. The pros and cons of the discriminatory industrial policy naturally reflect the flip side of each other and a successful implementation would require one to sort out and highlight the key factors of the pro side and to pay extra caution to minimizing the con side. In that respect the discussion in the Netherlands on what innovation policy to conduct, with the innovation platform favoring a policy of backing winners, can act as reference case.

3.1. *Robustness and Benefits of 'Backing Winners' Idea*

This subsection builds upon the theoretical insights sketched in section 2 to provide a thinking box for an innovation policy authority on how to select winners and on how this policy authority can economize upon the benefits of such a policy. The robustness[10] of the non-uniform industrial policy is illustrated first in order to highlight the superiority of a preferential innovation policy to uniform ones, when some of the assumptions of section 2 are relaxed. Then we extend our discussion to the issues that a policy authority needs to pay attention to and to be cautious about.

3.1.1. *Robustness of the Basic Rationale*

The trade model described above emphasized the benefits of creating an ex-post difference in marginal productivities through an asymmetric R&D policy. If the initial conditions were identical, then a government can simply realize the aggregate profit creation effect by redesigning or introducing a new policy to treat the firms unequally. If the firms' productivities were different initially, however, the optimal form of R&D policy would have been asymmetric as has been well-documented in the literature (see, e.g., Neary, 1994; Leahy and Montana, 1998; Kujal and Ruiz, 2007). Also, it has been pointed out that the optimal form of the policy is sensitive to the way firms interact. In addition, when the private R&D investments are allowed, an asymmetric policy may affect the R&D cost, possibly counteracting the welfare gain. The basic rationale of the aggregate profit creation sketched in section 2 however can be shown to be robust to the above three concerns.

(i) Heterogeneous Costs

When the firms are of different efficiency ex-ante, the optimal subsidy will be naturally asymmetric from the beginning, favoring the more efficient firms.[11] Suppose that the firms' marginal costs are asymmetric and denoted by c_i and c_j^* and thus the initially optimal R&D subsidy $\{s_i\}$ and $\{s_j^*\}$ are also asymmetric. We now consider a redesigned domestic – only domestic for simplicity – subsidy $\{\tilde{s}_i\}$ for which $\sum_{i=1}^{n} \tilde{s}_i = \sum_{i=1}^{n} s_i = S$ and the resulting new Nash equilibrium remains interior. Since the sum of the marginal costs $k_i \equiv c_i - \alpha(S - \tilde{s}_i) - \beta\tilde{s}_i$ and

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[10] Only the asymmetric cost case and various competition conjectures are reviewed in this report. See Jo (2009a) for the robustness to the other extensions such as various returns to scale in technology and 'international' spillover of an R&D activity etc.

[11] It can be shown that the more efficient firm should be given a greater subsidy, which contrasts with the conventional 'infant protection argument' which favors a policy to help those firms or industries who are lacking in competitiveness.

$k_j^* \equiv c_j^* - \alpha^*(S^* - s_j^*) - \beta^* s_j^*$ is preserved after the subsidy redesign, corollary 3 applies again and the aggregate profit creation effect is assured. The intuitive proof for an illustrative case that subsidies are rearranged at two firms is provided in the appendix. As to be mentioned below, the existing finding that the initially optimal policy is naturally asymmetric and the new finding from section 2 that an additional gain can be created by further increasing the degree of non-uniformity of the policy reinforce each other to shed a light on the main policy argument of this paper – back the winners rather than encourage the losers.

(ii) Various Competition Modes

Although different characterizations of oligopolistic behavior would give rise to different policy suggestions (Eaton and Grossman (1986)), it can be shown that the aggregate profit creation argument as discussed above remains valid regardless of the specific form of the initial policy. It can be illustrated using the conjectural variation parameters – developed by Bowley (1924) – following the convention in the literature. A firm's conjectural variation is defined as the output response by the other firms in the industry that it conjectures would co-vary with its own output change. Assuming that all firms have symmetric conjectures, a firm's conjectural variation is defined by v such that $dQ/dx_i = dQ/dy_j = 1 + v$. We can ignore the case of $v < -1$ since it implies a pricing below marginal cost. And since the equilibrium was assumed to be interior, the case of $v = -1$ can be excluded, in which case only the most efficient firm would export. Therefore we can only consider $v > -1$.[12] Now let's consider a domestic redesign of the initially uniform R&D subsidy $\{s\}$ to non-uniform subsidies $\{s_i\}$ in a way that the total subsidy expenditure does not change i.e. $\sum_{i=1}^{n} s_i = S$. Then the profit maximization conditions (5) after the subsidy redesign are modified as follows:

$$\pi_{x_i}^i = P(Q) + x_i P'(Q)(1+v) - k_i = 0 \; ; \; \pi_y^* = P(Q) + yP'(Q)(1+v) - k^* = 0 \, , \tag{13}$$

where $k_i \equiv c - \alpha(S - s_i) - \beta s_i$ and $k^* = c^* - ((n^* - 1)\alpha^* + \beta^*)s^*$. The sum of these net marginal costs $\sum_{i=1}^{n} k_i + \sum_{j=1}^{n^*} k^*$ remains unchanged and corollary 3 applies. Substituting $x_i = (k_i - P)/P'(1+v)$ from (13) and using the variance identity for $\{k_i\}$, the domestic aggregate cost is expressed as follows:

$$\sum_{i=1}^{n} k_i x_i = \frac{1}{P'(1+v)} \left(n\sigma_k^2 - \frac{\left(\sum_{i=1}^{n} k_i\right)^2}{n^2} \right) - \frac{P}{P'(1+v)} \sum_{i=1}^{n} k_i \tag{14}$$

[12] As special cases, $v = 0$ would correspond to the Cournot case, v > 0 represents the conjectures about more aggressive behavior than Cournot, and $v = n+n^*-1$ to the collusive case. Note that there would be no aggregate profit creation effect under homogeneous product Bertrand case of $v = -1$.

Since $P' > 0$ and $v > -1$, the above aggregate cost decreases when the variance σ_k^2 increases and the aggregate profit creation effect is assured for a wide range of conjectural variations parameters. In the special case of $v = -1$, the resulting equilibrium will involve corner solutions and only the most efficient firm is subsidized. In all the other cases in which the equilibrium remains interior, the aggregate profit creation effect holds true.

(iii) Three-stage game with private R&D investments explicitly introduced

The welfare-enhancing effect of the preferential innovation policy in the above has been explored through the cost-saving effects of the R&D process initiated by government. This assumption on the strategic benefits of R&D policy is made in order to avoid unnecessary complexity. However, the arguments can be extended to the practical case in which private R&D investments are explicitly introduced as well. This new three-stage game proceeds as follows: R&D policy is imposed in the first stage and firms make R&D investment decisions in the second stage and then output decisions in the third stage. Then given the uniform R&D subsidies (s, s^*) and the R&D investments (r, r^*)[13] by firms, domestic and foreign profits are defined by

$$\pi(x, y; r, r^*, s, s^*) = P(Q)x - kx - r\ ;\ \pi^*(x, y; r, r^*, s, s^*) = P(Q)y - k^* y - r^*, \qquad (17)$$

with $k = c - ((n-1)\alpha + \beta)(s + r)$ and $k^* = c^* - ((n^* - 1)\alpha^* + \beta^*)(s^* + r^*)$. Suppose that the domestic government reforms the uniform initial policy to a non-uniform policy $\{s_i\}$ such that $\sum_{i=1}^{n} s_i = ns = S$. This asymmetric policy would lead the domestic firms to alter their R&D investments to $\{r_i\}$ and the marginal costs after the new policy would be given by $k_i = c - \alpha(S - s_i + \sum_{l=1}^{n} r_l - r_i) - \beta(s_i + r_i)$ and $k_j^* = k^*$. Then it can be shown that a non-uniform alternative of the initial uniform subsidy with the sum of marginal costs $\sum_{i=1}^{n} k_i + \sum_{j=1}^{n^*} k_j^*$ remaining unchanged exists when the firms adjust their R&D investments. Then corollary 3 applies: the total industry production cost decreases while industry revenue does not change and aggregate profit and domestic welfare improve. Note that the R&D investments and the R&D costs are not treated separately here. However in many cases private R&D costs may be affected as the initially uniform R&D subsidies are redesigned in an asymmetric way. If overall private R&D costs do decrease, then the aggregate profit creation effect of non-uniform policy is further reinforced; however, if total private R&D cost increases, the aggregate profit gain would have to be weighed against the additional R&D cost incurred by the discriminatory R&D

[13] d'Aspermont and Jacquemin (1988) show that, in the absence of research joint venture and government intervention, R&D investments at the first stage would be symmetric.

policy redesign. The proof for the illustrative case in which the policy redesign is aimed only at two firms is sketched in the appendix.

3.1.2. *Implications for Backing Winners*

The unilaterally optimal subsidy in the conventional sense brings national benefits at the expense of trading rivals and thus the retaliation possibility seriously limits the practical applicability. A unilateral deletion of an on-going subsidy does not serve a national incentive. And a mutual reduction or deletion sounds ideal but is not self-enforcing due to its prisoners' dilemma property or, even if agreeable, the operational or transaction cost involved – both visible and invisible – may amount to a non-negligible level. As such, a trade-intervention, once made, has a tendency of lasting for long. One way or another, an on-going policy can be justified and then, the theoretical model shows, a non-uniform form outperforms a uniform structure. If the trade policy authority failed to realize it and the current subsidy were non-discriminatory, then the discussion of the previous section applies and the profit creation through an asymmetric policy can be sought for. A fairness argument for uniform subsidies might be raised but it should not necessarily be favored. Rather, a subsidy redesign had better be made in a way that helps those firms which are already cost-competitive. That is, *backing the winners* has to be the more relevant slogan innovation policy should stick to rather than protecting the laggards. A policy of 'helping loosers' has, by the way, been abolished by the Dutch government after a parliamentary enquiry in 1983/84 which revealed the failure of such industrial policy in the late 1960's (so called RSV-enquiry). However, unfortunately it again gained some momentum during the credit crisis in 2009, when worldwide protectionist policy measures in order to help domestic industries urged Dutch firms hit by the crisis to lobby for government support as well. In addition to the aggregate profit creation incentive, the idea of backing winners is further strengthened when the policy implementation process involves a mechanism through which the firms put extra efforts to improve upon their initial productivity to be eligible for beneficial policies. This may have been the intention of the Dutch innovation platform when it organized a beauty-contest-like process in order to select the winners to be backed, and be named as key innovative sectors. This point is discussed in a greater detail in later subsections.

3.1.3. *Degree of Industrial Competition and Backing Potential Winners*

As a caveat of the basic model in section 2, the argument of the model does not limit the degree of asymmetry in the way the firms are treated. In an extreme case the policy may try and create a national champion so that some firms are forced to exit as the degree of unequal treatment increases further. The market may become more concentrated and the fundamental prerequisite conditions for aggregate profit creation may be distorted. Not only the initially assumed uniform policy may be ungrounded but the strengthened market power of the exporting firms may also bring a detrimental effect to the trading partners, particularly the importing country, which may induce trading partners to impose a countervailing policy. It is also true that optimal form of the initial policy even before the preferential rearrangement of it may be sensitive to the relative size of the domestic and foreign firms. Too many domestic firms may induce over-competition among the domestic firms, jeopardizing the potential welfare benefits from a subsidy, and too few firms may case anti-competitive market distortions. As such, the policy authority should make sure that the right degree of competition in the industry should be maintained and in this regard lifting entry and exit barriers is important. The dynamic benefits of the preferential innovation policy as contrasted to a uniform structure therefore hinge upon the idea of backing potential winners as well as the existing winners. In other words, the policy should be keen on also 'backing challengers', as advocated by Jacobs and Theeuwes (2005).

3.2. *Economizing upon the Cost-Saving Effects (α, β) of an Innovation Policy and Importance of Commitment*

The basic rationale in section 2 relies on the following three key features: the ability of a policy authority to commit to a policy, the effectiveness of R&D in reducing own costs and the extent of spill-over effects. First, the commitment by government toward a particular policy and the detailed follow-ups of it constitutes an important part in the multi-stage game models. As a non-credible promise or threat does not constrain the choice of the other players of the game, the policy authority needs to commit to the policy to ensure the desired rationalization behavior by the firms. Therefore, the government policy which precedes the firms' decisions should be tangible and official so that it effectively constrains the firms' behavior. In view of the potential opportunistic behavior by the firms to be discussed in the following sub-sections, it is also important for the policy authority to commit to the follow-up programs if necessary.

The case of heterogeneous marginal costs discussed earlier already shows how the policy of backing winners can be designed when the initial marginal costs (c) vary across firms or sectors. In reality, however, the spill-over cost-improving effect (α) and the own cost-reducing effect (β) of an R&D policy would also vary depending on to whom the subsidy is given. An asymmetric structure of α and β would be a norm rather than an exception, which case can be illustrated by the following marginal cost to firm i after the R&D policy:

$$k_i = c_i - \sum_{j=1, j \neq i}^{n} \alpha_{ij} s_j - \beta_i s_i \tag{15}$$

A higher α_{ij} means a higher spillover effect and a higher β_i implies that a subsidy also improves the subsidy- recipient's cost in a greater degree. And in the aggregate production cost (12), it becomes obvious that the policy authority can further materialize the welfare-enhancing effect by distributing the subsidies in a way that the firms with a higher β receive higher subsidies and those with lower β receive lower subsidies. By the same token, the firms that create a higher spill-over effect in terms of improving other firms' efficiency are to be preferentially treated. The latter also implies that an industry which overall shows a higher spill-over is to be given a priority as well if selecting industries were the issue. The ideal selection of the beneficiary to be backed by the innovation policies therefore could begin by looking at the sizes of α and β for the firms across the industries to select the right industries first and then apply a non-uniform structure of subsidies to the firms in those industries, again in accordance with the sizes of the parameters.

3.3. *Mechanism Design for an Efficient Monitoring*

The criteria to back the right winners are rather straightforward as summarized above. The more challenging issue is developing an information-gathering mechanism to sort out the firms based on their productivities (c), self-cost-saving effects (β) and spill-over effects (α). The government needs to utilize the existing data to derive detailed intuitions about these parameters before and after R&D subsidies were imposed. And for a sustainable effect of welfare improvement, it is important to design and operate the mechanism through which the preferential selection of the firms be made in an efficient way. A well-designed mechanism may bring about an additional benefit to the economy by inducing the firms to take extra efforts to improve upon their pre-policy efficiency to be eligible for the subsidy rewards. On the other hand, the risk of rent-seeking behavior is present when the government's discriminatory policy is designed upon the observed performances of the firms. Therefore a successful implementation of the policy has to be one through which all the agents get to internalize the costs and benefits within their own behavioral incentive system. Below we non-technically address such issues related with the informational details and the behavioral incentives of the firms. Transaction cost issues arising from the opportunistic behavior concern are also discussed.

3.3.1. *Incomplete Information*

One of the major skepticisms against an interventionism is that it presumes good information of industry details – cost, demand, the mode of competition etc. – on the part of policy maker. Policy authority, however, is only limitedly informed. The first natural observation is that firms would behave opportunistically in order to influence their entitlement to policy benefits. This would particularly matter when the private R&D investments exist as illustrated in section 3.1.1. Over-investment can be a consequence. In such an incomplete information situation, a government may invent a policy menu combining a reward and a penalty through which the firms are motivated to reveal their true types so that the government can reflect on the actions taken by the firms to come up with the appropriate form of discriminatory policy (separating equilibrium). In that the uniform policy would be the alternative if the screening effort fails and the ex-ante private information were not revealed (pooling equilibrium), well-designed mechanism would be inevitable for a successful realization of the best welfare outcome. On the contrary, a separating equilibrium is not always a better option than a pooling equilibrium due to the transaction costs that may arise for the former equilibrium. In this regard, a policy maker should pay extra attention to the details of the incomplete information when designing an innovation policy.

3.3.2. *An Additional Benefit of Inducing Efficiency Improving Efforts*

When the innovation policy is to be imposed in a discriminatory way based on the pre-policy efficiency level of the firms, the firms would take it as an incentive scheme and would try to enhance their productivity even before the subsidy assignment to the firms. A virtuous cycle of high productivity-high subsidy-high productivity will further separate the good firms from the bad firms, and the preferential subsidy mechanism can set a binding platform for this self-selecting process. This additional efficiency-gaining effect is distinguished from the usual screening mechanism which is often useful under an asymmetric information situation. The latter solely aims to separate the good firms from the bad firms while the proposed R&D policy implementation mechanism would drive even the less efficient firms to put in their efforts not to further stay behind. That is, not only the separating equilibrium but also the pooling equilibrium may bring a welfare gain from the national perspective. To compensate those firms who improved in efficiency yet ended up receiving lower subsidies due to its lower-than-average productivity improvement, the government may introduce an additional subsidy if available.

3.3.3. *Concern of Rent-Seeking Behavior and Other Transaction Costs*

However, when selecting the right firms is the central focus of the mechanism, the firms' efforts to receive a high subsidy may lead the firms to behave to the selection mechanism only. The so-called rent-seeking behavior may prevail before the actual subsidy assignment. This rent-seeking incentive typically leads to the prisoners' dilemma situation, in which all firms tend to behave only to be picked for a higher subsidy but with no practical contribution toward the meaningful efficiency improvement, yielding the socially undesirable outcome. This phenomenon can be clearly captured by designing a game in which the order of movements between the firms and government is reversed (see e.g. Gruenspecht (1988)). If the government assigns subsidies *after* firms take an action to signal their types in terms of their productivities, all the firms would have an incentive to over-invest for a lower cost to be eligible for a more beneficial subsidy. The subsidy assignment mechanism can help to mitigate such an incentive if the mechanism contains the self-adjusting system in which those who received a higher subsidy yet did not show a meaningful performance in productivity gain ex-post should be further penalized later through a lower subsidy. The plausibility of an effective incentive mechanism for the genuine cost-reducing efforts prior to the subsidy assignment can be seen through the framework of the repeated games in game theory. Firms would select to play opportunistically when the game is played only once or just a few finite times. But when the firms are conscious of the through monitoring mechanism in which the policy authority regularly updates the details, they will necessarily weigh the potential gains and losses from such an opportunistic behavior. In this regard, a deliberately designed follow-up program of the industrial policy is needed to manipulate the subsidy recipients to behave toward the socially desirable outcome. The productivity gaining efforts by a firm to be eligible for a higher subsidy could be exercised through a visible investment in new technology or penetrating into a new market for a higher scale economy realization. Or firms might seek an efficiency gain through non-tangible resources which had been available yet not utilized. All kinds like operational, technical and managerial resources might have not been optimally exercised and the R&D policy mechanism would induce the firms to reach their optimal utilization for all possible business areas. These all contribute toward reducing the transaction costs, which need to be counted as the positive feature of the mechanism. The transaction costs can be saved on the policy authority side as well throughout the whole channels of sorting out the recipients – assigning subsidies – and monitoring the outcome for the next rounds of subsidy imposition.

4. MISCELLANEOUS INNUSES

4.1. *R&D Joint Venture versus Adversarial Approach*

As another meaningful intuition, the relative size of α and β in (15) can shed a light on the debate about which policy between R&D joint venture – i.e. cooperation among the firms – and adversarial approach is to be adopted (see e.g., Neary and O'Sullvan (1999)). One concern about the adversarial approach is that it provides a firm an incentive to over-invest or under-invest. The former case matters if the spill-over effect is negligible and thus a firm has an incentive to more-than-optimally invest to give itself a strategic advantage against its rivals in subsequent product-market competition. And the latter case becomes real if the spill-over effect is substantial but is not fully internalized in the private decision process. As such, encouraging an R&D joint venture could be an alternative option. Given the two-faced potential sub-optimality of an outcome when adversarial approach was adopted, we can at least suggest a rule-of-thumb criterion on the matter: when the spill-over effects (α_{ij}) dominate the own-cost reducing effect (β_i), an R&D joint venture had better be encouraged through which the cost-reducing effect of an R&D policy will be maximized although the aggregate profit creation may not be obtainable. Otherwise, an adversarial policy through an asymmetric treatment of individual firms should be given a priority. It is noteworthy that the innovation platform, in its beauty contest to select the key innovative sectors in the Netherlands, very much favored those sectors where firms appeared to be able to present themselves jointly in the beauty contest. The implicit intuition of the innovation platform behind this design of the contest may be the desire to enhance future spill-over effects in addition to finding out in which sectors there already were joint R&D ventures.

4.2. *Corrective Objective versus Strategic Objective*

While the main part of our analysis focuses on the strategic objective of an industrial policy, a policy authority may also have a distortion-corrective objective in mind. In particular, in connection with the R&D activity by the private firms that are to be influenced by an R&D policy, the possible sub-optimality of the private firm level investment as discussed previously, might induce a government to try to catch both rabbits. Therefore, it has to be understood that the optimal form of the industrial policy – subsidy or tax – depends on which incentive outweighs. From a corrective policy perspective, a tax would have to be imposed if the spill-over effect of an R&D subsidy causes an over-investment for a firm and a subsidy would be optimal if an under-investment is caused. Yet the optimal form of policy from a strategic perspective depends on the other factors such as consumer demand and the completion mode among the firms. If both motives reinforce each other, it is not a concern. However, if the two motives are counteractive, the relative importance of the two objects has to be well weighed before a preferential redesign of the policy is introduced.

4.3. *A Political Economic Concern: Redistribution Scheme*

From the usual perspective of positive economics, when there are winners and losers with the winners' gain larger than the losers' loss, an appropriate domestic redistribution scheme is necessary to ensure all participants gain. However, in light of the specific purpose of innovation policy, such as is the objective of e.g. the Dutch innovation platform, one may even leave the outcome as it is. In that way it can be utilized as an incentive scheme per se for the firms to improve their technology and cost conditions to further guarantee a higher subsidy. In a good scenario, the incentive scheme will lead all the firms in the industry to reach a higher efficiency in absolute terms. If then, the subsidy redesign may rely on the relative measure of efficiency gains to reward only those with high efficiency improvement while those firms with a below-average efficiency gain will still get penalized and receive a lower subsidy. A government may take another stance by rewarding all those with an efficiency gain yet in a discriminatory way. The firms' efforts will be praised although unevenly. Of course such non-uniform policy of 'backing strong winners' and 'backing ordinary winners' requires an additional fund for the subsidy spending. The opportunity cost of the public fund will become an issue again, and the government will have to weigh all the related costs and benefits. The costs side would involve both the visible cost and the invisible transaction costs while the benefits should entail the screening effects in this asymmetric information environment to effectively distinguish the low-cost firms from the high-cost firms as well as the usual cost-saving encouraging benefits.

5. CONCLUDING REMARKS

This paper discusses policy options for industrial and innovation policy using a new feature in strategic trade policy. It illustrates in a theoretical case under an international oligopolistic market that a non-uniform innovation policy through R&D subsidies is superior to a uniform policy in its national welfare enhancing effect. It is shown that the usual retaliation concern that arises from its adverse welfare effects abroad does not apply and that the case holds true under a variety of behavioural conjectures among the firms. The theoretical argument is found useful in the debate on whether a targeted innovation policy is warranted in case the government is to 'pick' or 'back' winners.

Although the benchmark model was sketched in the ideal world with symmetric Cournot firms and it can be extended to the non-Cournot cases as well, the ex-ante asymmetric costs cases are more realistic and also the cost-saving effect on the firms or sectors of R&D subsides will rather be differentiated. It implies that the government will have to exploit a priori information on the differences of cost reduction that the R&D subsidy will bring about. That is especially true for the size of the spill-over effects which are positive externalities and may lead to under-investment in R&D unless it is internalized within the system or through an industrial policy. The problem is that the government has incomplete information on the true initial efficiency levels of the firms and on the extent of cost reduction that the innovation policy will accomplish. Firms may behave strategically to impress the government, which could even lead to over-investment and to rent seeking. Therefore it is required for the government to design a carefully deliberated strategy for innovation policy and show consistency in implementation of it. Nonetheless, the rationale of the aggregate profit creation remains valid as long as the policy maker can sort out the informational asymmetry to clearly configure the right form of the optimal policy. Furthermore, it may bring about the additional benefit of inducing extra efforts on the firms' side.

From this perspective, our analysis discusses the various strategic issues for a targeted innovation policy with their pros and cons. It takes as example the strategy of the Dutch innovation platform, which designed a beauty contest in order to select key innovative sectors in the Netherlands following the policy proposals to conduct a policy of 'backing winners'. Informational configuration about the current efficiency conditions of the market participants has to be preceded and also the potential efficiency-gains through the policy has to be well estimated, while the potential opportunistic behavior by the firms should be discouraged. A carefully designed mechanism to provide the firms the right incentives and also to monitor their post-policy behavior should be combined as well. In addition, the 'challengers' should not be completely isolated from the whole picture and the strategic details of the policy should entail backing the right winners – both existing and potential.

As a final remark, we note that the analysis of this paper does, by no means, rule out the possibility that the ex-ante optimal form of the policy may be indeterminate or that the informational complexity may lead to a substantial transaction cost loss so that eventually it has negative welfare implications. The discussion of the policy options in this paper only has a qualitative character and is based on modern theory of strategic firm behavior. A more fully fledged analysis would need a formal treatment of the specific strategies. Then a quantification of the net welfare effects that the optimal design of the policy strategies can bring about, is to be made. These net welfare effects may turn out to be positive, but can also very well appear to be negative. In other words, in spite of the theoretical model of this paper, which provides an argument for backing winners, in practice the cons of such policy may outweigh the pros. This is the scope for future research.

APPENDIX

Proof of aggregate profit creation when the subsidies are rearranged only at two firms:

A1. Homogeneous cost case in section 2.2.

Suppose that the initially-uniform subsidies are asymmetrically rearranged only at two domestic firms, denoted by firm 1 and firm 2. Initially $s_1 = s_2$, $k_1 = k_2$ and $x_1 = x_2$s Assume the subsidy is reduced on firm 1 and raised on firm 2, preserving their sum. Then $\Delta k_1 > 0$, $\Delta k_2 < 0$, $\Delta k_1 + \Delta k_2 = 0$ and it follows from observations 1 and 2 that $\Delta x_1 < 0$, $\Delta x_2 > 0$ and $\Delta x_1 + \Delta x_2 = 0$. Given this, we explore the following change in domestic aggregate production cost:

$$\begin{aligned}&((k_1 + \Delta k_1)(x_1 + \Delta x_1) - k_1 x_1) + ((k_2 + \Delta k_2)(x_2 + \Delta x_2) - k_2 x_2) \\ &= (\Delta k_1 \Delta x_1 + \Delta k_2 \Delta x_2) + (k_1 \Delta x_1 + k_2 \Delta x_2) + (x_1 \Delta k_1 + x_2 \Delta k_2)\end{aligned} \tag{16}$$

In the above, the first term is negative since Δx_i and Δk_i take the opposite sign from each other and the second and the third terms are equal to zero because $k_1 = k_2$, $\Delta x_1 + \Delta x_2 = 0$ and $x_1 = x_2$, $\Delta k_1 + \Delta k_2 = 0$, respectively. Therefore, the aggregate cost decreases and the aggregate profit increases.

A2. Heterogeneous cost case in section 3.1.1.-(i)

Consider a subsidy redesign only on two firms, firm 1 and firm 2. Suppose that the firms' marginal costs and the subsidies were asymmetric initially and the subsidies are redesigned only on two firms, firm 1 and firm 2: $c_1 > c_2$ and $s_1 < s_2$ (thus $k_1 > k_2$ and $x_1 < x_2$) initially and subsidy redesign is made in a way that $\Delta s_1 < 0$, $\Delta s_2 > 0$ with $\Delta s_1 + \Delta s_2 = 0$. Then $\Delta k_1 > 0$, $\Delta k_2 < 0$ and $\Delta k_1 + \Delta k_2 = 0$ and it follows from observations 1 and 2 that $\Delta x_1 < 0$, $\Delta x_2 > 0$ with $\Delta x_1 + \Delta x_2 = 0$. From (17), the aggregate production cost is

$$\left(\Delta k_1 \Delta x_1 + \Delta k_2 \Delta x_2\right) + \left(k_1 \Delta x_1 + k_2 \Delta x_2\right) + \left(x_1 \Delta k_1 + x_2 \Delta k_2\right). \tag{17}$$

The first term is clearly negative. The second and third terms are also negative since $k_1 \Delta x_1 < 0$, $k_2 \Delta x_2 > 0$, $|k_1 \Delta x_1| > |k_2 \Delta x_2|$, and $x_1 \Delta k_1 > 0$, $x_2 \Delta k_2 < 0$. $|x_1 \Delta k_1| < |x_2 \Delta k_2|$. Hence the aggregate production cost decreases and the aggregate profit increases.

A3. Three-stage game case in section 3.1.1.-(iii)

Denote the cost to each domestic and foreign firm of investment r and r^* by $f(r)$ and $f^*(r^*)$, respectively and suppose that the uniform subsidies (s, s^*) prevails. Then, given (r, r^*) and (s, s^*), each domestic and foreign firm's profit is given by $\pi = P(Q)x - kx - f(r)$ and $\pi^* = P(Q)y - k^* y - f^*(r^*)$, where $k = c - ((n-1)\alpha + \beta)(s + r)$ and $k^* = c^* - ((n^* - 1)\alpha^* + \beta^*)(s^* + r^*)$.

Suppose that the uniform domestic subsidy s is redesigned only at two firms – firm 1 and firm 2 – into s_1 and s_2 in a way that $s_1 + s_2 = 2s$. Denote the new private R&D investments after this arrangement by $\tilde{\mathbf{r}} = (\mathbf{r}, \mathbf{r}^*)$: $\mathbf{r} = (r_1, r_2, r, \ldots, r)$ is $1 \times n$ vector of R&D investments by domestic firms after the subsidy redesign where r_1 and r_2 denote new investments by firms 1 and 2, and $\mathbf{r}^* = (r^*, \ldots, r^*)$ is $1 \times n^*$ vector of foreign firms' symmetric R&D investments. Then foreign marginal cost k^* does not change but the new domestic marginal costs change to $k_i = c_i - \alpha(S - s_i + \sum_{l=1}^{n} r_l - r_i) - \beta(s_i + r_i)$, where $r_l = r$, $\forall l = 3,4,\ldots,n$. Now let's define Ψ as the set of new R&D investments by firms 1 and 2 giving rise to the same sum of marginal costs in the production stage as follows:

$$\Psi \equiv \{(r_1, r_2): \textstyle\sum_{i=1}^{n} k_i + \sum_{j=1}^{n^*} k_j^* = nk + n^* k^*\}. \tag{18}$$

Then the implicit function theorem can be applied to represent r_1 as a function of r_2 for an r_2 within a neighborhood of r^*: $r_1 = g(r_2)$ where $g(r_2)$ is such that $(g(r_2), r_2) \in \Psi$. That is, a non-uniform redesign of the initial uniform subsidy can be found after which the sum of marginal costs does not change and the firms adjust their R&D investments, yielding an additional welfare gain. The aggregate profit creation argument remains valid. Note that the sum $f(r_1) + f(r_2)$ may be greater than $2f(r)$ depending on how R&D costs reacts to R&D investments, in which case the aggregate profit gain should more than offset the R&D cost increase for a welfare gain.

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