EFFECTS OF GOVERNMENT'S INTERVENTION ON STABILITY OF COOPERATION IN R&D PROVISION

by

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Abstract

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In this thesis the cross-influence of government’s decision and private economic agents’ choices at R&D field is analysed. The situation is modelled as a four-stage extensive game which is solved using backward induction to obtain subgame perfect equilibria. The model is based on three-stage extensive game analysed by Atallah (2003) which is treated as “no intervention” state. We examine the pattern of change in private R&D expenditures and change in cooperative decisions of private firms for two forms of government intervention: direct financing of R&D and tax reliefs to enhance private firms’ cooperation. We also determine the choice of government between two mentioned forms of intervention. Private R&D expenditures are found to be dependent on relation of an actual information leakage level to the critical thresholds for both strategies available to the government. Tax reliefs strategy of the government leads to a lower distortion of cooperative decisions that direct financing strategy. The government’s choice is determined with actual information leakage level. The thesis is ended with a set of implications for private economic agents.

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Chapter 1

INTRODUCTION

The foreword to Country Readiness Assessment Report "Towards a Knowledge-Based Economy" for Ukraine provided by United Nations Economic Commission for Europe (2003) contains the following statement: "It is knowledge that has become the engine of the social, economic and cultural development in today's world. Knowledge-intensive economic activities are now a factor of production of strategic importance in the leading countries".

Ukraine performs much lower level of innovations and investment in research activity than developed economies do. According to the data from United Nations Economic Commission for Europe report (2003), the level of R&D investments has not exceeded 1.91% of GDP; the developed economies tend to have this indicator at the level of 2.7% (http://energytrends.pnl.gov/netherlands/). In Ukraine where the level of production still has a reserve for extensive growth (not all enterprises fully exploit their production facilities; considerable part of potential market for Ukrainian products remains undeveloped because of barriers for international trade), the problem of underperformance of research activities is quite strong. According to Romanishyn (2005), the number of enterprises introducing innovations declined continuously from the year 1994 to 1999 and then showed a slight recovery in the years 2000-2001. Romanishyn (2005) reports also that "weight of the innovative activities of enterprises has decreased in 1,8 times during 1994-2000". The budget financing of R&D also declined from 0.46% of GDP in 1996 to 0.25% of GDP in 2002[1].

Ukrainian officials mentioned that Ukraine got threateningly closer to the status of retarded countries [enactment of the Supreme Council (Verkhovna Rada) of Ukraine, 06/16/2004]. The concerns about insufficient levels of public R&D financing and absence of direct link between scientific researches and private enterprises are also expressed by members of the National Academy of Sciences of Ukraine[2] (NUAS).

All above-mentioned facts may force the government to regard the possibilities of enhancing R&D activity in the country. Two basic kinds of strategies are available for this purpose: direct R&D financing and incentives creation for R&D provision. First strategy realizes in public R&D, second should increase private R&D activities and cooperation in R&D provision.

Wide variety of studies examine the relations between public and private R&D, effects of spillovers and information leakages on private R&D activities, private cooperation for R&D and cooperation of private and public agents for R&D. Belderbos et al. (2004) mention that late 1980s and 1990s saw the increase in R&D alliances and, consequently, growing academic interest to issue of R&D cooperation. The research topics usually touch upon spillover effects, risk management in cooperation, relationship between public and private investment in research activities, the questions on proper level and structure of cooperation in R&D provision. The debates include empirical studies and case studies as well as theoretical speculations on the topic. Empirical studies and case studies employ the data of different levels: firms (Streicher et al. (2004)) and industries (Tijssen

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[1] Source: Country Readiness Assessment Report "Towards a Knowledge-Based Economy" for Ukraine (United Nations Economic Commission for Europe, 2003)

[2] See, for example, the articles of Yaroslav Yatzkiv and Vadim Loktev (NUAS academicians) in *Mirror-Weekly*, # 17 (545), 2005, p.1 and p.15.

(2003)), particular countries (Inzelt (2004), Vavakova (2004)), cross-countries comparison (Czarnitzki et al. (2004)). Strategic-game approach to studying cooperation in R&D provision was exploited by Amir and Wooders (1998) and Amir, Evstigneev and Wooders (2003). Osborne et al. (2000) examine the influence of the cost of participation on Nash equilibrium in strategic games and make a conclusion about low participation and tendency for extreme solutions. Economides and Philippopoulos (2003) investigate dynamically efficient Nash tax rates for public good provision for the growing economy. Anderson, Mellor and Milyo (2004) provide experimental analysis of the group cohesion and public good provision.

Atallah (2003) in his paper analyzes the stability of cooperation in research joint ventures (RJV). He develops the three-stage game with T identical firms. M of them cooperate in RJV (make joint R&D investments); the remaining firms stay out of RJV and separately invest in R&D. The size of RJV is determined endogenously (in other words, the size is determined by decision of each firm to participate/not to participate in RJV). The members of RJV decide about the level of information sharing given the exogenous information leakage parameter k ($k \in [0,1]$). The parameter k shows the portion of information shared by members of RVJ (insiders) which becomes available to the non-participating firms (outsiders). All firms make separately their production decisions at the last stage of the game. Atallah (2003) provides the optimal choices of R&D investment and optimal decision function upon participation in RJV and information sharing for different values of k. He also defines the impact of changes in exogenous parameter on R&D investment decisions of firms and, therefore, R&D output. According to Atallah's results for information, there exists the tendency to extreme solutions (none or full information sharing). The stability of RJV falls with increase in information leakage parameter, but also the size of RJV increases to internalize externalities. Overall R&D output stays ambiguous since increase in k lessens R&D of RJV members and raises R&D of outsiders. Hence, the effect on welfare also stays ambiguous. However, Atallah (2003) concentrates only on private R&D and says little about possible public participation in R&D production. Namely, he points that the government has an option to influence k by installation of information protection.

Most of the studies mentioned are ended with policy implications, virtually, the recommendations for implementation of results obtained to policy development. Providing policy implications the authors generally concentrate on welfare effects of studied phenomena.

However, if we assume that the main problem solved by private firms is profit maximization we should treat the policies perceived by government as additional "constraints" for the private firms. Then private firms adapt their decisions of profit maximizing problems to the new conditions created by policy makers.

In each period the government has a "right of first move". It means that in each period, first, the government chooses its strategy and then private agents adapt their decisions to the choice of government. However, the posterior actions of private agents may change considerably the payoff for the government. If the government is a rational agent it takes this into account. One of my goals is, therefore, to examine to what extent the decisions of private economic agents can change the choice of government.

The economic theory (public economics) traditionally treated the government as benevolent disinterested (materially) ruler, "regulative principle", which uses delegated compulsion power to implement overall utility maximizing behaviour. The evidence of Ukraine (the misuse of budget funds, overbureaucracy followed with bribery, selling of state property with substantial law breaks) leads to conclusion that Ukrainian government does not satisfy the definition given.

From the mid XX century a number of researchers treated the government not as social welfare maximizing agent but linked government's decisions on economic regulation to its own utility maximization (studies of Demsetz (2002), Stigler (1971), Boycko, Shleifer and Vishny (1996) are representatives of the numerous investigations on the topic). The incentives for an actual government to implement a certain policy may lie in more egoistic considerations that social welfare maximization (e.g. for politicians it may be more important to be reelected that to increase the efficiency of the economy). Therefore, I treat the government as self-utility maximizing agent. The choice of government depends on its set of priorities and the range of problems it should solve simultaneously. The government's utility function may or may not coincide with other economic agents' utilities or other economic agents' conception of social welfare.

To summarize, in this thesis I study 1) the impact of direct budget financing of R&D and tax reliefs (as a tool of incentives creation) on the private R&D provision and on stability of cooperation of private firms for R&D provision; 2) the influence of private agents' choices of private R&D provision and of the level of cooperation on the decision of the government about the strategy of R&D support.

I consider game-theoretical framework as the most useful for my goals. I modify Atallah's model (Atallah, 2003) which is a three-stages extensive game determining the degree of cooperation of private firms in a particular industry for R&D provision, the choices of private R&D level and production decisions. I introduce the government as additional player which moves first in the extensive game. Of course, government collects revenues in the form of profit tax from each firm in the industry. Atallah's game is transformed into a four-stage one; at the first stage the government chooses the way of participating in R&D provision. I consider two main strategies available for the government: direct financing of R&D activities and creation of incentives for cooperation of private firms in research joint ventures (as R&D cooperation is considered to be generally beneficial (Atallah (2003))). Thus, in my model, the government may invest in R&D directly in the form of budget expenditures (providing public R&D); otherwise, it sets a tax relief for the firms participating in RJV. This choice of strategies is consistent with, for example, classification of toolkit of support of innovative activities given by Romanishyn (2005). The government is assumed to be own utility-maximizing player. In other words, it chooses own strategy so as to maximize its net tax revenue.

I assume also that for each unit of public R&D investment the government gets the amount of R&D output equal to Z (Z is exogenous). I assume that public R&D results may be used by private firms for cost reduction. Z reflects not physical output but rather a degree of relevance of public R&D output to private needs (unit cost reduction of private forms). Also I separate the pure public R&D and private R&D and do not allow for cooperation between public and private R&D agencies. Such structure is mentioned by Inzelt (2004) in her study on the forms of cooperation for R&D in Hungary. The degree of which a private firm uses public R&D output depends on its "absorption capacity", a 'limit to the rate or quantity of scientific or technological information that a firm can absorb' (the definition is from Econterms). In other words, if a private firm does not have own R&D, the public R&D is completely unusable for this firm.

Here I should explain the government's incentive to intervene into R&D provision. Government collects tax revenues from private firms. An increase in R&D is associated with the following increase in productivity, and/or cost reduction. Both effects give the firms the competitive advantages which may materialize in higher future profits. And higher future profits of private firms definitely mean higher future tax revenues for the government. Thus, it gives the incentives for government to participate in R&D provision.

Still the government takes more care about the present and makes the choice about the form of participation in R&D provision considering today's utility maximization.

Let me point one more time to the game structure: government moves first choosing between direct financing and tax reliefs; next three stages are similar to those in Atallah's model (determination of the RJV size, private R&D investments, and production decisions), with correction on effect of government's decision (which touches upon profit and cost functions of the firms). The payoff of the government is affected by the decisions made by private firms.

Next chapter I devote to literature review. The model description is given in chapter 3. Chapter 4 describes optimal production and R&D investment levels for private firms. Chapter 5 contains optimal RJV size determination and the choice of government's strategy. The last chapter provides the conclusions, implications and future research directions.

Chapter 2

LITERATURE REVIEW

A wide variety of studies, both theoretical and empirical, examines the cross-influence of private and public R&D. The first class of papers examines whether public R&D financing appears to be complement or substitute to private R&D financing. Empirical results on this question differ basing on regions of data collection. Streicher, Schibany and Gretzmacher (2004) present the results of 18 empirical investigations for the USA and Europe. Six studies covering the USA showed substitutability of public and private R&D, two indicated complementarity, and three gave mixed results. For Europe, one study provided conclusion in favour of substitutability, five pointed on complementarity and one reached mixed result. I hope to study the impact of public R&D on private R&D analyzing the sensitivity of the private R&D investment decisions for changes in exogenous parameter Z.

David and Hall (2000) discuss the crowding-out effects of public R&D on private R&D, based on the substitutability/complementarity question. The authors distinguish between static and dynamic effects; moreover, in each class they identify first- and second-order effects on private R&D. Summarizing static effects, they refer to Cohen and Levinthal (1989) pointing that "doing R&D to create a capacity to absorb R&D results being generated elsewhere should extend to absorbing public R&D results". In the long-run the authors' main concern is that reduction of public spending in certain R&D fields would lessen the private rates of return.

David and Hall's (2000) framework also permits to raise the question of making a difference between overall R&D public financing and intervention targeted to infrastructure. Public finance intervention raises the price of research inputs, so using this instrument the government could set the priorities of development.

Leahy and Neary (2004) develop a general model of absorptive capacity. They point that benefits obtained by a firm from rivals' R&D depend on firm's own R&D investment and also on the degree of which it may be difficult to implement the rivals' R&D results for own marginal cost reduction. They mention also that "making information freely available does not guarantee that it can be freely absorbed". Analyzing the impact of external sources of information the authors state that firms must have own R&D before they can benefit from out-of-industry knowledge. The authors conclude that for private firms the incentive to perform own R&D in order to create an absorptive capacity enhances non-cooperative behaviour in R&D provision. The another valuable conclusion is that for a particular firm the presence of external knowledge and the need to invest in own R&D in order to absorb it lowers the effective spillover coefficient ("the ratio of marginal returns to rivals' and own R&D"), thus, making own R&D more valuable that spillovers from rivals'

The next channel of influence on investment decision is risk controlling. Certain models of cooperation for R&D provision evolve different types of risks for contracting parties. One way to minimize the risks consists in constructing an "ideal" contract: the mechanism which efficiently allocates risk bearing between principal (buyer of research) and agent (supplier of research). Helm and Kloyer (2004) try to elaborate a model of the ideal contract taking *exchange risks* into account. The authors identify exchange risks as: 1) profitability risks – lower probability to obtain benefits than the exchange partner; 2) competition creation risk – lower "inter-partner-learning effect". The result of their model which is of main interest for my work shows that under opportunistically behaviour of contracting parties the input choice tends to be second-best (maximizing individual profits instead of maximizing total benefit). The model of Atallah (2003) takes both probability risk and competitor creation risk into account. Atallah (2003) analyzes carefully the incentives for cooperation and voluntary information sharing in research joint ventures for different level of information leakages. The outsiders in his model may benefit from these leakages without participating in RJV and, thus, having more freedom in R&D investment decisions than the RJV insiders have. Atallah concludes that for high values of leakage parameter the information sharing level between RJV members falls and stability of cooperation lowers.

Osborne et al. (2000) examine the influence of the cost of participation on the Nash equilibrium in strategic games and draw a conclusion about low participation and tendency for extreme solutions. The government as a player is likely to choose between direct financing of research and creating the environment (incentives) for private sector to cooperate for R&D provision. Demand-side market tendencies seem to enhance the attractiveness of the first variant.

Arundel and Garrelfs (1997), and Tijssen (2004) point out that private firms involved in developing of new products tend to consider public research the most important source of information. However, in my model the firms perform R&D not for new products creation but rather for unit cost reduction. So, the expected crowding-in/crowding-out effect stays unclear.

The immediate concern about commercialization may arise. The balance between "demand-side" and "supply-push" interactions between industry and research institutions is fragile. "Demand-side" commercialization tends to move the research from innovation in production forces (which necessarily suppose also the change in production relationship and may cause significant redistribution of profits) to improvement of existing production forces (which has its natural limit). "Supply-push" commercialization limits the availability of new information for the industry. The simplified example from Ukrainian reality may be informative (see http://www.zn.kiev.ua/nn/show/511/47737/). The government obliged enterprises to follow methodological recommendations, the elaboration of which was made by Kyiv State Institute of Economics of Chemical Industry. The research institute charged the price for these methodological recommendations, thus, limiting the access to them for SME. This situation is legally acceptable because the recommendations are registered by institute as an intellectual property.

However, since I assume no direct relationship between public and private R&D efforts (no cooperation between public and private research facilities) the question of balance between "demand-side" and "supply-push" interactions doesn't arise in my model.

The existing experience of transition from mostly public financing of R&D should be examined to stimulate a deeper insight for intuition. Vavakova (2004) presents a study based on French experience of changing innovation policy. Mostly publicly financed during 1960s-1970s French research institutions were in a critical situation in the middle of the 80s. After the long series of non-efficient measures, in 1999 the law of innovations and research was adopted. That law established a favorable infrastructure for knowledge transmission from research institutes to industry. The effective link was performed by firms created by publicly funded research institutions which were spin-offs from research results; also the institution of "scientific support" was created for the firms whish 'valorized' the result of research (such relationships were the matter of contract). Also the networks and technological platforms were introduced.

Inzelt (2004) concerns the measures and data sources of collaboration in R&D provision in transition economies. In her study made for Hungary Inzelt divides the indicators of research inputs, type of interaction, and outputs of government-industry collaboration. Based on this work, we should distinguish between R&D financing (the amount of grants and funding) and R&D performance (for example, the number of researchers working for certain public or private institutions or the engagement of business employees in research activity). The author distinguishes among 18 types of interaction between economic agents according to different levels and patterns of interaction. The most developed level of interaction appears to be individual-institutional with vertical interaction (like employing faculty members as regular consultants, buying university research results (patents) on an ad hoc basis, joint supervision of Ph.D. and master theses by university and firm members). According to Inzelt, the most progressive level is institutional with horizontal interaction between agents involved (knowledge flows through permanent or temporary mobility from universities to firms; knowledge flows through spin-off formations of new enterprises). The crucial output indicator is joint publications and joint patents. Unfortunately, I should mention that this indicator brings little information about the increase in productivity and profitability of an enterprise due to research activity undertaken.

Chapter 3

THE MODEL DESCRIPTION

The model is a modification of Atallah's (2003) three-stage extensive game for T identical firms (see Appendix 1 for setup, and Appendix 2 for the notations used in my model).

I introduce a new player, government. Government levies profit tax, τ, in form of percent of firm's profit. This immediately bounds τ to the range [0,1). I consider τ exogenous for my specification of the game. In reality, the tax rate may stay unchanged during the political cycle or during the period of activity of a particular government. For example, corporate income tax rate of 30 %, introduced in 1997, remained unchanged till the year 2004. During this period (1997-2004), four governments worked in Ukraine[3]. Still the government has an opportunity to provide tax exemptions (without changing the basic value of tax rate). Later, in simulation I will examine the influence of different values of tax rate on equilibrium decisions.

Government has two strategies for supporting R&D. First, it can finance R&D directly. Then budget subsidies are turned to financing of non-profit research institutions.

Public R&D output, Z, is a pure public good, and if is present once, becomes available for all private firms. Z is also modeled as exogenous parameter: I assume that government can not influence the quality of output of non-profit research organization *given* the amount of money the government spends on it, and also there is no interconnection between institution providing public R&D and private firms.

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[3] Source: www.kmu.gov.ua, own estimations.

The public R&D may perform different degrees of relevance for a particular industry. For example, the government finances National Academy of Sciences which provides R&D at different fields. Public good (R&D) is created. But for metallurgy a research in psychology is much less valuable than a research in, say, chemistry. Thus, changes in Z reflect the changes of public R&D relevance for a particular industry. I restrict the values of Z to the interval [1,2]. If the public R&D is not relevant for the industry, Z=1. Higher magnitudes of Z show higher relevance. In my simulations at stages 2 and 1 I will use the values of 1, 1.5 and 2.

For the government, per unit cost of public R&D output is assumed to be equal to ε. Thus, public R&D which is highly relevant is assumed to be more costly for the government. The total amount of subsidies needed is ε*Z.

The degree of the utility of public good for each particular firm depends on its own R&D activities as well as the relevance of public R&D output to the industry specifics. For a particular firm, an increase in own R&D raises its capability to assimilate public R&D. To reflect this effect of "absorptive capacity" I introduce Z in the revenue function of the firm as a multiplier of private R&D output of firm i, x_i.

The net government revenue of this strategy is $\sum_{i=1}^{T} \tau\pi_i - \varepsilon Z$ (1) ,

where τ is a tax rate, π_i is a profit of a firm i, ε is "unit cost" of public R&D output.

However, if a lot of firms do their R&D separately there could be huge duplication of efforts. Taking it into consideration, the government may be willing to stimulate the firms to cooperate in research joint ventures (RJV). According to Atallah (2003), RJV members decide jointly on their R&D expenditures. A possible strategy for government to stimulate RJV creation is setting τ=0 for RJV insiders. This induces no direct costs but lessens government revenues. The net government revenue is $\sum_{i=M+1}^{T} \tau\pi_i^n$, where π_i^n is a profit of a firm i (i=[M+1,T]) which does not enter RJV (here and after, a superscript ***n*** stands for "non-entrant", whereas a superscript ***m*** stands for "RJV member").

$$Government\ Payoff = \begin{cases} \sum_{i=1}^{T} \tau\pi_i - \varepsilon Z, & if\ \ subsidies; \\ \sum_{i=M+1}^{T} \tau\pi_i^n, & if\ \ tax\ relief. \end{cases} \tag{2}$$

Technically, an introduction of profit tax does not influence directly the optimal decisions of firms at stages 3 and 4, where optimal production levels and optimal R&D investment levels are chosen, for both strategies of the government. The (1-τ) multiplier of profit functions cancels out after setting first order conditions of profit maximization problems equal to zero. However, τ lessens after-tax profit and, thus, should change the decision on the number of RJV members (M), which then influences R&D investments and production levels.

According to the new setup, I modify the cost functions and profit functions of firms depending on the choice of government about the form of R&D support.

1) <u>Government chooses direct R&D subsidies</u>

The unit cost function of firm i becomes:

$$c_i(\Gamma_i, Z) = r - Zx_i - \Gamma_i \quad , \tag{3}$$

In (3) r stands for unit cost of production when R&D output (public or private) is absent. x_i is private R&D output of firm i. Γ_i is unit cost reduction enjoyed from voluntary information sharing for RJV-members and from information leakages for non-participants. Therefore,

$$\Gamma_i^m = gZX_{-i}^m, \quad where\ X_{-i}^m = \sum_{j \neq i}^{M} x_j^m$$

$$\Gamma_i^n = kgZX^m, \quad where\ X^m = \sum_{j=1}^{M} x_j^m \quad .$$

$$0 \le k \le 1, \qquad 0 \le g \le 1$$

According to the notation, Z is a public R&D output, g presents the degree of voluntary information sharing between RJV insiders.

After-tax profit of firm i is defined as:

$$\pi_i = (1-\tau) * \left[\left[p(Y) - c_i(\Gamma_i, Z) \right] y_i - u x_i^2 \right] \tag{4}$$

2) <u>Government chooses tax relieves</u>

The unit cost function of the firm remains the same as in Atallah's model:

$$c_i(\Gamma_i) = r - x_i - \Gamma_i \tag{5}$$

After-tax profit of a firm choosing to participate in RJV will be:

$$\pi_i^m = \left[\left[p(Y) - c_i^m(\Gamma_i^m) \right] y_i^m - u\left(x_i^m\right)^2 \right] \tag{6}$$

After-tax profit of a firm choosing to stay out of an RJV will be:

$$\pi_i^n = (1-\tau) * \left[\left[p(Y) - c_i^n(\Gamma_i^n) \right] y_i^n - u\left(x_i^n\right)^2 \right] \tag{7}$$

I should explain why some firms may choose to not to participate in RJV with the presence of tax reliefs. A participation in RJV requires the firms to decide jointly over R&D expenditures, which reduces the degree of freedom for each participant. Moreover, outsiders may benefit (in a form of unpaid cost reduction) from the information leakage from RJV insiders. Both these effect may overcome the benefits of having a tax relief as RJV member.

The game is an extensive 4-stage game. At the first stage, government chooses the support scheme (direct financing or tax relief). At the second stage, firms decide to enter or not to enter RJV. At the third stage, all firms determine their R&D expenditures (decide over x_i). At the last stage, every firm makes its production decision.

I should write down the problems to be solved at each stage.

I. First stage.

Government chooses its strategy so as to maximize its net revenue:

$$S = \max\left\{\left(\sum_{i=1}^{T}\tau\pi_i - \varepsilon Z\right);\left(\sum_{i=M+1}^{T}\tau\pi_i^n\right)\right\}$$

II. Second stage.

The size of RJV is determined. Modify the definition of Atallah (p.8).

Definition: Let $\pi_i^m(q)$ be the after-tax profit of an insider, and $\pi_i^n(q)$ represent the after-tax profit of outsider when RJV is of size q. Then a RJV of size M is stable if and only if, for M≤T

$i)\quad \pi_i^m(M) \geq \pi_i^m(M-1),\ and$

$ii)\quad \pi_i^m(M) \geq \pi_i^n(M-1),\ and$

$iii)\quad \pi_i^m(M) \geq \pi_i^m(M+1),\ or\ \pi_i^n(M) \geq \pi_i^m(M+1),\ or\ both.$

The definition of RJV size stability, endogenously determined RJV size implies that not only outsiders may be not willing to join RJV, but also RJV insiders have an opportunity to block additional entrance if it harms their profits (thus, the definition contains the conditions of internal and external stability of an RJV of given size M).

Condition i) and the first part of condition iii) state, that the RJV insiders permit the additional entrance only in case this entrance increases the profits of insiders. According to condition ii) the Mth member prefers to stay in RVJ only if his profit as outsider with the RJV of the size M-1 is less than his profit as Mth insider. The second part of condition iii) describes the condition under which no outsiders want to enter RJV.

III. Third stage.

The firms decide about their R&D expenditures.

Recall that Atallah (2003) defines $k \in [0,1]$ as a leakage factor from RJV to outsiders on voluntary information sharing g. Again, in our model the optimization problems of insiders as well as outsiders depend on the government's strategic choice.

As before, τ is a tax rate, π_i^m is a profit of i[th] RJV insider, π_i^n is a profit of i[th] outsider.

y_i^m stands for production of i[th] RJV insider, y_i^n is a production level of i[th] outsider.

1) Government chooses direct R&D subsidies

Problem of outsiders:

$$\max_{x_i^n} \quad \pi_i^n = (1-\tau)*\left[\left[a - w*\sum_{i=1}^{T} y_i - r + Zx_i^n + kgZX^m\right]y_i^n - u(x_i^n)^2\right] \tag{8}$$

As before, insiders decide jointly on their R&D investment. Optimization problem for insiders is:

$$\max_{x_1^m,\dots,x_M^m,g} \quad \sum_{i=1}^{M} \pi_i^m = \sum_{i=1}^{M} (1-\tau)*\left[\left[a - w*\sum_{i=1}^{T} y_i - r + Zx_i^m + gZX_{-i}^m\right]y_i^m - u(x_i^m)^2\right] \tag{9}$$

$$s.t \quad 0 \le g \le 1$$

2) Government chooses tax relieves

The optimization problem for outsiders is as following:

$$\max_{x_i^n} \quad \pi_i^n = (1-\tau)*\left[\left[a - w*\sum_{i=1}^{T} y_i - r + x_i^n + kgX^m\right]y_i^n - u(x_i^n)^2\right] \tag{10}$$

The maximization problem of insiders is:

$$\max_{x_1^m, \dots, x_M^m, g} \sum_{i=1}^{M} \pi_i^m = \sum_{i=1}^{M} \left[\left[a - w * \sum_{i=1}^{T} y_i - r + x_i^m + gX_{-i}^m \right] y_i^m - u(x_i^m)^2 \right]$$
$$s.t \quad 0 \leq g \leq 1 \qquad (11)$$

IV. Fourth stage.

The fourth stage contains the production decision of all firms (all firms decide separately, basing on own after-tax profit maximization). [Note that the profit functions of RJV insiders as well as outsiders are strictly concave and have a finite upper bound (the maximum exists).]

1) Government chooses direct R&D subsidies

All firms solve the profit maximization problem of the following form:

$$\max_{y_i} \quad \pi_i = (1-\tau) * \left[[p(Y) - c_i(\Gamma_i, Z)] y_i - ux_i^2 \right] \qquad (12)$$

2) Government chooses tax relieves

The after-tax profit functions will be different for insiders and outsiders since for the former the tax rate is equal to zero.

Then the optimization problem of outsiders is:

$$\max_{y_i^n} \quad \pi_i^n = (1-\tau) * \left[\left[a - w * \sum_{i=1}^{T} y_i - r + x_i^n + kgX^m \right] y_i^n - u(x_i^n)^2 \right] \qquad (13)$$

Optimization problem of RJV insiders is set up as follows:

$$\max_{y_i^m} \quad \pi_i^m = \left[\left[a - w * \sum_{i=1}^{T} y_i - r + Zx_i^m + gZX_{-i}^m \right] y_i^m - u(x_i^m)^2 \right] \qquad (14)$$

We have specified all stages of the game. In the next section we describe the subgame perfect equilibrium of the game. For this purpose we solve the game starting from the last stage (optimal production decision).

PRODUCTION DECISIONS AND CHOICES OF PRIVATE R&D INVESTMENT

We start from the **fourth stage** at which the firms decide non-cooperatively about their outputs, y_i.

1) Government chooses direct subsidies

Rewrite explicitly the condition (12)

$$\max_{y_i} \quad \pi_i = (1-\tau)*\left[\left[a - w*\sum_{i=1}^{T} y_i - r + Z*x_i + \Gamma_i\right]y_i - ux_i^2\right] \tag{15}$$

Recall that we've defined for RJV insiders $\Gamma_i^m = gZX^m_{-i}$, and for outsiders $\Gamma_i^n = kgZX^m$. Substituting these two conditions into f.o.c. of (15) gives optimal production decisions for RJV insiders and outsiders:

$\forall i = 1, M$

$$y_i^m = \frac{a - r + Zx_i^m(N(1+kg) + M(1-g) + g) + ZX_{-i}^m\left[-1 + g(2 + N(1-k))\right] - ZX^n}{(T+1)w}$$

$\forall i = M+1, T$

$$y_i^n = \frac{a - r + TZx_i^n - ZX_{-i}^n + ZX^m(-1 + gM(k-1) + g(k+1))}{(T+1)w} \tag{16}$$

2) <u>Government chooses tax reliefs for RJV members</u>

If government chooses tax reliefs we have the solutions equivalent to the Atallah's model since (1-τ) multiplier of profit function is neglected in finding optimal y_i from the first order conditions.

$\forall i = 1, T$

$$y_i = \frac{a - r + Tx_i - X_{-i} + T\Gamma_i - \sum_{j \neq i}^{T} \Gamma_j}{(T+1)w} \tag{17}$$

Then substituting $\Gamma_i^m = gX^m_{-i}$ for RJV insiders and $\Gamma_i^n = kgX^m$ for outsider into (17) we obtain, respectively, the following production decisions:

$\forall i = 1, M$

$$y_i^m = \frac{a - r + x_i^m (N(1+kg) + M(1-g) + g) + X_{-i}^m \left[-1 + g(2 + N(1-k))\right] - X^n}{(T+1)w}$$

$\forall i = M+1, T$

$$y_i^n = \frac{a - r + Tx_i^n - X_{-i}^n + X^m(-1 + gM(k-1) + g(k+1))}{(T+1)w} \tag{18}$$

Now, we turn to the solution of the **stage 3**. The choice of private R&D investment levels and the level of information sharing is determined by information leakage parameter, k.

Proposition 1. a) For a given RJV size $M = [2,...,T]$ ***and for given level of public R&D Z there exists a critical value information leakage parameter,***

$$k_c^1 = \frac{2MN - N - 2M + 2M^2 - M^2 N}{N(2M + 1 - M^2)}$$ ***, such that:***

i) ***for all k<k^1_c the RJV insiders choose full information sharing (g=1);***

ii) ***for all k> k^1_c the RJV insiders choose no information sharing (g=0);***

iii) ***for k= k^1_c there is an internal solution about information sharing,*** $g \in (0,1)$.

b) For a given RJV size $M = [2,...,T]$ and there exists a critical value information leakage parameter,

$$k_c^2 = \frac{MN + M - N - 1}{MN}$$ ***, such that:***

i) for all k<k_c^2 the RJV insiders choose full information sharing (g=1);

ii) for all k> k_c^2 the RJV insiders choose no information sharing (g=0);

iv) for k= k_c^2 there is an internal solution about information sharing, $g \in (0,1)$.

The proof of Proposition 1 is in Appendix 3.

In the tables 1 and 2 the critical levels of information leakage parameters are presented for different values of quantities of RJV members (M) and outsiders (N).

Table 1. Critical levels of information leakage parameter (k_c^1) at the presence of public R&D

	N									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
M										
2	3	1	0.333	0	-0.2	-0.33	-0.43	***-0.5***	-0.56	-0.6
3	-4	-1	0	0.5	0.8	1	***1.143***	1.25	1.333	1.4
4	-2.14	-0.43	0.143	0.429	0.6	***0.714***	0.796	0.857	0.905	0.943
5	-1.71	-0.29	0.19	0.429	***0.571***	0.667	0.735	0.786	0.825	0.857
6	-1.52	-0.22	0.217	***0.435***	0.565	0.652	0.714	0.761	0.797	0.826
7	-1.41	-0.18	***0.235***	0.441	0.565	0.647	0.706	0.75	0.784	0.812
8	-1.34	***-0.15***	0.248	0.447	0.566	0.645	0.702	0.745	0.778	0.804
9	***-1.29***	-0.13	0.258	0.452	0.568	0.645	0.7	0.742	0.774	0.8
10	-1.25	-0.11	0.266	0.456	0.57	0.646	0.7	0.741	0.772	0.797

Table 2. Critical levels of information leakage parameter (k_c^2) with tax reliefs strategy

	N									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
M										
2	1	0.75	0.667	0.625	0.6	0.583	0.571	***0.563***	0.556	0.55
3	1.333	1	0.889	0.833	0.8	0.778	***0.762***	0.75	0.741	0.733
4	1.5	1.125	1	0.938	0.9	***0.875***	0.857	0.844	0.833	0.825
5	1.6	1.2	1.067	1	***0.96***	0.933	0.914	0.9	0.889	0.88
6	1.667	1.25	1.111	***1.042***	1	0.972	0.952	0.938	0.926	0.917
7	1.714	1.2857	***1.143***	1.071	1.029	1	0.98	0.964	0.952	0.943
8	1.75	***1.3125***	1.167	1.094	1.05	1.021	1	0.984	0.972	0.963
9	***1.778***	1.3333	1.185	1.111	1.067	1.037	1.016	1	0.988	0.978
10	1.8	1.35	1.2	1.125	1.08	1.05	1.029	1.013	1	0.99

I should remind that the actual information leakage parameter's values (k) are bounded by interval [0,1]. Therefore, if k_c^1, k_c^2 are negative the RJV insiders always choose zero information sharing; if, on the other hand, k_c^1, k_c^2 are greater that 1 the RJV insiders always choose full information sharing.

Immediately we can see that:

$$\frac{\partial k_c^1}{\partial M} = \frac{2(-2MN + 2N - 1 + M^2 + 2M)}{(N(-2M - 1 + M^2))^2}$$

a) *and*

$$\frac{\partial k_c^1}{\partial N} = \frac{2M(-1 + M)}{(N^2(-2M - 1 + M^2))}$$

may be positive as well as negative depending on the values of M and N.

b) $\frac{\partial k_c^2}{\partial M} = \frac{(\mathrm{N}+1)}{(\mathrm{M}^2\mathrm{N})} > 0$ *and* $\frac{\partial k_c^2}{\partial N} = -\frac{(\text{-}1+\mathrm{M})}{(\mathrm{MN}^2)} < 0$, that is, critical level of information leakage grows with RJV size and falls with the number of outsiders.

According to Proposition 1, the choice of optimal private R&D levels, x_i^m for RJV insiders and x_i^n for outsiders, depend on actual level of information leakage parameter k. Therefore, substitution of the optimal value of information sharing parameter g=1 and g=0 to T f.o.c. for private R&D levels gives the following relations that determine the levels of private R&D activities.

1) Government chooses direct financing.

If $g(k_c^1) = 1$

$$x_i^n = \frac{((\mathrm{N}+\mathrm{M})*(\text{-}2\mathrm{ZM}^2\mathrm{Nk}+\mathrm{ZM}^2\mathrm{k}^2\mathrm{N}-\mathrm{uN}+\mathrm{ZM}^2\mathrm{N}-\mathrm{uM}-\mathrm{u}+\mathrm{ZM}^2-\mathrm{ZM}^2\mathrm{k})*(\mathrm{a}-\mathrm{r}))}{\gamma}$$

$$x_i^m = \frac{((\mathrm{a}-\mathrm{r})*(\text{-}1-\mathrm{N}+\mathrm{Nk})*(\text{-}\mathrm{NZ}+\mathrm{uN}-\mathrm{ZM}+\mathrm{uM}+\mathrm{u})*\mathrm{M})}{\gamma} \qquad (19)$$

where

γ=(-Z^2M^3-u^2-u^2N^3-3u^2N^2-Z^2M^3N-Z^2M^2N+2ZM^3u+3ZM^2u-$Z^2M^2N^2$-3u^2N^2M-3u^2M^2N-6u^2MN+uNZ+uZM-3u^2N+$Z^2M^2N^2k$+uN^2Z+Z^2M^3kN+ZM^2N^3u+ZM^3N^2u-2ZM^2N^3ku+3ZM^2uN^2+2ZM^3uN+5ZM^2uN-2ZM^3N^2ku-4ZM^2N^2ku-2ZM^3Nku-2ZM^2Nku+uN^2ZM+3uNZM+$ZM^2N^3k^2u$+$ZM^3N^2k^2u$+$ZM^2N^2k^2u$-u^2M^3-3*u^2M^2-3u^2M)

When $g(k_c^1)$**=0**

$$x_i^n = \frac{((N + M) * (uN - ZN - Z + u + uM) * (a - r))}{\varphi}$$

$$x_i^m = \frac{((N + 1) * (uN - ZN - MZ + uM + u) * (a - r))}{\varphi} \tag{20}$$

where

$$\varphi = (-ZN^3u+u^2N^3+3u^2N^2+Z^2N^2-4ZN^2u+3u^2N^2M-2MZN^2u-5MZNu+3u^2N-2M^2ZNu+MZ^2N+3u^2NM^2+6u^2NM+Z^2N-4ZNu+u^2+u^2M^3+MZ^2-2MZu-M^3Zu-2M^2Zu-uZ+3u^2M^2+3u^2M)$$

2) Government chooses tax reliefs.

If $g(k_c^2)=1$ then the R&D investment of the i[th] RJV insider (i=[1,M]) is determined by (21), and the R&D investment of the i[th] outsider (i=[M+1,T]) is described by (22).

$$x_i^m = \frac{-M((k-1)N-1)(-M-N+u(1+M+N))(a-r)}{u^2(1+M+N)^3 - M^2(M+N)(-1+(-1+k)N) - u(1+M+N)(N+M(1+N)+M^2(2-2(-1+k)N+(-1+k)^2N^2))} \tag{21}$$

$$x_i^n = \frac{-(M+N)(-(u(1+M+N))+(-1+k)M(-1+(-1+k)N))(a-r)}{u^2(1+M+N)^3 - M^2(M+N)(-1+(-1+k)N) - u(1+M+N)(N+M(1+N)+M^2(2-2(-1+k)N+(-1+k)^2N^2))} \tag{22}$$

When $g(k_c^2)=0$, the optimal levels of private R&D of RJV insiders and outsiders are determined as follows:

$$x_i^m = \frac{(1+N)(-M-N+u(1+M+N))(a-r)}{(1+N)(M+N)+u^2(1+M+N)^3 - u(1+M^3+4N+4N^2+N^3+2M^2(1+N)+M(2+5N+2N^2))} \tag{23}$$

$$x_i^n = \frac{(M+N)(-1-N+u(1+M+N))(a-r)}{(1+N)(M+N)+u^2(1+M+N) - u(1+M^3+4N+4N^2+N^3+2M^2(1+N)+M(2+5N+2N^2))} \tag{24}$$

Next two stages are solved with simulations. Since I want to take the model of Atallah (2003) as a benchmark for comparison for my results, I will use the same values of T=10, a=1000, r=60 and u=50. Also, I consider tax rate of 25% which is consistent with Ukrainian fiscal legislation.

C h a p t e r 5

RJV SIZE AND VOLUNTARY INFORMATION SHARING DETERMINATION AND THE CHOICE OF GOVERNMENT'S STRATEGY

The size of RJV (M) and voluntary information sharing between its members (g) vary with information leakage parameter (k) value. Tables 3, 4 and 5 show endogenously determined M and g for different degrees of relevance of public R&D; table 6 presents the choices under tax reliefs strategy of government. The RJV sizes were determined so as to satisfy the *Definition* of RJV stability, non-negativity of private R&D outputs constraint ($\forall\ i \in [1,T]:\ x_i \geq 0$), and positivity of the levels of production constraint ($\forall\ i \in [1,T]:\ y_i > 0$). In the case when more than one value of M satisfy all the conditions mentioned above, the highest value is chosen (higher value of M brings higher profit for RJV insiders).

1) The government chooses direct financing

Table 3. RJV size and voluntary information sharing level (Z=1)

T=10 τ=0.25 Z=1											
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
M	8	8	8	7	7	7	7	8	10	0*	0*
g	1	1	1	1	1	1	1	1	1	N/A**	N/A**

Table 4. RJV size and voluntary information sharing level (Z=1.5)

T=10 τ=0.25 Z=1.5											
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
M	8	8	8	7	7	6	7	8	9	10	0*
g	1	1	1	1	1	1	1	1	1	1	N/A**

Table 5. RJV size and voluntary information sharing level (Z=2)

T=10 τ=0.25 Z=2											
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
M	8	8	8	7	7	6	7	7	9	10	0*
g	1	1	1	1	1	1	1	1	1	1	N/A**

* No M=[2,10] satisfies all conditions of optimal RJV size simultaneously. Moreover, for all M=[2,10] the condition ii) of definition of the stability of RJV size is not fulfilled (for all M, a firm has higher profit staying out of RJV of the size (M-1) than entering the RJV as M^{th} insider). Therefore, I conclude that there are no firms willing to cooperate.

** Since there is no cooperation between firms we can not define the voluntary information sharing level

2) Government chooses tax reliefs.

Table 6. RJV size and voluntary information sharing level (full profit tax exemption for the RJV insiders)

T=10 τ=0.25											
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
M	6	6	6	6	6	7	7	8	10	10	10
g	1	1	1	1	1	1	1	1	1	1	1

I should mention also that setting tax rate equal to zero provides the same results as in Atallah's (2003) model. The difference between the models with and without taxation lies only in the choice under k=1. In a presence of tax reliefs, when k=1 (so the benefits from R&D activities coordination and voluntary information sharing gained by RJV insiders are fully available for outsider as well) all firms decide to cooperate in order to get access to tax reliefs. In Atallah's model for k=1 M is equal to 2 and g=0.

I have also checked the stability of optimal number of RJV insiders for tax reliefs lower than full tax exemption. I considered the cases when tax rate for RJV-insiders constituted 0.05, 0.1, 0.15, 0.2, fixing tax rate equal to 0.25 for outsiders. The lower tax reliefs did not change the optimal choice of the number of RJV-insiders.

Now I turn to comparison of optimal RJV sizes under different regimes chosen by government and optimal RJV size would be chosen without government intervention (see also Figures 1.1-1.3 and Figures 2.1-2.3 in Appendix 4).

For low levels of information leakages (k=[0,0.4]) the RJV size M is greater for direct financing strategy of government than for tax reliefs strategy for all levels of Z. Both insiders and outsider benefit from public R&D. If information leakage is low the effect of insiders' R&D on outsiders' profits is small. So the main variable determining decisions is an after-tax profit. In the **absence** of tax reliefs the firms obtain less disposable profits (comparing with tax reliefs for RJV insiders regime) even if they cooperate. The way to maintain certain level of profitability lies in the higher coordination of R&D expenditures, so RJV size grows. The RJV insiders choose voluntary information sharing level g=1.

For intermediate levels of k, in case of low relevance of public R&D to industry specifics the size of RJV determined under direct financing strategy of the government is the same as under tax reliefs strategy. If the relevance of public R&D grows for intermediate and high levels of information leakage parameter, endogenously determined RJV size falls for direct financing strategy comparing with the tax reliefs strategy. Such result is intuitive. Highly relevant public R&D brings additional benefits for all firms in the industry. Consequently firms are less willing to cooperate because cooperation may limit the freedom of their choices, and fewer firms are willing to share information about their R&D results since it enhances competition even more. Also this result goes in line with Leahy's and Neary's (2004) finding that the cooperation should decrease in the presence of external sources of information.

Now we turn to the determining of the government's choice over available strategies (solve stage 1).

The choice of government depends on Z and ε (in other words, on total cost of public R&D). I consider ε to be equal 250. This figure is approximately 5.5% of average (aggregated for all possible outcomes) tax revenue. I consider tax rate to be 25% and if we take tax rate as a proxy of budget to GDP relation, 5.5% of tax revenue corresponds to approximately 1.35% of GDP. Thus, in the case of low relevance (Z=1) of public R&D output for industry specifics the cost of public R&D is approximately 1.35 % of GDP, while in case of highly relevant public R&D output (Z=2) the cost of public R&D is close to 2.7% of GDP.

Table 7 presents the resulting choices of government. In this table, choice "1" stays for direct financing and choice "2" stays for tax reliefs.

Table 7. The government's choice of R&D supporting strategy

Z=1	**ε=250**										
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Choice	1	1	2	2	2	2	2	2	1	1	1
Z=1.5	**ε =250**										
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Choice	1	1	1	2	2	2	2	2	1	1	1
Z=2	**ε =250**										
k	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Choice	1	1	1	1	2	2	2	2	1	1	1

The range of information leakage parameter's values for which the tax reliefs strategy is chosen narrows with the increase of public R&D relevance (Z) for the industry specifics. The higher is Z the higher are the profits in the industry (since the firms obtain the cheap source of unit cost reduction), especially comparing with the state of no public R&D. So, it becomes relatively more costly to provide tax reliefs. Also the decision of private firms on cooperation analyzed at the previous stage explains the choice of government between the available R&D support strategies. For the medium levels of information leakage parameter k, the endogenously determined RJV size is lower than for low of high levels of k. Then, for the government, the motivation to enhance cooperation dominates the willingness to increase R&D with direct public investment.

C h a p t e r   6

CONCLUSIONS, IMPLICATIONS AND FUTURE RESEARCH DIRECTIONS

The level of both private and public R&D in Ukraine remains threateningly low during the past decade. Since insufficient progress in R&D may harm economic growth, it is growingly dangerous to tolerate the present state at the field. The problem is that the demand of private firms for innovations grows very slowly. The literature on the topic basically indicates the necessity of government intervention.

However, the government's interests and priorities may appear more tactical than it is needed for efficient intervention into innovative process. In this thesis I develop the four-stage extensive game which is aimed to determine the interdependence of choices of government and private firms in the process of stimulating the overall R&D activities and the cooperation of private firms for R&D provision. As a basis for my model and the basis for comparison of results I take Atallah's (2003) three-stage extensive game in which the stability of cooperation of private firms for R&D provision is studied in connection with information leakage level. I treat Atallah's model as the state of nature with no government intervention. I assume the presence of government concerned with one-period treasury interests more than with the long-run strategic considerations. Also I assume no direct link between public and private research facilities. I also differentiate the public R&D output in accordance to its relevance to the industry specifics of unit cost reduction rather than in accordance to the physical amount of public R&D output. However, even highly relevant public R&D output is applicable only for those firms which have own R&D investments.

The results obtained are summarized in the rest of this chapter.

For a given size of RJV the level of private R&D investment and the level of voluntary information sharing depend on the relation of the actual level of information leakage to the critical level of information leakage. For any strategy chosen by government the critical level of information leakage is determined only by the number of RJV insider and outsiders in a particular industry and does not depend directly on level of tax reliefs or on the relevance of public R&D to private firms' unit cost reduction in a particular industry. However, since the size of RJV itself is a function of after-tax profits of private firms and the relevance of public R&D output, the critical levels of information leakage change with the change of government's strategic choice.

In the case the government chooses direct financing critical level of information leakage is not a monotone function of the RJV size and the number outsiders. It is explained with the difference in relevance of public R&D to private firms' unit cost reduction.

In the case of tax reliefs the critical level of information leakage increases monotonically with increase in RJV size and falls monotonically with the number of the firms which do not join research joint venture. Thus, for a given industry size the bigger RJVs should be more stable to the increase in actual information leakage level.

Introducing tax reliefs for the firms which cooperate in research joint ventures, the government generally doesn't change the endogenously determined size of RJV comparing with the choice of RJV size with no government regulation. The exception is the unique case when there is full leakage of information obtained in R&D process from RJV members to outsider. In this case the benefits of RJV insiders from coordination of their efforts are fully transferred to outsiders; thus, there is no incentive to block new entrance. The industry then ends with industry-wide cooperation in order to realize benefits from tax reliefs.

For a given level of information leakage, the size of RJV under presence of public R&D may differ from RJV sizes determined in the state of no government's intervention and the state when tax reliefs strategy is chosen by the government. The magnitude of the difference in RJV size is then determined by the degree of relevance of public R&D to the industry specifics.

For low levels of information leakages (k=[0,0.4]) the RJV size M is greater for direct financing strategy of government than for tax reliefs strategy for all levels of Z. Both insiders and outsider benefit from public R&D. If information leakage is low the effect of insiders' R&D on outsiders' profits is small. So the main variable determining decisions is an after-tax profit. In the **absence** of tax reliefs the firms obtain less disposable profits (comparing with tax reliefs for RJV insiders regime) even if they cooperate. The way to maintain certain level of profitability is higher coordination of R&D expenditures, so RJV size grows. The RJV insiders choose voluntary information sharing parameter g=1.

For intermediate levels of k, in case of low relevance of public R&D to industry specifics the size of RJV determined under direct financing strategy of the government is the same as under tax reliefs strategy. If the relevance of public R&D grows for intermediate and high levels of information leakage parameter, endogenously determined RJV size falls for direct financing strategy comparing with the tax reliefs strategy. Highly relevant public R&D brings additional benefits for all firms in the industry. Consequently firms are less willing to cooperate because cooperation may limit the freedom of their choices and fewer firms are willing to share their research results since it enhances competition even more.

The government choice between tax relief strategy and direct financing of R&D depends on the degree of relevance of public R&D to private firms' unit cost reduction in a particular industry and on the information leakage level. For a given set of possible levels of information leakage parameter $k \in [0,0.1,...,1]$ the higher is relevance the more frequent is a choice of direct financing strategy. The other result is that the increase in frequency of the choice of direct financing strategy comes from "below". With increase in relevance direct financing is chosen for wider range of low values of k, whereas for the higher values of k the shift in government's choice from tax reliefs strategy towards direct financing of R&D happens after k exceeds 0.7 for any of degrees of relevance examined. This effect is explained with the changes in RJV size for a given value of k but different degree of relevance.

The presence of tax-levying government in the majority of case examined lowers the private R&D investment. In the case of low relevance of public R&D to industry specifics the R&D output of RJV insiders is equal across the strategies of government for those levels of information leakage for which the RJV sizes are equal. The outsiders' R&D output is generally lower in case the presence of public R&D compared to the tax reliefs case. The effect of government's strategic choice on total private R&D expenditures, therefore, stays ambiguous.

Now I turn to the possible implication of result obtained. This implication relate to the economic agents willing to influence the choice of government.

In the introduction to this thesis I have mentioned the dissatisfaction of NUAS academicians with the level of budget financing. The results obtained may indicate a strategy of solving this problem. According to my results, if the representatives of non-profit research institutions want to obtain more budget financing they should either prove their results are highly relevant for the specifics of industries which happen to be a subject of main interest of the existing government, or (and this option is also a valuable instrument) contribute to lowering of information leakages, or both. So I would recommend the promotion of better patent and intellectual property rights protection. If the information leakage is low the firms whose entrance was blocked by existing RJV members, would seek for outside-of-industry sources of knowledge which would create additional pressure for public R&D creation.

The other possible implication may be a better forecast of would-come regulation at R&D field in case of increasing pressure of treasury interests on policy making process.

The possible future research includes both theoretical and empirical directions. At theoretical field, the changing of government choices in dynamic may be an interesting topic. Public R&D is often presented with fundamental scientific research which materializes in private firms' cost reduction only after several periods. Underperforming of public R&D may, therefore, be harmful for future profits and future tax revenues.

At the empirical field it should be useful to approve the effects implied by the model using the real world data.

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APPENDICES

Appendix 1

The Atallah's (2003) Model Setup[4]

- T identical firms sell a homogeneous output.
- Inverse demand function is given by equation:

$$p=a-wY,\ Y=\sum_{i=1}^{T} y_i,$$

where Y presents total output. Total output is a arithmetic sum of individual firms' outputs, y_i (i=1,T).

- Atallah defines the unit cost of firm i as:

$$c_i(\Gamma_i)\ =\ r-x_i-\Gamma_i$$

r is unit cost if R&D output is absent. x_i is a unit cost reduction provided by one unit of own-firm R&D output. According to the model, the own-firm R&D output gives one-to one reduction in unit cost of production. Γ_i stands for information received by a firm i. unit cost is assumed to be strictly positive ($r > x_i + \Gamma_i$).

- Γ_i is different for research joint venture insiders and for outsiders. Atallah assumes that the size of RJV is equal M<T, and N = T - M firms are outsiders. Then he defines the Γ_i functions:
  - for insiders:

$$\Gamma_i^m \equiv gX_{-i}^m,\qquad i=1,\ldots,M,$$

where X^m_{-i} is the total R&D output of RJV **without** the firm's i output; g – is voluntary information sharing parameter between RJV members, $g \in [0,1]$.

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[4] Atallah, Gamal. *Information Sharing and the Stability of Cooperation in Research Joint Ventures.* Economics of Innovation and New Technology 12, 2003, p.p. 531-554.

- for outsiders:

$$\Gamma_j^n \equiv kgX^m, \qquad j = M+1, \ldots, T$$
,

where X^m is the total R&D output of RJV; g – is voluntary information sharing parameter between RJV members, $g \in [0,1]$; k is an information leakage parameter (exogenous), $k \in [0,1]$

- Atallah defines the profit function of the firm as:

$$\pi_i = [p(Y) - c_i(\Gamma_i)]y_i - ux_i^2$$
,

where ux_i^2 is a dollar cost of x units of private R&D output.

Appendix 2

The List of Notations Used

T – total number of firms in the industry (all firms are assumed to be identical);

M ($M \leq T$) – the number of firms in the industry which cooperate in RJV for joint R&D investment (RJV insiders);

N ($N \leq T$; $N + M = T$) – the number of firms in the industry which do not enter RJV (outsiders);

x_i^m – R&D output of i^{th} RJV insider ($i = 1, 2, ..., M$);

x_i^n – R&D output of i^{th} outsider ($i = M+1, M+2, ..., T$);

y_i^m – level of production of i^{th} RJV insider ($i = 1, 2, ..., M$);

y_i^n – level of production of i^{th} outsider ($i = M+1, M+2, ..., T$);

Z – public R&D output: the degree of relevance of public R&D to the industry specifics in unit cost reduction (Z=[1,2], with Z=1 indicating irrelevance and Z=2 indicating high relevance);

r – unit cost of production without R&D;

u – the cost of one unit of private R&D output;

ε – unit cost of public R&D output;

τ – profit tax rate (τ=[0,1));

k – information leakage parameter ($0 \leq k \leq 1$);

g – voluntary information sharing level ($0 \leq g \leq 1$)

a, w – inverse demand function's parameters (due to identity of the firms, I assume the preferences over the products of all firms to be such that w=1);

$X^m = \sum_{i=1}^{M} x_i^m$ - total R&D output of RJV insiders;

$X_{-i}^m = \sum_{j \neq i}^{M} x_j^m$ - total R&D output of RJV insiders **except** the i[th] insider's R&D output;

$X^n = \sum_{i=M+1}^{T} x_i^n$ - total R&D output of outsiders;

$\Gamma_i^m = gZX_{-i}^m$ - unit cost reduction for i[th] RJV insider due to voluntary information sharing (if the direct financing strategy is chosen by government);
$\Gamma_i^m = gX_{-i}^m$ - unit cost reduction for i[th] RJV insider due to voluntary information sharing (if the tax relief strategy is chosen by government);

$\Gamma_i^n = kgZX^m$ - unit cost reduction for i[th] outsider due to leakage of the information which is voluntary shared by RJV insiders (if the direct financing strategy is chosen by government);
$\Gamma_i^n = kgX^m$ - unit cost reduction for i[th] outsider due to leakage of the information which is voluntary shared by RJV insiders (if the tax relief strategy is chosen by government);

1) $c_i^m = r - Zx_i^m - gZX_{-i}^m$;
2) $c_i^m = r - x_i^m - gX_{-i}^m$.
- unit cost functions of i[th] RJV insider in cases of 1) direct financing strategy of the government; 2) tax reliefs strategy of the government.

1) $c_i^n = r - Zx_i^n - kgZX^m$;
2) $c_i^n = r - x_i^n - kgX^m$.
- unit cost functions of i[th] outsider in cases of 1) direct financing strategy of the government; 2) tax reliefs strategy of the government.

π_i^m - after-tax profit of i[th] RJV insider;
π_i^n - after-tax profit of i[th] outsider.

Appendix 3
Proof of Proposition 1

a) To obtain the expression for critical level of k, I solve problems (8) and (9) and obtain T first order conditions for choice of the firms on own R&D expenditures and one f.o.c for voluntary information sharing parameter. In the optimum each of T f.o.c. for private R&D expenditures is set equal to zero. Each of T f.o.c is solved for corresponding x_i. The ex ante symmetry implies that in optimum $x_1^m = x_2^m = x_3^m = ... = x_M^m \;\; and \;\; x_{M+1}^n = x_{M+2}^n = x_{M+3}^n = ... = x_T^n$.

Substitution of first T f.o.c. to the T+1 f.o.c. for voluntary information sharing level gives the expression:

$$f_{T+1} = \frac{(\text{-}R(\text{a - r})^2(\text{TZ - u(T}+1))^2((1+\text{N})(\text{g}(1\text{ - M})\text{ - }1)\text{ - NM}(1\text{ - k})\text{g})\text{uMZ}}{\phi^2}$$

where R=**(2MN-N-2M-2MkN-kN+2M^2-M^{2}N+M^{2}kN)**

and ϕ is a function $\phi = y(M, N, Z, k, g, u, a, r)$.

The denominator is always positive.

Given the restrictions on g: $0 \le g \le 1$, the restrictions on k: $0 \le k \le 1$, and restriction imposed on M by proposition 1: $M \ge 2$, given also u and Z are positive, **((1+N)*(g*(1-M)-1)-N*M*(1-k)*g)** is always negative

Therefore, the sing of f_{T+1} is determined only by the sign of R.

R is positive if $k < \frac{2MN - N - 2M + 2M^2 - M^2N}{N(2M + 1 - M^2)}$. Then f_{T+1} is also positive for all values of g which means the profits of RJV insiders grow monotonically with growth in g. Then the RJV insiders choose g=1.

R is negative if $k > \frac{2MN - N - 2M + 2M^2 - M^2N}{N(2M + 1 - M^2)}$. Then f_{T+1} is also negative for all values g which means the profits of RJV insiders fall monotonically with growth in g. Then the RJV insiders choose g=0.

In case $k = \frac{2MN - N - 2M + 2M^2 - M^2N}{N(2M + 1 - M^2)}$ we have internal solution for g.

b) Obtained applying the same analysis as in a) to the problems (10) and (11).

Appendix 4
Graphical comparison of endogenously determined optimal RJV sizes under different regimes of government intervention and without government intervention

Figure 1.1

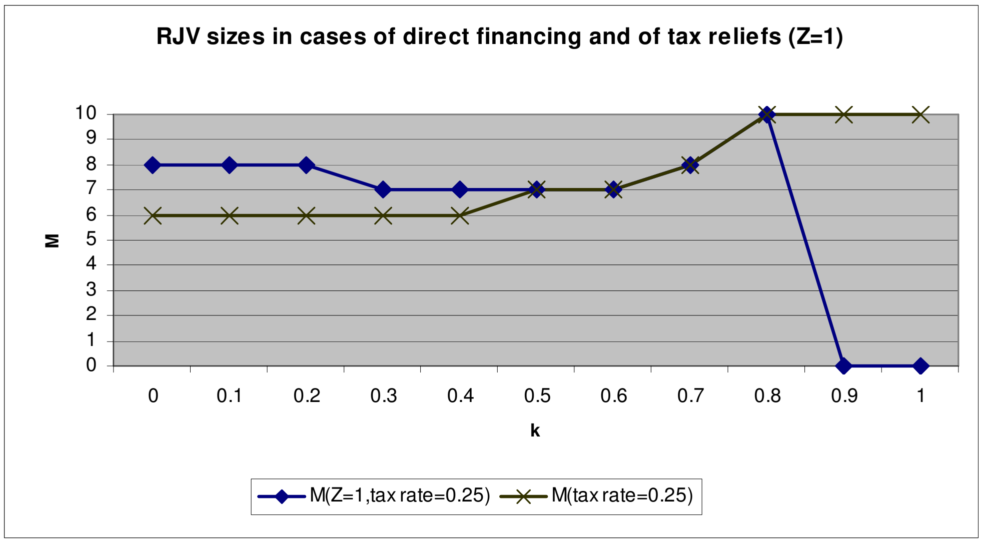

Figure 1.2

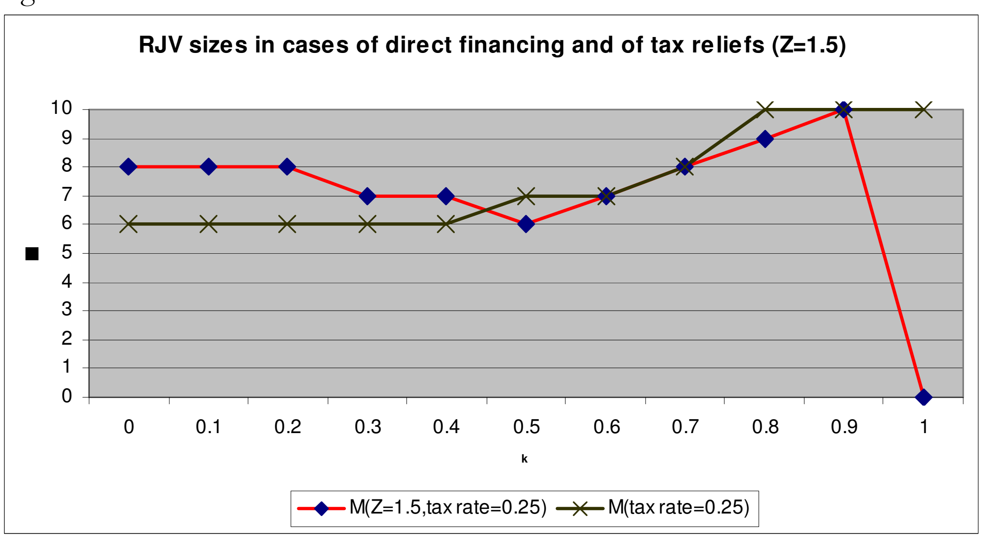

Figure 1.3

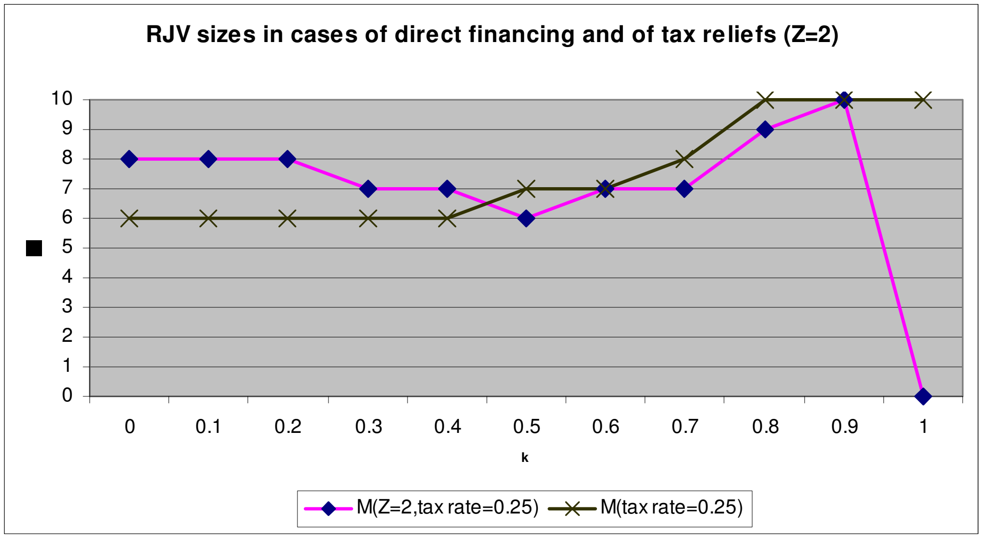

Figure 2.1

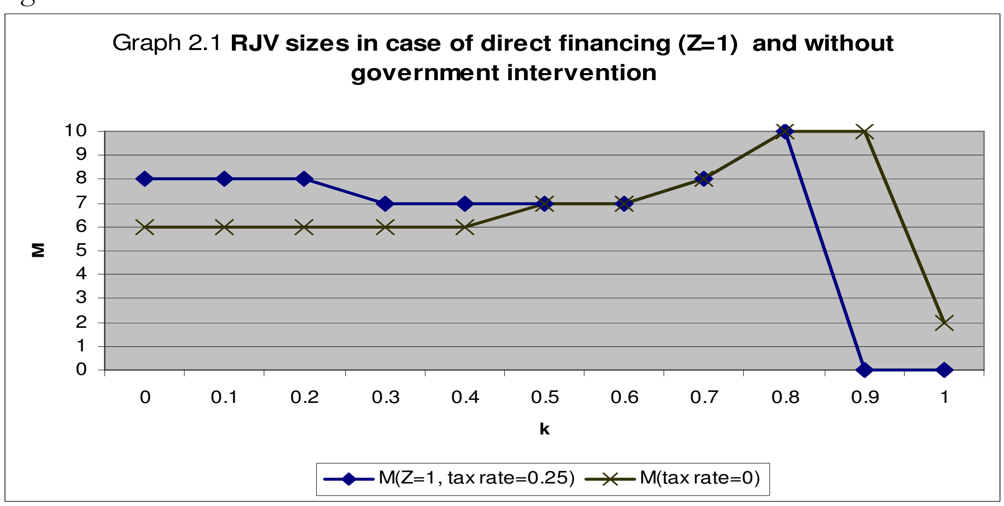

Figure 2.2

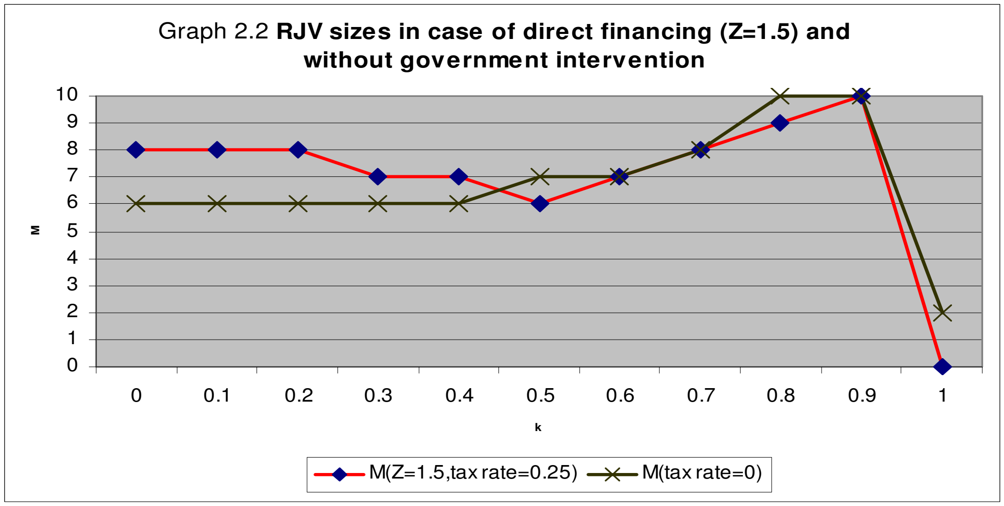

Figure 2.3