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R&D, Innovation and the Policy Mix

Marcel J.L. de Heide

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R&D, Innovation and the Policy Mix

O&O, Innovatie en de Policy Mix

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For my father.
How I wish he could see me now.
For Ludovico,
for showing me what is really important.
And for Tommaso,
because there is always something new in life.

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Chapter 1

The policy mix concept as a basis for R&D and innovation policy

Introduction, scope and main results of the thesis

At the end of the first decade of the twenty-first century, an unprecedented financial crisis hit the world economy. This crisis deepened an already downward cyclical trend, and subsequently initiated one of the most virulent recessions in decades (OECD 2010a). Stabilizing the world economy has required governments to act with great urgency and respond with drastic measures (OECD 2010a) (Commission of the European Communities 2010). These turbulent times however also indicate again the importance of policies aimed at creating stable and sustainable economic growth (OECD 2008). For the industrialized countries in the world, this implies that remaining competitive in the future demands not only intervention in (financial) markets and the way they function. It requires also increasing labour productivity levels by strengthening their research and innovation capacity. The limits of further capital deepening have been reached and future demographic changes and an ageing population will hinder increasing deployment of labour (Commission of the European Communities 2010).

The OECD and the European Commission have encouraged countries to adopt the concept of *policy mix* as a basis for long-term innovation driven growth strategies (OECD 2010b) (Commission of the European Communities 2010). This concept is rather new, and a clear, univocal and widely adopted definition is still lacking (Flanagan et al. 2010): "The concept in itself is seen as self-explanatory and unproblematic. [...] Imported from economic policy debates, the term implies a focus on interactions and interdependencies between different policies as they affect the extent to which intended outcomes are realized. The recent popularity of the term seems to reflect, then, an aspiration towards a more realistic approach to policy complexity. However, we argue that in practice the term is largely used to black box this complexity." Concerning the role of the policy mix concept in policy formulation, it is argued that (OECD 2010b): "[...] the task of policy makers is to develop an optimal mix of policies and instruments for stimulating innovation performance that takes into account possible positive and negative interactions among instruments. [...] In practice, given the uncertainties and limitations faced, the policy mix should be sufficiently good in terms of the overall net benefits."

In *Section 1.1* of this chapter we define the characteristics of the policy mix concept. We subsequently outline how the concept of policy mix supports the process of policy formulation in *Section 1.2*. We then describe in *Section 1.3* the current approach concerning the formulation of R&D and innovation policy, and its shortcomings with respect to designing a policy mix. In *Section 1.4* we present the results of our research, and how they contribute to the further implementation of the concept of policy mix. In *Section 1.5* we summarize the implications of our result for the current instruments aimed at strengthening the innovation system.

1.1 Characteristics of the policy mix

For our definition of the concept of policy mix, we build on (Boekholt et al. 2006), (Flanagan et al. 2010) and (OECD 2010b):

Definition 1.1 *A policy mix is the combined set of interacting policy instruments of a country addressing R&D and innovation.*

Implementation of a policy instrument results from a government intervention originating from a public policy. We define public policy and policy instruments based on (Schram et al. 2004) and (Howlett and Ramesh 2003)) as:[1]

Definition 1.2 *A public policy is a deliberate plan of action by a government to guide decisions, and achieve rational outcomes which are set out in broad objectives and goals.*

Definition 1.3 *A policy instrument (also called measure or tool) translates the plan of action and its accompanying objectives and goals as defined by a public policy into concrete interventions.*

The interaction of measures as mentioned in the definition is an important aspect of the policy mix concept. The impact of an instrument addressing R&D and innovation is influenced by other measures belonging to the mix. In other words: the effect of a specific measure is determined by its own characteristics, and by the impact of other instruments with which it interacts. This interaction occurs in different ways: instruments could for example complement each other, strengthen each other's impact, or act as substitutes.

The policy instruments belonging to the policy mix are limited to those with the following characteristics:

- *They stem from a wide variety of different policies, which in some way refer to R&D and innovation.* The advanced economies in the world all have implemented public policies aimed at enhancing prosperity, stability and growth. A subset of all the instruments originating from these policies addresses R&D and innovation, and therefore belongs to the policy mix. Obvious examples are: macro-economic policy, education and research policy, innovation policy, and labour policy. But also other policies on for example defence and health generally cover certain aspects of research and innovation.
- *They address different phases of the R&D and innovation process:* from knowledge creation to knowledge transfer to the translation of knowledge into

[1] There are already well-known definitions on policy in the literature. These definitions are however inadequate within the framework of this research, as they do not discern policy instruments clearly from public policy.

market applications. The scope of the instruments belonging to the policy mix is limited to what is allowed under the *EU State Aid rules* (Commission of the European Communities 2006) and *WTO Disciplines on Subsidies*, and refers to the creation of new knowledge and new applications.

- *They cover generic as well as specific R&D and innovation within specific technologies or sectors.*
- *They focus on different actors involved in R&D and innovation* such as (new or existing) firms and the (public) research infrastructure, or on collaboration between the actors.
- *They offer different modalities of support* such as various types of funding, taxation, regulation and providing of information.

In order to describe and cluster instruments that constitute a policy mix, it is essential to adopt a framework that allows for an assessment of their characteristics, the actors involved and their interaction. Early efforts in research on policy have resulted in different methods for describing instruments, such as in (Clark 1985) and (Llerena and Avadikyan 2005). They have however never been widely adopted by policy makers involved in R&D and innovation policy because of their inability to capture the diversity and complexity of especially recent measures. Specific valuation criteria for policy instruments addressing the process of innovation and research have been suggested by for example (Elmore 1987) and (Schneider and Ingram 1990). Also their approach has not been embraced, as the identified categories are so large that they are not mutually exclusive (Linder and Peters 1990).

The approach suggested in this study builds on the concept of *System of Innovation* (SI) (Nelson 1993), (Lundvall 1992).[2] According to the SI approach, innovation is an interactive, non-linear process in which firms interact with a manifold of other organizations (e.g. research institutes, customers, authorities, financial organizations) and institutions (e.g. Intellectual Property Rights, regulations, culture). The framework enables the identification of the actors involved in R&D and innovation, and the analysis of their role and functioning, based on the assessment

[2] In practice, our approach to describe the policy mix is a simplification of the approach suggested in (Flanagan et al. 2010) and (OECD 2010b).

of the flows of funding and knowledge between the stakeholders (Barber 2003). The SI approach has been adopted by many policy makers as a basis for policy formulation (Klein Woolthuis et al. 2005). Our framework gives a representation of the relevant actors in the system, and their role in the research and innovation process. It introduces three dimensions that allow for the unambiguous clustering and description of instruments:

- *Actor*, which refers to the targeted group of the measure: *Industry*, *Research Institutes* (public as well as private) and *Higher Education* (i.e. universities and polytechnics).[3]
- *Objective*, which describes the phase of the R&D and innovation process that is addressed by the measure:[4]
  - *Education and Training of Human Resources*, as people are "carriers" of knowledge, and therefore play a role in the transfer of knowledge.
  - *Knowledge Creation* (i.e. R&D oriented measures).
  - *Knowledge Transfer and Application* (i.e. innovation oriented measures including creation of spin-offs).
- *Modality*, which refers to the functionality of the measure (i.e. how it accommodates cost for R&D and innovation):
  - *Regulations* such as Intellectual Property Rights (IPR), regulations addressing functioning and interaction of actors to allow cooperation (between firms and other actors of the innovation system) and collaboration (between firms)

[3]It should be noted that certain instruments focus on several actors (such as tools aimed at supporting cooperation and collaboration), or just a selection within groups of actors (such as measures addressing specific technologies or sectors).

Bridging Institutes are not identified as *Actor*, but as an instrument addressing actors by providing advice for example concerning *Knowledge Transfer and Application*.

[4]Important to mention within the framework of this dimension are measures providing basic funding for institutions (such as universities). The objective of these measures is equal to the objective of the corresponding organizations.

– *Taxation* such as fiscal measures offering a tax relief on turnover or profit from products resulting from R&D and innovation.

– *Direct Funding* such as subsidies and grants, but also basic funding. It involves a transfer of actual funds, which are not recoverable by the government from the actors.

– *Indirect Funding* such as access to research infrastructure, vouchers, rebate on social insurance, and advice. With this kind of support a government tries to compensate for the cost not by transferring funds, but by providing in kind resources.

– *Loans and Guarantees* involves an actual funds, but which have to be reimbursed by the actors to the government (sometimes with a certain interest rate).

1.2 An optimal policy mix: effectiveness and efficiency

The concept of policy mix originates from economic policy literature from the 1960's. It refers to the coordination of fiscal and monetary policy to attain the economy's macro-economic goals (Friedman 1968). The concept has more recently been adopted by international organizations, such as the OECD and the European Commission, when advising governments on their research and innovation policies (OECD 2010b).

When intervening to strengthen the innovation capacity of a country, governments are looking for: "[...] the cheapest one (i.e. measure) to implement, which least distorts the market whilst still achieving its objective." (Flanagan et al. 2010) The policy mix concept now provides policy makers with a conceptual framework that allows them to consider the design of an *optimal* set of instruments. Optimal in this respect refers to *effectiveness* in initiating R&D and innovation, and subsequently create sustainable economic growth, and *efficiency* concerning the cost of the intervention. Optimizing the policy mix towards higher levels of effectiveness and efficiency is referred to as *coordination of measures* (Boekholt et al. 2006).

The coordination in policy design in order to compose an optimal set of instruments indicates a change from the past. In the framework of a more traditional approach towards policy formulation, the innovation system is supported by different dedicated research, education and innovation policies and instruments addressing specific but single market or system imperfections. The impact of, and interaction with other instruments is hitherto not considered. As a consequence, the policy mix effective in a country is as a *product* of previously developed coexisting instruments, which interact de facto (Boekholt et al. 2006).

There are clear differences in the design and scope of the existing policy mixes amongst countries. This is caused by for example the structure of the economy and its industry, the role of universities and research institutes, the interaction between the actors involved in research and innovation, and the process of policy making. An average sized EU member state such as the Netherlands has about a hundred instruments addressing research performed by actors from the (public) research infrastructure, and about a hundred measures addressing R&D and innovation conducted by industry.[5]

Further implementation of the policy mix concepts will change the set of instruments into a *construct* resulting from an intentional combination of policy instruments shaped ex ante by policy-makers. The rationale for coordination of instruments towards higher levels of effectiveness and efficiency is the apparent difference in impact between publicly funded research and privately funded R&D. The contribution of R&D and innovation to productivity and growth has been established by for example (Jones 2002) (Mankiw et al. 1992) (Baumol 2002). Results of empirical analysis however are ambiguous with respect to the effectiveness of instruments supporting (industry-oriented) research, and give a negative view concerning their efficiency. In (David et al. 2000) it is argued that "[...] econometric results tend to be running in favour of findings of complementarity between public and private R&D investments, but that reading is simply an unweighted summary based upon some 30 diverse studies: it is not a conclusion derived from a formal statistical meta-analysis." The results in (González et al. 2006) suggest that: "[...] subsidies stimulate R&D activities, and [...] some firms would stop performing these activities in their absence, but also reveal that most actual subsidies go to

[5] Source: www.nlinnovatie.nl and www.nwo.nl. Inventarisation of June 2011.

firms that would have performed R&D otherwise. In these firms, however, subsidies are found to increase R&D spending with no crowding out of private funds." This last conclusion is refuted in (Wallsten 2000), which concludes, based on an assessment of the SBIR programme that: "[...] grants crowd out firm-financed R&D spending dollar for dollar."[6] The decisive argument for further coordination of instruments is given in (David et al. 2000), where it is concluded that: "The burden of econometric findings concerning the productivity growth effects of R&D seems to be that there is a significantly positive and relatively high rate of return to R&D investments at both the private and social levels. Yet, quite generally, privately funded R&D in manufacturing industries is found to yield a substantial premium over the rates of return from own productivity improvements derived from R&D performed with government funding."

1.3 Further implementation of the policy mix concept

The current practice concerning policy formulation

The rationale for government intervention supporting research has been established by (Nelson 1959) and (Arrow 1962). They argue that the difficulty of selecting potentially marketable research and the uncertainty with respect to its successful outcome limits incentives of industry to conduct R&D. The indivisible and nonexcludable character of basic research, and the fact that its results are almost freely available in scientific publications further enhances the tendency to under-invests in R&D. Since such research is socially beneficial there is a strong argument for government to fund this investment.

This market failure argument has been further sophisticated by considering the different types of spillovers that occur during the R&D and innovation process. These spillovers refer according to (Jaffe 1996) to: (a) the appropriability of knowledge (for example through imitation), the benefits to users of the innovation not captured in its price, and (b) to network spillovers (when successful innovation relies

[6]SBIR: "Small Business Innovation Research" programme. See www.sbir.gov.

upon developments in related technologies) .

The arguments above constitute the rationale for intervention in public sector science and for financial support in the early stages of industrial research. In the latter case, the argument is that R&D, particularly when it is further from the market (i.e. 'pre-competitive' research), merits investment, but that development activities should be left to the market (Georghiou et al. 2003).

The concept of market failure remains the guiding principle for countries as the rationale for government intervention (Martin and Scott 2000). But this approach has limitations when applied as a basis for the formulation of the policy mix. Market failure as such is very difficult to demonstrate, and even more difficult to translate into policy and supporting measures. Moreover, by applying the market failure argument, it is not possible to address the complex process of innovation as a whole. Instead it is limited to sub-problems within this bigger entity. The basis for policy formulation in most countries is therefore the already mentioned concept of System of Innovation.

Within the framework of the SI approach, innovation is considered an interactive, non-linear process in which firms interact with a manifold of other organizations. By analyzing the interactions between the actors in the system, the SI approach allows for the identification of actors and mechanisms that lead to successful innovation. It also enables the detection of issues that hinder the creation and application of knowledge,that are left untouched by the market failure approach. As a result, it is argued that "[...] it offers a greater potential for identifying where public support should go. This model is more helpful for policy makers from a practical and specific point of view." (Edquist et al. 1998). By introducing this alternative view on innovation, the SI approach has provided a basis for the identification of new rationales for government intervention, the so-called system failures.

In practice, the SI model is used by policy makers in the process of policy formulation as a basis for the comparison of the actors, interactions, and flows of knowledge and funding of their system with those of their peers. These peers are normally best practice examples of systems in other countries. Based on this assessment, strengths and weaknesses (typified as system failures) of their innovation system are identified, which are then addressed by the policy with its accompanying specific instruments.[7] When formulating policy and instruments, countries seem to adopt the main features of policy and measures implemented by countries identified as best-practices addressing similar system imperfections. This tendency is reflected in the many institutionalized consultative bodies initiated by the OECD and EC focussing on policy learning.

SI approach as a basis for coordination of tools

Optimizing the policy mix is about defining a set of instruments that addresses the right actors and supports the appropriate objectives, such that it is effective in initiating R&D, and efficient with respect to the contribution required. Based on an analysis of the discussions on the formulation of public policy within the framework of the many institutionalized consultative bodies initiated by the OECD and EC, we conclude that the countries that have adopted the policy mix concept seem to focus on two major policy questions when coordinating their instruments.[8]

The first issue of concern for the countries adopting the policy mix concept is which combination of instrument (i.e. which modalities) to use. In order not to impede future economic recovery, most countries have decided to further rationalize their national budgets. The consequential retrenchments of public expenditure requires them to consider the efficiency of instruments in initiating R&D and innovation.

[7] In (Klein Woolthuis et al. 2005) eight of such system failures are identified: (1) Infrastructural failures, referring to the physical infrastructure that actors need to function and the science and technology infrastructure. (2) Transition failures, which involve the inability of firms to adapt to new technological developments. (3) Path dependency failures, which refer to the inability of complete systems to adapt to new technological paradigms. (4) Hard institutional failure resulting from the framework of regulation and the general legal system. (5) Soft institutional failure being failures in the social institutions such as political culture and social values. (6) Strong network failures being the blindness that evolves if actors have close links and as a result miss out on new outside developments. (7) Weak network failures, referring to the lack of linkages between actors as a result of which insufficient use is made of complementarities, interactive learning, and creating new ideas. (8) Capabilities' failure which refers to the phenomenon that firms may lack the capabilities to learn rapidly and effectively and hence may be locked into existing technologies, thus being unable to jump to new technologies.

[8] See www.proinno-europe.eu and www.ec.europa.eu/invest-in-research (and especially www.ec.europa.eu/invest-in-research/coordination/coordination01_en.htm).

The second issue is whether a government, in order to effectively enable future sustainable economic growth, should implement a generic set of instruments, adopt a thematic policy focus, or embrace a combination of both policy settings. In case of a thematic policy, a government identifies and selects specific sectors or technologies, and implements a dedicated set of instruments directing support towards this specific target. In this way, a government tries to create additional growth by focussing its limited resources on specific sectors or technologies that have the potential to create high returns. The subsequent question is how to identify the most promising specific technology field or sector. A government will conversely implement a generic policy mix if it assumes that the innovation system will either create new scientific or technological paradigms by itself, or adopt that technology which is most promising for growth. Either way, the government feels that it is not able, or not in the position, to identify the appropriate sector or technology field.

We argue that the currently common methodology for policy formulation (i.e. the SI approach) is not appropriate for the design of an optimal policy mix. It is subsequently also not able to address the main policy questions as formulated above. The SI approach allows for the analysis of flows of funding and knowledge between the actors of the system. But because of its basic principles, it does not provide insight in the behavior of the actors (and the underlying rationale), resulting from intervention by the government in the market place. As a consequence, with the help of the SI approach, it is not possible to assess the effectiveness of instruments in initiating research. It also does not allow for the consideration of the efficiency of tools, as it is not possible to evaluate the contribution required to start R&D and innovation.

1.4 Main results of the thesis: contribution to the policy mix concept

With this thesis we contribute to further implementation of the policy mix by addressing the issues that dominate the current discussion on the formulation of public policy: which instruments to select, and what should be there scope.

Theoretical framework for the selection of instruments

Analysis of the literature reveals that little is known about the performance of a single instrument (i.e. effectiveness and efficiency) in comparison to other tools (Boekholt et al. 2006). It is even argued that "[...] from a purely logical and technical point of view, policy tools appear to be perfectly interchangeable." (Landry and Varone 2005) Theoretical research on policy formulation focusses on the impact of measures enabling collaboration in research between firms, in combination with subsidies and generic tax measures (Hinloopen 2001) (Spencer and Brander 1983) (Inci 2008). Empirical research, such as (Guellec and De La Potterie 2003), addresses substitution effects between government funding and tax incentives. Policy evaluations seem limited to individual measures, and do not address a set of instruments (Flanagan et al. 2010).

With no methodological framework to guide the process of policy formulation, and no empirical basis for decision making, we see that: "The choice of which instrument to use to put a decision into effect is often no less contentious than the decision itself and is very much the subject of discussion, deliberation, and dispute amongst subsystem members active in the policy process." (Howlett and Ramesh 2003)

We define a theoretical framework for the selection of instruments supporting industry-oriented R&D and innovation. Because of the complexity of the policy mix concept, we are not able to address all of its the dimensions as identified in our model. We limit our scope to industry-oriented research and innovation. Moving further towards innovation driven growth requires a change in behavior from the actors of the innovation system. It involves the creation of renewal within the economy: in technologies, products and markets. Industry has a fundamental role in instigating this change.

The environment in which firms conduct research has changed dramatically in the recent decades. As a result, firms have changed the way R&D activities are organized, implemented, and managed (OECD 2010b). As an example, due to increasing global competition, the market position of firms is constantly challenged. Firms subsequently have reconsidered their approach towards research and adopted a more result-oriented R&D strategy that supports their overall strategic objectives (Chesbrough 2003) (Coombs et al. 2001). For pre-competitive research and knowledge, they consequently rely more on more on the results from the public research infrastructure (Chesbrough 2003) (OECD 2001).[9]

Another important driver for change is the increased complexity of the different stages of the innovation process, and the shortened time-to-market for new products and services. This induces firms to collaborate in R&D with the other actors from the innovation system, as they are not able to maintain in-house all the required competencies (Chesbrough 2003).

In order to address the current practice concerning industry-oriented R&D and innovation, we adopt a series of specific assumptions concerning the innovation process. These assumptions reflect the behavior of firms concerning their decision on conducting research, and the way they are supported in this by governments.

We embrace a problem driven innovation model, in which research originates from an idea addressing a specific problem. We assume this research is conducted within the framework of a predefined project with corresponding fixed cost, based on an estimation of the required input (e.g. use of equipment and deployment of researchers). Such a set-up of the project is in line with for example what is suggested according to the best practice guidelines for industry-oriented research by the US National Science Foundation.[10] Just a subset of the total population of firms will be involved in the research project, collaborating in a Research Joint Venture (RJV). We ignore immediate spill-over effects from the consortium to those firms not involved in research.

We assume that successful execution of the research project involves a certain risk, as argued by (Stiglitz and Mathewson 1986). We presume however that the outcome of the R&D process in case of successful completion of the research project, and the corresponding impact it will have on the firm (i.e. the eventual return) is predetermined. This is in line with what is argued by (Rogers 1995): "The innovation-development process often begins with the recognition of a problem or need, which stimulates research and development activities designed to create an

[9] This development is illustrated for example by the closing of the Philips Natlab in 2001 and the subsequent setup of the High Tech Campus Eindhoven, and the changes in structure of the Bell Labs.

[10] See www.erc-assoc.org.

innovation to solve the problem or need. [...] Scientists [...] perceive a future problem and launch research to find a solution." In practice only a limited number of sectors appear to be able to sustain an innovation model which is not problem driven, but which is purely R&D based. For these sectors, potential technological breakthroughs are likely to result in a dominant competitive advantage with high payoffs exceeding the considerable and risky investments (Chesbrough 2003).

With these assumptions, we argue that a firm will decide on conducting research by comparing the expected gross gain in profit resulting from successful implementation of the new technology (i.e. the amount the firm is willing to invest in the project), with the foreseen project cost. In practice, this is as a decision under risk, given the probability of success and cost of the project, and the foreseen impact on the firm.

If there is a shortfall in what the firm is willing to invest in comparison to the project cost, a government has the possibility to intervene. The corresponding support should be such that it is effective in changing behavior of firms regarding investment in research, and efficient concerning the cost of the intervention. We therefore argue that a government should define its intervention such that it minimizes its expenditure on a single project, such that it is just enough to initiate the research. If we assume that a government has a limited budget, this allows for support of other additional research, thereby creating additional surplus. The actual intervention is limited: a government should provide support only if implementation of the research results (with corresponding cost for the government) lead to an increase in social surplus.

We model the government intervention such that it is directed towards those involved with the R&D project. The suggested set-up of the intervention, aimed at supporting a predefined research project, is also in line with the current practice concerning government support for industry-oriented R&D and innovation as governed by the EU State Aid rules (Commission of the European Communities 2006) and WTO Disciplines on Subsidies.

With these assumptions concerning industry-oriented R&D and innovation, the investment decision in research by firms, and the way it is supported by governments, we progress towards the formulation of a framework for the selection of instruments constituting an optimal policy mix.

In *Chapter 2* of this thesis, we assess the effectiveness and efficiency of the instruments we identified in *Section 1.1* with the help of a multi-stage strategic investment game. The set-up is such that in the final stage, firms involved in research define what they are willing to invest in the R&D project, based on the foreseen change in profit and the probability of failure of the research. We assume the firms offer a homogeneous product in a market competing on output (i.e. classical Cournot competition model). For the computation of this willingness to invest, we assume a linear perception of risk and profit. In the first stage of the game, the government defines the optimal set of instruments in order to address the shortfall in the willingness to invest from the firm (i.e. it defines the intervention such that it minimizes the contribution required to initiate the R&D project). The game is solved by means of backward induction.

Our results indicate that funding (e.g. subsidies or in kind contributions), tax measures and loans perform equally well: they initiate similar levels of innovation, and require similar levels of expected contribution. Implementation of a regulatory framework allowing for collaboration between firms entails the lowest cost for the government in comparison to the other tools. Allowing for collaboration however is not always sufficient to initiate research. In other words: regulations are the most efficient, but not always effective.

In *Chapter 3* of the thesis, we repeat the analysis for different types of competition: a market offering homogeneous products competing on price (i.e. classical Bertrand competition model), and a market with differentiated products competing on price and on quantity (i.e. Bertrand and Cournot for differentiated products).

The results show that for certain market structures, allowing for collaboration between firms does not change their willingness to conduct research. As a consequence, regulations are in that case not effective at all. The order of performance of the other tools remains the same.

Based on our findings in these two chapters, we formulate a generalized framework for the design of an optimal policy mix, which is applicable for different market structures. We argue that if a firm is not willing to invest in a predefined research project, then a government should first consider the possibility of allowing for collaboration with the help of a regulatory framework. If regulations are not effective, a government should provide financial support, allocated either by means of funding, tax measures or loans. The government should impose the appropriate number of partners in the consortium, such that it minimizes its contribution.

In the following chapters of the thesis, we analyze the functioning of specific measures to further contribute to the framework for the selection of instruments. In *Chapter 4* we analyze the effectiveness of regulations for a hybrid market form of perfect competition and monopolistic competition. Within the framework of this market structure (as introduced by (Varian 1980)), some consumers seek to buy at the lowest price without regard for product characteristics, whereas others have a brand preference (e.g. the automobile market).

The results indicate that if a firm with an idea for innovation decides on investing in research under this form of competition (i.e. the expected gain in profit meets the project cost), it will either conduct the project all alone, or it will establish a RJV with all firms of the population as its partners in the consortium. This is different than for the market structures we analyzed in the previous chapters, where other optimal sizes for the RJV are also feasible.

In *Chapter 5* we assess the efficiency of funding, tax schemes, and loans. We apply Prospect Theory as introduced by (Kahneman and Tversky 1979) to describe the behavior of firms concerning their decision on investment in research. In practice this implies that we assume a non-linear perception of risk by the firms involved in R&D.

Our analysis indicates that there exists a critical value for the probability of success of the project at which the modality of the most efficient instruments changes. For a probability of success smaller than the critical value, a tax measures offering support only in case of successful completion of the project is preferred. For a probability exceeding the critical value, a loan is most efficient. The value of the critical probability depends on the perception of risk and loss aversion of the firm involved in the research.

Assessment of the effectiveness of thematic policy

When designing a set of measures supporting the innovation system, many governments seem particularly concerned with how to identify sectors (or technologies) that, in comparison to others, have the potential to create additional growth. Analysis of the relevant literature indicates however that there is no theoretical or empirical evidence that specific policy is preferred over generic policy. The history of research and innovation policy includes examples where government policies have had an influence on the speed and direction of technological change. But there are also many other unsuccessful examples of thematic policies and instruments. We argue in line with (Arnold et al. 2007) that priority setting is context dependent, changes over time in rationale and goals, and alters for different innovation systems. In practice, "[...] it is not appropriate to give a general assessment of whether these type of programmes work or not. The outcome depends on the specific context of each of these programmes (e.g. scope, size, match with existing actors, programme management, timing, etc.). An overall and systematic assessment of all innovation programmes in a country is hardly ever done."

Within the framework of this thesis, we intended to analyze the effectiveness of thematic R&D and innovation policy as a basis for the choice of the scope of the policy mix. *Chapter 6* outlines our approach for the assessment of the impact of government intervention on labour productivity growth for different countries, with a divergent approach towards focus in policy. Labour productivity growth is chosen as the dependent variable because it reflects the innovative performance of the entire innovation system as addressed by the policy mix. The characteristics of the mix itself, such as focus, modality and intensity of support, are represented in the explanatory variables.

Based on the results from the data-collection process, we conclude that an empirical analysis of the impact of specific policy supporting R&D and innovation on labour productivity on sector level is not feasible. Due to a lack of publicly available data on the characteristics of policy, and contribution allocated by means of the supporting instruments, it is not possible to conduct an econometric analysis that will result in reliable conclusions. Such an analysis would require the set-up of a database with information on the characteristics of the policy mix for countries for which labour productivity data on sector level are available. A first step would be the collection of data on allocated funding and other forms of support at micro-level (i.e. firm-level), as administered by organizations involved in policy delivery. A next step would be the gathering of information on the scope of the measures constituting a policy mix from local data-sources (i.e. on country-level).

1.5 Conclusions and recommendations

The policy mix concept has been embraced by many of the industrialized countries as a basis for consultation and debate on the design of R&D and innovation policy.[11] But further adoption of the concept as a basis for policy formulation is hindered by the lack of a clear definition and scope.

We define a policy mix as: 'A combined set of interacting policies and their supporting instruments, addressing R&D and innovation.' Application of the concept provides a basis for the coordination of measures, such that they are effective in initiating research (and subsequently create sustainable economic growth), and efficient with respect to the cost of the intervention.

The rationale for coordination of instruments is the apparent difference in impact between publicly funded research and privately funded R&D. We define a theoretical framework for the selection of instruments which supports the design of an optimal intervention, and consequently addresses this difference in impact.

Our research results contribute to the estimation of what a firm is willing to invest in R&D given the characteristics of a research project, for different market structures. Based on the potential shortfall between the willingness to invest and the project cost, we are able to define the optimal intervention such that the contribution required from the government is minimized, and exactly enough to initiate the R&D. Our research subsequently also identifies the most efficient instrument to implement in case a financial contribution is required, based on the characteristics of the firm (i.e. risk aversion and perception of risk).

Based on our results, we conclude that an optimal intervention differs for each project, and is defined by the expected change in profit and cost of the project,

[11] See for example www.ec.europa.eu/invest-in-research/coordination/coordination01_en.htm.

as well as the form of competition in the market. Flexibility in the modality of support would subsequently contribute for example to limiting the crowding out effects between public and private expenditure on R&D.

Our conclusions do have an immediate relevance for the current practice concerning funding of (collaborative) research. As an example, the State Aid rules (Commission of the European Communities 2006) governing government support for industry-oriented R&D and innovation (which are endorsed also by the WTO Disciplines on Subsidies) foresee in a fixed contribution to the cost of a project. The contribution is not based on the characteristics of the project (i.e. risks involved in the R&D, expected outcome, and structure of the market), and the corresponding willingness to invest by the firm, but defined by the type of research conducted (e.g. experimental research, or industry-oriented research close to the market), or actor involved (e.g. SMEs, MNFs).[12] Based on our model we argue that under this legal framework, projects requiring a higher level of support will not be conducted, as a firm will not receive sufficient funding to make up its willingness to invest in the required research. We therefore claim that under these conditions the measures are not effective as they are not able to change the behavior of the firm. We also argue that projects which have been conducted with the help of support according to State Aid rules in practice most likely would have required less contribution than provided. We therefore contend that under these conditions the instruments are not efficient.

Our framework for the selection of instruments has limitations that should be considered when applying the results in practice. We ignore immediate spillover-effects from the RJV to the firms not involved in the research. This has an impact on the market in equilibrium. In practice, the amount a firm is willing to invest will as a consequence be lower than estimated with our model. Firms will furthermore have an incentive to exaggerate the risks involved in the project and downplay the expected change in profit. This will intensify their shortfall in the willingness to invest such that they are eligible for an extended contribution by the government.

Successful adoption of the policy mix concept however requires further insight in the factors which define the investment decision of firms (i.e. perception of risk

[12] In general (e.g. for almost all of the instruments of the industrialized countries) the contribution for industry-oriented research equals 50% of the project costs.

and loss aversion), and how they vary (e.g. for type of firm, or sector). Additional empirical analysis is needed to confirm our theoretical findings. Important in this respect is that governments record policy development, and monitor policy delivery. Consistent and comprehensive data on characteristics of policy in time are required, which are currently not available. Further implementation of the policy mix concept entails that we learn from the past in order to be able to design an optimal policy mix in the future.

Chapter 2

Framework for the design of a policy mix supporting R&D and innovation

The OECD and the European Commission have encouraged countries to adopt the concept of *policy mix* as a basis for long-term innovation driven growth strategies (OECD 2010b) (Commission of the European Communities 2010). This concept is rather new, and a clear, univocal and widely adopted definition is still lacking (Flanagan et al. 2010). We built on (Boekholt et al. 2006), (Flanagan et al. 2010) and (OECD 2010b), and define a policy mix as: 'A combined set of interacting policies and their supporting instruments, addressing R&D and innovation.'

The policy mix concept provides policy makers with a conceptual framework that allows them to consider the design of an *optimal* set of instruments. Optimal in this respect refers to *effectiveness* in changing behavior of firms regarding investment in research, and *efficiency* concerning the cost of the intervention. When intervening, countries are looking for: "[...] the cheapest one (i.e. measure) to implement, which least distorts the market whilst still achieving its objective" (adapted from (Flanagan et al. 2010)).

Optimizing the policy mix towards higher levels of effectiveness and efficiency is referred to as *coordination of measures* (Boekholt et al. 2006). Analysis of the literature indicates that little is known about the performance of a single instruments in comparison to other tools (Boekholt et al. 2006). It is even argued that "[...] from a purely logical and technical point of view, policy tools appear to be perfectly interchangeable" (Landry and Varone 2005).

In this chapter, we present a theoretical framework which allows for the assessment of the effectiveness and efficiency of instruments supporting industry-oriented research and innovation. For our analysis, we cluster instruments according to the following modalities of support (i.e. types or functionalities): *funding* (e.g. subsidies or in kind contributions), *tax schemes*, *loans* and *regulations* allowing for collaboration.[1] Based on a comparison of the performance of these instruments we define the optimal set of measures constituting a policy mix.

We build on the results of a multi-stage strategic investment game from industrial organization theory on R&D expenditure and cooperation as introduced by (d' Aspremont and Jacquemin 1988). This paper analyses the behavior of firms concerning investment in research for different forms of collaboration. A research driven innovation model is therefore adopted, in which all firms of the population get involved in R&D. The impact of this research, conveyed as a decrease in marginal cost, is defined as a function of investment in R&D. The game introduced involves a stage where all firms determine their input on R&D, given a certain level of spillover from research activity. This spillover coefficient reflects the level of coordination in research. In the final stage the firms engage in competition to define market price and output in equilibrium. The game is solved by means of backward induction.

Important contributions to the theory include the analysis of asymmetric equilibria resulting from for example product differentiation (Lambertini and Orsini 2000), asymmetric spillovers (Atallah 2007), and cost functions (Amir et al. 2008). Relevant for our study is the paper by (Poyago-Theotoky 1995), which analyses expenditure on R&D in equilibrium if only a subset of the total population establishes the highest level of coordination in the form of a Research Joint Venture.

Multi-stage strategic investment game theory has been applied before as a basis for formulation of R&D and innovation policy. In (Hinloopen 2001) and (Inci 2008) the effects of R&D cooperation and direct R&D subsidies on private investment in research are analyzed. The assumptions concerning impact of research and in-

[1] Almost all industrialized countries have implemented these types of specific and dedicated measures. Some governments limit their set of eligible modalities of support because of institutional settings, or because of tradition. For an overview, check: www.proinno-europe.eu, www.cordis.europa.eu/erawatch, or www.oecd.org.

novation model are as in (d' Aspremont and Jacquemin 1988). In order to define the intervention a model is adopted, introduced in (Spencer and Brander 1983), which ordains how governments could encourage firms to conduct research. It is suggested that taxes on profits or price are reallocated in the form of a subsidy to firms conducting R&D. In practice this implies that a generic intervention reallocates flows of money such that it incites all firms to conduct research. The set-up of the corresponding game is as in (d' Aspremont and Jacquemin 1988), but preceded by a stage aimed at determining the level of taxation and subsidizing required to establish the socially desirable level of firm-financed R&D spending.

We argue that the assumptions made in the current literature do not reflect the current practice concerning industry-oriented R&D and innovation, and the way it is supported by governments *(see Chapter 1).* As a consequence, it does not accurately describe the impact of different instruments on the behavior of firms concerning their decision on conducting research. In order to define an optimal policy mix, we therefore deviate from the existing theory. We adopt a problem driven innovation model, in which research originates from an idea addressing a specific problem. We assume this research is conducted within the framework of a predefined project with corresponding fixed cost. The outcome of the R&D process and the impact it could have on the marginal cost of production is predetermined. Just a subset of the total population of firms will be involved in the research project, operating as a Research Joint Venture (RJV). Application of the foreseen results depends on the successful execution of the project, which involves a certain risk.

Because of our assumptions, also the setup of the game deviates from the existing literature. In the final stage firms involved in research define the foreseen changes in market price and output in equilibrium resulting from successful implementation of the project results. Based on the corresponding change in profit and the probability of failure of the research, firms decide on what they are willing to invest in the R&D project. For the computation of this willingness to invest, we assume a linear perception of risk and profit. If the willingness to invest does not meet the foreseen project cost, a firm will decide not to conduct the research. We consequently argue that a government could decide to intervene and provide support by means of the different measures identified. The intervention is directed towards those involved in research. In the first stage of the game the government thereupon defines the optimal set of instruments. This implies that we assume that the government defines its intervention such that it minimizes the contribution required to initiate the R&D project. The change in total surplus resulting from implementation of the research results constitutes the rationale for this intervention.

The suggested set-up of the intervention, aimed at supporting a predefined research project, is in line with the current practice concerning government support for industry-oriented R&D and innovation as governed by the EU *State Aid rules* (Commission of the European Communities 2006) and WTO *Disciplines on Subsidies.*

Based on the assessment of the performance of the individual measures, we conclude that an optimal policy mix allows for the collaboration of firms by means of regulations. If the foreseen expected gain in profit ensuing from implementation of the research results is not sufficient to cover the shared project cost by the project partners, a government should provide additional financial support in order to initiate research. This contribution could subsequently be allocated either by means of funding, tax measures or loans. The government should however impose the appropriate number of partners in the consortium, such that it minimizes its contribution. We argue that minimizing contribution per project allows for the support of other additional research, thereby creating additional surplus.

In the next section, we define a model to assess the willingness of a firm to invest in a research project. We subsequently establish the basis for intervention for a government. This constitutes the framework for the assessment of the performance of the instruments. In *Section 2.3* we calculate market equilibria and total surplus for a market under Cournot as a function of the size of the Research Joint Venture. We use this result in *Section 2.4* to describe the behavior of the firms resulting from implementation of the different instruments. We compare the cost for the government to alter the investment decision of firms concerning research for each of the tools. Based on this assessment, we define the optimal policy mix in *Section 2.5.* In *Section 2.6* we describe implications for policy formulation and future research.

2.1 Investment in R&D by firms

As starting point for the formulation of a model for our multi-stage strategic investment game, we assume that there is a total and fixed population N containing n firms . We furthermore assume that there is a variable sub-population $R \subseteq N$ containing r firms conducting R&D. The firms operate in a market offering similar products. The corresponding inverse demand function equals:

$$P(r) = a - b\left[\sum_k^r Q_k + \sum_{i \neq k}^n Q_i\right] \tag{2.1}$$

with P as the *market price*, Q as the *quantity* sold, and $i \in N$, $k \in R$.

We consider the initial *marginal cost* c of production to be equal and constant for all firms, and determined by the state of the art in production technology within a certain industry or sector. Reduction of the marginal cost results from successful completion of a predefined research project implemented to explore a specific idea to improve the production process. As a consequence the impact of the results on the change in the cost of production is foreseen. We subsequently define the marginal cost as $c_k = \underline{C}$ for $k \in R$ and $c_i = \overline{C}$ for $i \in N \wedge i \neq k$, with $0 < \underline{C} < \overline{C} < a$. The change in marginal cost resulting from a successful completion of the research project is represented as $\Delta C = \overline{C} - \underline{C}$.

We assume that for $r > 1$ the firms involved in R&D will form a RJV. These firms will coordinate their research activities by sharing R&D cost and results, and by avoiding duplication for the duration of the project. This implies that we assume that the internal spillover coefficient equals 1 (Kamien et al. 1992). We ignore immediate spill-over effects to and from firms from outside the RJV while the research project is conducted.

Conducting the research project involves a certain risk of failure. We define $p \in [0, 1]$ as the *probability of failure of the project.* This probability depends on the current level of knowledge concerning production for this sector. If the required knowledge is not available, and lies beyond the current state of the art, the probability of failure will be close to one. If the required knowledge is available, this probability will be close to zero.[2]

We assume that the *project cost* K of the research are fixed, and based on an estimation of the required input (e.g. use of equipment and deployment of researchers). When producing we suppose that these firms face no fixed cost.

Based on the above, we get the following profit functions:

$$\pi_i(r) = P(r)Q_i(r) - \overline{C}Q_i(r) \tag{2.2}$$

$$\pi_k(r) = P(r)Q_k(r) - \underline{C}Q_k(r) - K/r \tag{2.3}$$

with $\overline{\pi}_k(r) \equiv P(r)Q_k(r) - \underline{C}Q_k(r)$ as the *gross profit* for firm k (i.e. the maximum possible profit).

We argue that a firm k will decide on joining the RJV and conducting the required R&D by comparing the expected profit resulting from conducting the research with the initial profit. If we define $\pi_i = \pi^0$ as the *initial profit in equilibrium*, and $(\pi_i(r), \pi_k(r)) = (\pi^-(r), \pi^+(r))$ as the *profit in equilibrium after successful implementation of the research results*, we get that this investment decision can be represented as:

$$\begin{aligned}(1-p)\left(\overline{\pi}^+(r) - K/r\right) + p\left(\pi^0 - K/r\right) &\gtrless \pi^0 \Leftrightarrow \\ (1-p)\left(\overline{\pi}^+(r) - \pi^0\right) &\gtrless K/r\end{aligned}$$

The inequality shows that firm k will decide by comparing what it is willing to invest in R&D (i.e. the expected gross gain in profit) with the individual project cost. Behavior of firms concerning investment is pivotal in our framework for the selection of instruments. We will represent the *willingness to invest in R&D* as:

$$x(r,p) = (1-p)\left(\overline{\pi}^+(r) - \pi^0\right)$$

with $\overline{x}(r) \equiv \overline{\pi}^+(r) - \pi^0$ as the *gross investment in R&D*.

[2]Within the framework of this paper, we ignores immediate spillover effects. The impact of knowledge creation however is ultimately captured in the probability of failure of research projects.

2.2 Intervention by the government

Firm k will conduct the R&D if the probability of failure of the project is such that $x(r,p) > K/r$. But if the firm is not willing to cover the individual project cost (i.e. $x(r,p) \leq K/r$), then k will not consider implementing the project as the required investment would lead to an expected profit lower than (or equal to) that in the initial situation. We define the corresponding *shortfall* S of the willingness to invest as:

$$S\,(r,p) = K - x(r,p) \tag{2.4}$$

If the willingness of the firm does not meet the project cost, a government has the possibility to intervene, and implement measures such that the firm will alter its behavior, and decide on conducting the research. A medium-sized country like the Netherlands for example has implemented about a hundred measures aimed at supporting industry oriented R&D and innovation on national level.[3] We identify four modalities of support which we will analyze in this chapter:

- *Funding*: direct support in the form of subsidies, grants or a rebate on social insurances, and indirect support such as vouchers and access to research infrastructure (i.e. in kind contributions).
- *Taxation*: fiscal measures offering a tax relief on turnover or profit from products resulting from the research project.
- *Loans*: support which has to be reimbursed by the firms involved in research to the government.
- *Regulations* such as Intellectual Property Rights (IPR) and laws governing the functioning and interaction of actors, aimed at establishing cooperation (between firms and actors of the research infrastructure) and collaboration (between firms).

The objective of our research is to design an optimal policy mix, constituted by a set of instruments which is not only effective, but also efficient. We therefore

[3]Source: www.nlinnovatie.nl on January 2011.

argue that a government should define its intervention such that it minimizes its expenditure on a single project. This allows for support of other additional research, thereby creating additional surplus.

Rationale for intervention by a government is the expected increase in surplus resulting from conducting the project. The intervention as such is limited: the corresponding government cost (on project level) for the intervention should never be too high, in that they should not undo the gain in social surplus. This rationale for intervention and corresponding condition for support will act as our set of criteria to assess the design of an optimal policy mix.[4]

2.3 Profit and surplus in equilibrium

In order to assess the amount firms are willing to invest in research, we need to get insight in the profit in equilibrium. In this chapter, we analyze the optimal policy mix for a market under Cournot. Given the demand function (2.1) and the profit functions (2.2) and (2.3), we get that (see *Appendix A* for computations):

$$\pi^0 = \frac{\left(a - \overline{C}\right)^2}{b\,(n+1)^2}$$

$$\pi^+(r) = \begin{cases} \pi_k^*(r) & \text{for} \quad r\Delta C < a - \overline{C} \\ \pi_k^O(r) & \text{for} \quad r\Delta C \geq a - \overline{C} \end{cases}$$

$$\pi^-(r) = \begin{cases} \pi_i^*(r) & \text{for} \quad r\Delta C < a - \overline{C} \\ \pi_i^O(r) & \text{for} \quad r\Delta C \geq a - \overline{C} \end{cases} \tag{2.5}$$

[4]In practice, a government could condition its intervention, and limit support to projects that exceed a certain threshold concerning probability of success or foreseen change in marginal costs (or a combination of the two). Selection on the basis of these project characteristics normally is associated with a certain thematic focus in policy. The effectiveness of thematic policy is addressed in *Chapter 6*.

with:

$$\pi_k^*(r) = \frac{\left[(a-\underline{C})+(n-r)\,\Delta C\right]^2}{b\,(n+1)^2} - K/r$$
$$\pi_i^*(r) = \frac{\left[\left(a-\overline{C}\right)-r\Delta C\right]^2}{b\,(n+1)^2}$$
$$\pi_k^O(r) = \frac{(a-\underline{C})^2}{b\,(r+1)^2} - K/r$$
$$\pi_i^O(r) = 0$$

We can see from the expression for $\pi_i^*(r)$ in (2.5) that the firms not conducting R&D remain producing only in case $r\Delta C < a-\overline{C}$. We define this as an *incremental* change in marginal cost. These firms however cease production if $r\Delta C \geq a-\overline{C}$. We define this as a *radical* change in marginal cost. The members of the RJV will in that case act as an oligopoly.[5]

Figure 2.1 shows as an example the gross profit in equilibrium as a function of r for $1 < \left(a-\overline{C}\right)/\Delta C < n$. The gross investment $\overline{x}(r)$ for a certain r can be graphically visualized as the distance between $\overline{\pi}^+(r)$ and π^0. The figure indicates that under Cournot, $\pi^+(r) \geq \pi^0 > \pi^-(r)$. This implies that a firm has a clear incentive to pursue research lowering its marginal cost.[6]

Successful application of the research result leads to a change in surplus. This change confines support by a government, as defined in our criteria for intervention.

[5]Note that the number of firms in the market after the implementation of the research results (i.e. whether the change in production is either incremental or radical) does not depend only on the quality of the idea, which is reflected in ΔC. It also depends on the number of firms of the population involved in the research project, which is represented by r.

[6]We argue that for $p = 0$, the project itself does no longer refer to research, but should be seen as a regular investment. Theory developed within the framework of this paper is in that case as a concequence no longer relevant.

In case $p = 1$, firm k will not invest in the research project. The government should in that case not intervene.

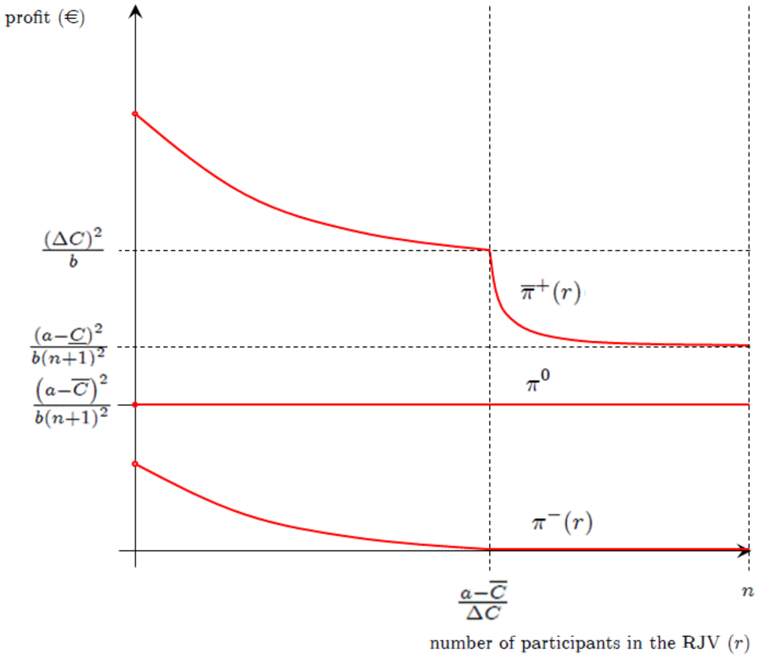

Figure 2.1: Profit for $1 < \left(a - \overline{C}\right)/\Delta C < n$

The total surplus is given by (see *Appendix A* for computations):

$$W^0 = \frac{1}{2} n (n+2) \left[\frac{(a - \underline{C})^2}{b(n+1)^2} \right]$$

$$W^+(r) = \begin{cases} W^*(r) & \text{for} \quad r\Delta C < a - \overline{C} \\ W^O(r) & \text{for} \quad r\Delta C \geq a - \overline{C} \end{cases}$$

with:

$$W^*(r) = \frac{(n+2)\left[(n-r)(a-\overline{C})^2 + r(a-\underline{C})^2\right]}{2b\left(2+(n-1)\right)^2} +$$
$$\frac{(2n+3)\,r\,(n-r)\,\Delta C^2}{2b\left(2+(n-1)\right)^2} - K$$
$$W^O(r) = \frac{1}{2}r\,(r+2)\left[\frac{\left(a-\underline{C}\right)^2}{b\left(r+1\right)^2}\right] - K$$

and W^0 as the *initial surplus*, and $W^+(r)$ as the *surplus after implementation of the research results*. We define $\overline{W}^+(r)$ as the *gross surplus*.(i.e. the total surplus without the cost of the project).

2.4 Assessment of instruments

In this section, we assess the effectiveness and efficiency of the instruments we identified. As a starting point we consider a single firm k from the total population of firms N, which has an idea for an improvement of its production technology. We assume that the characteristics of the corresponding research project are such that the willingness to invest does not meet the project cost: $x(p^*) \leq K$ (see *Figure 2.2*).

We model the different modalities of the measures by varying the moment of intervention in the innovation process, and by changing the conditionality of support with respect to the outcome of the project. In practice, we cover all relevant possibilities for intervention.

We also model the instruments such that the willingness of the firm exactly equals the project cost. In this way we are able to compute, and therefore compare, the exact contribution required for each of the instruments to initiate research.

Note that we assume that each intervention is targeted, and therefore limited, to those involved in research.

Funding

A government could choose to contribute to the project cost of firm k by means of *Funding* (F) offered in direct or indirect means. A firm will consider conducting the research project if a government provides resources lowering the cost of the project from K to K^F (see *Figure 2.2*).

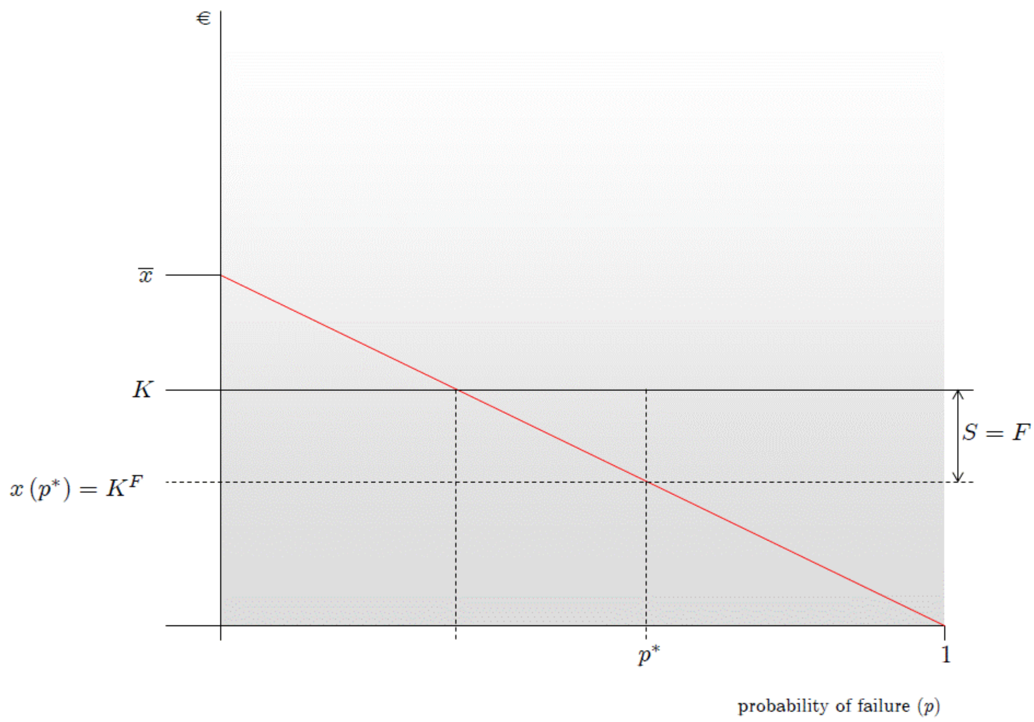

Figure 2.2: Funding

The contribution is offered at the beginning of the project, and unconditional with respect to the outcome. If F is the minimum amount of funding required to initiate the research project, then:

$$(1 - p^*)\left(\overline{\pi}^{+} - \pi^{0}\right) + F = K$$

Taxation

A government could also choose to contribute to the project cost by means of *Taxation*. We identify two different options for offering a tax relief: a reduction in case of the successful implementation of the research results, and a reduction for firms conducting research, unconditional to the outcome of the project. Note that we model tax measures such that they contribute to profit.

Conditional tax-rebate

By offering a tax relief on turnover or profit from products resulting from the project, a government could try to increase the gross investment $\overline{x}$ of a firm to $\overline{x}^T$ such that the corresponding willingness to invest meets the project cost (see *Figure 2.3*)

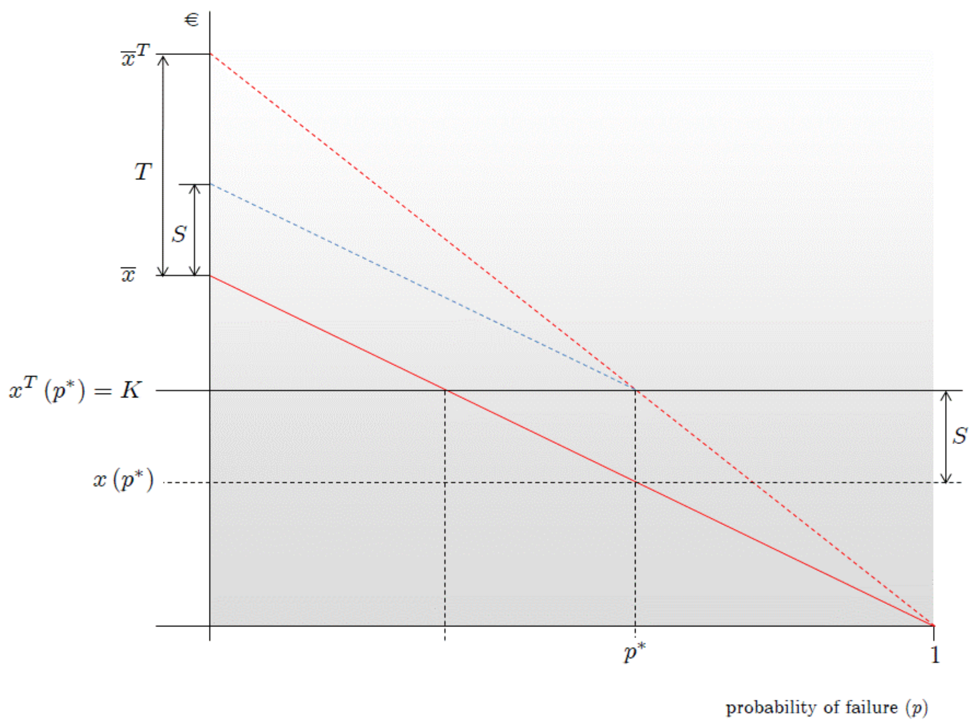

Figure 2.3: Conditional tax-rebate

The percentual increase t of the profit required to to initiate the research should be such that:

$$(1-p^*)\left((1+t)\,\overline{\pi}^+ - \pi^0\right) = K$$

The actual contribution T in case of successful implementation of the research results equals:

$$T = \left(\overline{x}^T - \overline{x}\right) = \frac{K - x(p^*)}{1-p^*}$$

Figure 2.3 indicates that the actual contribution to the firm is higher than shortfall in its willingness to invest.[7] The resulting tax surplus should be considered as a premium for the firm for taking the risk of not receiving support in case the project fails.

Unconditional tax-rebate

An alternative form of tax relief can be offered to a firm for conducting research regardless of the outcome of the project. The corresponding percentual increase τ required to alter the investment decision of the firm is in that case computed with:

$$(1-p^*)\left(\overline{\pi}^+ - \pi^0\right) + \tau\left((1-p^*)\,\overline{\pi}^+ + p^*\pi^0\right) = K$$

The actual contribution Γ is defined by the probability of failure of the research, and depends on the outcome of the project:

$$\Gamma = \begin{cases} \frac{K-x(p^*)}{(1-p^*)} - \frac{p^*}{(1-p^*)}\tau\pi^0 & \text{for successful completion of the project} \\ \frac{K-x(p^*)}{p^*} - \frac{(1-p^*)}{p^*}\tau\overline{\pi}^+ & \text{for unsuccessful completion of the project} \end{cases}$$

Loans

In case the willingness of a firm to invest does not meet the project cost, a government could also consider providing the support required to initiate the research project in the form of a *Loan (L)*. We assume that the firm will have to redeem the loan only in case of successful completion of the research project, and that no interest will be charged.

[7] Nota that the contribution T is as the projection of $K - x(p^*)$ on the left vertical axis from $p = 1$.

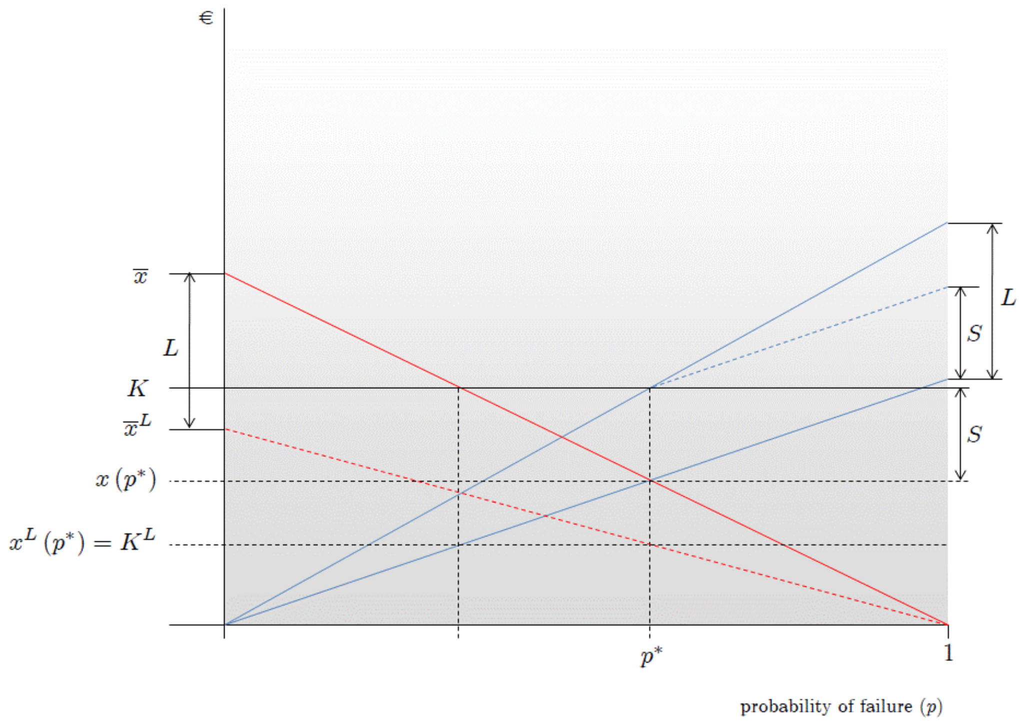

Figure 2.4: Loans

If a firm accepts a loan to cover its shortfall in investment, it would in practice lower its gross investment such that $\overline{x}^L = \overline{x} - L$. This is shown in *Figure 2.4* on the left vertical axis. The loan required to initiate the research should consequently be such that the loan itself plus the resulting actual investment meet the project cost:

$$L + (1 - p^*)\,(\overline{x} - L) = K$$

The actual contribution L in case of failure of the research equals therefore:

$$L = \left(\overline{x}^L - \overline{x}\right) = \frac{K - x(p^*)}{p^*}$$

Figure 2.4 indicates that also in this case the actual contribution to the firm is higher than shortfall in its willingness to invest.[8] The resulting surplus should

[8]Note that the loan L is as the projection of $K - x(p^*)$ on the right vertical axis from $p = 0$.

again be considered as a premium for the firm, for taking the risk of having to pay back the support. Note that a loan can be applied in theory only if $K \leq \overline{x}$.

Regulations

In order to initiate industry-oriented research and innovation, a government could also try to establishes the necessary preconditions for collaboration between firms within an R&D project. Collaborating firms are able to share the risks and thereby the cost of the research project such that its individual project cost will be lowered to K/r. Their profit however will also decrease. Firm k will therefore try to select an optimal number of research partners, such that it maximizes its individual profit while covering the individual project cost.

In practice, establishing collaboration requires a legal framework that allows for the formalization of agreements into binding contracts, regulates their compliance, and protects foreground and background knowledge of firms participating in a RJV.

Lemma 2.1 *Firm k will establish a RJV with r^+ consortium members if $x(r^+, p^*) > K/r^+$ such that:*

$$\widehat{r} = \begin{cases} r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+(n)\right), \\ \quad \{r^* \in R^* : r^* \in [1, n]\} \ \textit{for} \ \left(a - \overline{C}\right)/\Delta C \geq n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+\left(\left(a - \overline{C}\right)/\Delta C\right)\right), \\ \quad \left\{r^* \in R^* : r^* \in \left[1, \left(a - \overline{C}\right)/\Delta C\right]\right\} \ \textit{for} \ 1 < \left(a - \overline{C}\right)/\Delta C < n \\ 1 \ \textit{for} \ 1 \geq \left(a - \overline{C}\right)/\Delta C \end{cases}$$

with:

$$R^* = \left\{ \begin{array}{c} -\Psi\left(\frac{1}{2}i\sqrt{3} + \frac{1}{2}\right) + \frac{\frac{1}{9}\alpha(\alpha+5)}{\Psi\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)} - \frac{\alpha}{3}, \\ \Psi\left(\frac{1}{2}i\sqrt{3} - \frac{1}{2}\right) - \frac{\frac{1}{9}\alpha(\alpha+5)}{\Psi\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)} - \frac{\alpha}{3}, \\ \Psi - \frac{\frac{1}{9}\alpha(\alpha+5)}{\Psi} - \frac{\alpha}{3} \end{array} \right\}$$

given that:

$$\Psi = \sqrt[3]{\frac{-\left(\frac{2}{27}\alpha^3+\beta\right) \pm \left(\left(\frac{2}{27}\alpha^3+\beta\right)^2 + \frac{4\left(\frac{1}{3}\alpha(\alpha+5)\right)^3}{27}\right)^{\frac{1}{2}}}{2}}$$
$$\alpha = \frac{-2\Delta C\left[(a-\underline{C}) - n\Delta C\right]}{2\left(\Delta C\right)^2}$$
$$\beta = \frac{Kb\left(n+1\right)^2}{2\left(\Delta C\right)^2}$$

Proof. The optimal size of the consortium, such that firm k will maximize its profit, is computed with:

$$\max_r \left(\pi^+(r)\right) \tag{2.6}$$
$$\textit{subject to}:$$
$$x(r,p^*) > K/r \tag{a}$$
$$1 \leq r \leq n \tag{b}$$

Constraint (2.6 (a)) stipulates that if it is not possible to formulate a RJV such that the willingness to invest meets the individual project cost, no research consortium will be established, and firm k will consequently decide not to conduct the R&D.

The optimal size of the consortium depends on the impact of the research result on the market. Optimizing for an incremental change in marginal cost gives $\pi^+(r) = \pi_k^*(r)$. On $r \in (0,\infty)$ this profit function is continuous, and increasing and concave for $r \downarrow 0$ and convex and increasing for $r \to \infty$. On the interval as defined by constraint (2.6 (b)), none of the extremes of the solution set $\widehat{R} \in \mathbb{C}$ can be excluded beforehand, or subsequently be identified as a local maximum or minimum. The computation for the solution set $\widehat{R}$ is given in *Appendix B*.

For a radical change in marginal cost we get that $\pi^+(r) = \pi_k^O(r)$. The profit for firms acting as an oligopoly decreases with an increasing number of firms in a RJV (see *Appendix C*). Firm k has therefore an incentive to limit the number of partners in the research project. ■

Comparison of tools

With the help of our framework, we demonstrate the functioning of each instruments (i.e. the way it changes the investment decision of the firm). We therefore argue that we are able to assess the effectiveness of the different tools. We also define for each of the instruments the exact contribution required by a firm to initiate research when its willingness to invest does not meet the cost of an R&D project.[9] We therefore conclude that we have defined a framework for the selection of instruments, such that they are efficient. We consequently argue that we are able to compare the instruments, as a basis for the formulation of an optimal policy mix.

Lemma 2.2 *The expected contribution by a government required to initiate research is equal for Funding, Taxation or Loans.*

The previous section indicates that these measure induce a similar level of effort in R&D. The support necessary to alter the investment decision of the firm differs. The expected contribution however is identical for the different tools, and equal to the shortfall in investment:

$$S = F = (1 - p^*)\, T = \tau \left((1 - p^*)\, \overline{\pi}^+ + p^* \pi^0\right) = p^* L$$

Lemma 2.3 *Regulations are most efficient in inducing research by firms. They are however not always effective.*

Measures aimed at allowing collaboration between firms do not require a contribution to the cost of the research. As we have seen however, it is not always possible to establish a consortium with an appropriate number of participants.

The actual implementation of instruments aimed at supporting industry-oriented research brings about more cost than the contribution required to initiate the R&D project. From a government perspective, these additional cost result from policy

[9]The expected gain in profit results from the foreseen implementation of the research results, and not from the transfer of support. The contribution itself is appropriated merely to amend the expectations of the firm such that it will initiate the project.

delivery. We represent these as *implementation cost* I and define them as all cost of the intervention not part of the contribution required to address the shortfall in investment. For simplicity, we will assume that the cost of implementation are equal for all instruments, resulting from evaluation of the project proposal and monitoring of the progress and results of the project. We will consequently not alter our conclusions concerning the preference of the instruments.[10]

2.5 Main result: combination of measures in a policy mix

The assessment of the instruments in the previous section forms the basis for the formulation of an effective policy mix for the support of industry-oriented R&D and innovation. For the formulation of the actual set of tools, we will have to analyze if they comply with the restrictions as set by our criteria for intervention.

Theorem 2.4 *If a firm k is not willing to invest in a predefined research project because the expected change in profit does not cover the corresponding fixed cost, then a government should consider allowing for collaboration. In other words, if $x(p) \leq K$ a government could implement regulations.*

If it is not possible to formulate a RJV such that the cumulative willingness of the

[10] The cost for policy delivery could in practice change with the modality of instruments, because of the moment of intervention or conditionality of support with respect to the outcome of the project. In case a government for example considers providing support by means of a loan, it will have to allocate an actual contribution higher than the shortfall in investment, at the beginning of the project. And although the expected contribution equals that for other instruments, its implementation cost would be higher because of the opportunity cost of the associated surplus in support.

Also operational aspects of the policy delivery process affect the cost for implementation. Evaluation of a Dutch measure called WBSO ("Wet Bevordering Speur- en Ontwikkelingswerk" or "R&D Work Stimulation Act") indicated, on the basis of results of a questionnaire, that firms and the government prefer fiscal measures over other forms of financial support, because of the simplicity of application, and the fact that a large part of the infrastructure required for the policy delivery is available (Brouwer et al. 2002). Especially this last issue reduces the implementation cost in comparison to other means of support.

members covers the total project cost, then a government might consider contributing to the cost of the project. This implies that if $x(\widehat{r}, p^*) \leq K/\widehat{r}$ a government could implement regulations, accompanied with funding, tax measures or loans. The government however should impose a size $\widetilde{r}$ of the RJV that minimizes its expected contribution to $K - x(\widetilde{r}, p^*)$, with:

$$\widetilde{r} = \begin{cases} r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+(n)\right), \\ \quad \{r^* : r^* \in [1, n]\} \text{ for } \left(a - \overline{C}\right)/\Delta C \geq n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+\left(\left(a - \overline{C}\right)/\Delta C\right)\right), \\ \quad \left\{r^* : r^* \in \left[1, \left(a - \overline{C}\right)/\Delta C\right]\right\} \text{ for } 1 < \left(a - \overline{C}\right)/\Delta C < n \\ 1 \text{ for } 1 \geq \left(a - \overline{C}\right)/\Delta C \end{cases}$$

and:

$$r^* = \frac{2\left(\left(a - \underline{C}\right) + n\Delta C\right) - \left[\left(\left(a - \underline{C}\right) + n\Delta C\right)^2 + 3\left(a - \overline{C}\right)^2\right]^{1/2}}{3\Delta C}$$

The actual intervention is constrained. In practice, a government should intervene only if:

$$(1 - p)\left(\overline{W}^+(r) - W^0\right) \geq I + K \qquad (2.7)$$

The decision tree for an optimal the intervention supporting industry-oriented can consequently be depicted as in Figure 2.5 of Appendix C.[11]

Proof. We build on *Lemma 2.1*, *Lemma 2.2 and Lemma 2.3.* Our analysis indicates that because of its efficiency, a regulatory framework is preferred as a basis

[11]Note that if we assume that all firms are involved in research (i.e. $r = n$, as in line with the current multi-stage strategic investment game literature on policy formulation), our conclusions concerning the order of performance of the instruments providing a financial contribution still hold. The intervention as such however might not be efficient.

Because of our objectives and corresponding assumptions with which we deviate from the current literature (e.g. predefined project with fixed cost, no immediate spill-overs, objective function for the government), our results are not comparable with those from the existing literature.

for a set of measures supporting R&D. But regulations alone are not always sufficient to initiate research. The policy mix becomes effective if regulations are accompanied with measures contributing to the cost of the project.

Minimizing the government contribution given the constraints about intervention and the size of the population is computed according to:

$$\min_r \left[r \left(\frac{K}{r} - x(r, p^*) \right) \right] \tag{2.8}$$

$$\textit{subject to}:$$

$$x(r, p^*) \leq K/r \tag{a}$$

$$1 \leq r \leq n \tag{b}$$

In practice this implies computing the size of the consortium that generates the highest cumulative willingness to invest.

Constraint (2.8 (a)) stipulates that a government should contribute to a consortium only if it is not possible to formulate a RJV such that the partners are willing and able to cover the total project cost.

The optimal size of the consortium in depends also in this case on the impact of the research result on the market structure. For an incremental change in marginal cost, with $\pi^+(r) = \pi_k^*(r)$, we get that the cumulative willingness to invest has a maximum at $\widetilde{r}$ (see *Appendix D*). The actual size of the consortium depends on the orientation of $\widetilde{r}$ with respect to the interval as defined by constraint (2.8 (a)).

For a radical change in marginal cost we get that $\pi^+(r) = \pi_k^O(r)$. The cumulative willingness to invest for firms acting as an oligopoly decreases with an increasing number of firms in an RJV (see *Appendix D*). A government therefore has an incentive to limit the number of partners in the research project.

A government should test the actual intervention against the criteria for support. First, a government should only contribute to the cost of the project if it leads to an expected increase in the total surplus. Second, the total government cost should not exceed the gain in surplus created by the change in marginal cost. Combining this gives:

$$(1-p)\left(\overline{W}^+(r) - rx(r, p^*)\right) + p\left(W^0 - rx(r, p^*)\right) - W^0 \geq I + (K - rx(r, p^*))$$

Reformulating this gives an expression according to (2.7) as a condition for intervention. ■

We argue that if the criteria for intervention or any of the other conditions are not met, a government should not support the research project. It should instead focus its effort on other projects.[12]

We are aware that a government is not always willing to restrict the intervention, or even impose the optimal size of the consortium. It might wish to create a competitive advantage for firms in comparison to their foreign competitors. We argue however that this type of support should be considered as industry policy, and not R&D and innovation policy.

2.6 Conclusions and recommendations

For the formulation of an effective policy mix, we have made assumptions with which we deviate from the existing literature (see *Table 2.1* in *Appendix E* for an overview of our assumptions, and how we deviate from those in the existing literature). We assume that investment in R&D is as a decision under risk about conducting a predefined research project with corresponding outcome and fixed cost. We argue that this approach is a more accurate representation of the current practice concerning industry-oriented competitive R&D and innovation. The resulting impact of the research on the market is thereupon also a more realistic reflection of reality. Our model shows that if research is conducted successfully, it creates a competitive advantage for the members of the RJV over those not involved in R&D, such that they might capture the entire market.

Because of our different assumptions, also the set-up of the corresponding multi-stage strategic investment game differs from the existing literature (see *Table 2.2* in *Appendix E*). Our model for intervention allows furthermore for an estimation of the shortfall in what the firm is willing to invest to cover the individual project

[12] The restrictions concerning the change in surplus are of importance in this respect. Only in case all firms are involved in the research, or in case of an oligopoly, will the surplus always be higher than in the initial stage with no R&D. In other situations, the change in surplus has to be analyzed.

cost. We are subsequently able to show that although the expected contribution required to initiate the project is equal for funding, tax measures and loans, the actual support which has to be allocated differs for these instruments. If we apply the current framework for a different market structure, their order of performance would remain unchanged. Such a change in structure will however have an impact on the effectiveness of regulations. The results suggest also that if we were to apply a non-linear perception of risk and (or) utility, we would find a difference in the performance for all measures.

Our model has limitations that should be considered when applying the results in practice. We ignore immediate spillover-effects from the RJV to the firms not involved in the research. This has an impact on the market in equilibrium. In practice, the amount a firm is willing to invest will therefore be lower than estimated with our model. Firms will furthermore have an incentive to exaggerate the risks involved in the project and downplay the expected change in profit. This will intensify their shortfall in the willingness to invest such that they are eligible for an extended contribution by the government.

Regardless of these limitations, our results do have implications for the current practice concerning support of industry-oriented R&D and innovation. The State Aid rules (Commission of the European Communities 2006) governing government support for industry-oriented R&D and innovation (which are endorsed also by the WTO Disciplines on Subsidies) foresee in a fixed contribution to the cost of a project. The contribution is not based on the characteristics of the project (i.e. risks involved in the R&D, expected outcome, and structure of the market), and the corresponding willingness to invest by the firm, but defined by the type of research conducted (e.g. experimental research, or industry-oriented research close to the market), or actor involved (e.g. SMEs, MNFs).[13] Based on our model we argue that under this legal framework, projects requiring a higher level of support will not be conducted, as a firm will not receive sufficient funding to make up its willingness to invest in the required research. We therefore claim that under these conditions the measures are not effective as they are not able to change the behavior of the firm. We also argue that projects which have been conducted with

[13] In general (e.g. for almost all of the EU and national programmes), the contribution for industry-oriented research equals 50% .

the help of support according to State Aid rules in practice most likely would have required less contribution than provided. We therefore contend that under these conditions the instruments are not efficient.

Appendix A: market equilibria and surplus

To demonstrate out framework for the selection of instruments, we need insight in the market characteristics in equilibrium. We demonstrate the computation for $r > 0$. The initial market equilibrium with $r = 0$ is calculated in a similar way.

We first rewrite the profit function for firms not involved in research:

$$\begin{aligned}\pi_i(r) &= \left[a - b\left[\textstyle\sum_k^r Q_k + Q_i + \sum_{j\neq i, j\neq k}^n Q_j\right]\right] Q_i - \overline{C}Q_i \\ \pi_j(r) &= \left[a - b\left[\textstyle\sum_k^r Q_k + Q_j + \sum_{i\neq j, i\neq k}^n Q_i\right]\right] Q_j - \overline{C}Q_j\end{aligned} \tag{2.9}$$

and we do the same for the firms of the RJV:

$$\begin{aligned}\pi_k(r) &= \left[a - b\left[Q_k + \textstyle\sum_{l\neq k}^r Q_l + \sum_{i\neq k, i\neq l}^n Q_i\right]\right] Q_k - \underline{C}Q_k - K/r \\ \pi_l(r) &= \left[a - b\left[Q_l + \textstyle\sum_{k\neq l}^r Q_l + \sum_{i\neq k, i\neq l}^n Q_i\right]\right] Q_k - \underline{C}Q_l - K/r\end{aligned} \tag{2.10}$$

We will assume that each firm maximizes profit based on quantity produced, and that each rival will consider the other's quantity as a fixed number that will not respond to its own product decision.[14] Maximizing profit for firms not involved in

[14] The assumptions of our model allow for the calculation of quantity and profit in equilibrium according to Cournot:

- There is more than one firm and all firms produce a homogeneous product, i.e. there is no product differentiation;
- Firms do not cooperate, i.e. there is no collusion;
- Firms have market power, i.e. each firm's output decision affects the good's price;
- The number of firms is fixed;
- Firms compete in quantities, and choose quantities simultaneously;
- The firms are economically rational and act strategically, usually seeking to maximize profit given their competitors' decisions.

R&D according to Cournot implies:

$$\max_{Q_i} \left[a - b\left[\sum_{l\neq k}^{r} Q_k + Q_i + \sum_{j\neq i, j\neq k}^{n} Q_j\right]\right] Q_i - \overline{C}Q_i$$

which yields as the best-response function:

$$a - b\left[\sum_{k}^{r} Q_k + 2Q_i + \sum_{j\neq i, j\neq k}^{n} Q_j\right] - \overline{C} = 0 \Rightarrow$$

$$a - b\left[\sum_{k}^{r} Q_k + 2Q_i + Q_j + \sum_{h\neq i, h\neq j, h\neq k}^{n} Q_h\right] - \overline{C} = 0 \tag{2.11}$$

Maximizing profit for firm j according to $\partial\pi_j/\partial Q_j$ gives, in a similar way as a best-response function:

$$a - b\left[\sum_{k}^{r} Q_k + 2Q_j + Q_i + \sum_{h\neq i, h\neq j, h\neq k}^{n} Q_h\right] - \overline{C} = 0 \tag{2.12}$$

With $\partial\pi_i/\partial Q_i = \partial\pi_j/\partial Q_j$ we see that in equilibrium $Q_i^* = Q_j^*$. Substituting that in (2.11) gives:

$$a - b\left[\sum_{k}^{r} Q_k + (n - r + 1)Q^*\right] - \overline{C} = 0 \tag{2.13}$$

Optimizing profit with respect to quantity for firms involved in the research project with $\partial\pi_k/\partial Q_k = 0$ results in a best-response function according to:

$$a - b\left[2Q_k + \sum_{l\neq k}^{r} Q_l + \sum_{i\neq k, i\neq l}^{n} Q_i\right] - \underline{C} = 0 \tag{2.14}$$

With $\partial\pi_k/\partial Q_k = \partial\pi_l/\partial Q_l$ we get that in equilibrium $Q_k^* = Q_l^*$. Substituting that in (2.14) leads to:

$$a - b\left[(r + 1)Q_k^* + \sum_{i\neq k, i\neq l}^{n} Q_i\right] - \underline{C} = 0 \tag{2.15}$$

From (2.13) and (2.15) we obtain that in equilibrium the relation between the output from firms not involved in R&D, and the quantity produced by the members of the RJV, is given by:

$$Q_k^*(r) = Q_i^*(r) + \frac{\Delta C}{b} \tag{2.16}$$

Incremental change in marginal cost

Substitution of $Q_k^*(r)$ according to (2.16) in (2.13) yields for the output by firms not involved in research:

$$a - b\left[r[Q_i^*(r) + \frac{\Delta C}{b}] + (n - r + 1)Q_i^*(r)\right] - \overline{C} = 0 \Leftrightarrow$$

$$Q_i^*(r) = \frac{\left(a - \overline{C}\right) - r\Delta C}{b(n+1)} \tag{2.17}$$

We can see from equation (2.17) that in theory it is possible that firms not involved in research will seize their production. We define the change in marginal cost to be incremental, if it is such that the firms not involved in the research project remain producing output, given the number of firms participating in the RJV. Equation (2.17) indicates that $Q_i^*(r) > 0$ for $r\Delta C < a - \overline{C}$.

By inserting (2.17) in (2.16) we get the output for firms involved in R&D for an incremental change in cost:

$$Q_k^*(r) = \frac{(a - \underline{C}) + (n - r)\,\Delta C}{b(n+1)} \tag{2.18}$$

The corresponding market price in equilibrium equals, after substituting $Q_i^*(r)$ and $Q_k^*(r)$ in (2.1) becomes:

$$P^*(r) = \frac{a + n\overline{C} - r\Delta C}{n+1}$$

With $Q_i^*(r) = Q_j^*(r)$, equation (2.9) generates the profit for firms not conducting R&D:

$$\pi_i^*(r) = \left[a - b\left[rQ_k^*(r) + (n-r)Q_i^*(r)\right]\right] Q_i^*(r) - \overline{C}Q_i^*(r) \tag{2.19}$$

By substituting $Q_i^*(r)$ and $Q_k^*(r)$ in (2.19) we can compute this profit as a function of the changes in marginal cost:

$$\pi_i^*(r) = \frac{[\left(a - \overline{C}\right) - r\Delta C]^2}{b\,(n+1)^2}$$

In order to obtain the profit for the firms of the RJV, we rewrite (2.10) with $Q_k^*(r) = Q_l^*(r)$:

$$\pi_k^*(r) = \left[a - b\left[rQ_k^*(r) + (n-r)Q_i^*(r)\right]\right] Q_k^*(r) - \underline{C}Q_k^*(r) - K/r \tag{2.20}$$

Substitution of $Q_i^*(r)$ and $Q_k^*(r)$ in (2.20) yields as a profit for firms conducting R&D:

$$\pi_k^*(r) = \frac{[(a-\underline{C}) + (n-r)\,\Delta C]^2}{b\,(n+1)^2} - K/r$$

The corresponding total surplus is calculated according to:

$$\begin{aligned} W^*(r) &= \frac{1}{2}\left(rQ_k^*(r) + (n-r)\,Q_i^*(r)\right)\left(a - P^*(r)\right) + \\ &\left(r\pi_k^*(r) + (n-r)\,\pi_i^*(r)\right) - K \\ &= \frac{(n+2)\left[(n-r)\,(a-\overline{C})^2 + r(a-\underline{C})^2\right]}{2b\,(2+(n-1))^2} + \\ &\frac{(2n+3)\,r\,(n-r)\,\Delta C^2}{2b\,(2+(n-1))^2} - K \end{aligned}$$

Radical change in marginal cost: oligopoly

We define the change in marginal cost of production to be radical if $Q_i^*(r) = 0$. In the given market situation, this will happen if $r\Delta C \geq a - \overline{C}$. As a consequence the members of the RJV will act as an oligopoly. The corresponding profit functions can be rewritten from (2.10) as:

$$\begin{aligned} \pi_k^o(r,K) &= \left[a - b\left[Q_k + \textstyle\sum_{l\neq k}^{r} Q_l\right]\right] Q_k - \underline{C}Q_k - K/r \\ \pi_l^o(r,K) &= \left[a - b\left[Q_l + \textstyle\sum_{k\neq l}^{n} Qk\right]\right] Q_l - \underline{C}Q_l - K/r \end{aligned} \tag{2.21}$$

Maximizing profit according to Cournot implies optimizing (2.21) with respect to quantity: $\partial\pi_k/\partial Q_k = 0$. This yields for the best response function:[15]

$$a - b\left[2Q_k + \textstyle\sum_{l\neq k}^{r} Q_l\right] - \underline{C} = 0 \tag{2.22}$$

[15] Note that if we assume that $Q_m = Q_m^*$ with $m \neq k \wedge m \neq l$, we get that if we differentiate the best-response function (2.22) that $|dQ_k/dQ_l| = 1/2$. With a similar assumption, we get that the absolute value of the slope of the best response function for firm in the neighborhood of the equilibrium for firm l is also 1/2. With that the stability condition is fulfilled (Henriques 1990).

In a similar way, we can show that stability conditions are met in case of an incremental change in marginal cost, and in the initial situation (i.e. without successful implementation of research results).

And with $\partial\pi_k/\partial Q_k = \partial\pi_l/\partial Q_l$ we get that in equilibrium: $Q_k^O = Q_l^O$. Substitution in (2.22) gives:

$$a - b\left[2Q_k^O + (r-1)Q_k^O\right] - \underline{C} = 0 \Leftrightarrow$$
$$Q_k^O(r) = \frac{a - \underline{C}}{b(r+1)}$$

By substituting Q_k^O in (2.1) we obtain for the price in equilibrium:

$$P^O(r) = \frac{a + r\underline{C}}{r+1}$$

With $Q_k^O = Q_l^O$ the expression (2.21) for firms conducting R&D becomes:

$$\pi_k^o(Q_k^O, r) = \left[a - b\left[rQ_k^O(r)\right]\right]Q_k^O(r) - \underline{C}Q_k^O(r) - K/r$$

Substitution of the equilibrium quantity $Q_k^O(r)$ gives a profit in equilibrium:[16]

$$\pi_k^O(r) = \frac{(a-\underline{C})^2}{b\,(r+1)^2} - K/r$$

The corresponding total surplus is calculated with:

$$\begin{aligned} W^O(r,K) &= \frac{1}{2}rQ_k^O(r)\left(a - P^O(r)\right) + r\pi_k^O(r) - K \\ &= \left(\frac{1}{2}a - \frac{1}{2}P^O(r) + bQ_k^O(r)\right)rQ_k^O(r) - K \\ &= \frac{1}{2}r\,(r+2)\left[\frac{(a-\underline{C})^2}{b\,(r+1)^2}\right] - K \end{aligned}$$

[16]Note that because the demand function is linear and marginal cost is constant, the second order condition is met, and the profit calculated is therefore indeed a maximum (Martin 2002).

This condition is also met in case of an incremental change in marginal cost, and in the initial situation (i.e. without successful implementation of research results).

Appendix B: regulations and the optimal size of a consortium

In case of an incremental change in marginal cost, we get that $\pi^{+}(r) = \pi_{k}^{*}(r)$. The corresponding extremes are calculated with:

$$\frac{\partial\left[\frac{[(a-\underline{C})+(n-r)\Delta C]^2}{b(n+1)^2}-\frac{K}{r}\right]}{\partial r}=0 \Leftrightarrow$$
$$2\left(\Delta C\right)^2 r^3 - 2\Delta C[(a-\underline{C})+n\Delta C]r^2 + Kb\left(n+1\right)^2 = 0$$

Rewriting this equation with:

$$\alpha = \frac{-2\Delta C\left[(a-\underline{C})-n\Delta C\right]}{2\left(\Delta C\right)^2}$$
$$\beta = \frac{Kb\left(n+1\right)^2}{2\left(\Delta C\right)^2}$$

and $r = x + y$, we get that:

$$x^3 + \left(3y+\alpha\right)x^2 + \left(3y^2+2\alpha y\right)x + y^3 + \alpha y^2 + \beta = 0$$

With $y = -\frac{\alpha}{3}$, $\gamma = \frac{1}{3}\alpha\left(\alpha+5\right)$ and $\delta = \frac{2}{27}\alpha^3 + \beta$ the equation reduces to:

$$x^3 + \gamma x + \delta = 0$$

We can now apply "Viata's substitution". With $x = z + \frac{s}{z}$ we arrive at:

$$z^6 + \left(3s+\gamma\right)z^4 + \delta z^3 + s\left(3s+\gamma\right)z^2 + s^3 = 0$$

By substituting $s = -\frac{\gamma}{3}$ and $z^3 = t$ we get:

$$t^2 + \delta t - \frac{\gamma^3}{27} = 0$$

Solving this gives:

$$t = \frac{-\delta \pm \left(\delta^2 + \frac{4\gamma^3}{27}\right)^{\frac{1}{2}}}{2}$$

Based on the above, we get as a set of solutions:

$$R^* = \left\{ \begin{array}{c} -\Psi\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)+\frac{\frac{1}{9}\alpha(\alpha+5)}{\Psi\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)}-\frac{\alpha}{3}, \\ \Psi\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)-\frac{\frac{1}{9}\alpha(\alpha+5)}{\Psi\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)}-\frac{\alpha}{3}, \\ \Psi-\frac{\frac{1}{9}\alpha(\alpha+5)}{\Psi}-\frac{\alpha}{3} \end{array} \right\}$$

$$\Psi = \sqrt[3]{\frac{-\left(\frac{2}{27}\alpha^3+\beta\right)\pm\left(\left(\frac{2}{27}\alpha^3+\beta\right)^2+\frac{4\left(\frac{1}{3}\alpha(\alpha+5)\right)^3}{27}\right)^{\frac{1}{2}}}{2}}$$

In case of a radical change in marginal cost, we see that $\pi^+(r)=\pi_k^O(r)$. We first note that constraint (2.6 (a)) stipulates that firms will only conduct research if their willingness to invest meets the project cost. In practice this implies that in order to invest, firms have to make a profit after implementation of the research results:

$$(1-p^*)\left(\overline{\pi}^+(r)-\pi^0\right) > K/r \Rightarrow \overline{\pi}^+(r) - K/r > 0 \Rightarrow \frac{(a-\underline{C})^2}{b\,(r+1)^2} > \frac{K}{r}$$

Maximizing this profit on the interval as defined by constraint (2.6 (b)) gives:

$$\frac{\partial\left[\frac{(a-\underline{C})^2}{b(r+1)^2}-\frac{K}{r}\right]}{\partial r} = -\frac{2\,(a-\underline{C})^2}{b\,(r+1)^3}+\frac{K}{r^2} < 0$$

$$\text{because: } \frac{(a-\underline{C})^2}{b\,(r+1)^2} > \frac{K}{r} \wedge \frac{2}{r+1} \geq \frac{1}{r}$$

Appendix C: decision tree for an optimal policy mix

Based on our analysis we argue that an optimal intervention supporting industry-oriented R&D can be depicted as in *Figure 2.5*.

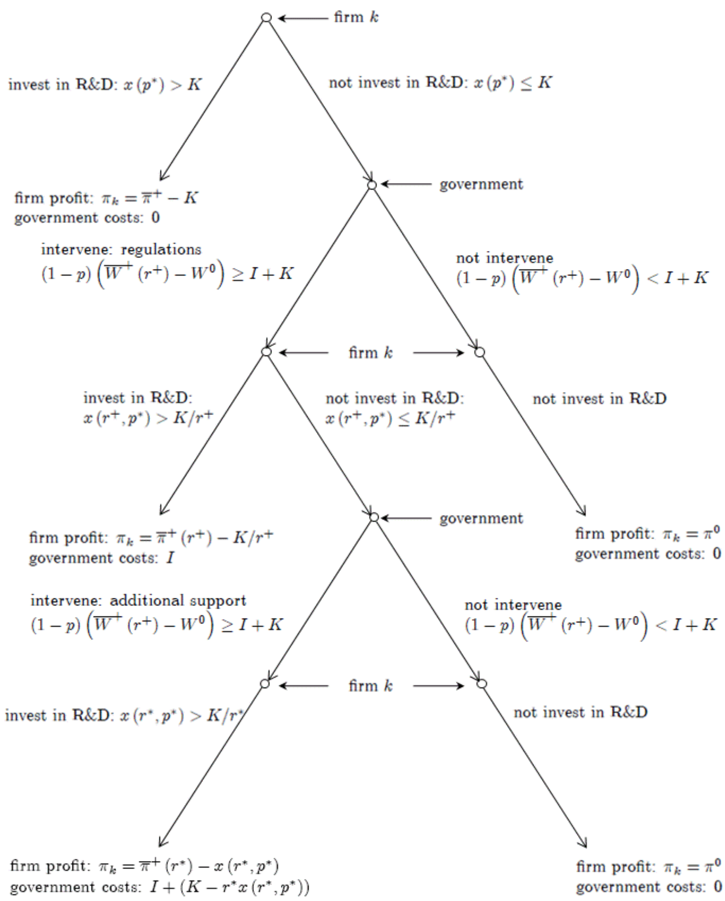

Figure 2.5: Decision tree for an optimal policy mix

Appendix D: government intervention and the minimal contribution

For an incremental change in marginal cost, we get that $\pi^{+}(r) = \pi_k^{*}(r)$. Maximizing the cumulative willingness to invest implies:

$$\frac{\partial \left[r\left(1-p^{*}\right) \left[\frac{[(a-\underline{C})+(n-r)\Delta C]^2}{b(n+1)^2} - \frac{\left(a-\overline{C}\right)^2}{b(n+1)^2} \right] \right]}{\partial r} = 0 \Leftrightarrow$$

$$\left(1-p^{*}\right) \left[\begin{array}{c} \frac{[(a-\underline{C})+(n-r)\Delta C]^2}{b(n+1)^2} - \frac{\left(a-\overline{C}\right)^2}{b(n+1)^2} - \\ \frac{2r\Delta C[(a-\underline{C})+(n-r)\Delta C]}{b(n+1)^2} \end{array} \right] = 0$$

Reformulating this gives:

$$3\left(\Delta C\right)^2 r^2 - 4\Delta C\left[(a-\underline{C}) + n\left(\Delta C\right)\right] r + \left[(a-\underline{C}) + n\left(\Delta C\right)\right]^2 - \left(a-\overline{C}\right)^2 = 0$$

Solving this gives as a solution set:

$$R^{*} = \left\{ \frac{2\Phi \pm \left[\Phi^2 + 3\left(a-\overline{C}\right)^2\right]^{1/2}}{3\Delta C} \right\}$$

with: $\Phi = [(a-\underline{C}) + n\Delta C]$.

The function for the cumulative willingness is increasing from 0 for $r \downarrow 0$, and increasing for $r \to \infty$. If $\widetilde{R} \in \mathbb{N}$ then the local maximum is given by:

$$r^{*} = \left[2\Phi - \left[\Phi^2 + 3\left(a-\overline{C}\right)^2\right]^{1/2}\right] / 3\Delta C$$

For an incremental change in marginal cost, we get that $\pi^{+}(r) = \pi_k^{O}(r)$. Maximizing the corresponding cumulative willingness to invest on the interval defined by

(2.8 (a)) gives:

$$\begin{aligned}\frac{\partial\left[rx(r,p^{*})\right]}{\partial r}&=(1-p^{*})\left[\left[\frac{(a-\underline{C})^{2}}{b\,(r+1)^{2}}-\frac{\left(a-\overline{C}\right)^{2}}{b\,(n+1)^{2}}\right]-\frac{2r\,(a-\underline{C})^{2}}{b\,(r+1)^{3}}\right]\\&=(1-p^{*})\left[\left[\overline{\pi}_{k}^{O}(r)-\pi^{0}\right]-\frac{2r}{r+1}\overline{\pi}_{k}^{O}(r)\right]\\&=(1-p^{*})\left[\frac{-r+1}{r+1}\overline{\pi}_{k}^{O}(r)-\pi^{0}\right]<0\\\text{because: }&\frac{-r+1}{r+1}\leq 0\end{aligned}$$

Appendix E: characteristics of multi-stage strategic investment games

In order to define an optimal policy mix, we build on the results of a multi-stage strategic investment game. We deviate from the existing literature as to reflect the current practice concerning industry-oriented R&D and innovation, and the way it is supported by governments (see *Table 2.1*).

Traditional approach	**Approach for formulation of the policy mix**
Research driven innovation approach	Problem driven innovation approach
All firms of the population conduct R&D	Only a subset of the population is involved in a research project
Change in marginal cost is a function of the investment in R&D	Project results and corresponding impact on marginal costs are predefined Project costs are fixed Conducting the project involves a probability of failure
Government intervention addresses all firms in the population	Government intervention is directed to firms conducting the research project

Table 2.1: Assumtions concerning the innovation process for multi-stage strategic investment games

The assumptions concerning the innovation process define the set-up of the multi-stage strategic investment game. As a result of our approach, the stages of our game deviate also from those adopted in the existing literature (see *Table 2.2*).

Traditional approach	**Approach for formulation of the policy mix**
First stage: government decides on intervention *Contribution is defined such that it maximizes total surplus*	First stage: government decides on intervention *Intervention is defined such that the costs are minimized*
Second stage: firms decide on investment in research *Investment is defined such that it maximizes profit*	Second stage: firms decide on what they are willing to invest in research *Willingness to invest is defined by foreseen change in profit and probability of failure* *Foreseen change in profit is defined by maximizing profit*
Third stage: firms decide on output *Output is defined such that it maximizes profit*	

Table 2.2: Set-up of multi-stage strategic investment games

Chapter 3

Framework for the design of a policy mix supporting R&D and innovation

Extension: the optimal set of instruments for different market structures

The policy mix concept provides policy makers with a conceptual framework that allows them to consider the design of an optimal set of instruments supporting industry-oriented research and innovation (see *Chapter 1*). Optimal in this respect refers to *effectiveness* in changing behavior of firms regarding investment in research, and *efficiency* concerning the cost of the intervention . In *Chapter 2* we define a theoretical framework that allows for the assessment of the effectiveness and efficiency of instruments. Our research indicates that funding (e.g. subsidies or in kind contributions), tax measures and loans perform equally well: they initiate similar levels of innovation, and require equal levels of expected contribution. Implementation of a regulatory framework allowing for collaboration between firms entails the lowest cost for the government in comparison to the other tools. Allowing for collaboration however is not always sufficient to initiate research. In other words: regulations are the most efficient, but not always effective.

We demonstrate our framework in *Chapter 2* for a market offering similar products, competing on quantity (i.e. classical Cournot competition model). In this chapter we analyze if our conclusions hold for different market structures. Our results in *Chapter 2* reveal that the order of performance of funding, tax measures and loans does not alter for different market structures. We therefore focus in this chapter on the impact of regulations on collaboration in order to define an optimal policy mix.

Our analysis in this chapter shows that for certain market structures, regulations are not effective at all. We therefore generalize our conclusions concerning an optimal policy mix as defined in *Chapter 2*. We argue that if a firm is not willing to invest in a predefined research project, than a government should first consider the possibility of allowing for collaboration with the help of a regulatory framework. If regulations are not effective, a government should provide financial support, allocated either by means of funding, tax measures or loans. If possible, the government should try to impose the appropriate number of partners in the consortium, such that it minimizes its contribution. The actual intervention is limited: a government should provide support only if implementation of the research results lead to an increase in surplus.

In the next section, we present the model to assess the willingness of a firm to invest in a research project as a basis for intervention for a government, as defined in *Chapter 2*. In *Section 3.3* we analyze the impact of regulations for a market with homogeneous products competing on price (i.e. classical Bertrand competition model), and a market with differentiated products competing on price, and on quantity (i.e. Bertrand and Cournot for differentiated products). We subsequently compute the size of the consortium that minimizes the financial support. In *Section 3.4* we define the optimal policy mix. Implications for policy formulation and future research are given in *Section 3.5*.

3.1 Investment in R&D by firms

For our analysis, we build on the results of a multi-stage strategic investment game, as introduced by (d' Aspremont and Jacquemin 1988).

We assume that there is a total and fixed population N containing n firms (with $i \in N$). We further presume that there is a variable sub-population $R \subseteq N$ containing r firms conducting R&D (with $k \in R$).

We consider the initial *marginal cost* c of production to be equal and constant for all firms, and determined by the state of the art in production technology within a certain industry or sector. Reduction of the marginal cost results from successful completion of a predefined research project implemented to explore a specific idea to improve the production process. As a consequence, the impact of the results on the change in the cost of production is foreseen. We subsequently define the marginal cost as $c_k = \underline{C}$ for $k \in R$ and $c_i = \overline{C}$ for $i \in N \wedge i \neq k$, with $0 < \underline{C} < \overline{C} < a$. The change in marginal cost resulting from a successful completion of the research project is represented as $\Delta C = \overline{C} - \underline{C}$.

We presume that for $r > 1$, the firms involved in R&D will form a Research Joint Venture (RJV). These firms will coordinate their research activities by sharing R&D results and avoiding duplication for the duration of the project. This implies that we assume that the internal spillover coefficient equals one (Kamien et al. 1992), and that they share the cost equally. We ignore immediate spill-over effects to and from firms from outside the RJV while the research project is conducted.

Conducting the research project involves a certain risk of failure. We define $p \in [0, 1]$ as the *probability of failure of the project.* This probability depends on the current level of knowledge concerning production for this sector. If the required knowledge is not available, and lies beyond the current state of the art, the probability of failure will be close to one. If the required knowledge is available, this probability will be close to zero.[1]

We assume that the *project cost* K of the research are fixed, based on an estimation of the required input (e.g. use of equipment and deployment of researchers). When producing we suppose that these firms face no fixed cost.

We argue that a firm k will decide on joining the RJV and conducting the required R&D by comparing the expected profit resulting from conducting the research with the initial profit. If we define $\pi_i = \pi^0$ as the *initial profit in equilibrium*, and $(\pi_i (r), \pi_k (r)) = (\pi^- (r), \pi^+ (r))$ as the *profit in equilibrium after successful implementation of the research results*, we get that this investment decision can be

[1] Our framework ignores immediate spillover effects. The impact of knowledge creation however is ultimately captured in the probability of failure of research projects.

represented as:

$$(1-p)\left(\overline{\pi}^{+}(r)-K/r\right)+p\left(\pi^{0}-K/r\right)\gtrless\pi^{0}\Leftrightarrow$$
$$(1-p)\left(\overline{\pi}^{+}(r)-\pi^{0}\right)\gtrless K/r$$

The inequality shows that firm k will decide by comparing what it is willing to invest in R&D (i.e. the expected gross gain in profit) with the individual project cost. Behavior of firms concerning investment is pivotal in our framework for the selection of instruments. We will represent the *willingness to invest in R&D* as:

$$x(r,p)=(1-p)\left(\overline{\pi}^{+}(r)-\pi^{0}\right)$$

with $\overline{x}(r)\equiv\overline{\pi}^{+}(r)-\pi^{0}$ as the *gross investment in R&D*.

3.2 Intervention by the government

Firm k will conduct the R&D if the probability of failure of the project is such that $x(r,p)>K/r$. But if the firm is not willing to cover the individual project cost (i.e. $x(r,p)\leq K/r$), then k will not consider implementing the project as the required investment would lead to an expected profit lower than (or equal to) that in the initial situation. We define the corresponding *shortfall* S of the willingness to invest as:

$$S\left(r,p\right)=K-x(r,p)$$

If the willingness of the firm does not meet the project cost, a government has the possibility to intervene, and implement measures such that the firm will alter its behavior, and decide on conducting the research. The objective is to design an optimal policy mix, constituted by a set of instruments which is not only effective, but also efficient. We therefore argue that a government should define its intervention such that it minimizes its expenditure on a single project. This allows for support of other additional research, thereby creating additional surplus.

Rationale for intervention by a government in our framework would be an expected increase in surplus if the research project is conducted. Intervention as such is limited: the corresponding government cost (on project level) for the intervention should never be too high, in that they should not undo the gain in social surplus. This rationale for intervention and corresponding condition for support will act as our set of criteria to assess the design of the (set of) measures resulting from our framework.

3.3 Assessment of instruments

As a starting point for the formulation of an optimal policy mix, we consider a single firm k from the total population of firms N, which has an idea for an improvement of its production technology. We assume that the characteristics of the corresponding research project are such that the willingness to invest does not meet the project cost. A government has different measures available to alter the investment decision of the firm and initiate research. In *Chapter 1* we identify four modalities of support:

- *Funding*: direct support in the form of subsidies, grants or a rebate on social insurances, and indirect support such as vouchers and access to research infrastructure (i.e. in kind contributions).
- *Taxation*: fiscal measures offering a tax relief on turnover or profit from products resulting from the research project.
- *Loans*: support which has to be reimbursed by the firms involved in research to the government.
- *Regulations* such as Intellectual Property Rights (IPR) and laws governing the functioning and interaction of actors, aimed at establishing cooperation (between firms and actors of the research infrastructure) and collaboration (between firms).

Almost all industrialized countries have implemented these types of measures supporting industry-oriented research.[2] Note that we assume that each intervention is targeted, and therefore limited, to those involved in research.

[2]For an overview, check: www.proinno-europe.eu, www.cordis.europa.eu/erawatch or www.oecd.org.

The analysis in *Chapter 2* reveals that funding, taxation and loans induce similar levels of effort in R&D. For a linear perception of risk and valuation of profit and cost, the expected contribution for these tools is identical, and equal to the shortfall in investment. This implies that their effectiveness and efficiency is the same. The order of performance remains unchanged for a different market structure.

The analysis in *Chapter 2* also indicates that measures aimed at allowing collaboration between firms do not require a contribution to the cost of the research. It is however not always possible to establish a consortium with an appropriate number of participants. The effectiveness of regulations furthermore varies for different market structures.

As a result of these findings, we therefore focus in this chapter on the impact of regulations on collaboration in order to define an optimal policy mix. By implementing regulations, a government tries to establish the necessary preconditions for collaboration between firms within an R&D project. Collaborating firms are able to share the risks of the research project such that the total project cost will be equally shared, and thereby lowered. Their profit however will also decrease. In this paragraph, we will compute the optimal size of an RJV for firm k (i.e. select an optimal number of research partners) such that that it maximizes its individual profit, while covering the individual project cost for different market structures.

If it is not possible to create a consortium such that $x\,(r, p) > K/r$, a government could provide additional financial support to the regulatory framework. Under the current assumptions, the government will be indifferent between funding, tax measures or loans. We will compute the appropriate number of partners in the consortium, such that it minimizes its contribution for different types of competition.

Bertrand Classic

We start our analysis of the impact of regulations for a market with firms offering homogeneous products, but competing on price. The inverse demand function we use is similar to the one used in *Chapter 2*, and builds on (Kamien et al. 1992) (see *Appendix A*):

$$P(r) = a - b\left[\textstyle\sum_k^r Q_k + \sum_{i \neq k}^n Q_i\right] \tag{3.1}$$

with P as the market price, Q as the quantity sold, $a > 0$ as the demand intercept, and $b > 0$ to ensure production.

Competing according to Bertrand implies that firms compete by setting prices simultaneously, and that consumers buy everything from a firm they randomly select among those that offer the lowest price. If no firm is involved in research than the market price equals the initial marginal cost: $P^0 = \overline{C}$, such that the profit of the firms $\pi^0 = 0$.

Successful implementation of the project results will allow firm k to offer a price $P_k < \overline{C}$ such that takes the entire market, with $\pi^- = 0$ and:

$$\pi_k = \frac{(a - P_k)(P_k - \underline{C})}{b} - K$$

Maximizing profit yields:

$$\begin{aligned} \frac{\partial \pi_k}{\partial P_k} &= \frac{a - 2P_k^* + \underline{C}}{b} = 0 \Leftrightarrow \\ P_k^* &= \frac{a + \underline{C}}{2} \end{aligned}$$

The actual monopoly *price in equilibrium* P^+ is restricted. If the marginal cost resulting from implementation of the research results are such that $P_k^* < \overline{C}$, then $P^+ = P_k^*$. In the existing literature, this is referred to as a major innovation. If $P_k^* \geq \overline{C}$ however, then $P^+ = P_k^O = \overline{C} - \epsilon$. This is referred to as a minor innovation. The corresponding profit is given by:

$$\pi^+ = \begin{cases} \frac{(a-\underline{C})^2}{4b} - K & \text{for } \underline{C} < 2\overline{C} - a \\ \frac{\left(a-\overline{C}+\epsilon\right)(\Delta C - \epsilon)}{b} & \text{for } \underline{C} \geq 2\overline{C} - a \end{cases}$$

Lemma 3.1 *In a market under Bertrand with homogeneous products, regulations are not effective.*

Proof. A RJV with r participating firms in a market competing on price will offer firms a price $P_k(r) < \overline{C}$ such that they take the entire market, and act as an oligopoly with: $\pi^-(r) = 0$ and:

$$\pi_k(r) = \frac{(a - P_k(r))(P_k(r) - \underline{C})}{br} - K/r$$

But in a market where firms compete on price, the r firms of the RJV will inevitably select a price in equilibrium $P^+(r)$ such that they will make no profit (i.e. $\pi^+(r) = 0$). Firm k will therefore not collaborate in research. ■

Cournot with differentiated products

Next we analyze the impact of regulations on a market with firms offering horizontally differentiated products, competing on output. "Differentiation is said to be horizontal when [...] between two products the level of some characteristics is augmented while it is lowered for some others, as in cases of different versions [...] of a car. A consumer will buy the 'closest' products in terms of a certain distance. Differentiation is called vertical when [...] between two products the level of characteristics is augmented or lowered, as in the case of cars of different series [...]. There is unanimity to rank the products according to a certain order." (Phlips and Thisse 1982)

For the inverse demand curve for a market with differentiated products, we build on (3.1). We introduce a *substitutability coefficient* $\kappa \in [0,1]$ which indicates the level of differentiation of the products offered by the population of firms (Bowley 1925).[3]

$$P_i(r) = a - b\left[\kappa \sum_k^r Q_k + Q_i + \kappa \sum_{j\neq i,\ j\neq k}^n Q_j\right] \quad (3.2)$$

$$P_k(r) = a - b\left[Q_k + \kappa \sum_{l\neq k}^r Q_l + \kappa \sum_{i\neq k,\ i\neq l}^n Q_i\right] \quad (3.3)$$

Note that as κ is constant in this model, the products offered are differentiated, but their level of differentiation is equal. In other words, they are equally different.

In order to define what the firm is willing to invest, we need to compute the profit in equilibrium. In a market under Cournot, firms compete on the amount of output they will produce, which they decide on independently of each other and at the

[3]For $\kappa = 0$ the varieties are independent in demand, and each firm acts as a monopolist. For $\kappa < 1$ firms offer differentiated goods. As κ approaches 1, the varieties become closer and closer substitutes. For $\kappa = 1$ all goods are perfect substitutes.

same time. Their profit in equilibrium is given by (see *Appendix B*):

$$\pi^0 = \frac{\left(a - \overline{C}\right)^2}{b\left[2 + \kappa\left(n-1\right)\right]^2}$$

$$\pi^+(r) = \begin{cases} \pi_k^*(r) & \text{for} \quad r\Delta C < \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa} \\ \pi_k^O(r) & \text{for} \quad r\Delta C \geq \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa} \end{cases}$$

$$\pi^-(r) = \begin{cases} \pi_i^*(r) & \text{for} \quad r\Delta C < \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa} \\ \pi_i^O(r) & \text{for} \quad r\Delta C \geq \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa} \end{cases} \tag{3.4}$$

with:

$$\pi_k^*(r) = \frac{\left[\left(a - \underline{C}\right) + \frac{\kappa}{2-\kappa}\left(n-r\right)\Delta C\right]^2}{b\left[2+\kappa\left(n-1\right)\right]^2} - K/r$$

$$\pi_i^*(r) = \frac{\left[\left(a - \overline{C}\right) - \frac{\kappa}{2-\kappa} r\Delta C\right]^2}{b\left[2+\kappa\left(n-1\right)\right]^2}$$

$$\pi_k^O(r) = \frac{\left(a - \underline{C}\right)^2}{b\left[2+\kappa\left(r-1\right)\right]^2} - K/r$$

$$\pi_i^O(r) = 0$$

We can see from the expression for $\pi_i^*(r)$ in (3.4) that the firms not conducting R&D remain producing only in case $r\Delta C < \left(a - \overline{C}\right)\left(2-\kappa\right)/\kappa$. We define this as an *incremental* change in marginal cost. These firms however cease production if $r\Delta C \geq \left(a - \overline{C}\right)\left(2-\kappa\right)/\kappa$. We define this as a *radical* change in marginal cost. The members of the RJV will in that case act as an oligopoly.

With the profit in equilibrium, we can assess the impact of regulations on what a firm is willing to invest in research. We analyze the possibilities of formulating a RJV in case $x\left(p\right) \leq K$.

Lemma 3.2 *In a market under Cournot with differentiated products, firm k maximizes its profit by establishing a RJV with* $\widehat{r}_C$ *consortium members if* $x(\widehat{r}_C, p) >$

$K/\widehat{r}_C$ *such that:*

$$\widehat{r}_C = \begin{cases} r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+(n)\right), \\ \quad \{r^* \in R^* : r^* \in [1, n]\} \ \mathit{for} \ \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C} \geq n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+\left(\frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C}\right), \pi^+\left(r^O\right), \pi^+(n)\right), \\ \quad \left\{r^* \in R^* : r^* \in \left[1, \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C}\right)\right\}, \\ \quad \left\{r^O \in R^O : r^O \in \left[\frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C}, n\right]\right\} \\ \quad \mathit{for} \ 1 < \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C} < n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+\left(r^O\right), \pi^+(n)\right), \\ \quad \left\{r^O \in R^O : r^O \in [1, n]\right\} \ \mathit{for} \ 1 \geq \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C} \end{cases}$$

with:

$$R^* = \left\{ \begin{array}{c} -\Psi^*\left(\frac{1}{2} i\sqrt{3} + \frac{1}{2}\right) + \frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)} - \frac{\alpha^*}{3}, \\ \Psi^*\left(\frac{1}{2} i\sqrt{3} - \frac{1}{2}\right) - \frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)} - \frac{\alpha^*}{3}, \\ \Psi^* - \frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*} - \frac{\alpha^*}{3} \end{array} \right\}$$

$$\Psi^* = \sqrt[3]{\frac{-\left(\frac{2}{27}(\alpha^*)^3 + \beta^*\right) \pm \left[\left(\frac{2}{27}(\alpha^*)^3 + \beta^*\right)^2 + \frac{4\left(\frac{1}{3}\alpha^*(\alpha^*+5)\right)^3}{27}\right]^{\frac{1}{2}}}{2}}$$

$$\alpha^* = -\frac{(a - \underline{C}) + \frac{\kappa}{2-\kappa} n \Delta C}{\frac{\kappa}{2-\kappa}\Delta C}$$

$$\beta^* = \frac{Kb\left[2 + \kappa(n-1)\right]^2}{2\left[\frac{\kappa}{2-\kappa}\Delta C\right]^2}$$

and with:

$$R^O = \left\{ \begin{array}{c} -\Psi^O \left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right) - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{-3\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)} - \frac{\alpha^O}{3}, \\ \Psi^O \left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right) - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)} - \frac{\alpha^O}{3}, \\ \Psi^O - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O} - \frac{\alpha^O}{3} \end{array} \right\}$$

$$\Psi^O = \sqrt[3]{\frac{-\omega^O \pm \left[\left(\omega^O\right)^2 + \frac{4\left[\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right]^3}{27}\right]^{\frac{1}{2}}}{2}}$$

$$\omega^O = \frac{2}{27}\left(\alpha^O\right)^3 - \frac{1}{3}\gamma^O\alpha^O + \beta^O$$

$$\alpha^O = \frac{3Kb\kappa^2(2-\kappa) - 2\kappa\left(a-\underline{C}\right)^2}{Kb\kappa^3}$$

$$\beta^O = \frac{-Kb\left(\kappa\left(\kappa^2 - 6\kappa + 12\right) - 8\right)}{Kb\kappa^3}$$

$$\gamma^O = \frac{3Kb\kappa\left(\kappa-2\right)^2}{Kb\kappa^3}$$

Proof. The optimal size of the consortium, such that firm k maximizes its profit, is computed with:

$$\max_r \left(\pi^+(r)\right) \tag{3.5}$$

$$subject\ to:$$

$$x(r,p) > K/r \tag{a}$$

$$1 \leq r \leq n \tag{b}$$

The computations for this maximization are given in *Appendix B*.

Constraint (3.5 (a)) stipulates that if it is not possible to formulate a RJV such that the willingness to invest meets the individual project cost, no research consortium will be established, and firm k will consequently decide not to conduct the R&D.

The optimal size of the consortium depends on the impact of the research result on the market (i.e. number of firms operating in the market). Optimizing for an incremental change in marginal cost, with $\pi^+(r) = \pi_k^*(r)$, gives the solution set $R^* \in \mathbb{C}$. On $r \in (0,\infty)$ this profit function is continuous. It is increasing and concave for $r \downarrow 0$ and convex and increasing for $r \to \infty$. On the interval as defined by constraint (b), none of the extremes of R^* can be excluded beforehand, or subsequently be identified as a local maximum or minimum.

For a radical change in marginal cost we get that $\pi^+(r) = \pi_k^O(r)$. Optimization of the profit function gives us as a solution set $R^O \in \mathbb{C}$. Also this function is continuous on $r \in (0, \infty)$. For $r \downarrow 0$, we see that $\pi_k^O(r) \to \infty$, and for $r \to \infty$, we get that $\pi_k^O(r) \to 0$. On the interval as defined by constraint (b) however, the profit function could be increasing as well as decreasing under the given conditions. Therefore none of the extremes of R^O can be excluded beforehand, or subsequently be identified as a local maximum or minimum. ■

Lemma 3.2 indicates that regulations have an impact on the investment decision concerning research of firms. A government could therefore minimize its contribution to a project to initiate research, by imposing a specific size of the RJV.

Lemma 3.3 *In a market under Cournot with differentiated products, a government minimizes its contribution to a project in order to initiate research by imposing a size* $\widetilde{r}_C$ *on a RJV if* $x(\widetilde{r}_C, p) \leq K/\widetilde{r}_C$ *such that:*

$$\widetilde{r}_C = \begin{cases} r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+(n)\right), \\ \quad \{r^* : r^* \in [1, n]\} \; \mathit{for} \; \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C} \geq n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+\left(\frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C}\right), \pi^+(\underline{\widetilde{r}}), \pi^+(n)\right). \\ \quad \left\{r^* : r^* \in \left[1, \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C}\right)\right\}, \left\{r^O \in R^O : r^O \in \left[\frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C}, n\right]\right\} \\ \quad \mathit{for} \; 1 < \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C} < n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+\left(r^O\right), \pi^+(n)\right), \\ \quad \left\{r^O \in R^O : r^O \in [1, n]\right\} \; \mathit{for} \; 1 \geq \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa \Delta C} \end{cases}$$

with:

$$
\begin{aligned}
r^* &= \frac{2\Xi - \left[\Xi^2 - 3\left(\Xi^2 - \left(a-\overline{C}\right)^2\right)\right]^{1/2}}{3\Theta} \\
\Xi &= \left[(a-\underline{C}) + n\frac{\kappa}{2-\kappa}\Delta C\right] \\
\Theta &= \left(\frac{\kappa}{2-\kappa}\Delta C\right)
\end{aligned}
$$

and with:

$$
\begin{aligned}
R^O &= \left\{\begin{array}{c}
-\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right) - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{-3\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)} - \frac{\alpha^O}{3}, \\
\Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right) - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)} - \frac{\alpha^O}{3}, \\
\Psi^O - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O} - \frac{\alpha^O}{3}
\end{array}\right\} \\
\Psi^O &= \sqrt[3]{\frac{-\omega^O \pm \left[\left(\omega^O\right)^2 + \frac{4\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)^3}{27}\right]^{\frac{1}{2}}}{2}} \\
\omega^O &= \frac{2}{27}\left(\alpha^O\right)^3 - \frac{1}{3}\gamma^O\alpha^O + \beta^O \\
\alpha^O &= \frac{-3\left(\kappa-2\right)}{\kappa} \\
\beta^O &= \frac{(\kappa-2)\left[2+\kappa(n-1)\right]^2\left(a-\underline{C}\right)^2 - \left[\kappa\left(\kappa^2-6\kappa+12\right)-8\right]\left(a-\overline{C}\right)^2}{\kappa^3\left(a-\overline{C}\right)^2} \\
\gamma^O &= \frac{3\left(\kappa-2\right)^2\left(a-\overline{C}\right)^2 + \left[2+\kappa(n-1)\right]^2\left(a-\underline{C}\right)^2}{\kappa^2\left(a-\overline{C}\right)^2}
\end{aligned}
$$

Proof. The optimal size of the consortium such that the government minimizes its contribution is given by:

$$
\min_r \left[r\left(\frac{K}{r} - x(r,p^*)\right)\right] \tag{3.6}
$$

$$
\textit{subject to}:
$$

$$
x(r,p^*) \leq K/r \tag{a}
$$

$$
1 \leq r \leq n \tag{b}
$$

In practice this requires computing the size of the consortium that generates the highest cumulative willingness to invest. The computations are given in *Appendix B*.

Constraint (3.6 (a)) stipulates that a government should contribute to a consortium only if it is not possible to formulate a RJV such that the cumulative willingness to invest covers the total project cost.

Again the optimal size of the consortium depends on the impact of the research result on the market. For an incremental change in marginal cost we get that the cumulative willingness to invest has a maximum at r^*. The actual size of the consortium depends on the orientation of r^* with respect to the interval as defined by constraint (3.6 (b)).

Optimizing the cumulative willingness to invest for a radical change in marginal cost gives a solution set $R^O \in \mathbb{C}$. Also this function is continuous on $r \in (0, \infty)$. This function goes through the origin, and for $r \to \infty$, we get that $\pi_k^O(r) \to -\infty$. On the interval as defined by constraint (b) however, none of the extremes of R^O can be excluded. ■

Bertrand with differentiated products

Last we analyze the impact of regulations on a market offering differentiated products competing on price (i.e. Bertrand with differentiated products). We therefore first need to invert the demand functions (3.2) and (3.3), which gives:

$$\begin{aligned}
Q_i(r) = {} & \frac{1}{1+\kappa(n-1)}\frac{a}{b} + \frac{\kappa}{(1-\kappa)[1+\kappa(n-1)]}\sum\nolimits_k^r \frac{1}{b}P_k + \\
& \frac{-[1+\kappa(n-2)]}{(1-\kappa)[1+\kappa(n-1)]}\frac{1}{b}P_i + \frac{\kappa}{(1-\kappa)[1+\kappa(n-1)]}\sum\nolimits_{j\neq i,\ j\neq k}^n \frac{1}{b}P_j \\
Q_k(r) = {} & \frac{1}{1+\kappa(n-1)}\frac{a}{b} + \frac{\kappa}{(1-\kappa)[1+\kappa(n-1)]}\sum\nolimits_{i\neq k,\ i\neq l}^n \frac{1}{b}P_i + \\
& \frac{-[1+\kappa(n-2)]}{(1-\kappa)[1+\kappa(n-1)]}\frac{1}{b}P_k + \frac{\kappa}{(1-\kappa)[1+\kappa(n-1)]}\sum\nolimits_{l\neq k}^r \frac{1}{b}P_l
\end{aligned}$$

The corresponding profit which we require to get insight in the willingness to invest in the research project is given by (see *Appendix C* for computations):

$$\pi^0 = \Omega\Pi\left(a-\overline{C}\right)^2$$
$$\pi^+(r) = \begin{cases} \pi_k^*(r) & \text{for} \quad r\Delta C < \left(a-\overline{C}\right)/\Lambda \\ \pi_k^O(r) & \text{for} \quad r\Delta C \geq \left(a-\overline{C}\right)/\Lambda \end{cases}$$
$$\pi^-(r) = \begin{cases} \pi_i^*(r) & \text{for} \quad r\Delta C < \left(a-\overline{C}\right)/\Lambda \\ \pi_i^O(r) & \text{for} \quad r\Delta C \geq \left(a-\overline{C}\right)/\Lambda \end{cases} \tag{3.7}$$

with:

$$\pi_k^*(r) = \Omega\Pi\left[\left(a-\underline{C}\right)+\Lambda\left(n-r\right)\Delta C\right]^2 - K/r$$
$$\pi_i^*(r) = \Omega\Pi\left[\left(a-\overline{C}\right)-\Lambda r\Delta C\right]^2$$
$$\pi_k^O(r) = \frac{\left(1-\kappa\right)\left(1+\kappa\left(r-2\right)\right)}{b\left(1+\kappa\left(r-1\right)\right)\left(2+\kappa\left(r-3\right)\right)^2}\left(a-\underline{C}\right)^2 - K/r$$
$$\pi_i^O(r) = 0$$

given that:

$$\Lambda = \frac{\kappa\left(1+\kappa\left(n-2\right)\right)}{\left(1-\kappa\right)\left(2+\kappa\left(2n-3\right)\right)}$$
$$\Pi = \frac{\left(1+\kappa\left(n-2\right)\right)}{b\left(1+\kappa\left(n-1\right)\right)\left(2+\kappa\left(n-3\right)\right)}$$
$$\Omega = \frac{\left(1-\kappa\right)}{\left(2+\kappa\left(n-3\right)\right)}$$

Again we see from expression (3.7) that there is a transition point for which those firms not part of the RJV cease production. If $r\Delta C < \left(a-\overline{C}\right)/\Lambda$, than we define this as an incremental change in marginal cost. We refer to a radical change in marginal cost in case $r\Delta C \geq \left(a-\overline{C}\right)/\Lambda$.

Lemma 3.4 *In a market under Bertrand with differentiated products, firm k will establish a RJV with $\widehat{r}_B$ consortium members if $x(\widehat{r}_B, p) > K/\widehat{r}_B$ such that:*

$$\widehat{r}_B = \begin{cases} r : \pi^+(r) = \max\left(\pi^+, \pi^+(\widehat{r}), \pi^+(n)\right), \\ \quad \{r^* \in R^* : \widehat{r} \in [1,n]\} \ \textit{for} \ \left(a - \overline{C}\right)/\Lambda\Delta C \geq n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(\widehat{r}), \pi^+\left(\left(a-\overline{C}\right)/\Lambda\Delta C\right), \pi^+(n)\right), \\ \quad \left\{r^* \in R^* : r^* \in \left[1, \left(a-\overline{C}\right)/\Lambda\Delta C\right)\right\} \ \textit{for} \ 1 < \left(a-\overline{C}\right)/\Lambda\Delta C < n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(n)\right) \ \textit{for} \ 1 \geq \left(a-\overline{C}\right)/\Lambda\Delta C \end{cases}$$

with:

$$R^* = \left\{ \begin{array}{c} -\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right) + \frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)} - \frac{\alpha^*}{3}, \\ \Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right) - \frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)} - \frac{\alpha^*}{3}, \\ \Psi^* - \frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi} - \frac{\alpha^*}{3} \end{array} \right\}$$

$$\Psi^* = \sqrt[3]{\frac{-\left(\frac{2}{27}(\alpha^*)^3 + \beta^*\right) \pm \left[\left(\frac{2}{27}(\alpha^*)^3+\beta^*\right)^2 + \frac{4\left(\frac{1}{3}\alpha^*(\alpha^*+5)\right)^3}{27}\right]^{\frac{1}{2}}}{2}}$$

$$\alpha^* = \frac{-\left[(a-\underline{C}) + \Lambda n \Delta C\right]}{\Lambda\Delta C}$$

$$\beta^* = \frac{K}{2\Omega\Pi\Lambda^2(\Delta C)^2}$$

Proof. We adopt a similar approach as for the proof of *Lemma 3.2*. The optimal size of the consortium, such that firm k will maximize its profit, is computed with:

$$\max_r \left(\pi^+(r)\right) \tag{3.8}$$

$$\textit{subject to}:$$

$$x(r,p) > K/r \tag{a}$$

$$1 \leq r \leq n \tag{b}$$

Results of the computation are given in see *Appendix C*.

Again constraint (3.8 (a)) ordains that if it is not possible to formulate a RJV such that the willingness to invest meets the individual project cost, no research will be conducted.

Optimizing for an incremental change in marginal cost gives the solution set $R^* \in \mathbb{C}$. On $r \in (0, \infty)$ this profit function is continuous. It is increasing and concave for $r \downarrow 0$ and convex and increasing for $r \to \infty$. On the interval as defined by constraint (b), none of the extremes of R^* can be excluded beforehand, or subsequently be identified as a local maximum or minimum.

Maximizing profit for a radical change in marginal cost does not give a closed form solution. We will interpret this as if firm k has no insight in the market and its competitors. We'll therefore assume that firm k will limit its search for an optimal size of the RJV to the end points of the interval for which it acts as an oligopoly.

■

Lemma 3.4 indicates that regulations have an impact on the investment decision of firms concerning research in case of a market with differentiated products competing on price.

Lemma 3.5 *In a market under Bertrand with differentiated products, a government minimizes its contribution to a project in order to initiate research by imposing a size* r_B^* *on a RJV if* $x(r_B^*, p) \leq K/r_B^*$ *such that:*

$$\widetilde{r}_C = \begin{cases} r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+(n)\right) \\ \quad \{r^* : r^* \in [1, n]\} \ \textit{for} \ \left(a - \overline{C}\right)/\Lambda\Delta C \geq n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(r^*), \pi^+\left(\left(a - \overline{C}\right)/\Lambda\Delta C\right), \pi^+(n)\right) \\ \quad \left\{r^* : r^* \in \left[1, \left(a - \overline{C}\right)/\Lambda\Delta C\right)\right\} \ \textit{for} \ 1 < \left(a - \overline{C}\right)/\Lambda\Delta C < n \\ r : \pi^+(r) = \max\left(\pi^+, \pi^+(n)\right) \ \textit{for} \ 1 \geq \left(a - \overline{C}\right)/\Lambda\Delta C \end{cases}$$

with:

$$r^* = \frac{2\left(\left(a - \underline{C}\right) + n\Lambda\Delta C\right) - \left[\left(\left(a - \underline{C}\right) + n\Lambda\Delta C\right)^2 + 3\left(a - \overline{C}\right)^2\right]^{1/2}}{3\Lambda\Delta C}$$

Proof. We adopt an approach as used for *Lemma 3.3.* The minimal government contribution is calculated with:

$$\min_{r} \left[r \left(\frac{K}{r} - x(r, p^*) \right) \right] \tag{3.9}$$

$$subject\ to:$$

$$x(r, p^*) \leq K/r \tag{a}$$

$$1 \leq r \leq n \tag{b}$$

The computations for this problem are given in *Appendix C*.

Constraint (3.9 (a)) stipulates again that a government should contribute to a consortium only if it is not possible to formulate a RJV such that the partners are willing and able to cover the total project cost.

For an incremental change in marginal cost we get that the function for cumulative willingness to invest has a maximum at r^*. The actual size of the consortium depends on the orientation of r^* with respect to the interval as defined by constraint (3.9 (b)).

Minimizing the government contribution for a radical change in marginal cost does not give a closed form solution. We will interpret this also as if the government has no insight in the market and its actors. We'll therefore assume that a government will impose one of the end points of the interval in which firm k will act as an oligopoly as the potential optimal size of the consortium. ■

3.4 Main result: combination of measures in a policy mix

The results of our analysis of the impact of regulations on the willingness of firms to invest in research compels us to generalize the main theorem of *Chapter 2* concerning the design of an optimal policy mix.

Theorem 3.6 *If a firm is not willing to invest in a predefined research project because the expected change in profit does not cover the corresponding fixed cost,* *then a government should consider allowing for collaboration.*

If it is not possible to formulate a RJV such that the cumulative willingness of the members covers the total project cost, then a government might consider contributing to the cost of the project. The government should try to impose a size of the RJV that minimizes its expected contribution. This contribution could subsequently be allocated either by means of funding, tax measures or loans.

The actual intervention is constrained: a government should intervene only if it leads to an increase in total surplus.

Proof. We build on *Lemma 3.1* to *Lemma 3.5* for the formulation of *Theorem 3.6*.

As in *Chapter 2*, we argue that a government should assess the intervention against the criteria for support as defined in *Section 3.1*. First, a government should only contribute to the cost of the project if it leads to an expected increase in the total surplus. Second, the total government cost should not exceed the gain in surplus. These total cost consist of the contribution to the project (i.e. the shortfall $S(r,p)$), and *Implementations cost* I, which refer mainly to monitoring and evaluation. We assume that they are equal for all the instruments. Combining the two constraints gives us:

$$(1-p)\left(\overline{W}^{+}(r) - W^{0}\right) \geq I + K$$

■

For the sake of completeness, we give the surplus for all market structures analyzed in this chapter in *Appendix D*.

3.5 Conclusions and recommendations

The analysis of the impact of successful R&D on the market shows that innovating firms create a competitive advantage over their competitors not involved in research. This competitive advantage might be such that they take the entire market. Our results suggest therefore that R&D and innovation policy contributes to the strengthening and renewal of the economy. We argue that firms that are not innovative, and consequently are not able to adapt to the increasing global competition, are ultimately excluded because of the contribution to research that is allocated by instruments supporting R&D and innovation.

Our analysis furthermore indicates that for certain market structures, allowing for collaboration between firms does not change their willingness to conduct research. We therefore maintain that existing research programmes that compel collaborative industry-oriented research with a fixed number of consortium partners (e.g. the EU framework programmes[4]) are not efficient. Based on our results we argue that an optimal policy mix diversifies its modality of support to industry, based on market structure and project characteristics.

The results of our analysis of the market equilibria allow us to compare the contribution required to initiate research for different forms of competition. Additional research could subsequently contribute to the identification of a thematic scope of a policy mix. A government might consider supporting actors operating in a market that requires a limited contribution in comparison to other markets (as that would be more efficient in order to initiate research). This additional analysis could contribute to theory on the formulation of an optimal policy mix in the same way as (Qiu 1997) contributed to theory on multi-stage strategic investment games for policy formulation.

Appendix A: demand and profit function

Our analysis builds on the results of a multi-stage strategic investment game. When applied to analyze the behavior of industry concerning their investment decision research, this type of game involves a stage where firms determine their input on R&D, allocated either in order to lower marginal cost or to differentiate the product. It also includes a stage where firms engage in competition, as to define either their output. The entire game is solved by means of backward induction (De Bondt 1997).

[4]See www.cordis.europa.eu/fp7.

When a multi-stage strategic investment game is used to define an intervention by a government to support R&D and innovation, an additional stage should be introduced to assess the contribution required to initiate the research.

The basis for our model for our multi-stage strategic investment game is the one introduced by (Kamien et al. 1992). Within the framework of this chapter, it is assumed that all firms participate in R&D and innovation. Firms face an inverted individual demand function given by:

$$P_k = a - Q_k - \kappa \textstyle\sum_{l \neq k}^{r} Q_l$$

with P as the market price, Q as the quantity sold, and $a > 0$ as the demand intercept. The *substitutability coefficient* $\kappa \in [0, 1]$ indicates the level of differentiation of the products offered by the population of firms (Bowley 1925).[5]

In this model the effective R&D investment is defined as:

$$X_k = x_k + \beta \textstyle\sum_{l \neq k}^{r} x_l$$

with $\beta \in [0, 1]$ as the spillover parameter, and x_k as the individual investments of the firms in R&D.

The corresponding *marginal cost* $c_k > 0$ equal a constant minus the impact of the effective R&D investment on this constant:

$$c_k = c - f(X_k)$$

There are no additional fixed cost. The corresponding profit function than equals:

$$\pi_k = \left[a - Q_k - \kappa \textstyle\sum_{l \neq k}^{r} Q_l\right] Q_k - \left[c - f(X_k)\right] Q_k - x_k$$

Inverting the inverted demand function gives:

$$Q_k = \frac{1}{1 + \kappa (n-1)} a + \frac{-\left[1 + \kappa (n-2)\right]}{(1-\kappa)\left[1 + \kappa (n-1)\right]} P_k + \frac{\kappa}{(1-\kappa)\left[1 + \kappa (n-1)\right]} \textstyle\sum_{l \neq k}^{r} P_l$$

[5] For $\kappa = 0$ the varieties are independent in demand, and each firm acts as a monopolist. For $\kappa < 1$ firms offer differentiated goods.
As κ approaches 1, the varieties become closer and closer substitutes. For $\kappa = 1$ all goods are perfect substitutes.

The corresponding profit function becomes:

$$\pi_k = [P_k - (c - f(X_k))]\, Q_k - x_k$$

Appendix B: Cournot with product differentiation

Market equilibria

To see how the firms in the population behave when a RJV is conducting research in order to lower their marginal cost, we start with the formulation of two profit functions for firms not involved in the research project, for $r > 0$:

$$\pi_i(r) = \left[a - b\left[\kappa \textstyle\sum_k^r Q_k + Q_i + \kappa \textstyle\sum_{j\neq i,\, j\neq k}^n Q_j\right]\right] Q_i - \overline{C} Q_i \tag{3.10}$$

$$\pi_j(r) = \left[a - b\left[\kappa \textstyle\sum_k^r Q_k + Q_j + \kappa \textstyle\sum_{i\neq j,\, i\neq k}^n Q_i\right]\right] Q_j - \overline{C} Q_j$$

We will assume that each firm maximizes profit based on quantity produced, and that each rival will consider the other's quantity as a fixed number that will not respond to its own product decision. Maximizing profit for firms not involved in R&D according to Cournot implies:

$$\max_{Q_i} \left[a - b\left[\kappa \textstyle\sum_k^r Q_k + Q_i + \kappa \textstyle\sum_{j\neq i,\, j\neq k}^n Q_j\right]\right] Q_i - \overline{C} Q_i$$

which yields:

$$a - b\left[\kappa \textstyle\sum_k^r Q_k + 2Q_i + \kappa \textstyle\sum_{j\neq i,\, j\neq k}^n Q_j\right] - \overline{C} = 0 \tag{3.11}$$

And with $\partial\pi_i/\partial Q_i = \partial\pi_j/\partial Q_j$ we obtain that in equilibrium: $Q_i^* = Q_j^*$. Substituting that in (3.11) gives:

$$a - b\left[\kappa \textstyle\sum_k^r Q_k + [2 + (n - r - 1)\kappa]\, Q_i^*\right] - \overline{C} = 0 \tag{3.12}$$

The profit function for firms of the RJV can be written as:

$$\pi_k(r) = \left[a - b\left[Q_k + \kappa \textstyle\sum_{l\neq k}^r Q_l + \kappa \textstyle\sum_{i\neq k,\, i\neq l}^n Q_i\right]\right] Q_k - \underline{C} Q_k - K/r \tag{3.13}$$

$$\pi_l(r) = \left[a - b\left[Q_l + \kappa \textstyle\sum_{k\neq l}^r Q_l + \kappa \textstyle\sum_{i\neq k,\, i\neq l}^n Q_i\right]\right] Q_l - \underline{C} Q_l - K/r$$

Optimizing profit with respect to quantity for firms involved in the research project with $\partial\pi_k/\partial Q_k = 0$ results in:

$$a - b\left[2Q_k + \kappa\sum\nolimits_{l\neq k}^{r} Q_l + \kappa\sum\nolimits_{i\neq k,\ i\neq l}^{n} Q_i\right] - \underline{C} = 0 \tag{3.14}$$

With $\partial\pi_k/\partial Q_k = \partial\pi_l/\partial Q_l$ we get that in equilibrium: $Q_k^* = Q_l^*$. Substituting that in (3.14) leads to:

$$a - b\left[\left[2 + (r-1)\kappa\right] Q_k^* + (n-r)\,\kappa Q_i^*\right] - \underline{C} = 0 \tag{3.15}$$

From (3.12) and (3.15) we obtain that in equilibrium the relation between the output from firms not involved in R&D, and the quantity produced by the members of the RJV, is given by:

$$Q_k^*(r) = Q_i^*(r) + \frac{\overline{C} - \underline{C}}{(2-\kappa)\,b} = Q_i^*(r) + \frac{\Delta C}{(2-\kappa)\,b} \tag{3.16}$$

with $\Delta C = \left(\overline{C} - \underline{C}\right)$ as the change in marginal cost of production, resulting from the impact of the research project.

<u>Incremental change in marginal cost</u>

Substitution of $Q_k^*(r)$ according to (3.16) in (3.12) yields for the output by firms not involved in research:

$$a - b\left[r\kappa\left[Q_i^*(r) + \frac{\Delta C}{(2-\kappa)\,b}\right] + \left[2 + (n-r-1)\kappa\right] Q_i^*(r)\right] - \overline{C} = 0 \Leftrightarrow$$

$$Q_i^*(r) = \frac{\left(a - \overline{C}\right) - \frac{\kappa}{2-\kappa} r\Delta C}{b\left[2 + \kappa\,(n-1)\right]} \tag{3.17}$$

We can see from equation (3.17) that in theory it is possible that these firms will seize their production for certain levels of change in marginal cost of production, given the number of firms participating in the RJV.

We define the change marginal cost to be *incremental* if it is such that the firms not involved in the research project remain producing output. Equation (3.17) reveals that $Q_i^*(r) > 0$ for $r\Delta C < \left(a - \overline{C}\right)(2-\kappa)/\kappa$.

By inserting (3.17) in (3.16) we get the output for firms involved in R&D for an incremental change in cost:

$$Q_k^*(r) = \frac{(a - \underline{C}) + \frac{\kappa}{2-\kappa}(n-r)\Delta C}{b\left[2 + \kappa(n-1)\right]}$$

The corresponding market price in equilibrium, after substituting Q_i^* and Q_k^* in the respective inverse demand curves becomes:[6]

$$P_i^*(r) = \frac{a + (1 + \kappa(n-1))\overline{C} - \frac{\kappa}{2-\kappa} r\Delta C}{2 + \kappa(n-1)}$$
$$P_k^*(r) = \frac{a + (1 + \kappa(n-1))\underline{C} + \frac{\kappa}{(2-\kappa)}(n-r)\Delta C}{2 + \kappa(n-1)}$$

With $Q_i^*(r) = Q_j^*(r)$, equation (3.10) generates the profit for firms not conducting R&D:

$$\pi_i^*(r) = \left[a - b\left[\kappa r Q_k^*(r) + \left[1 + \kappa(n - r - 1)\right] Q_i^*(r)\right] - \overline{C}\right] Q_i^*(r)$$

By substituting $Q_i^*(r)$and $Q_k^*(r)$ in this expression, we can compute this profit as a function of the changes in marginal cost for firms not involved in research:

$$\pi_i^*(r) = \frac{\left[(a - \overline{C}) - \frac{\kappa}{2-\kappa} r\Delta C\right]^2}{b\left[2 + \kappa(n-1)\right]^2}$$

In order to obtain the profit for the firms of the RJV, we rewrite (3.13) with $Q_k^*(r) = Q_l^*(r)$ so that we get:

$$\pi_k^*(r) = \left[a - b\left[\left[1 + \kappa(r-1)\right] Q_k^*(r) + \kappa(n-r) Q_i^*(r)\right] - \underline{C}\right] Q_k^*(r) - K/r \quad (3.18)$$

Substitution of $Q_i^*(r)$ and $Q_k^*(r)$ in (3.18) yields as a profit for firms conducting R&D:

$$\pi_k^*(r) = \frac{\left[(a - \underline{C}) + \frac{\kappa}{2-\kappa}(n-r)\Delta C\right]^2}{b\left[2 + \kappa(n-1)\right]^2} - K/r$$

[6]Note that $P_i^*(r) \geq P_k^*(r) \geq 0$.

Radical change in marginal cost: oligopoly

We define the change in marginal cost of production to be *radical* if $Q_i^*(r) = 0$ because of the changes in marginal cost resulting from the research project. In the given market situation, this will happen if $r\Delta C \geq \left(a - \overline{C}\right)(2-\kappa)/\kappa$. As a consequence, the members of the RJV will act as an oligopoly. The corresponding profit functions can be rewritten as:

$$\begin{aligned} \pi_k^o(r) &= \left[a - b\left[Q_k + \kappa \textstyle\sum_{l \neq k}^r Q_l\right]\right] Q_k - \underline{C} Q_k - K/r \\ \pi_l^o(r) &= \left[a - b\left[Q_l + \kappa \textstyle\sum_{k \neq l}^n Qk\right]\right] Q_l - \underline{C} Q_l - K/r \end{aligned} \tag{3.19}$$

Maximizing profit according to Cournot implies optimizing (3.19) with respect to quantity: $\partial\pi_k/\partial Q_k = 0$. This yields:

$$a - b\left[2Q_k^O + \kappa \textstyle\sum_{l \neq k}^r Q_l\right] - \underline{C} = 0 \tag{3.20}$$

And with $\partial\pi_k/\partial Q_k = \partial\pi_l/\partial Q_l$ we get that in equilibrium: $Q_k^O = Q_l^O$. Substitution in (3.20) gives:

$$\begin{aligned} a - b\left[2Q_k^O + \kappa(r-1)Q_k^O\right] - \underline{C} = 0 \Leftrightarrow \\ Q_k^O(r) = \frac{a - \underline{C}}{b\left[2 + \kappa(r-1)\right]} \end{aligned}$$

and a corresponding price in equilibrium:

$$P^O(r) = \frac{a + \underline{C}\left(1 + \kappa\left(r-1\right)\right)}{2 + \kappa(r-1)}$$

With $Q_k^O = Q_l^O$ the profit according to (3.19) for firms conducting R&D becomes:

$$\pi_k^O(r) = \left[a - b\left[Q_k^O(r) + \kappa\left(r-1\right)Q_k^O(r)\right]\right] Q_k^O(r) - \underline{C} Q_k^O(r) - K$$

Substitution of the equilibrium quantity $Q_k^O(r)$ gives a profit in equilibrium:

$$\begin{aligned} \pi_k^O(r, K) &= \frac{\left(a - \underline{C}\right)^2}{b\left[2 + \kappa(r-1)\right]^2} - K/r \\ &= \overline{\pi}_k^O(r) - K/r \end{aligned}$$

Regulations and the optimal size of a consortium

In case of an incremental change in marginal cost, we get $\pi^{+}(r) = \pi_k^{*}(r)$. The corresponding maximum profit is calculated with:

$$\frac{\partial\left[\frac{\left[(a-\underline{C})+\frac{\kappa}{2-\kappa}(n-r)\Delta C\right]^2}{b[2+\kappa(n-1)]^2}-\frac{K}{r}\right]}{\partial r}=0 \Leftrightarrow$$

$$\frac{\kappa}{2-\kappa}\Delta C r^3-\left[(a-\underline{C})+\frac{\kappa}{2-\kappa}n\Delta C\right]r^2+\frac{Kb\left[2+\kappa(n-1)\right]^2}{2\frac{\kappa}{2-\kappa}\Delta C}=0$$

Rewriting this equation with:

$$\alpha^{*}=-\frac{(a-\underline{C})+\frac{\kappa}{2-\kappa}n\Delta C}{\frac{\kappa}{2-\kappa}\Delta C}$$

$$\beta^{*}=\frac{Kb\left[2+\kappa(n-1)\right]^2}{2\left[\frac{\kappa}{2-\kappa}\Delta C\right]^2}$$

and $r = x + y$, we get that:

$$x^3+(3y+\alpha)x^2+\left(3y^2+2\alpha y\right)x+y^3+\alpha y^2+\beta=0$$

With $y = -\frac{\alpha}{3}$, $\gamma = \frac{1}{3}\alpha(\alpha+5)$ and $\delta = \frac{2}{27}\alpha^3+\beta$ the equation reduces to:

$$x^3+\gamma x+\delta=0$$

We can now apply "Viata's substitution". With $x = z + \frac{s}{z}$ we arrive at:

$$z^6+(3s+\gamma)z^4+\delta z^3+s(3s+\gamma)z^2+s^3=0$$

By substituting $s = -\frac{\gamma}{3}$ and $z^3 = t$ we get:

$$t^2+\delta t-\frac{\gamma^3}{27}=0$$

Solving this gives:

$$t=\frac{-\delta\pm\left(\delta^2+\frac{4\gamma^3}{27}\right)^{\frac{1}{2}}}{2}$$

Based on the above, we get as a set of solutions:

$$R^* = \left\{ \begin{array}{c} -\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)+\frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)}-\frac{\alpha^*}{3}, \\ \Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)-\frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)}-\frac{\alpha^*}{3}, \\ \Psi^*-\frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*}-\frac{\alpha^*}{3} \end{array} \right\}$$

with:

$$\Psi^* = \sqrt[3]{\frac{-\left(\frac{2}{27}(\alpha^*)^3+\beta^*\right)\pm\left[\begin{array}{c}\left(\frac{2}{27}(\alpha^*)^3+\beta^*\right)^2+ \\ \frac{4\left(\frac{1}{3}\alpha^*(\alpha^*+5)\right)^3}{27}\end{array}\right]^{\frac{1}{2}}}{2}}$$

In case of a radical change in marginal cost, we get that $\pi^+(r) = \pi_k^O(r)$. Maximizing this profit gives:

$$\begin{aligned} \frac{\partial\left[\frac{(a-\underline{C})^2}{b[2+\kappa(r-1)]^2}-\frac{K}{r}\right]}{\partial r} &= 0 \Leftrightarrow \\ r^3+\alpha^O r^2+\gamma^O r+\beta^O &= 0 \end{aligned}$$

with:

$$\begin{aligned} \alpha^O &= \frac{\left(3Kb\kappa^2(2-\kappa)-2\kappa(a-\underline{C})^2\right)}{Kb\kappa^3} \\ \beta^O &= \frac{-Kb\left(\kappa\left(\kappa^2-6\kappa+12\right)-8\right)}{Kb\kappa^3} \\ \gamma^O &= \frac{3Kb\kappa(\kappa-2)^2}{Kb\kappa^3} \end{aligned}$$

We solve this equation by substituting $r = x + y$:

$$x^3+\left(3y+\alpha^O\right)x^2+\left(3y^2+2\alpha^O y+\gamma^O\right)x+y^3+\alpha^O y^2+\gamma^O y+\beta^O = 0$$

With $y = -\frac{\alpha^O}{3}$, $\delta = \gamma^O - \frac{1}{3}\left(\alpha^O\right)^2$ and $\epsilon = \frac{2}{27}\left(\alpha^O\right)^3 - \frac{1}{3}\gamma^O\alpha^O + \beta^O$ the equation reduces to:

$$x^3+\delta x+\epsilon = 0$$

We can now apply *Viata's substitution.* With $x = z + \frac{s}{z}$ we arrive at:

$$z^6+(3s+\delta)z^4+\epsilon z^3+s(3s+\delta)z^2+s^3 = 0$$

By substituting $s = -\frac{\delta}{3}$ and $z^3 = t$ we get:

$$t^2 + \epsilon t - \frac{1}{27}\delta^3 = 0$$

Solving this gives:

$$t = \frac{-\epsilon \pm \left(\epsilon^2 + \frac{4\delta^3}{27}\right)^{\frac{1}{2}}}{2}$$

Based on the above we get as a set of solutions:

$$R^O = \left\{ \begin{array}{c} -\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right) - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{-3\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)} - \frac{\alpha^O}{3}, \\ \Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right) - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)} - \frac{\alpha^O}{3}, \\ \Psi^O - \frac{\left(\gamma^O - \frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O} - \frac{\alpha^O}{3} \end{array} \right\}$$

with:

$$\Psi^O = \sqrt[3]{\frac{-\omega^O \pm \left[\left(\omega^O\right)^2 + \frac{4\left(\gamma^O - \frac{1}{3}(\alpha^O)^2\right)^3}{27}\right]^{\frac{1}{2}}}{2}}$$

$$\omega^O = \left[\frac{2}{27}\left(\alpha^O\right)^3 - \frac{1}{3}\gamma^O\alpha^O + \beta^O\right]$$

Government intervention and the minimal contribution

For an incremental change in marginal cost the profit $\pi^+(r) = \pi_k^*(r)$. Maximizing the cumulative willingness to invest implies:

$$\frac{\partial\left[r(1-p)\left[\frac{\left[(a-\underline{C})+\frac{\kappa}{2-\kappa}(n-r)\Delta C\right]^2 - \left(a-\overline{C}\right)^2}{b[2+\kappa(n-1)]^2}\right]\right]}{\partial r} = 0 \Leftrightarrow$$

$$0 = (1-p)\left[\frac{\left[(a-\underline{C}) + \frac{\kappa}{2-\kappa}(n-r)\Delta C\right]^2 - \left(a-\overline{C}\right)^2}{b\left[2+\kappa(n-1)\right]^2}\right] -$$
$$(1-p)\left[\frac{2\frac{\kappa}{2-\kappa}\Delta C r\left[(a-\underline{C}) + \frac{\kappa}{2-\kappa}(n-r)\Delta C\right]}{b\left[2+\kappa(n-1)\right]^2}\right]$$

Reformulating this gives:

$$3\Theta^2 r^2 - 4\Xi\Theta r + \Xi^2 - \left(a - \overline{C}\right)^2 = 0$$

with:

$$\Theta = \left(\frac{\kappa}{2-\kappa}\Delta C\right)$$
$$\Xi = \left[(a - \underline{C}) + n\frac{\kappa}{2-\kappa}\Delta C\right]$$

Solving this gives as a solution set:

$$R^* = \frac{2\Xi \pm \left[\Xi^2 - 3\left(\Xi^2 - \left(a - \overline{C}\right)^2\right)\right]^{1/2}}{3\Theta}$$

The function for the cumulative willingness to invest is increasing from 0 for $r \downarrow 0$, and increasing for $r \to \infty$. The local maximum is therefore given by:

$$r^* = \frac{2\Xi - \left[\Xi^2 - 3\left(\Xi^2 - \left(a - \overline{C}\right)^2\right)\right]^{1/2}}{3\Theta}$$

For a radical change in marginal cost we get that $\pi^+(r) = \pi_k^O(r)$. Maximizing the cumulative willingness to invest gives:

$$\frac{\partial r(1-p)\left[\frac{(a-\underline{C})^2}{b[2+\kappa(r-1)]^2} - \frac{\left(a-\overline{C}\right)^2}{b[2+\kappa(n-1)]^2}\right]}{\partial r} = 0 \Leftrightarrow$$

$$0 = (1-p)\left[\frac{(a-\underline{C})^2}{b\left[2+\kappa(r-1)\right]^2} - \frac{\left(a-\overline{C}\right)^2}{b\left[2+\kappa(n-1)\right]^2}\right] -$$
$$(1-p)\left[2\kappa r\frac{(a-\underline{C})^2}{b\left[2+\kappa(r-1)\right]^3}\right]$$

Reformulating this gives:

$$r^3 + \alpha^O r^2 + \gamma^O r + \beta^O = 0$$

with

$$\alpha^O = \frac{-3(\kappa-2)}{\kappa}$$

$$\beta^O = \frac{-\left[\kappa\left(\kappa^2-6\kappa+12\right)-8\right]\left(a-\overline{C}\right)^2+(\kappa-2)\left[2+\kappa(n-1)\right]^2\left(a-\underline{C}\right)^2}{\kappa^3\left(a-\overline{C}\right)^2}$$

$$\gamma^O = \frac{3(\kappa-2)^2\left(a-\overline{C}\right)^2+\left[2+\kappa(n-1)\right]^2\left(a-\underline{C}\right)^2}{\kappa^2\left(a-\overline{C}\right)^2}$$

Solving this gives:

$$R^O = \left\{\begin{array}{c} -\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)-\frac{\left(\gamma^O-\frac{1}{3}\left(\alpha^O\right)^2\right)}{-3\Psi^O\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)}-\frac{\alpha^O}{3}, \\ \Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)-\frac{\left(\gamma^O-\frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)}-\frac{\alpha^O}{3}, \\ \Psi^O-\frac{\left(\gamma^O-\frac{1}{3}\left(\alpha^O\right)^2\right)}{3\Psi^O}-\frac{\alpha^O}{3} \end{array}\right\}$$

with:

$$\Psi^O = \sqrt[3]{\frac{-\omega^O \pm \left[\left(\omega^O\right)^2+\frac{4\left(\gamma^O-\frac{1}{3}(\alpha^O)^2\right)^3}{27}\right]^{\frac{1}{2}}}{2}}$$

$$\omega^O = \frac{2}{27}\left(\alpha^O\right)^3-\frac{1}{3}\gamma^O\alpha^O+\beta^O$$

Appendix C: Bertrand with product differentiation

Market equilibria

To see how the firms in the population behave when a RJV is conducting research in order to lower their marginal cost, we start with the formulation of two profit functions for firms not involved in the research project, for $r > 0$:

$$\pi_i(r) = \left(P_i-\overline{C}\right)\left[V_1\frac{a}{b}+V_2{\sum}_k^r\frac{1}{b}P_k+V_3\frac{1}{b}P_i+V_2{\sum}_{j\neq i,\ j\neq k}^n\frac{1}{b}P_j\right]$$

$$\pi_j(r) = \left(P_j-\overline{C}\right)\left[V_1\frac{a}{b}+V_2{\sum}_k^r\frac{1}{b}P_k+V_3\frac{1}{b}P_j+V_2{\sum}_{i\neq j,\ i\neq k}^n\frac{1}{b}P_i\right]$$

with:

$$V_1 = \frac{1}{1+\kappa(n-1)}$$
$$V_2 = \frac{\kappa}{(1-\kappa)[1+\kappa(n-1)]}$$
$$V_3 = \frac{-[1+\kappa(n-2)]}{(1-\kappa)[1+\kappa(n-1)]}$$

Maximizing profit for firms not involved in R&D according to Bertrand implies:

$$\max_{P_i} \left(P_i - \overline{C}\right)\left[V_1\frac{a}{b} + V_2\textstyle\sum_k^r \frac{1}{b}P_k + V_3\frac{1}{b}P_i + V_2\sum_{j\neq i,\ j\neq k}^n \frac{1}{b}P_j\right]$$

which yields:

$$V_1\frac{a}{b} + V_2\textstyle\sum_k^r \frac{1}{b}P_k + 2V_3\frac{1}{b}P_i^* + V_2\sum_{j\neq i,\ j\neq k}^n \frac{1}{b}P_j - V_3\frac{1}{b}\overline{C} = 0 \tag{3.21}$$

With $\partial\pi_i/\partial P_i = \partial\pi_j/\partial P_j$ we obtain that in equilibrium: $P_i^* = P_j^*$. Substituting that in (3.21) gives:

$$V_1\frac{a}{b} + V_2\textstyle\sum_k^r \frac{1}{b}P_k + \left((n-r-1)V_2 + 2V_3\right)\frac{1}{b}P_i^* - V_3\frac{1}{b}\overline{C} = 0 \tag{3.22}$$

We also formulate two profit functions for firms participating in the RJV:

$$\pi_k(r) = (P_k - \underline{C})\left[V_1\frac{a}{b} + V_2\textstyle\sum_{i\neq k,\ i\neq l}^n \frac{1}{b}P_i + V_3\frac{1}{b}P_k + V_2\sum_{l\neq k}^r \frac{1}{b}P_l\right] - K$$
$$\pi_l(r) = (P_l - \underline{C})\left[V_1\frac{a}{b} + V_2\textstyle\sum_{i\neq k,\ i\neq l}^n \frac{1}{b}P_i + V_3\frac{1}{b}P_l + V_2\sum_{k\neq l}^r \frac{1}{b}P_k\right] - K$$

Optimizing profit with respect to price for firms involved in the research project with $\partial\pi_k/\partial P_k = 0$ results in:

$$V_1\frac{a}{b} + V_2\textstyle\sum_{i\neq k,\ i\neq l}^n \frac{1}{b}P_i + 2V_3\frac{1}{b}P_k^* + V_2\sum_{l\neq k}^r \frac{1}{b}P_l - V_3\frac{1}{b}\underline{C} = 0 \tag{3.23}$$

With $\partial\pi_k/\partial P_k = \partial\pi_l/\partial P_l$ we get that in equilibrium $P_k^* = P_l^*$. Substituting that in (3.23) gives:

$$V_1\frac{a}{b} + (n-r)V_2\frac{1}{b}P_i^* + \left((r-1)V_2 + 2V_3\right)\frac{1}{b}P_k^* - V_3\frac{1}{b}\underline{C} = 0 \tag{3.24}$$

From (3.22) and (3.24) we obtain that in equilibrium the relation between the price set by firms not involved in R&D, and by the members of the RJV, is given by:

$$P_k^*(r) = P_i^*(r) + \frac{V_3 \Delta C}{V_2 - 2V_3} \tag{3.25}$$

with $\Delta C = \left(\overline{C} - \underline{C}\right)$ as the change in marginal cost of production, resulting from the impact of the research project.

Incremental change in marginal cost

Substitution of our result according to (3.25) in (3.22) yields:

$$P_i^*(r) = \frac{(1-\kappa)\, a + (1+\kappa\,(n-2))\, \overline{C} - \frac{\kappa(1+\kappa(n-2))}{(2+\kappa(2n-3))} r \Delta C}{(2+\kappa\,(n-3))}$$

$$P_k^*(r) = \frac{(1-\kappa)\, a + (1+\kappa\,(n-2))\, \underline{C} + \frac{\kappa(1+\kappa(n-2))}{(2+\kappa(2n-3))} (n-r)\, \Delta C}{(2+\kappa\,(n-3))}$$

With the price in equilibrium, we can calculate the quantity sold by firms not involved in research:

$$Q_i^*(r) = \Pi \left[\left(a - \overline{C}\right) - \Lambda r \Delta C \right] \tag{3.26}$$

with:

$$\Pi = \frac{(1+\kappa\,(n-2))}{b\,(1+\kappa\,(n-1))\,(2+\kappa\,(n-3))}$$

$$\Lambda = \frac{\kappa\,(1+\kappa\,(n-2))}{(1-\kappa)\,(2+\kappa\,(2n-3))}$$

We can see from equation (3.26) that in theory it is possible also for a market under Bertrand with differentiated products that firms not involved in the research project will seize their production. We define the change marginal cost to be *incremental* if it is such that the firms not involved in the research project remain producing output. Equation (3.26) indicates that $Q^-(r) > 0$ for $r\Delta C < \left(a - \overline{C}\right)/\Lambda$. The corresponding quantity produced by firms involved in the research equals:

$$Q_k^*(r) = \Pi \left[\left(a - \underline{C}\right) + \Lambda\,(n-r)\, \Delta C \right]$$

The profit in equilibrium is consequently given by:

$$\pi_i^*(r) = \Omega\Pi\left[\left(a - \overline{C}\right) - \Lambda r \Delta C\right]^2$$
$$\pi_k^*(r) = \Omega\Pi\left[\left(a - \underline{C}\right) + \Lambda\left(n - r\right)\Delta C\right]^2 - K/r$$

with

$$\Omega = \frac{(1-\kappa)}{(2+\kappa\,(n-3))}$$

Note that $\{\Pi, \Lambda, \Omega\}$ are all positive and larger than zero for $n \geq 1$.

Radical change in marginal cost: oligopoly

We define the change in marginal cost of production to be *radical* if $Q_i^*(r) = 0$ because of the changes in marginal cost resulting from the research project, given the number of firms involved in research. In the given market situation, this will happen if $r\Delta C \geq \left(a - \overline{C}\right)/\Lambda$As a consequence, the members of the RJV will act as an oligopoly. The inverted inverse demand curve for firms involved in research is given by:

$$Q_k^o(r) = V_1\frac{a}{b} + V_3\frac{1}{b}P_k + V_2{\textstyle\sum_{l\neq k}^{r}}\frac{1}{b}P_l$$

The corresponding profit functions can be rewritten as:

$$\pi_k^o(r,K) = \left(P_k - \underline{C}\right)\left[V_1\frac{a}{b} + V_3\frac{1}{b}P_k + V_2{\textstyle\sum_{l\neq k}^{r}}\frac{1}{b}P_l\right] - K$$
$$\pi_l^o(r,K) = \left(P_l - \underline{C}\right)\left[V_1\frac{a}{b} + V_3\frac{1}{b}P_l + V_2{\textstyle\sum_{k\neq l}^{r}}\frac{1}{b}P_k\right] - K$$

Optimizing profit with respect to price for firms involved in the research project with $\partial\pi_k/\partial P_k = 0$ results in:

$$V_1\frac{a}{b} + 2V_3\frac{1}{b}P_k^O + V_2{\textstyle\sum_{l\neq k}^{r}}\frac{1}{b}P_l - V_3\frac{1}{b}\underline{C} = 0$$

With $\partial\pi_k/\partial P_k = \partial\pi_l/\partial P_l$ we get that in equilibrium $P_k^O = P_l^O$. Substituting that in the differentiated profit function gives:

$$V_1\frac{a}{b} + \left(\left(r-1\right)V_2 + 2V_3\right)\frac{1}{b}P_k^O - V_3\frac{1}{b}\underline{C} = 0$$

which implies that:

$$P_k^O(r) = \frac{(1-\kappa)\,a + (1+\kappa\,(r-2))\,\underline{C}}{(2+\kappa\,(r-3))}$$

By substituting P_k^O in the inverse demand function we obtain for the quantity in equilibrium:

$$Q_i^O(r) = \frac{(1+\kappa\,(r-2))}{b\,(1+\kappa\,(r-1))\,(2+\kappa\,(r-3))}\,(a-\underline{C})$$

And by inserting P_k^O and $Q_i^O(r)$ in the profit function we get that the profit for the firms of the RJV in case of an oligopoly equals:

$$\pi_k^O(r) = \frac{(1-\kappa)\,(1+\kappa\,(r-2))}{b\,(1+\kappa\,(r-1))\,(2+\kappa\,(r-3))^2}\,(a-\underline{C})^2 - K/r$$

Regulations and the optimal size of a consortium

In case of an incremental change in marginal cost, we get that $\pi^+(r) = \pi_k^*(r)$. The corresponding maximum profit is calculated with:

$$\frac{\partial\left[\Omega\Pi\left[((a-\underline{C})+\Lambda\,(n-r)\,\Delta C)^2\right]-\frac{K}{r}\right]}{\partial r} = 0 \Leftrightarrow$$

$$\Lambda\Delta C r^3 - \left[(a-\underline{C})+\Lambda n\Delta C\right]r^2 + \frac{K}{2\Omega\Pi\Lambda\Delta C} = 0$$

In a similar way as for a market with differentiated products under Cournot we get as a solution set:

$$R^* = \left\{\begin{array}{c} -\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)+\frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}+\frac{1}{2}\right)}-\frac{\alpha^*}{3}, \\ \Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)-\frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*\left(\frac{1}{2}i\sqrt{3}-\frac{1}{2}\right)}-\frac{\alpha^*}{3}, \\ \Psi^*-\frac{\frac{1}{9}\alpha^*(\alpha^*+5)}{\Psi^*}-\frac{\alpha^*}{3} \end{array}\right\}$$

with:

$$\Psi = \sqrt[3]{\frac{-\left(\frac{2}{27}(\alpha^*)^3+\beta^*\right) \pm \left(\left(\frac{2}{27}(\alpha^*)^3+\beta^*\right)^2+\frac{4\left(\frac{1}{3}\alpha^*(\alpha^*+5)\right)^3}{27}\right)^{\frac{1}{2}}}{2}}$$

In case of a radical change in marginal cost, we get that $\pi^{+}(r) = \pi_k^O(r)$. Maximizing this profit gives:

$$\frac{\partial\left[\frac{(1-\kappa)(1+\kappa(r-2))}{b(1+\kappa(r-1))(2+\kappa(r-3))^2}\left(a-\underline{C}\right)^2-\frac{K}{r}\right]}{\partial r}=0 \Leftrightarrow$$

$$-\frac{\kappa\left(1-\kappa\right)\left(2\left(r\kappa+1\right)^2-\kappa\left(8+7\kappa\left(r-1\right)\right)\right)}{b\left(r\kappa-\kappa+1\right)^2\left(r\kappa-3\kappa+2\right)^3}\left(a-\underline{C}\right)^2+\frac{K}{r^2}=0$$

Solving this equation does not give a closed form solution. This implies that in theory firm k lacks insight in how to formulate a consortium that would maximize its profit.

Government intervention and the minimal contribution

For an incremental change in marginal cost the profit $\pi^{+}\left(r\right) = \pi_k^{*}\left(r\right)$. Maximizing the cumulative willingness to invest implies:

$$\frac{\partial\left[r(1-p)\Omega\Pi\left[\left(\left(a-\underline{C}\right)+\Lambda\left(n-r\right)\Delta C\right)^2-\left(a-\overline{C}\right)^2\right]\right]}{\partial r}=0 \Leftrightarrow$$

$$\left[\left(a-\underline{C}\right)+\Lambda\left(n-r\right)\Delta C\right]^2-2\Lambda\Delta C\left[\left(a-\underline{C}\right)+\Lambda\left(n-r\right)\Delta C\right]-\left(a-\overline{C}\right)^2=0$$

Solving this gives as a solution set:

$$R^{*}=\left\{\frac{2\left(\left(a-\underline{C}\right)+n\Lambda\Delta C\right)\pm\left[\left(\left(a-\underline{C}\right)+n\Lambda\Delta C\right)^2+3\left(a-\overline{C}\right)^2\right]^{1/2}}{3\Lambda\Delta C}\right\}$$

The function for the cumulative willingness to invest is increasing from 0 for $r \downarrow 0$, and increases for $r \longrightarrow \infty$. the local maximum is therefore given by:

$$r^{*}=\frac{2\left(\left(a-\underline{C}\right)+n\Lambda\Delta C\right)-\left[\left(\left(a-\underline{C}\right)+n\Lambda\Delta C\right)^2+3\left(a-\overline{C}\right)^2\right]^{1/2}}{3\Lambda\Delta C}$$

For a radical change in marginal cost we get that $\pi^{+}\left(r\right) = \pi_k^O\left(r\right)$. Maximizing the cumulative willingness to invest gives:

$$\frac{\partial r(1-p)\left[\frac{(1-\kappa)(1+\kappa(r-2))}{b(1+\kappa(r-1))(2+\kappa(r-3))^2}\left(a-\underline{C}\right)^2-\Omega\Pi\left(a-\overline{C}\right)^2\right]}{\partial r}=0 \Leftrightarrow$$

$$0 = (1-p)\left[\frac{(1-\kappa)(1+\kappa(r-2))}{b(1+\kappa(r-1))(2+\kappa(r-3))^2}(a-\underline{C})^2 - \Omega\Pi\left(a-\overline{C}\right)^2\right] -$$
$$(1-p)\left[\frac{\kappa r(1-\kappa)\left(2(r\kappa+1)^2-\kappa(8+7\kappa(r-1))\right)}{b(1+\kappa(r-1))^2(2+\kappa(r-3))^3}(a-\underline{C})^2\right]$$

Solving this equation does not give a closed form solution. This implies that in theory the government lacks insight in how to formulate a consortium that would minimize its contribution.

Appendix D: surplus in equilibrium as a constraint for intervention

The actual intervention by the government is limited: it should only provide support in case of an increase in surplus. The total consumer and producer surplus for Bertrand Classic is given by:

$$W^0 = \frac{1}{2}\left(a-P^0\right)nQ^0 = \frac{\left(a-\overline{C}\right)^2}{2b}$$

$$W^+ = \begin{cases} \frac{3(a-\underline{C})^2}{8b} & \text{for } \underline{C} < 2\overline{C} - a \\ \frac{\left(a-\overline{C}+\epsilon\right)\left(a-\overline{C}+2\Delta C-\epsilon\right)}{2b} & \text{for } \underline{C} < 2\overline{C} - a \end{cases}$$

For a market under Cournot with differentiated products, this is given by:

$$W^0 = \frac{1}{2b\left(2+\kappa(n-1)\right)^2}\left[(3+\kappa(n-1))\,n\left(a-\overline{C}\right)^2\right]$$

$$W^+(r) = \begin{cases} \overline{W}^*(r) - K & \text{for } r\Delta C < \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa} \\ \overline{W}^O(r) - K & \text{for } r\Delta C \geq \frac{\left(a-\overline{C}\right)(2-\kappa)}{\kappa} \end{cases}$$

with:

$$
\begin{aligned}
\overline{W}^{*}(r) &= (n-r)\left(\frac{1}{2}\left(a-P_i^{*}(r)\right)Q_i^{*}(r)+\pi_i^{*}(r)\right)+\\
&\quad r\left(\frac{1}{2}\left(a-P_k^{*}(r)\right)Q_k^{*}(r)+\pi_k^{*}(r)\right)\\
&= \frac{\left(3+\kappa(n-1)\right)\left[(n-r)\left(a-\overline{C}\right)^2+r\left(a-\underline{C}\right)^2\right]}{2b\left(2+\kappa(n-1)\right)^2}+\\
&\quad \frac{\frac{\kappa}{2-\kappa}\left[\left(4+\kappa(n-1)\right)+\frac{\kappa}{(2-\kappa)}n\right]r(n-r)\left(\Delta C\right)^2}{2b\left(2+\kappa(n-1)\right)^2}\\
\overline{W}^{O}(r) &= r\left(\frac{1}{2}\left(a-P_k^{O}(r)\right)Q_k^{O}(r)+\pi_k^{O}(r)\right)\\
&= \frac{\left(3+\kappa(r-1)\right)r\left(a-\underline{C}\right)^2}{2b\left(2+\kappa(r-1)\right)^2}
\end{aligned}
$$

For a market under Bertrand with differentiated products, we get:

$$
W^{0} = \frac{1}{2b\left(2+\kappa(n-1)\right)^2}\left[\left(3+\kappa(n-1)\right)n\left(a-\overline{C}\right)^2\right]
$$

$$
W^{+}(r) = \begin{cases} \overline{W}^{*}(r)-K & \text{for} \quad r\Delta C < \left(a-\overline{C}\right)/\Lambda \\ \overline{W}^{O}(r)-K & \text{for} \quad r\Delta C \geq \left(a-\overline{C}\right)/\Lambda \end{cases}
$$

with:

$$
\begin{aligned}
\overline{W}^{*}(r) &= (n-r)\left(\frac{1}{2}\left(a-P_i^{*}(r)\right)Q_i^{*}(r)+\pi_i^{*}(r)\right)+\\
&\quad r\left(\frac{1}{2}\left(a-P_k^{*}(r)\right)Q_k^{*}(r)+\overline{\pi}_k^{*}(r)\right)\\
&= \frac{\Pi\left(3+\kappa(n-4)\right)\left[(n-r)\left(a-\overline{C}\right)^2+r\left(a-\underline{C}\right)^2\right]}{2\left(2+\kappa(n-3)\right)}+\\
&\quad \frac{\Pi\left[\left(4+\kappa(n-5)\right)\left(2+\kappa(2n-3)\right)+n\kappa\left(1+\kappa(n-2)\right)\right]}{2\left(2+\kappa(n-3)\right)}\frac{\Omega\Lambda r(n-r)\left(\Delta C\right)^2}{(1-\kappa)}\\
\overline{W}^{O}(r) &= r\left(\frac{1}{2}\left(a-P_k^{O}(r)\right)Q_k^{O}(r)+\overline{\pi}_k^{O}(r)\right)\\
&= \frac{\left(3+\kappa(r-4)\right)\left(1+\kappa(r-2)\right)r\left(a-\underline{C}\right)^2}{2b\left(1+\kappa(r-1)\right)\left(2+\kappa(r-3)\right)^2}
\end{aligned}
$$

Chapter 4

R&D collaboration in a hybrid market form of perfect and monopolistic competition

The behavior of firms concerning investment in R&D has been the subject of study within the framework of Industrial Organization (IO) theory. The theory of IO distinguishes two basic modeling approaches for the analysis of this behavior: tournament and non-tournament modeling (Suetens 2006). A basic feature of tournament models is that it is like a race where the first firm that succeeds in innovating enters the market first, and subsequently conquers it (e.g. patent race). A non-tournament model is characterized by the fact that firms can conduct research successfully at the same time.

The emergence of non-tournament models as the dominant theoretical basis for the analysis of the investment decision of firms in R&D started with (d' Aspremont and Jacquemin 1988). It is closely connected to the general recognition of knowledge spillovers (Suetens 2006). The (d' Aspremont and Jacquemin 1988) paper describes the behavior of firms concerning investment in research for different forms of collaboration with the help of a multi-stage strategic investment game. A research driven innovation model is therefore adopted, in which all firms of the population get involved in R&D. The impact of this research, conveyed as a decrease in marginal cost, is defined as a function of the investment on R&D. The game introduced involves a stage where all firms determine their input on R&D, given a certain level of spillover from research activity. This spillover coefficient reflects the level of coordination in research. In the final stage the firms engage in competition to define market price and output in equilibrium. The game is solved by means of backward induction.

Important other contributions to this line of theory include the analysis of asymmetric equilibria resulting from for example product differentiation (Lambertini and Orsini 2000), and asymmetric spillovers (Atallah 2005). Relevant is also the paper by (Poyago-Theotoky 1995), which analyses expenditure on R&D in equilibrium if only a subset of the total population establishes the highest level of coordination in the form of a Research Joint Venture.

For our model we adopt a series of assumptions with which we deviate from the current literature in order to reflect more accurately the current practice concerning industry-oriented R&D (see *Chapter 1*). We adopt a problem driven innovation model, in which research originates from an idea addressing a specific problem. We assume this research is conducted within the framework of a predefined project with corresponding fixed cost. The outcome of the R&D process and the impact it could have on the marginal cost of production is predetermined. Just a subset of the total population of firms will be involved in the research project, operating as a Research Joint Venture (RJV). Application of the foreseen results depends on the successful execution of the project, which involves a certain probability of failure.

Because of our assumptions the setup of the strategic intervention deviates from the existing literature. In the final stage firms involved in research define the foreseen changes in market price and output in equilibrium resulting from successful implementation of the project results. Based on the corresponding change in profit and the probability of failure of the research, firms decide on what they are willing to invest in the R&D project. For the computation of this willingness to invest, we assume a linear perception of risk and profit. If the willingness to invest does not meet the foreseen project cost, a firm will decide not to conduct the research.

In the existing literature building on (d' Aspremont and Jacquemin 1988) assumes a market structure where firms compete on price or quantity (i.e. Bertrand or Cournot). In *Chapter 2* and *Chapter 3* we adopt a similar structure for our model with its accompanying assumptions, and subsequently expand in for a market offering differentiated products. In this paper we analyze the behavior of firms concerning their decision on investment in research for a hybrid market form of perfect competition and monopolistic competition, as introduced by (Varian 1980). Within the framework of this market structure, some consumers seek to buy at the lowest price without regard for product characteristics, whereas others have a brand preference. In practice this implies that there is differentiation in supplier preferences.

Our main conclusion resulting from the analysis of this specific market structure is that if a firm decides to invest in research, it will either conduct the project all alone, or it will establish a RJV with all firms of the population as its partners in the consortium.

In the next section, we define a model to assess the behavior of firms facing an investment decision concerning an R&D project. In *Section 4.2* we compute the output in equilibrium for a hybrid market form, to define the willingness of a firm to invest in a research. The main result of our analysis are given in *Section 4.3*. The conclusions and implications for policy are given in *Section 4.4*.

4.1 Investment in R&D by firms

For our analysis, we assume that there is a population N containing n firms. We furthermore assume that there is a variable sub-population $R \subseteq N$ containing r firms conducting R&D.

We consider the *initial marginal cost of production* $c_i = \overline{C}$ for $i \in N$ to be equal and constant for all firms, and determined by the state of the art in production technology within a certain industry or sector.

We assume firms operate in a hybrid market form of perfect competition and monopolistic competition, where some consumers seek to buy at the lowest price without regard for product characteristics, whereas others have a brand preference. Let Ω be the *number of price-conscious customers*. Each price conscious customer purchases one unit of product from the lowest pricing firm, provided $P_i \leq \widehat{P}$, with $\widehat{P}$ as the reservation price. Furthermore let Ψ denote the *number of brand-conscious customers*, which is equal for all firms of the population. Each brand conscious customer purchases one unit of product from their preferred firm's product, provided $P_i \leq \widehat{P}$. If $P_i > \widehat{P}$, customers will refuse to buy from firm i, and purchase from $-i$.

Suppose a firm k has an idea for an improvement of its production technology, such that it reduces its marginal cost: $c_k = \underline{C}$ for $k \in R$, with $0 < \underline{C} < \overline{C}$ and $\Delta C = \overline{C} - \underline{C}$.[1] Reduction of the marginal cost results from successful completion of a predefined research project with fixed *project cost* K. Conducting the research project involves a certain risk. Let $p \in [0,1]$ be the *probability of failure of the project.* This probability depends on the current level of knowledge concerning production for this sector. If the required knowledge is not available, and lies beyond the current state of the art, p will be close to one. If the required knowledge is available, p will be close to zero.

We presume that for $r > 1$, the firms involved in R&D will form a Research Joint Venture (RJV). These firms will coordinate their research activities by sharing R&D results and avoiding duplication for the duration of the project. This implies that we assume that the firms in the consortium share the project cost equally (Kamien et al. 1992), and that the internal spillover coefficient equals one. We ignore immediate spill-over effects to firms from outside the RJV while the research project is conducted. When producing we suppose that these firms face no additional fixed cost.

Based on the above, we get the following profit functions:

$$\pi_i(P) = P_i Q_i(P) - \overline{C} Q_i(P)$$

$$\pi_k(P, r) = P_k Q_k(P) - \underline{C} Q_k(P) - K/r$$

We subsequently define $\overline{\pi}_k(P) \equiv P_k Q_k(P) - \underline{C} Q_k(P)$ as the *gross profit* for firm k (i.e. the maximum possible profit, without the project cost).

We argue that a firm k will decide on joining the RJV and conducting the required R&D by comparing the expected profit resulting from conducting the research with the initial profit. We define $\pi_i(P) = \pi^0(P)$ as the *initial profit in equilibrium*, and $(\pi_i(P), \pi_k(P, r)) = (\pi^-(P), \pi^+(P, r))$ as the *profit in equilibrium after successful implementation of the research results.* We get that this investment decision can

[1] Note that implementation of the research results has no influence on the characteristics and preferences of the consumers.

be represented as:

$$(1-p)\left(\overline{\pi}^{+}(P,r)-K/r\right)+p\left(\pi^{0}(P)-K/r\right)\gtrless\pi^{0}(P)\Leftrightarrow$$
$$(1-p)\left(\overline{\pi}^{+}(P)-\pi^{0}(P)\right)\gtrless K/r$$

The inequality shows that firm k will decide by comparing what it is willing to invest in R&D (i.e. the expected gross gain in profit) with the individual project cost. It implies that if $(1-p)\left(\overline{\pi}^{+}(P)-\pi^{0}(P)\right)\leq K/r$, then firm k will not consider implementing the project. The required investment would in that case lead to an expected profit lower than (or equal to) that in the initial situation. If on the other hand the project cost are covered by the expected gross gain in profit, then firm k will conduct the research required to lower the project cost.

4.2 Market equilibria

Initial equilibrium with no research

In order to define the amount a firm is willing to invest in research, we first analyze the initial equilibrium and profit. We therefore need to assess the implications for a firm selecting a price P_i. Based on the above, we argue that the initial output equals:

$$Q_i^0(P_i)=\begin{cases}\Omega+\Psi & \text{for} \quad P_i<P_{-i}\leq\widehat{P}\\ \Psi & \text{for} \quad P_{-i}<P_i\leq\widehat{P}\\ \Psi+\Omega/m & \text{for} \quad P_i=P_j=.....=P_m\leq\widehat{P}\\ 0 & \text{for} \quad P_i>\widehat{P}\end{cases} \tag{4.1}$$

Lemma 4.1 *There exists a unique symmetric mixed-strategy equilibrium if firm i of the population chooses a price $P_i\in S_i^0$ at random from a distribution function*

$F_i^0(P)$ *such that* $E\pi_i^0(P) = \left(\widehat{P} - \overline{C}\right)\Psi$, *with:*[2, 3]

$$F_i^0(P) = 1 - \left(\frac{\left(\widehat{P} - P\right)\Psi}{\left(P - \overline{C}\right)\Omega}\right)^{\frac{1}{n-1}} \tag{4.2}$$

Our result implies that each firm is torn between low pricing to capture the price conscious customers, and a high price to exploit its monopolistic power over the brand loyal customers. These two repelling forces can be balanced by following a mixed pricing strategy.

Proof. The strategy space for the firms of the population is given by:

$$S_i^0 = \left[P^0, \widehat{P}\right] = \left[\overline{C} + \frac{\left(\widehat{P} - \overline{C}\right)\Psi}{\Psi + \Omega}, \widehat{P}\right]$$

The left end point of the strategy space is defined such that $\pi_i(P^0) = \pi_i\left(\widehat{P}\right)$. On this interval $F_i^0(P)$ is a well-defined distribution function, as it is continuous and increasing, with $F_i^0(P^0) = 0$ and $F_i^0\left(\widehat{P}\right) = 1$ (see *Appendix A*).

To calculate the distribution function, we define the probability that firm i chooses a prices such that it is higher than the price of firm j as $\Pi(P_i > P_j) = F_j(P_i)$. Firm i chooses a price $P_i \in S_i^0$, such that:

$$\Pi(P_i < P_{-i}) = \prod_{j \neq i}^{n} (1 - F_j(P_i))$$

$$\Pi(P_i > P_{-i}) = 1 - \prod_{j \neq i}^{n} (1 - F_j(P_i))$$

with corresponding expected profit:

$$E\pi_i^0 = \Pi(P_i > P_{-i})\left(P - \overline{C}\right)\Psi + \Pi(P_i < P_{-i})\left(P - \overline{C}\right)(\Psi + \Omega)$$

[2] The results are in line with (Varian 1980)

[3] There is also a continuum of asymmetric equilibria but nevertheless mixed if $n > 2$, see (Baye et al. 1996).

On S_i^0 the highest pay-off firm i can obtain with certainty equals $\pi_i\left(\widehat{P}\right) = \left(\widehat{P}-\overline{C}\right)\Psi$. With $F_i^0(P) = F_j^0(P)$ in equilibrium, we get that:

$$\left(\widehat{P}-\overline{C}\right)\Psi = \left(1-\left(1-F_i^0(P)\right)^{n-1}\right)\left(P-\overline{C}\right)\Psi+ \\ \left(1-F_i^0(P)\right)^{n-1}\left(P-\overline{C}\right)(\Psi+\Omega)$$

which results in (4.2) after solving for $F_i^0(P)$.

The firms of the population have no incentive to select a price outside the strategy space or to deviate from their strategy (i.e. the distribution function). A price above $\widehat{P}$ implies zero demand, and pricing below P^0 yields a similar demand as pricing at P^0. ∎

Research by a single firm

Next we analyze the impact on the market if a single firm k conducts a successful research project lowering its marginal cost. Our approach is as in the previous section, but we only show the most important steps. We first note that $Q_i^- = Q_i^0$ and:

$$Q_k^+(P) = \begin{cases} \Omega+\Psi & \text{for} \quad P_k < P_i \leq \widehat{P} \\ \Psi & \text{for} \quad P_i < P_k \leq \widehat{P} \\ \Psi+\Omega/m & \text{for} \quad P_k = P_s \leq \widehat{P} \text{ with } s=\{1,...,m\} \\ 0 & \text{for} \quad P_k > \widehat{P} \end{cases} \tag{4.3}$$

Lemma 4.2 *There exists a semi-symmetric mixed-strategy equilibrium if the firms* (i,k) *choose a price* $(P_i, P_k) \in \left[P^0, \widehat{P}\right]$ *at random from* $\left(F_i^-(P), F_k^+(P)\right)$ *such that* $E\pi_i^-(P) = \left(\widehat{P}-\overline{C}\right)\Psi$ *and* $E\pi_k^+(P) = \left(\widehat{P}-\overline{C}\right)\Psi + \Delta C(\Psi+\Omega) - K$, *with:*[4]

$$F_i^-(P) = \begin{cases} 1-\left(\frac{\Omega\Delta C+\left(\widehat{P}-P\right)\Psi}{(P-\underline{C})\Omega}\right)^{\frac{1}{n-1}} & \textit{for} \quad P_i \in \left[P^0,\widehat{P}\right\rangle \\ 1 & \textit{for} \quad P_i = \widehat{P} \end{cases} \tag{4.4}$$

[4]The equilibrium is symmetric for the firms not involved in innovation.

with a mass point μ at $P_i = \widehat{P}$ according to:

$$\mu = 1 - \lim_{P_i \to \widehat{P}} F_i^- (P) = \left(\Delta C / \left(\widehat{P} - \underline{C} \right) \right)^{\frac{1}{n-1}}$$

and:

$$F_k^+ (P) = 1 - \frac{\left(\widehat{P} - P \right) \Psi}{\left(P - \overline{C} \right) \Omega} \left(\frac{\Omega \Delta C + \left(\widehat{P} - P \right) \Psi}{\left(P - \underline{C} \right) \Omega} \right)^{-\frac{n-2}{n-1}} \tag{4.5}$$

Proof. For the firms not involved in research, the strategy space remains unchanged: $S_i^- = S_i^0$. On this interval $F_i^0 (P)$ is a well-defined distribution function. It is continuous and increasing (see *Appendix A*), with $F_i^- (P^0) = 0$ and $F_i^- \left(\widehat{P} \right) = 1$.[5] [6]

We see that $\pi_k (P^+) = \pi_k \left(\widehat{P} \right)$ for $P^+ = \underline{C} + \left(\widehat{P} - \underline{C} \right) \Psi / (\Psi + \Omega)$. But If $P_k \in [P^+, P^0)$ then $P_i = \widehat{P}$ and $\pi_k^+ (P_k) < \pi_k^+ (P^0)$. The strategy space for the firm involved in research is therefore also given by: $S_k^+ = S_i^0$. In practice, this implies that it does not pay to undercut the price.

On this interval defined by S_k^+ the distribution function $F_k^+ (P)$ is a well-defined distribution function, as it is continuous and increasing (see *Appendix A*), with $F_k^+ (P^0) = 0$ and $F_k^+ \left(\widehat{P} \right) = 1$.

To calculate the distribution functions, we fist analyze the expected pay-off for firm k. If $P_k \in \left[P^+, \widehat{P} \right]$ then:

$$\Pi (P_k < P_i) = \prod_{i \neq k}^{n} (1 - F_i (P_k))$$

$$\Pi (P_k > P_i) = 1 - \prod_{i \neq k}^{n} (1 - F_i (P_k))$$

and the corresponding expected profit in that case equals:

$$E\pi_k^+ = \Pi (P_k > P_i) ((P_k - \underline{C}) \Psi - K) + \Pi (P_k < P_i) ((P_k - \underline{C}) (\Psi + \Omega) - K)$$

[5] Note that the function is discontinuous for $P < P^0$, at $P = \left(\overline{C} - \Delta C \right)$.

[6] In practice $F_i^- \left(P^R \right) < 1$ and therefore by definition: $F_i^- \left(P^R \right) = 1$.

For firm k the highest profit it can obtain with certainty on its strategy space equals $\pi_k^+ (P^0) = (P^0 - \underline{C})(\Psi + \Omega) - K = \left(\widehat{P} - \overline{C}\right)\Psi + \Delta C (\Psi + \Omega) - K$. With $F_i^- (P) = F_{-i}^- (P)$ in equilibrium, we subsequently get:

$$\left(\widehat{P} - \overline{C}\right)\Psi + \Delta C (\Psi + \Omega) - K = \left(1 - \left(1 - F_i^- (P)\right)^{n-1}\right)\left((P - \underline{C})\Psi - K\right) + \left(1 - F_i^- (P)\right)^{n-1}\left((P - \underline{C})(\Psi + \Omega) - K\right) \quad (4.6)$$

For firm i we get for $P_i^- \in \left[P^0, \widehat{P}\right]$ that:

$$\Pi (P_i < P_{-i,k}) = (1 - F_k (P_i)) \prod_{j \neq i}^{n-1} (1 - F_j (P_i))$$

$$\Pi (P_i > P_{-i,k}) = 1 - (1 - F_k (P_i)) \prod_{j \neq i}^{n-1} (1 - F_j (P_i))$$

with a corresponding expected profit given by:

$$E\pi_i^- = \Pi (P_i > P_{-i,k})\left(\left(P_i - \overline{C}\right)\Psi\right) + \Pi (P_i < P_{-i,k})\left(P_i - \overline{C}\right)(\Psi + \Omega)$$

On S_i^0 the highest sure pay-off for firm i (i.e. the firms not involved in research) equals $\pi_i^- \left(\widehat{P}\right) = \left(\widehat{P} - \overline{C}\right)\Psi$. With $F_k^+ (P) = F_{-k}^+ (P)$ in equilibrium we get:

$$\left(\widehat{P} - \overline{C}\right)\Psi = \left(1 - \left(1 - F_k^+ (P)\right)\left(1 - F_{-i}^- (P)\right)^{n-2}\right)\left(P - \overline{C}\right)\Psi + \left(1 - F_k^+ (P)\right)\left(1 - F_i^- (P)\right)^{n-2}\left(P - \overline{C}\right)(\Psi + \Omega) \quad (4.7)$$

Solving the system of equations (4.6) and (4.7) gives (4.4) and (4.5). Note that all the firms of the population have no incentive to select a price from outside their strategy space, or to deviate from their strategy. ■

Note that $F_k^+ (P) > F_i^- (P)$ on $\left(P^0, \widehat{P}\right)$ (see *Appendix A*), so that firm k is more likely to charge lower prices than firm i, and therefore will capture the price-conscious customers more often. The fact that $F_i^- (P)$ has a mass point $\mu > 0$ implies that firm i will charge $P_i = \widehat{P}$ with positive probability. The probability that two firms charge the same price however is zero, as $F_k^+(P)$ is continuous at $\widehat{P}$ (see (Baye and de Vries 1992)).

Research within a RJV

In case firm k decides to share its idea and conduct a research project within a RJV, we get that Q_i^- is given by (4.1), Q_k^+ by (4.3).

Lemma 4.3 *There exists a symmetric mixed-strategy equilibrium if firms k choose a price $P_k \in \left[P^+, \widehat{P}\right]$ at random from a distribution function $F_k^+(P)$ such that $E\pi_k^+(P,r) = \left(\widehat{P} - \underline{C}\right)\Psi - K/r$, and $\Pi\left(P_i = \widehat{P}\right) = 1$ such that $E\pi_i^-(P) = \left(\widehat{P} - \overline{C}\right)\Psi$, with:*

$$F_k^+(P) = 1 - \left(\frac{\left(\widehat{P} - P_k\right)\Psi}{\left(P_k - \underline{C}\right)\Omega}\right)^{\frac{1}{r-1}} \tag{4.8}$$

In practice *Lemma 4.3* implies that the firms involved in research randomize their price, while the firms outside the RJV price at $\widehat{P}$.

Proof. The strategy space for the firms involved in research is now given by:

$$S_k^+ = \left[P^+, \widehat{P}\right] = \left[\underline{C} + \frac{\left(\widehat{P} - \underline{C}\right)\Psi}{(\Psi + \Omega)}, \widehat{P}\right]$$

On this interval, $F_k^+(P)$ is a well-defined distribution function as it is continuous and increasing with $F_k^+(P^+) = 0$ and $F_k^+\left(\widehat{P}\right) = 1$ (see *Appendix A*).[7]

To compute the cumulative distribution function, we assume that firm k chooses a price $P_k \in \left[P^+, \widehat{P}\right]$ such that:

$$\Pi\left(P_k < P_{-k,i}\right) = \prod_{k \neq l}^{r} \left(1 - F_l\left(P_k\right)\right),$$

$$\Pi\left(P_k > P_{-k,i}\right) = 1 - \prod_{k \neq l}^{r} \left(1 - F_l\left(P_k\right)\right),$$

[7] Note that the function is discontinuous for $P_k < P^+$, at $P = \left(\overline{C} - \Delta C\right)$.

and the corresponding expected profit in that case equals:

$$E\pi_k^+ = \Pi\left(P_k > P_{-k}\right)\left(\left(P_k - \underline{C}\right)\Psi - \frac{K}{r}\right) + \\ \Pi\left(P_k < P_{-k}\right)\left(\left(P_k - \underline{C}\right)\left(\Psi + \Omega\right) - \frac{K}{r}\right)$$

On S_k^+ the highest sure pay-off for firms involved in research equals $\pi_k^+\left(\widehat{P}, r\right) = \left(\widehat{P} - \underline{C}\right)\Psi - K/r$. In equilibrium, with $F_k^+(P) = F_{-k}^+(P)$, we subsequently get that:

$$\left(\widehat{P} - \underline{C}\right)\Psi - K/r = \left(1 - \left(1 - F_k^+(P)\right)^{r-1}\right)\left(\left(P_k - \underline{C}\right)\Psi - \frac{K}{r}\right) + \\ \left(\left(1 - F_k^+(P)\right)^{r-1}\right)\left(\left(P_k - \underline{C}\right)\left(\Psi + \Omega\right) - \frac{K}{r}\right)$$

Solving this for $F_k^+(P)$ gives the distribution according to (4.8).

In order to prove that $\Pi\left(P_i = \widehat{P}\right) = 1$ the following should hold:

$$\left(R - \overline{C}\right)\Psi > \Pi\left(P_i > P_{k,-i}\right)\left(P_i - \overline{C}\right)\Psi + \Pi\left(P_i < P_{k,-i}\right)\left(P_i - \overline{C}\right)\left(\Psi + \Omega\right)$$

with:

$$\Pi\left(P_i < P_{k,-i}\right) = \prod_1^r \left(1 - F_k\left(P_i\right)\right),$$

$$\Pi\left(P_i > P_{k,-i}\right) = 1 - \prod_1^r \left(1 - F_k\left(P_i\right)\right).$$

Substituting $F_k(P_i)$ according to (4.8) gives:

$$\left(\frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\underline{C}\right)\Omega}\right)^{\frac{r}{r-1}} < \frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\overline{C}\right)\Omega} \Leftrightarrow$$

$$\frac{\left(P-\overline{C}\right)\Omega}{\left(\left(P-\underline{C}\right)\Omega\right)^{\frac{r}{r-1}}}\frac{\left(\left(\widehat{P}-P\right)\Psi\right)^{\frac{r}{r-1}}}{\left(\widehat{P}-P\right)\Psi} < 1 \Leftrightarrow$$

$$\frac{\left(P-\overline{C}\right)\Omega}{\left(\left(P-\underline{C}\right)\Omega\right)}\frac{\left(\left(\widehat{P}-P\right)\Psi\right)^{\frac{1}{r-1}}}{\left(\left(P-\underline{C}\right)\Omega\right)^{\frac{1}{r-1}}} < 1 \Leftrightarrow$$

$$\frac{\left(P-\overline{C}\right)\Omega}{\left(P-\underline{C}\right)\Omega}\left(\frac{\left(\left(\widehat{P}-P\right)\Psi\right)}{\left(\left(P-\underline{C}\right)\Omega\right)}\right)^{\frac{1}{r-1}} < 1$$

This holds because:

$$\frac{\left(P-\overline{C}\right)\Omega}{\left(P-\underline{C}\right)\Omega} < 1 \wedge \left(\frac{\left(\left(\widehat{P}-P\right)\Psi\right)}{\left(\left(P-\underline{C}\right)\Omega\right)}\right)^{\frac{1}{r-1}} < 1$$

Again the firms of the population have no incentive to select a price outside the strategy space, or to deviate from their strategy. ■

The rationale behind the behavior of firm i can be explained by the fact that $S_i^- \neq S_k^+$. Firm k competes with firm $-k$ on $P_k \in [P^+, P^0]$ and therefore $\Pi(P_k \leq P^0) > 0$. As a consequence $P_i = \widehat{P}$ as $\left[\pi_i^0(P^0) = \left(P^0 - \overline{C}\right)\Psi\right] < \left[\pi_i^0\left(\widehat{P}\right) = \left(\widehat{P} - \overline{C}\right)\Psi\right]$. We consequently argue that if $P_k \in \left[P^+, \widehat{P}\right]$ then $\Pi\left(P_i = \widehat{P}\right) = 1$.

4.3 Main result: investment decision and size of the RJV

Base on the previous analysis, we obtain conclusions concerning collaboration in R&D for a hybrid market form of perfect competition and monopolistic competition.

Theorem 4.4 *If $E\pi_k^+(P) \geq E\pi_k^+(P,n)$ and the expected change in marginal cost is larger than the foreseen total cost of the project per product sold, a firm will invest in the required research, but it will not form a RJV.*

If $E\pi_k^+(P) < E\pi_k^+(P,n)$ and the expected change in marginal cost is larger than the total cost of the project per total population of brand-loyal customer, a firm will implement the research project, but with a RJV containing all firms of the population.

In all other cases, the firm will not pursue the potential change in marginal cost by means of conducting a research project.

Recapitulating this gives for the optimal size of the RJV:

$$r = \begin{cases} 1 & \text{for} \quad \frac{n-1}{n}\frac{K}{\Omega} \leq \Delta C \wedge (1-p)\,\Delta C > \frac{K}{\Psi+\Omega} \\ n & \text{for} \quad \frac{n-1}{n}\frac{K}{\Omega} > \Delta C \wedge (1-p)\,\Delta C > \frac{K}{n\Psi} \\ 0 & \text{for} \quad \text{all other cases} \end{cases} \tag{4.9}$$

Proof. For our proof, we build on *Lemma 4.1*, *Lemma 4.2* and *Lemma 4.3* for the expected profits in the different equilibrium. We see that $E\pi_k^+(P,n) \geq E\pi_k^+(P,r) > E\pi_i^0(P)$, and $E\pi_k^+(P) > E\pi_i^0(P)$, indicating that firms have an incentive to innovate, as it increases their profit. It also shows that if firm k decides to conduct research within a RJV, it will formulate a consortium such that $r = n$. This is caused by the fact that the gross earnings of the firm (i.e. the profit without the project cost) are defined by the characteristics of the market and the (change in) marginal costs, and not by the number of firms in the RJV. The actual project cost however are equally shared by the research partners, and subsequently will be lower if all firms of the population are involved.

Firm k will decide on the size of the consortium by comparing profit for $r = 1$ with that for $r = n$:

$$E\pi_k^+(P,n) \gtrless E\pi_k^+(P_k) \Leftrightarrow$$
$$\left(\widehat{P}-\overline{C}\right)\Psi + \Delta C\Psi - \frac{K}{n} \gtrless \left(\widehat{P}-\overline{C}\right)\Psi + \Delta C(\Psi+\Omega) - K \Leftrightarrow$$
$$\frac{n-1}{n}\frac{K}{\Omega} \gtrless \Delta C$$

Firm k will decide on actually conducting the research by comparing the individual project cost with what it is willing to invest in R&D, given the foreseen change in profit and the probability of success of the research project:

$$(1-p)\left(\overline{\pi}^+(P,r) - \pi^0(P)\right) \gtrless K/r \Leftrightarrow$$

$$(1-p)\Delta C \gtrless \tfrac{K}{(\Psi+\Omega)} \quad \text{for} \quad r=1$$

$$(1-p)\Delta C \gtrless \tfrac{K}{n\Psi} \quad \text{for} \quad r=n$$

■

Our result according to (4.9) implies that in practice, firm k will decide about conducting the research project, and subsequently about the number of partners in the research project, by comparing the expected profit for different sizes of the consortium. The expected profit is defined by the pricing strategy of the firm when engaging in competition with the other firms of the population. Within our setting, this pricing strategy is defined by the marginal cost and its anticipated change.

4.4 Conclusions and recommendations

In the traditional approach of a multi-stage strategic investment game (i.e. with a market under Cournot or Bertrand), we see that firms involved in successful R&D will dominate the market for a certain change in marginal cost and size of the consortium (see *Chapter 2* and *Chapter 3*). Our result indicates that successful implementation of the research results will not lead to an oligopoly, such that the firms not involved in research are driven out of the market. In practice we will have to assume however that for a hybrid market form of perfect and monopolistic competition, firms not involved in successful research will eventually loose also their brand-conscious customers. Because these firms would charge a price which consistently exceeds that of the consortium members, even the brand-conscious customers would ultimately change their preferences.

Our results furthermore indicate that if a firm decides to pursue innovation, it either conducts the required research by itself, or it involves all firms of the population in the project. This last conclusion seems inconsistent with common economic intuition that the firm would give away its potential competitive advantage by sharing its idea with all of its competitors. One might argue that this is caused by the fact that we ignore immediate spillover effects in our approach. We contend however that the impact of knowledge creation is ultimately captured in the probability of success of research projects. This result is explained by the characteristics of the profit function: within the framework of our model, a firm might want to share its idea because the profit increases with the number of firms in the project.

In practice we should interpret this result as though firms want to collaborate in research by establishing a consortium, and subsequently increase its size to an extend that is practically possible and strategically desirable. In reality, this does happen for pre-competitive research, as illustrated for example by the EU Technology Platforms.[8] But it also happens for example within the automobile industry, a sector operating in a market pre-eminently characterized by brand-conscious and price-conscious customers. Multiple car manufacturers jointly develop and share essential parts, such as platforms and engines, in order to divide the cost for development.[9]

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[8] See www.cordis.europa.eu/technology-platforms.

[9] As an example of collaboration within the automobile industry on platfroms: the PSA/Fiat joint venture for the development of large MPVs such as the Citroën Evasion (Synergie), Fiat Ulysse, Lancia Zeta, Peugeot 806 and its successors Fiat Freemont, Lancia Grand Voyager and Citroën DS5. But also smaller cars are jointly developed, such as the Peugeot 107, Citroen C1 and Toyota Aygo.

Appendix A: characteristics of the distribution function

Initial equilibrium with no research

In order to verify that the distribution functions are well-defined, we have to analyze if they are increasing on the interval from which the firm selects its price. If no firm is involved in research (i.e. $r = 0$), we get that:

$$\begin{aligned}
\frac{dF_i^0(P)}{dP} &= \frac{d\left(1-\left(\frac{(\widehat{P}-P)\Psi}{(P-\overline{C})\Omega}\right)^{\frac{1}{n-1}}\right)}{dP} \\
&= \frac{1}{(n-1)}\frac{\Psi\left(\widehat{P}-\overline{C}\right)}{\Omega\left(P-\overline{C}\right)^2}\left(\frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\overline{C}\right)\Omega}\right)^{-\frac{n-2}{n-1}} \Rightarrow \\
\frac{dF_i^0(P)}{dP} &> 0 \text{ for } P \in \left[P^0, \widehat{P}\right]
\end{aligned}$$

Research by a single firm

If a single firm is involved in research (i.e. $r = 1$), we see for its distribution function:

$$\begin{aligned}
\frac{dF_k^+(P)}{dP} &= \frac{d\left(1-\frac{(\widehat{P}-P)\Psi}{(P-\overline{C})\Omega}\left(\frac{\Omega\Delta C+\Psi(\widehat{P}-P)}{(P-\underline{C})\Omega}\right)^{-\frac{n-2}{n-1}}\right)}{dP} \\
&= \frac{d\left(-\frac{(\widehat{P}-P)\Psi}{(P-\overline{C})\Omega}\right)}{dP}\left(\frac{\Omega\Delta C+\Psi\left(\widehat{P}-P\right)}{\left(P-\underline{C}\right)\Omega}\right)^{-\frac{n-2}{n-1}} - \\
&\quad \frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\overline{C}\right)\Omega}\frac{d\left(\left(\frac{\Omega\Delta C+\Psi(\widehat{P}-P)}{(P-\underline{C})\Omega}\right)^{-\frac{n-2}{n-1}}\right)}{dP}
\end{aligned}$$

Reformulating gives:

$$\frac{dF_k^+(P)}{dP} > 0 \Leftrightarrow$$
$$\frac{\left(\widehat{P}-P\right)\Psi}{\left(\left(P-\overline{C}\right)\Omega\right)} > \frac{n-2}{n-1}\frac{\left(\widehat{P}-P\right)\Psi}{\left(\left(P-\underline{C}\right)\Omega\right)} -$$
$$\Psi\left(\frac{\left(\widehat{P}-P\right)\Psi+(n-1)\,\Omega\Delta C}{(n-1)\left(\widehat{P}-P\right)\Psi+\Omega\Delta C}\right)$$

This holds because for $P \in \left[P^0, \widehat{P}\right]$ we see that:

$$-\Psi\left(\frac{\left(\widehat{P}-P\right)\Psi+(n-1)\,\Omega\Delta C}{(n-1)\left(\widehat{P}-P\right)\Psi+\Omega\Delta C}\right) < 0$$
$$\frac{n-2}{n-1} < 1$$
$$\frac{\left(\widehat{P}-P\right)\Psi}{\left(\left(P-\overline{C}\right)\Omega\right)} > \frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\underline{C}\right)\Omega}$$

For the firms not involved in research we get that:

$$\frac{dF_i^-(P)}{dP} = \frac{d\left(1-\left(\frac{\Omega\Delta C+\left(\widehat{P}-P\right)\Psi}{\left(P-\underline{C}\right)\Omega}\right)^{\frac{1}{n-1}}\right)}{dP}$$
$$= \frac{1}{(n-1)}\frac{\left(\Omega\Delta C+\left(\widehat{P}-\underline{C}\right)\Psi\right)}{\Omega\left(P-\underline{C}\right)^2\left(\frac{\left(\Omega\Delta C+\left(\widehat{P}-P\right)\Psi\right)}{\left(P-\underline{C}\right)\Omega}\right)^{\frac{(n-2)}{n-1}}} \Rightarrow$$
$$\frac{dF_i^-(P)}{dP} > 0 \text{ for } P \in \left[P^0, \widehat{P}\right].$$

In order to prove that firm k is more likely to charge lower prices than firm i, we show that $F_k^+(P) > F_i^-(P)$ on $\left(P^0, \widehat{P}\right)$:

$$\begin{aligned}
F_k^+(P) &> F_i^-(P) \Leftrightarrow \\
\frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\overline{C}\right)\Omega} &< \left(\frac{\Omega\Delta C+\left(\widehat{P}-P\right)\Psi}{\left(P-\underline{C}\right)\Omega}\right)^{\frac{n-2}{n-1}+\frac{1}{n-1}} \Leftrightarrow \\
\frac{\left(P-\overline{C}\right)\Omega+\Delta C\Omega}{\left(P-\overline{C}\right)\Omega} &< \frac{\Omega\Delta C+\left(\widehat{P}-P\right)\Psi}{\left(\widehat{P}-P\right)\Psi} \Leftrightarrow \\
\frac{\Omega\Delta C}{\left(P-\overline{C}\right)\Omega} &< \frac{\Omega\Delta C}{\left(\widehat{P}-P\right)\Psi} \Leftrightarrow \\
\frac{\left(\widehat{P}-P_i\right)\Psi}{\left(P-\overline{C}\right)\Omega} &< 1
\end{aligned}$$

Research within a RJV

If firm k establishes a Research Joint Venture to conduct the research project (i.e. $r > 1$), then we see for the distribution function:

$$\begin{aligned}
\frac{dF_k^+(P)}{dP} &= \frac{d\left(1-\left(\frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\underline{C}\right)\Omega}\right)^{\frac{1}{r-1}}\right)}{dP} \\
&= \frac{1}{(r-1)}\frac{\Psi\left(\widehat{P}-\overline{C}\right)}{\Omega\left(P-\underline{C}\right)^2}\left(\frac{\left(\widehat{P}-P\right)\Psi}{\left(P-\underline{C}\right)\Omega}\right)^{-\frac{r-2}{r-1}} \Rightarrow \\
\frac{dF_k^+(P)}{dP} &> 0 \text{ for } P \in \left[P^0, \widehat{P}\right].
\end{aligned}$$

Chapter 5

The efficiency of instruments providing financial support to industry-oriented R&D and innovation[1]

Cost of intervention, given the willingness of firms to invest

The global economy is showing signs of recovery after an unprecedented financial crisis initiated one of the most virulent recessions in decades (OECD 2010a). These turbulent times have indicated again the importance of policies aimed at creating stable and sustainable economic growth. Countries therefore need to increase their labour productivity levels by strengthening their research and innovation capacity.

Governments have acknowledged the relevance of long-term innovation driven growth strategies. They have consequently implemented specific interventions aimed at increasing public as well as private expenditure on research (Commission of the European Communities 2010) (OECD 2010b). In general, a government has several *instruments* at its disposal encouraging firms to invest in research. Within the framework of this paper, we focus on the following modalities of support: *funding* (e.g. subsidies or in kind contributions), *tax schemes*, and *loans*. Almost all industrialized countries have implemented these types of specific and dedicated measures supporting industry-oriented research.[2]

In order not to impede future economic recovery, most countries have decided to further rationalize their national budgets. The consequential retrenchments of

[1] This chapter has been co-authored with Amit Kothiyal.

[2] For an overview, check: www.proinno-europe.eu, or www.cordis.europa.eu/erawatch, or www.oecd.org.

public expenditure requires them to consider the *efficiency* of instruments. In other words, and adapted from (Flanagan et al. 2010), countries are looking for: "[...] the cheapest one (i.e. measure) to implement, which least distorts the market whilst still achieving its objective."

In this paper, we present a theoretical framework that allows for a comparison of the efficiency of instruments. Within the framework of this paper efficiency refers to: 'the costs of the government intervention required to change the behavior of the firm concerning investment in R&D, and initiate research.'

Analysis of the literature reveals that little is known about the performance of a single instrument in comparison to other tools (Boekholt et al. 2006). It is even argued that "[...] from a purely logical and technical point of view, policy tools appear to be perfectly interchangeable." (Landry and Varone 2005)

Theoretical research on policy formulation focusses on the impact of measures enabling collaboration in research between firms, in combination with subsidies and generic tax measures (Hinloopen 2001) (Spencer and Brander 1983) (Inci 2008). Empirical research, such as (Guellec and De La Potterie 2003), indicates that direct government funding and tax incentives have an immediate and positive effect on business-financed R&D. But it also reveals that direct government funding and R&D tax incentives are substitutes: increased intensity of one reduces the effect of the other on business R&D. Policy evaluations seem limited to individual measures, and do not address a set of instruments (Flanagan et al. 2010). A rare exception such as the evaluation of the Dutch fiscal measure WBSO[3] indicates, on the basis of results of a questionnaire, that firms and governments favor tax-deductions over other forms of financial support. Rationale for this preference is the simplicity of the application process, and the fact that a large part of the infrastructure required for the policy delivery is available (Brouwer et al. 2002).

For our analysis of the efficiency of instruments, we adopt a series of assumption in order to reflect the current practice concerning industry-oriented research (see *Chapter 1*). We embrace a problem driven innovation model, in which R&D is conducted within the framework of a predefined project, originating from an idea addressing a specific issue. We assume that the accompanying cost of the project

[3] WBSO: "Wet Bevordering Speur- en Ontwikkelingswerk" or "R&D Work Stimulation Act".

are predetermined, and the outcome of the R&D process is foreseen. Successful execution of a research project involves a certain probability of failure, which is known in advance. Only a subset of the population of firms will conduct research. Intervention is directed towards those involved with the idea and the related R&D. Our assumptions concerning the characteristics of the innovation process are in line with how industry-oriented research and innovation is supported under the *EU State Aid rules* (Commission of the European Communities 2006) and the *WTO Disciplines on Subsidies.*

In order to assess the willingness of the firm to invest in this research project with an associated risk, we apply Prospect Theory as introduced by (Kahneman and Tversky 1979). The willingness to invest is defined by the valuation of the potential gains and losses associated with the implementation of the project, and the weighing of the risk involved in conducting the research.

We argue that if a firm is not willing to invest, a government has the possibility to intervene, and implement measures so that the firm will alter its behavior, and decide to conduct the R&D. For each instrument we calculate the exact amount of support required by the firm from the government to implement the project. We identify the most efficient instrument by comparing the expected earnings resulting from the intervention for a government. We apply Expected Value theory to describe the behavior of a government concerning valuation of its earnings

Our choice for these specific behavioral models is motivated by the characteristics of the actors in our analysis. In decision analysis, Expected Utility theory (EU) is considered to be the right normative model for decision under uncertainty (Bleichrodt et al. 2001). We therefore apply EU to analyze the behavior of a government. As the expected contribution required to initiate the research is relatively small for a government, we assume that its utility function can well be approximated by a linear function. EU consequently reduces in our case to Expected Value theory, as suggested in (Arrow 1970). Prospect Theory (PT) on the other hand does a much better job than EU in predicting the behavior of individuals and small entities (e.g. SMEs) in risky situations (Kahneman and Tversky 1979). We therefore analyze the behavior of the firm under uncertainty using PT. In order to verify our conclusions, we also compare our outcome under PT with the result obtained in case the behavior of firms is described by EU.

Our analysis indicates that there exists a critical value for the probability of failure of the project at which the modality of the most efficient instruments changes. For a probability of failure exceeding the critical value, a tax measures offering support only in case of successful completion of the project is preferred. For a probability smaller than the critical value, a loan is most efficient. The value of the critical probability depends on the perception of risk and loss aversion of the firm involved in the research.

Our results for EU confirm at least partly the order of efficiency under PT (i.e. the results for a probability smaller than the critical value). But the preference in case of EU does not change for the probability of failure of the project. This is caused by the inability to assess the perception of risk of firms under EU.

Our paper shows furthermore that the current approach towards support for industry-oriented research, which is defined by the *State Aid rules* (Commission of the European Communities 2006) and the *WTO Disciplines on Subsidies*, results in the implementation of measures such that they are not effective in initiating research, and not efficient with respect to the contribution required to start an R&D project.

The next sections describe the model used, the main results, and the conclusions and recommendations with emphasis on the implications for policy formulation. The annex includes the technical proofs.

5.1 Investment in R&D by a firm

For the assessment of the efficiency of the instruments, we analyze an industry-sector consisting of two firms with corresponding initial profit $\Pi^0 = \{\pi_1^0, \pi_2^0\}$. Firm 1 now has an idea to increase its profit. Successful translation of this idea into a market application requires conducting a research project with cost K, and probability of failure $p \in [0, 1]$. The project cost K are predefined, and budgeted according to foreseen allocation of resources. The probability p depends on the current level of knowledge and state of the art in the research field of the project. If the required knowledge is not available, and lies beyond the current state of the art p will be close to one. If the required knowledge is available p will be close to zero. Successful implementation of the research results will lead to a change in profit according to $\Pi^+ = \{\pi_1^+ - K, \pi_2^-\}$, with $\pi_1^+ > \pi_1^0 + K$.[4] If the research project fails, the corresponding profit remains unchanged.

Investing in the research project involves a risk, and we assume that Prospect Theory (Kahneman and Tversky 1979) describes the behavior of the firm in this situation. Within the framework of Prospect Theory (PT), losses and gains relative to some predefined *reference point* are the carriers of value (Wakker 2010). It is a well known empirical phenomenon that "losses loom larger than gains" (Kahneman and Tversky 1979). PT models this phenomenon by weighting the losses relative to gains with a *loss aversion parameter* $\lambda > 1$.

Also in Prospect Theory, probabilities are distorted by a *probability weighting function*, which over-weighs low probabilities and under-weighs high probabilities. (Kahneman and Tversky 1992) propose the following family of weighting functions:

$$w(p) = \frac{p^\beta}{(p^\beta + (1-p)^\beta)^{\frac{1}{\beta}}} \tag{5.1}$$

with *parameter* $\beta \in [0.28, 1)$. On this interval the lower the value of β the more the distortion in probabilities ((Kahneman and Tversky 1992) estimate $\beta = 0.61$, see Figure 5.1).[5]

In Prospect Theory, gains and losses are furthermore evaluated by means of a utility function. We will assume however that the risk attitude of the firm is reflected in the probability distortion function and loss aversion parameter. For simplicity, we therefore assume the utility function to be piecewise linear within the framework of our paper.

The outcome of the investment in the research project as described in this paper can be represented as a binary prospect yielding $(\pi_1^+ - K)$ with probability $(1-p)$,

[4] Our model can be applied for different market structures. As an example, consider two firms competing in a market on quantity (i.e. Cournot competition). Now assume that firm 1 has an idea that will change the marginal cost of production. Successful implementation of the research results will increase the pay-off for the innovating firm, while decreasing the profit for the other firm.

[5] For $\beta < 0.28$ the probability weighting functions are not strictly increasing; for $\beta > 1$ they over-weight small probabilities rather than under-weight them; and for $\beta = 1$ the function is linear (i.e. no distortion of the probabilities).

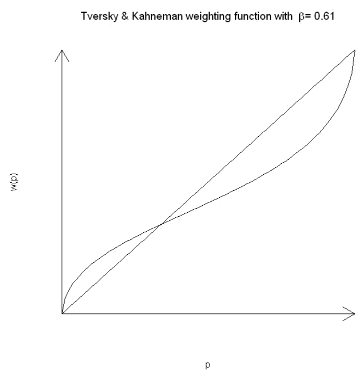


Figure 5.1: Weighting function

and $(\pi_1^0 - K)$ with probability p. We adopt a notation which represents this as $(\pi_1^0 - K)_p(\pi_1^+ - K)$. The decision problem for the firm is to choose between this prospect or the initial profit before innovation. The natural reference point for this decision problem is π_1^0.

The value function, which shows the result of the aggregation of gains and losses of the firm (Kahneman and Tversky 1979) (Kahneman and Tversky 1992), is consequently given by:

$$V = w\left(1-p\right)\left(\left(1-f\right)\left(\left(\pi_1^+ - K\right) - \pi_1^0\right)\right) + \lambda w(p)\left(-\left(1-f\right)K\right) \tag{5.2}$$

In our model, we assume a fraction f of tax collected by the government on the profit. The value function shows the gain as the profit after successful implementation of the research result, minus the project cost, relative to the reference point. The loss reflects the other outcome of the binary prospect relative to the reference point. Both the gain and the loss are weighted, but only the latter includes the loss aversion parameter.

The firm will decide on investing in the research project if and only if the result of the value function is not less than zero.

5.2 Intervention by the government

If the result of the value function is negative, a government has the possibility to intervene, and implement policy instruments such that firm 1 will consider altering its behavior, and decide on conducting the R&D. The rationale for government intervention supporting basic research has been established by (Nelson 1959) and (Arrow 1962). They argue that the difficulty of selecting potentially marketable research and the uncertainty with respect to its successful outcome limits incentives of industry to conduct R&D. The indivisible and non-excludable character of this type of research, and the fact that its results are almost freely available in scientific publications further enhances the tendency to under-invests in R&D. This market failure argument has been further developed by (Jaffe 1996) as a rationale for supporting pre-competitive industry oriented research. In his work he identifies additional types of spill-overs that negatively affect decisions of firms concerning investments in research. These types refer to appropriability of knowledge (for example through imitation), the benefits to users of the innovation not captured in its price, and network spill-overs (when successful innovation relies upon developments in related technologies.

We argue that a government should select the instrument that maximizes its expected earning E_y. The subindex represents the type of measure. The earnings are defined by the taxation on firms with a *fraction* f on the profit, and the *expected contribution* I_y corresponding to a specific instrument required to initiate the research:

$$E_y = (1-p)\, f\left(\left(\pi_1^+ - K\right) + \pi_2^-\right) + pf\left(\left(\pi_1^0 - K\right) + \pi_2^0\right) - I_y \qquad (5.3)$$

5.3 Assessment of instruments

We identify four different modalities of support for firms conducting research. The contribution is provided in different stages of the project, depending on success or failure of the outcome.

Funding

A government can contribute to the project cost by offering direct funding (e.g. subsidies and grants), or indirect funding (e.g. as access to research infrastructure, vouchers, rebate on social insurance, and advice). The first type of funding involves an actual transfer of funds, which are not recoverable by the government from the beneficiary. With the latter, a government tries to compensate for the cost by providing in kind resources. We assume that funding is allocated unconditionally (i.e. it is allocated in case of success as well as in case of failure of the research project).

If F is the minimum amount of funding required to initiate the research project, then the corresponding value function of the firm, as given in (5.2) becomes:

$$w\,(1-p)\left((1-f)\left(\left(\pi_1^+ - K\right) - \pi_1^0\right) + F\right) + \lambda w(p)\left(F - (1-f)\,K\right) = 0 \qquad (5.4)$$

And the corresponding expected government earnings E_F (5.3) is:

$$E_F = (1-p)\,f\left(\left(\pi_1^+ - K\right) + \pi_2^-\right) + pf\left(\left(\pi_1^0 - K\right) + \pi_2^0\right) - F \qquad (5.5)$$

Unconditional tax-rebate

Support can also be offered proportional to the expected profit. We first analyze a tax rebate given unconditionally on whether the project succeeds or fails. Let t be the minimum fraction of tax rebate required to initiate the research project, then the value function of the firm is:

$$w\,(1-p)\left((1-f)\left(\left(\pi_1^+ - K\right) - \pi_1^0\right) + t\pi_1^+\right) + \lambda w(p)\left(t\pi_1^0 - (1-f)\,K\right) = 0 \qquad (5.6)$$

with corresponding expected government earnings E_t denoted by:

$$E_t = (1-p)\,f\left(\left(\pi_1^+ - K\right) + \pi_2^-\right) + pf\left(\left(\pi_1^0 - K\right) + \pi_2^0\right) - t\left((1-p)\,\pi_1^+ + p\pi_1^0\right) \qquad (5.7)$$

Conditional tax-rebate

A tax rebate can be provided also only in case the project is completed successfully. Let τ be the minimum fraction of conditional tax rebate, then the value function of the firm is:

$$w(1-p)\left((1-f)\left(\left(\pi_1^+ - K\right) - \pi_1^0\right) + \tau\pi_1\right) + \lambda w(p)\left(-(1-f)K\right) = 0$$

with corresponding expected government earnings E_τ denoted by:

$$E_\tau = (1-p)f\left(\left(\pi_1^+ - K\right) + \pi_2^-\right) + pf\left(\left(\pi_1^0 - K\right) + \pi_2^0\right) - (1-p)\tau\pi_1^+$$

Loans

Loans involve the allocation of funds which have to be reimbursed by the firm to the government in case the research project is implemented successfully. Let L be the minimum amount provided by means of a loan required to initiate the research project, then the value function of the firm is:

$$w(1-p)\left((1-f)\left(\left(\pi_1^+ - K\right) - \pi_1^0\right)\right) + \lambda w(p)\left(L - (1-f)K\right) = 0$$

with corresponding expected government earnings E_L denoted by:

$$E_L = (1-p)f\left(\left(\pi_1^+ - K\right) + \pi_2^-\right) + pf\left(\left(\pi_1^0 - K\right) + \pi_2^0\right) - pL$$

5.4 Main result: order of preference of instruments

By comparing the expected earnings from the government resulting from the implementation of the different instruments, we can assess the performance of measures compared to other tools.

Theorem 5.1 *there exists a critical probability of failure of the research project, given by:*

$$p_c = \frac{1}{1 + \lambda^{\frac{-1}{1-\beta}}}$$

for which the order of preference for the instruments changes. For $p > p_c$ the order of measures in terms of efficiency from best to worst equals: conditional tax-rebate, unconditional tax-rebate, funding, loan. For $p < p_c$ the above ordering is reversed. For $p = p_c$ all instruments perform equally well.

The proof for *Theorem 5.1* is given in *Appendix A*. The intuition behind the theorem can be explained by the risk attitude of the firm. For $p > p_c$ (i.e. for a relatively high probability of failure) a fiscal measure that allocates support only in case of success provides the highest *actual* transfer of resources to a firm in comparison to the other tools. For a conditional tax-rebate, this contribution is of course granted only in case the research project is conducted successfully. But the the weighing of the probability of success and the loss aversion of the firm are such that it is willing to take the risk, and conduct the research for an indemnification that results in the lowest *expected* contribution by a government. For a relatively high probability of success of the research project, this reasoning is similar for a loan. In practice, a measure is preferred over other instruments if its corresponding *expected* contribution, allocated by a government to a firm, is lower than that of other tools

Corollary 5.2 *For $p > p_c$ a conditional tax-rebate is most efficient. For $p < p_c$ a loan is the optimal strategy.*

With the help of our model, we are able to define for each of the instruments the exact contribution required by the firm to alter its decision. The change in market equilibria causing the expected gain in profit by the firm results from the foreseen implementation of the research results, and not from the transfer of support. The contribution itself is appropriated merely to amend the prospect of the firm such that it will initiate the project. We also have defined our model such that all measure induce a similar level of efforts in R&D. We therefore argue that we are able to compare the cost of the intervention, and as a consequence also the earnings of a government. Based on our analysis, we thereupon conclude that unconditional tax rebates and loans are most efficient.

Remark 5.3 *If we assume $\lambda = \beta = 1$ within the framework of our model, Prospect Theory reduces to Expected Value theory, and all instruments perform equally well.*

When applying a linear perception of risk and no loss aversion, we find that all instruments require the same level of expected contribution to initiate research. This is in line with what is argued in the literature (Landry and Varone 2005). Our framework indicates that there are differences in the efficiency of instruments, resulting from our assumptions concerning loss aversion and the perception of risk involved in conducting the research by the firm.

5.5 Comparison of outcome with results under Expected Utility theory

In order to verify our conclusions, we compare the outcome of our analysis under PT with results obtained with EU. We therefore assume that the firm evaluates the potential outcomes of its decision on investing in the research project with a concave utility function $U(x)$ such that:

$$(1-p)\,U((1-f)\left(\pi_1^+ - K\right)) + pU((1-f)\left(\pi_1^0 - K\right)) \gtrless U((1-f)\pi_1^0) \qquad (5.8)$$

Firm 1 will decide on investing in the project if and only if the expected utility of the total profit with R&D exceeds the utility of the initial total profit without research. If this is not the case, the government might intervene as specified in the previous sections. We subsequently compute the contribution required for the different instruments in order to initiate research. For funding this implies that if F is the minimum amount of funding required to initiate the research project, then:

$$(1-p)\,U((1-f)\left(\pi_1^+ - K\right) + F) + pU((1-f)\left(\pi_1^0 - K\right) + F) = U((1-f)\pi_1^0)$$

For the other instruments of our analysis, the approach is as in *Section 5.3.* For an unconditional tax-rebate we get that:

$$(1-p)\,U((1-f)\left(\pi_1^+ - K\right) + t\pi_1^+) + pU((1-f)\left(\pi_1^0 - K\right) + t\pi_1^0) = U((1-f)\pi_1^0)$$

For a conditional tax-rebate we subsequently get that:

$$(1-p)\,U((1-f)\left(\pi_1^+ - K\right) + \tau\pi_1^+) + pU((1-f)\left(\pi_1^0 - K\right)) = U((1-f)\pi_1^0$$

and for a loans we see:

$$(1-p)\,U((1-f)\left(\pi_1^+ - K\right)) + pU((1-f)\left(\pi_1^0 - K\right) + L) = U((1-f)\pi_1^0$$

We do not change our approach towards how we describe the behavior of the government. The government earnings in case of funding are consequently described according to (5.5). The earnings for the government for the other tools are as given in *Section 5.3*. By comparing the expected earnings for the government resulting from the implementation of the different instruments, we can assess the performance of each measure compared to other tools.

Theorem 5.4 *The order of performance, from most efficient to least efficient instrument is: loan, funding, unconditional tax-rebate, conditional tax-rebate.*

The proof for *Theorem 5.4* is given in *Appendix B*. The intuition behind the theorem can be explained by the perception of value of the firm. The pay-off in case of successful implementation of the research results is higher than the pay-off for failure. Because of the concavity of the utility function, this pay-off for success is distorted more than that for failure. Additional contribution allocated in case of success is consequently also undervalued more than support in case of failure. A loan allocates no contribution in case of success, while a conditional tax rebate provides the most support. The order of efficiency of the instruments in practice is reflected in the amount of contribution required in case of failure.

The results with Expected Utility theory are similar to those for Prospect Theory for a probability of failure smaller than the critical value. This can be explained by the loss aversion parameter. For $p < p_c$, the probability of failure is lower than for $p > p_c$. The potential loss in that case is therefore less over-valued by firms with this parameter. The effect of increasing undervaluation in case of success as we have seen for EU, is the same as diminishing over-valuation in case of failure as we get with PT for $p < p_c$. We therefore get the same order of preference.

Prospect Theory however performs better in describing the behavior of firms than Expected Utility theory (Kahneman and Tversky 1992). Applying PT allows us therefore to provide insight in how to diversify the support in order to increase the efficiency of instruments supporting industry-oriented research, and to calculate the exact amount of contribution required to initiate research.

5.6 Conclusions and recommendations

Theorem 5.1 indicates that our results do not depend on initial profit, or a change in pay-off after implementation of the project. This implies that the result holds under different market structures (e.g. differentiated markets under Cournot or Bertrand). We therefore argue that our result is robust.

Our conclusions do have an immediate relevance for the current practice concerning funding of (collaborative) research. As an example, the State Aid rules (Commission of the European Communities 2006) governing government support for industry-oriented R&D and innovation (which are endorsed also by the WTO Disciplines on Subsidies) foresee in a fixed contribution to the cost of a project. The contribution is not based on the characteristics of the project (i.e. risks involved in the R&D, expected outcome, and structure of the market), and the corresponding willingness to invest by the firm, but defined by the type of research conducted (e.g. experimental research, or industry-oriented research close to the market), or actor involved (e.g. SMEs, MNFs).[6] Based on our model we argue that under this legal framework, projects requiring a higher level of support will not be conducted, as a firm will not receive sufficient funding to make up its willingness to invest in the required research. We therefore claim that under these conditions the measures are not effective as they are not able to change the behavior of the firm. We also argue that projects which have been conducted with the help of support according to State Aid rules in practice most likely would have required less contribution than provided. We therefore contend that under these conditions the instruments are not efficient.

Our paper suggests that redefining the approach towards support for industry oriented research, and the legal framework governing it, could improve the efficiency of policy aimed at strengthening the innovation system. Adopting our model as a basis for policy delivery however requires further analysis of the factors which define the investment decision of firms (i.e. perception of risk and loss aversion), and how they vary (e.g. for type of firm, or sector). As an example, if we assume the perception of risk to be given and constant, we see that the critical probability

[6] In general (e.g. for almost all of the EU and national programmes), the contribution for industry-oriented research equals 50% .

of success changes with the loss aversion of the firm involved. This implies that if firms within a certain sector are more risk averse than those in other sectors, their corresponding p_c is different, and as a consequence a loan might be more attractive as a tool to support their research projects.

Our results seem to contradict the conclusions of (Tinbergen 1952), which states that: "Consistent economic policy requires that the number of instruments equal the number of targets. [...] More instruments than targets makes instruments alternative; that is, one instrument may be used instead of another or a combination of others." We argue however that R&D and innovation with a high probability of failure is different from that with a large probability of success. It involves different actors, knowledge and technologies, and should consequently be supported in different ways, with different instruments. We therefore endorse the conclusions by (Tinbergen 1952).

Appendix A: proof for Prospect Theory

The proof of *Theorem 5.1* follows from *Lemma 5.5*, *Lemma 5.7* and *Lemma 5.6* below. Since the proofs of these lemmas are similar, we only provide the proof for *Lemma 5.7*.

Lemma 5.5 *For $p > p_c$ conditional tax-rebate is more efficient than unconditional tax-rebate, and for $p < p_c$ reverse is true.*

Lemma 5.6 *For $p > p_c$ funding is more efficient than a loan, and for $p < p_c$ reverse is true.*

Lemma 5.7 *For $p > p_c$ unconditional tax-rebate is more efficient than funding, and for $p < p_c$ reverse is true.*

Proof. Funding is more efficient than unconditional tax-rebate if and only if $E_F > E_t$, where E_F and E_t are defined according to equation (5.5) and (5.7). From (5.4) and (5.6) we get:

$$(w\,(1-p) + \lambda w(p))F = (w\,(1-p)\,\pi_1^+ + \lambda w(p)\pi_1^0)t$$

If we let $\theta = \pi_1^+/\pi_1^0$ then from the above equation it follows that:

$$E_F > E_t \iff \frac{w((1-p))\theta + \lambda w(p)}{((1-p)\,\theta + p)\,(w\,(1-p) + \lambda w(p))} < 1$$

With (5.1) we get that:

$$E_F > E_t \iff (1-p)^{\beta}\,\theta + \lambda p^{\beta} < ((1-p)\,\theta + (p))((1-p)^{\beta} + \lambda p^{\beta})$$

Let $r = (1-p)\,/p$, then:

$$\begin{aligned}
E_F > E_t &\iff \\
r^{\beta}\theta + \lambda < ((1-p)\,\theta + p)(r^{\beta} + \lambda) &\iff \\
r^{\beta}\theta p - r^{\beta}p < \lambda((1-p)\,\theta + p - 1) &\iff \\
pr^{\beta}(\theta - 1) < \lambda\,(1-p)\,(\theta - 1) &\iff \\
r^{\beta-1} < \lambda &
\end{aligned}$$

$$E_F > E_t \iff r > \lambda^{\frac{-1}{1-\beta}} \text{ as } \beta < 1$$
$$E_F > E_t \iff p < \frac{1}{1+\lambda^{\frac{-1}{1-\beta}}}$$

For $p < p_c$ funding performs better than unconditional tax-rebate, and for $p > p_c$ reverse is true. ■

Appendix B: proof for Expected Utility theory

The proof of *Theorem 5.4* follows from *Lemma 5.8*, *Lemma 5.10* and *Lemma 5.9* below. Since the proofs of these lemmas are similar, we only provide the proof for *Lemma 5.10.*

Lemma 5.8 *A loan is more efficient than funding.*

Lemma 5.9 *An unconditional tax-rebate is more efficient than a conditional tax-rebate.*

Lemma 5.10 *Funding is more efficient than an unconditional tax-rebate.*

Proof. Let F be the minimum amount of funding required to initiate research, then:

$$(1-p)\,U((1-f)\left(\pi_1^+ - K\right)+F)+pU((1-f)\left(\pi_1^0 - K\right)+F) = U((1-f)\pi_1^0) \quad (5.9)$$

Let $a = (1-f)\left(\pi_1^+ - K\right)$ and $b = (1-f)\left(\pi_1^0 - K\right)$ then (5.9) can be written as

$$(1-p)\,U(a+F) + pU(b+F) = U(b+(1-f)K) \quad (5.10)$$

The corresponding government earnings E_F is given by:

$$E_F = (1-p)\,f\left(\left(\pi_1^+ - K\right) + \pi_2^-\right) + pf\left(\left(\pi_1^0 - K\right) + \pi_2^0\right) - F \quad (5.11)$$

In a similar way we get for t as the minimum unconditional tax-rebate that:

$$(1-p)\,U(a+t\pi_1^+) + pU(b+t\pi_1^0) = U(b+(1-f)K) \quad (5.12)$$

The corresponding expected earnings by the government E_t is given by:

$$E_t = (1-p)\,f(\pi_1^+ + \pi_2^-) + pf(\pi_1^0 + \pi_2^0) - t((1-p)\,\pi_1^+ + p\pi_1^0) \quad (5.13)$$

With (5.10) and (5.12) we get that:

$$(1-p)\,U(a+F) + pU(b+F) = (1-p)\,U(a+t\pi_1^+) + pU(b+t\pi_1^0) \Leftrightarrow$$
$$(1-p)\,(U(a+t\pi_1^+) - U(a+F)) = p(U(b+F) - U(b+t\pi_1^0))$$

By applying the Mean Value Theorem we get, with $\alpha \in (a+F, a+t\pi_1^+)$ and $\beta \in (b+t\pi_1^0, b+F)$, that:

$$(1-p)\left(t\pi_1^+ - F\right)U'(\alpha) = p(F - t\pi_1^0)U'(\beta) \quad (5.14)$$

Since U is concave and $\alpha > \beta$ we get that $U'(\alpha) \leq U'(\beta)$. With (5.14) we subsequently get that:

$$(1-p)\,(t\pi_1^+ - F) \geq p(F - t\pi_1^0) \Leftrightarrow$$
$$(1-p)\,t\pi_1^+ + (p)t\pi_1^0 \geq F \Leftrightarrow$$
$$E_F \geq E_t$$

■

Chapter 6

The choice for thematic policy[1] [2]

An important policy question for a government when optimizing the policy mix in order to effectively enable future sustainable economic growth is whether to implement a generic set of instruments, adopt a thematic policy focus, or embrace a combination of both policy settings.

In case of a thematic focus, a government identifies and selects specific sectors or technologies, and designs an accompanying set of instruments directing resources and corresponding research efforts towards this target. In (Gassler et al. 2004) the following rationale for priority setting in research and innovation policy are identified: (1) As a reaction to the emergence of new scientific or technological paradigms (also known as science push). (2) In order to promote key sectors of strategic industrial importance (i.e. industrial missions). (3) To anticipate and react to new societal challenges, as a form of policy-pull. (4) In order to ensure presence on emerging future markets (i.e. anticipated demand-pull). (5) To adapt to international trends in science and technology, and act as a fast second mover.

In case of a generic policy, a government implements a policy mix which provides optimal support for R&D and innovation in general. A government chooses for a generic approach if it assumes that the innovation system will either create new scientific or technological paradigms by itself, or adopt that technology which is most promising for growth. Either way, the government feels that it is not able,

[1] The author wishes to thank Hugo Erken for his contribution.

[2] Thematic policy is also referred to as specific policy in the policy formulation domain.

or not in the position, to identify the appropriate sector or technology field.

Within the framework of this thesis, we intended to analyze the effectiveness of thematic R&D and innovation policy. Our plan was to assess the impact of government intervention on labour productivity growth for different countries, with a divergent approach towards focus in policy. We chose labour productivity growth as the dependent variable because it reflects the innovative performance of the entire innovation system as addressed by the policy mix. The characteristics of the mix itself, such as focus, modality and intensity of support, were to be represented in the explanatory variables.

Based on the results from the data-collection process, we conclude that an empirical analysis of the impact of specific policy supporting R&D and innovation on labour productivity on sector level is not feasible. Due to a lack of data on the characteristics of policy, and contribution allocated by means of the supporting instruments, it is not possible to conduct an econometric analysis that will result in reliable conclusions.

This chapter provides a short overview of our data collection process, as a basis for the subsequent conclusion concerning the feasibility of an empirical analysis. The results of the analysis could consequently form a basis for future research on the effectiveness of thematic policy.

6.1 Priority setting: objective and scope

Priority setting as a basis for research and innovation policy is not something from recent date. As described in (Gassler et al. 2004), during the post-war period it was assumed that priority setting could be left best to the science and technology community. In the then prevailing science-push paradigm based on the linear model of innovation, there consequently was no need for focus in scientific research. Unguided, curiosity driven, mostly basic research would lead to results which then would (occasionally) be taken up by society and industry. In the 1960s and 1970s this model of priority setting was expanded to include commercial and market-oriented R&D in single large-scale projects. In the late 1970s and early 1980s, some countries even went a step further by identifying priorities for the whole of public R&D and innovation policies. In general, the results were not as successful or as effective as expected: governments seemed unable to predict developments in the market. Especially when the thematic area prioritized was outside the public domain, the success rate of programmes became smaller. In the 1990s, after some disillusion about priority setting following the experiences of the 1970s and 1980s, the main focus of R&D and innovation policy was on general improvement of the systemic performance of innovation systems.

Recently, more and more countries have adopted a thematic scope for their policy mix, inspired by successful examples from Korea, Finland and Singapore. This renewed interest emanates from retrenchments in public expenditure, and from further internationalization of research. Governments respond to these developments by concentrating research efforts on a limited set of thematic areas as to try to improve the effectiveness and efficiency of their intervention.

6.2 The impact of specific policy supporting R&D and innovation

The history of research and innovation policy includes examples where government policies have had an influence on the speed and direction of technological change. But there are also many other unsuccessful examples of thematic policies and instruments. We argue in line with (Arnold et al. 2007) that priority setting is context dependent, changes over time in rationale and goals, and alters for different innovation systems. In practice, "[...] it is not appropriate to give a general assessment of whether these type of programmes work or not. The outcome depends on the specific context of each of these programmes (e.g. scope, size, match with existing actors, programme management, timing, etc.). An overall and systematic assessment of all innovation programmes in a country is hardly ever done." (Arnold et al. 2007)

Within the framework of this thesis, we therefore tried to assess the impact of a policy mix on labour productivity growth for countries with divergent approaches towards focus in policy. We choose labour productivity growth as the dependent variable because it reflects the innovative performance of the entire innovation system as addressed by the policy mix. The characteristics of the mix itself, such as focus, modality and intensity of support, are reflected in the explanatory variables.

Model for the analysis of the impact of thematic policy

As a starting point for the assessment of the impact of thematic policies, we define a simplified model (based on (Solow 1956), (Solow 1957), (Mankiw et al. 1992), (Romer 1996)) with parameters α_k, β_l to be estimated with the help of the following two stage least square model:

$$\Delta \ln \frac{Y_{i,t}}{L_{i,t}} = \alpha_0 + \alpha_1 \Delta \ln \frac{K_{i,t}}{L_{i,t}} + \alpha_2 \Delta \ln RDC_{i,t} + \\ \alpha_3 \Delta \ln HC_{i,t} + \alpha_4 dum_{i.t} + \varepsilon_{i,t}$$

$$\Delta \ln RDC_{i,t} = \beta_0 + \beta_1 \Delta \ln RD_{i,t}^{gov} + \beta_2 \Delta \ln RD_{i,t}^{firm} + \\ \beta_3 specdum_{i,t} + \delta_{i,t}$$

with i as the index for the sector, and t for the year. In the model, $RD_{i,t}^{gov}$ represents R&D expenditure by firms funded by government, and $RD_{i,t}^{firm}$ the expenditure on R&D by firms. Additional variables are: $Y_{i,t}$ as gross output, $L_{i,t}$ as labour, $K_{i,t}$ as capital and $HC_{i,t}$ as human capital. Effects of other drivers of labour productivity growth (as mentioned in for example (Erken et al. 2008)), such as knowledge produced abroad (i.e. catching up effects), and entrepreneurship are obviated with the help of $dum_{i.t}$. The R&D capital stock is represented by $RDC_{i,t}$. For simplicity, R&D expenditure by others than firms and depreciation of capital stock is disregarded. Qualitative aspects of the policy mix, such as modality and focus, are to be captured by a policy matrix $specdum_{i,t}$. An important issue not yet addressed in our model is that although a policy mix and its supporting instruments might be generic and not targeted, they might still be absorbed by a single dominant sector or technology in the economy or system. In that case, generic policy is absorbed by the innovation system as specific policy. Analysis of the parameters for different countries should provide the basis for conclusions on the effectiveness of specific policy.

The critical set of data required for the successful completion of the analysis is $RD_{i,t}^{gov}$. The type of data chosen to represent R&D expenditure by firms funded by government subsequently defines the representation of $RD_{i,t}^{firm}$ and the characteristics and dimensions of the policy matrix. In the following sections, we describe in detail our efforts concerning the collection of these critical data, and the difficulties encountered in finalizing the research. We provide an overview of the different options for $RD_{i,t}^{gov}$ we tried, and their implications for the model.

Impact of ICT policy in the UK, the Netherlands and Finland

In order to analyze the effectiveness of specific policy, we first tried to compare and assess three countries with comparable innovation systems, but with different approached towards specific policies: the UK (with almost no targeted instruments), Finland (with almost only targeted instruments) and the Netherlands (with a balance in generic as well as specific policy).

Because of the comparability of the innovation system (in role and functioning of actors of the innovation system, political and social system, structure of the economy), we assume that the policy matrix could be limited to a dummy addressing just this difference in policy orientation. The Impact of the policy would be measured by means of labour productivity growth in the ICT sector.[3]

An elaborate analysis of public data sources from the OECD and Eurostat indicates that no figures are available on contribution to research by governments to a specific sector. A series of meetings with representatives from relevant ministries in the Netherlands, and contacts with statistical offices and ministries in the UK and Finland, reveals that these countries do not have mechanisms implemented which oversee policy delivery. Budgets are defined on aggregated level, but the actual resources allocated (by instrument) to the actors of the innovation system are not monitored. The reason is that in general the framework of support is structured such that different measures allocate resources from a number of specific and dedicated funds. These funds are not structured according to a specific technology.

An equally insurmountable problem is that labour productivity data on sector

[3] Note that we focus on the ICT sector, and not on the contribution of ICT in general to labour productivity.

We limit the ICT sector, in line with the relevant literature, to the sector represented as *computer related activities* according to NACE rev1.1 code 72.

level are not available for the UK and the Netherlands.

Impact of ICT policy in a selection of OECD countries

As data on labour productivity and financial support by the government are not available for our selected countries, we decided to expand our selection of countries, and search for other data sources covering government contribution to industry-oriented research and innovation. We therefore considered next the OECD Going for Growth database. This set contains data on *Direct public funding of business R&D* and *Rate of tax subsidies for one dollar R&D* for almost all OECD countries. In practice, all public financial support for industry-oriented research is covered under these headings. Applying these data for different countries in our model would in practice imply that the policy matrix should address not only the focus of the mix, as the innovation systems are no longer comparable. It should furthermore be extended to capture also the intensity of the support towards the ICT sector. Due to the limited number of data-points (8 data points from 2000 - 2008), we have to conclude that also this data-set is not suitable.

As an alternative, we also analyzed the possibility of using data on *GBAORD* (Government Budget Appropriations or Outlays for R&D) from the Eurostat and OECD databases. GBAORD covers both current costs and capital expenditure. It includes government-financed R&D and *GUF* (public general university funds). We have to exclude also this set as data are not available on industry-sector level, but only by socio-economic objective.

Impact of sector specific policy in a selection of OECD countries

Analysis of the previous data-sets indicates that information on contribution by governments to expenditure on R&D by firms is not available in a way such that we can apply it for this study. We therefore decided to analyze the possibility of using data collected on industry-level (i.e. firms reporting on the contribution to research by government). Relevant data on R&D expenditure reported by firms is given by *GERD* (Gross Domestic Expenditure on R&D). This is defined as total intramural expenditure on R&D performed by the business sector on the national territory during a given period. It includes R&D performed within a country and funded from abroad but excludes payments for R&D performed abroad. *Appendix*

A gives the characteristics of BERD and GERD, and the difference with GBOARD data.

Part of the GERD data cover $BERD$ (Business Enterprise Expenditure on R&D). $RD_{i,t}^{gov}$ could be represented by $BERD$ financed by government on sector level (according to NACE rev1.1 code 72). We will represent this as $BERD_{i,t}^{gov}$. And as a consequence, $RD_{i,t}^{firm}$ could be represented by $BERD_{i,t} - BERD_{i,t}^{gov}$. The use of $BERD_{i,t}^{gov}$ data within the framework of this study is not without consequences:

- The data set covers all financial contributions by a government to R&D expenditure by firms. This implies that besides subsidies and tax measures also payments resulting from contract research are included. Loans however are excluded, as there is a possibility that they could be refunded (OECD 2002).
- Furthermore, the data-set for $BERD_{i,t}^{gov}$ for the ICT sector for countries for which we have labour productivity data on sector level is in practice limited.[4] An econometric analysis will therefore not result in a basis for reliable conclusions on the effectiveness of specific policy. As a consequence, we decided to enlarge the data-set, and include other sectors with sufficient data points for the selected ten countries, and within the time frame of our analysis.[5]

The limitations of the resulting data-set are such that we have to define a policy matrix that addresses the characteristics of the policy mix in order to analyze the effectiveness of specific policy. There is a vast collection of publications on the policy mix in different countries. The most relevant sources describing policies and instruments providing to industry-oriented research and innovation are, besides national sources, the EU and its PRO-INNO and ERAWATCH initiatives, and the OECD.[6]

[4] The dataset with $BERD_{i,t}^{gov}$ covers the period 1987 - 2007 for: Australia, Austria, Finland, France, Germany, Japan, Portugal, Spain, Sweden, US.

[5] The sectors which are covered are (defined according to NACE rev1.1.): A, C, D: 15-16, 17-19, 20-22, 20, 21, 22, 23-25, 24, 24 (less 24.4), 24.4, 25, 26, 27, 28-35, 29, 30, 31, 32, 33, 34, 35, 36, E,F, G-Q, H, I, J, K: 72, 72.2, 73, 74, L-Q.

[6] As an example for some relevant sources of information:

The information gathered has to be translated into the policy matrix. There is very little relevant literature on quantifying the measures providing financial contribution to industry oriented research. A potential basis for quantifying non-financial support (e.g. a regulatory framework) is given by for example (Nicoletti and Scarpetta 2003) and The Global Competitiveness Report from the World Economic Forum[7].

In order to analyze the feasibility of the formulation of the policy mix, we analyzed the above mentioned data-sources on the availability of information on instruments supporting industry-oriented R&D and innovation. We focus on instruments as they represent the actual interventions by a government in the innovation system.[8]

- www.ec.europa.eu/invest-in-research, a website of the 3% Action Plan, which acts as a portal to studies commissioned by the EC on policy mix.
- www.proinno-europe.eu and more specifically www.proinno-europe.eu/trendchart, the Trendchart homepage, with info on industry-oriented policy.
- www.cordis.europa.eu, and specifically www.cordis.europa.eu/erawatch.
- www.europa.eu/pol/enter/index_en.htm (EU legislation on competitivenss and innovation)
- www.weforum.org/en/initiatives/gcp/index.htm, a website on intellectual property protection.
- The OECD International Regulation Database

[7] See www.weforum.org.

[8] We reject the use of data on public policy. A policy is defined as: "a plan of action of a government to guide decisions, and achieve rational outcomes which are set out in broad objectives and goals." These plans are than implemented by means of instruments. As such, policies are merely intentions to intervene (and in practice sometimes nothing more than words). Including these policies in the policy matrix would not contribute to a successful econometric analysis of the impact of specific policies. As an illustration of this point an example from Spain and Portugal. For the EU presidencies in 2002 (Spain) and 2000 (Portugal), both countries drafted well formulated policies on R&D and innovation in the ICT sector (i.e. in accordance with OECD best practices, and after thorough international scientific consultations), following the example of Finland. These policies however have never been translated into concrete actions and measures due to the limited absorptive capacity of the respective innovation systems. Furthermore, these policies have never been properly assessed, making it impossible to include them into the policy matrix.

Our analysis indicates that the information available is not sufficient to design an appropriate policy matrix because the OECD and EC data-sources do not provide information on instruments for the period before the year 2000. Furthermore, they contain hardly any information on instruments which are terminated.[9]

6.3 Conclusions and recommendations

When designing a set of measures supporting the innovation system, many governments seem particularly concerned with how to identify sectors (or technologies) that, in comparison to others, have the potential to create additional growth. Analysis of the relevant literature indicates however that there is no theoretical or empirical evidence that specific policy is preferred over generic policy. Identification of thematic priorities in existing R&D and innovation policy seems therefore to be infused by the interests of dominant actors within of the innovation system (e.g. the EU Framework Programmes), or clearly politically motivated (as in the case of the US with its focus on defence related R&D and innovation policy).

The scope of the policy mix in many EU countries seems to change in time from a generic focus of the set of instruments to a thematic policy approach, with a combination of these policy settings in between. This change in time is being pushed by the different stakeholders involved in the process of policy formulation. We classify these stakeholders in two groups. On one side of the spectrum we have the *engineers*. They have a problem driven view on innovation, and embrace the concept of *System of Innovation* (SI) (Nelson 1993) as the basis for policy formulation. They believe in a thematic focus in policy, with priorities defined bottom-up. On the other side we have the *economists*, with a more top-down view on how innovation policy should be formulated. They have adopted the market failure approach (Nelson 1959), (Arrow 1962), (Jaffe 1996) as a rationale for intervention. They believe in research driven innovation, and subsequently adhere to a generic scope as the basis for the policy mix.

[9] As an example to illustrate this point: an average-sized country like the Netherlands has currently over 90 instruments on national level addressing industry-oriented R&D and innovation active. The OECD and EC data-sources provide insight on about 40 of these tools.

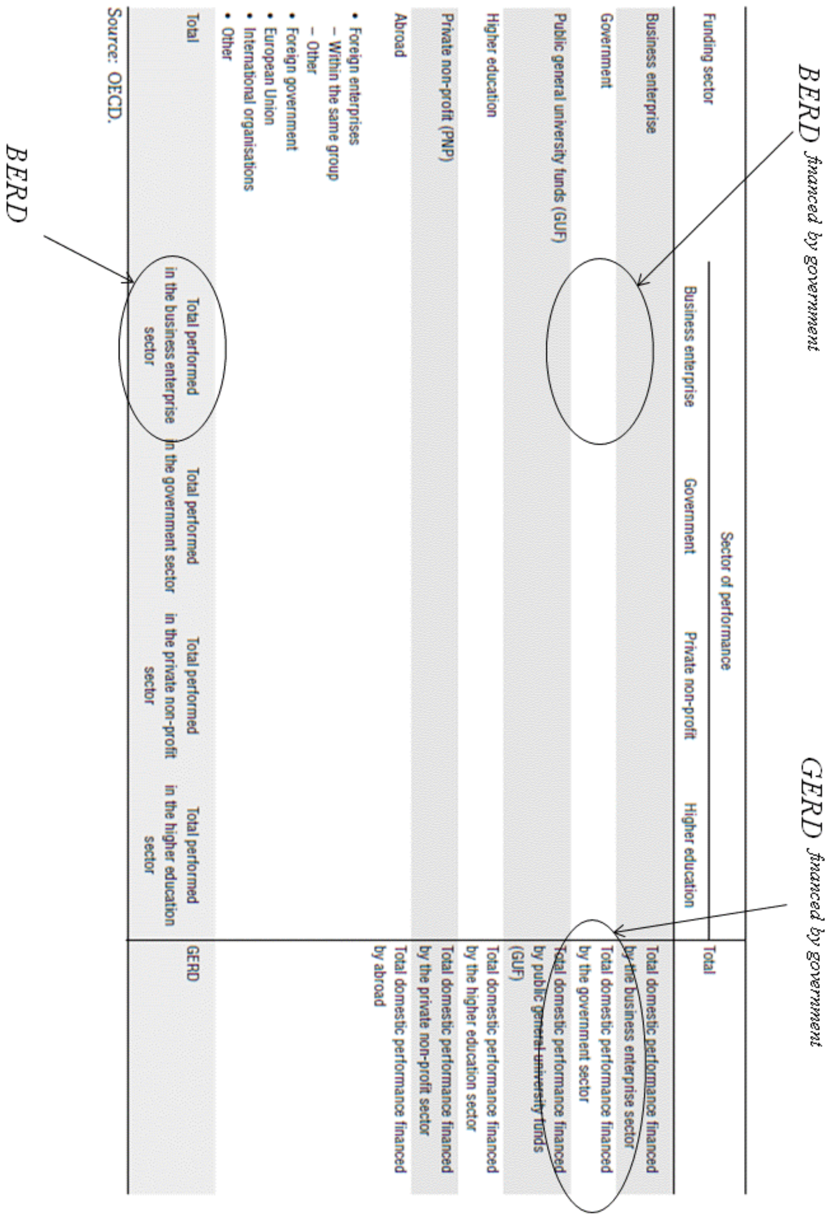
Our assessment indicates that it seems not possible with the current (publicly) available information to conduct an empirical analysis of the impact of thematic policy on labour productivity. Such an analysis would require the set-up of a database with information on the characteristics of the policy mix for countries for which labour productivity data on sector level are available. A first step would be the collection of data on allocated funding and other forms of support at micro-level (i.e. firm-level), as administered by organizations involved in policy delivery. A next step would be the gathering of information on the scope of the measures constituting a policy mix from local data-sources (i.e. on country-level). Such data collection is hindered by the absence of a format for structuring information (such as present in the OECD and EC data-sources). Also information with respect to policies and instruments from the past (especially if they are proven to be ineffective or inefficient) is limited. And in some countries, measures are defined as a law providing a certain modality of support (e.g. subsidy, tax reduction, loan). This tool is then to be used for different interventions, not specifically targeted at industry-oriented R&D or innovation.

Appendix A: data on R&D expenditure

BERD data are a subset of GERD (see *Figure 6.1*). The main differences with GBAORD data are:

- Government-financed GERD and GERD objectives data are based on reports by R&D performers, whereas GBAORD is based on reports by funders. Second, the GERD-based series cover only R&D performed on national territory, whereas GBAORD also includes payments to foreign performers, including international organizations.
- Differences may also occur because the periods covered are different (calendar or fiscal years), because the money is finally spent by the performer in a later year than the one in which it was committed by the funder, and because the performer may have a different and more accurate idea of the R&D content of the project concerned.

- In addition to the general differences, government-financed GERD should include R&D financed by central (or federal), provincial (or state) and local government, whereas GBAORD excludes local government and sometimes also provincial government.



Funding sector	Sector of performance: Business enterprise	Government	Private non-profit	Higher education	Total
Business enterprise					Total domestic performance financed by the business enterprise sector
Government					Total domestic performance financed by the government sector
Public general university funds (GUF)					Total domestic performance financed by public general university funds (GUF)
Higher education					Total domestic performance financed by the higher education sector
Private non-profit (PNP)					Total domestic performance financed by the private non-profit sector
Abroad					Total domestic performance financed by abroad
• Foreign enterprises – Within the same group – Other • Foreign government • European Union • International organisations • Other					
Total	Total performed in the business enterprise sector	Total performed in the government sector	Total performed in the private non-profit sector	Total performed in the higher education sector	GERD

Source: OECD.

Figure 6.1: Data on R&D expenditure: GERD and BERD.

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Summary in Dutch
Nederlandse samenvatting

Het policy mix concept is door de geïndustraliseerde landen omarmt als een basis voor consultatie en discussie over de ontwikkeling van overheidsbeleid voor O&O en innovatie. Verdere implementatie van het concept als theoretisch kader voor beleidsformulering wordt echter gehinderd door een een beperkte theoretische onderbouwing, en een niet eenduidige definitie en scope.

Wij definieren de policy mix in dit proefschrift als de totale set van instrumenten die O&O en innovatie ondersteunen. Een belangrijk aspect van het concept is de notie dat deze instrumenten elkaars werking beïnvloeden. Toepassing van het concept verschaft een theoretische basis voor de coördinatie van instrumenten tot een optimale set, dusdanig dat deze effectief (doeltreffend) is in het initiëren van onderzoek en innovatie en efficiënt (doelmatig) wat betreft de kosten van de interventie.

In het eerste deel van het proefschrift definiëren we een theoretisch framework voor de selectie van een optimale set van instrumenten ter ondersteuning van industrie-georiënteerd onderzoek. We doen hierbij een aantal aannames over hoe innovatie plaatsvindt bij bedrijven. We gaan uit van een innovatieproces waarbij onderzoek voortkomt uit een idee, gericht op het oplossen van dat specifieke probleem (probleemgedreven innovatie in plaats van een onderzoeksgedreven innovatie). We nemen aan dat het benodigde onderzoek wordt uitgevoerd in de vorm van onderzoeksproject. De uitkomst bij een succesvolle afronding van het project en de bijbehorende impact op het bedrijf zijn daarom voorzien. De kosten van het project worden constant geacht, en gebaseerd op een inschatting van de benodigde middelen. De uitvoering van het onderzoek is niet zonder risico: de kans op falen van het project is van te voren bekend, en bepaald door de beschikbare kennis op het gebied van het onderzoeksproject. Het onderzoek wordt uitgevoerd door een subset van de totale populatie van bedrijven, die zal opereren als een Research Joint Venture (RJV). We verontachtzamen kennis-spillover effecten van het consortium naar bedrijven van buiten het RJV die niet betrokken zijn bij het onderzoeksproject.

Met als basis deze aannames wat betreft het innovatieproces redeneren we nu dat een bedrijf zal besluiten om te investeren in het onderzoek door de verwachte verandering van de winst te vergelijken met de kosten van het project. Als deze kosten niet gedekt worden, en het bedrijf zou besluiten het project niet uit te voeren, dan kan de overheid besluiten in te grijpen. De interventie moet dan dusdanig zijn dat deze effectief alsmede efficient is. Dit betekent dat we aannemen dat de overheid haar bijdrage aan het project moet minimaliseren zodanig dat deze juist genoeg is om het onderzoeksproject te initieren. De overheid moet alleen dan ingrijpen als haar bijdrage de verwachte toename in welvaart niet ongedaan maakt.

Voor het onderzoek analyseren we de volgende instrumenten: subsidies (financiële tegemoetkoming in de projectkosten alsmede 'in-kind' ondersteuning), fiscale stimulering (tegemoetkoming proportioneel aan omzet of winst), leningen (subsidie die moeten worden terugbetaald in geval van succes) en regelgeving gericht op het creëren samenwerking tussen bedrijven.

Onze aannames wat betreft het innovatieproces en de bijbehorende projectmatige interventie geven een accurate weergave van de praktijk van overheidsondersteuning voor O&O en innovatie, zoals gereguleerd door de internationale afspraken (EU en WTO regels voor staatssteun).

In hoofdstuk 2 van dit proefschrift analyseren we de doeltreffendheid en de doelmatigheid van de instrumenten middels een 'multi-stage strategic investment game'. In the laatste fase van het spel bepalen de bedrijven van het RJV wat zij bereid zijn te investeren in het onderzoeksproject, gegeven de kans op falen van het project en de verwachte winst bij toepassing van de onderzoeksresultaten. Uitgangspunt is een markt waar geconcurreerd wordt met homogene producten op basis van output (klassieke Cournot-competitie). We nemen aan dat bedrijven een lineaire perceptie hebben van de risico's van het project en de verwachte winst. In de eerste fase van het spel bepaalt de overheid haar optimale interventie. Het spel wordt opgelost middels achterwaartse inductie. Onze resultaten geven aan dat de instrumenten die een financiële tegemoetkoming leveren aan de projectkosten gelijkwaardig zijn. Dit betekent dat het initiëren van onderzoek middels een een subsidie, een fiscaal voordeel of een lening een gelijke verwachte bijdrage vereist. Regelgeving gericht op samenwerking is het meest efficient, maar niet altijd effectief.

In hoofdstuk 3 herhalen we de analyse voor een zelfde markt waarbij bedrijven concurreren op prijs (klassieke Bertrand-competitie), en voor een markt met gedifferentieerde producten met competitie op prijs en op output. Op basis hiervan concluderen we dat voor bepaalde marktstructuren samenwerking niet leidt tot een verandering in de investeringsbeslissing van bedrijven, en dat regelgeving derhalve helemaal niet effectief is. Wat betreft de ordening naar doeltreffendheid en doelmatigheid van de instrumenten die een financiële bijdrage leveren aan de projectkosten verandert niets.

Op basis van de resultaten van deze twee hoofdstukken concluderen we dat een optimale policy mix samenwerking tussen bedrijven in de vorm van een RJV toestaat middels specifieke gerichte regelgeving. Bedrijven zullen een consortium vormen met het aantal partners dat hun winst maximaliseert. Alleen indien samenwerking niet voldoende is om het onderzoeksproject te initiëren (omdat de cummulatieve investering van de projectpartners de kosten niet zal dekken) moet de overheid een additionele financiële tegemoetkoming in de projectkosten geven. De overheid moet daarbij het aantal partners van het consortium bepalen, dusdanig dat haar bijdrage wordt geminimaliseerd.

In hoofdstuk 4 analyseren we de effectiviteit van regelgeving voor een hybride marktstructuur van perfecte mededinging en markt monopolie (zoals geintroduceerd door (Varian 1980)). Bij deze marktvorm zal een bedrijf, als het besluit te investeren in een onderzoeksproject, dat alleen willen uitvoeren of een RJV willen vormen met alle andere bedrijven van de populatie.

In hoofdstuk 5 onderzoeken we de efficiëntie van de verschillende instrumenten die voorzien in een financiële tegemoetkoming in de projectkosten. We passen Prospect Theory toe (zoals geïntroduceerd door (Kahneman and Tversky 1979)) om de investeringsbeslissing van bedrijven te analyseren. Dit betekent in de praktijk dat we aannemen dat bedrijven een niet-lineaire perceptie hebben van de risico's van het project. Ons onderzoek geeft aan dat deze instrumenten alleen voor een bepaalde kritische kans op falen van het onderzoeksproject hetzelfde presteren. Voor een project met een verwacht risico hoger dan deze waarde is het gebruik van een voorwaardelijke belastingbijdrage (die alleen in werking treedt in geval dat de onderzoeksresultaten succesvol worden geïmplementeerd) het meest efficiënt om een onderzoeksproject te initiëren. In volgorde van doelmatigheid komen vervolgens: onvoorwaardelijke belastingbijdrage, subsidie en een lening. Voor een verwacht risico lager dan deze kritische kans is deze ordening omgekeerd.

Onze theoretische resultaten laten de beperkingen van de huidige praktijk van ondersteuning voor industrie-georiënteerd onderzoek zien. De internationale afspraken die overheidsondersteuning voor O&O en innovatie reguleren voorzien in een specifieke, vaste bijdrage voor onderzoek voor en door bedrijven aan de projectkosten. Het exacte niveau van de tegemoetkoming wordt bepaald door het type bedrijf (bijvoorbeeld MKB of grotere onderneming) en onderzoek (bijvoorbeeld fundamenteel of toegepast). Risico's wat betreft de uitvoering van het onderzoek of de potentiële verandering van de winst worden niet meegenomen in de beslissing over de hoogte van de ondersteuning. De implicatie van toepassing van een vaste vergoeding is dat bedrijven die een hogere tegemoetkoming nodig hebben, niet zullen innoveren. Dat betekent dat de regelgeving een effectieve ondersteuning verhindert. Daarnaast zou het kunnen dat bedrijven die wel besluiten te innoveren voor de toegestane vaste vergoeding dit misschien ook hadden gedaan voor een lagere bijdrage. Dit betekent dat ondersteuning volgens de internationale regelgeving niet efficiënt is.

Naast de formulering van een theoretisch framework voor de selectie van een optimale set van instrumenten hebben we getracht inzicht te krijgen in de effectiviteit van thematisch O&O en innovatiebeleid. Overheden proberen de policy mix verder te optimaliseren door de instrumenten te focussen op die sectoren of technologieën waarvan men verwacht ze additionele groei creëren. Hoofdstuk 6 geeft een kort overzicht van onze poging om te komen tot een econometrische analyse van de impact van thematisch innovatiebeleid op de arbeidsproductiviteit in specifieke sectoren. Door een gebrek aan bruikbare data hebben we moeten concluderen dat zo'n analyse niet mogelijk is. Het hoofdstuk geeft aanbevelingen over hoe deze analyse in de toekomst zou kunnen worden uitgevoerd.

The Tinbergen Institute is the Institute for Economic Research, which was founded in 1987 by the Faculties of Economics and Econometrics of the Erasmus University Rotterdam, University of Amsterdam and VU University Amsterdam. The Institute is named after the late Professor Jan Tinbergen, Dutch Nobel Prize laureate in economics in 1969. The Tinbergen Institute is located in Amsterdam and Rotterdam. The following books recently appeared in the Tinbergen Institute Research Series:

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The policy mix concept provides policymakers with a conceptual framework that allows them to consider the design of an optimal set of instruments supporting R&D and innovation. Optimal in this respect refers to effectiveness in changing behavior of firms regarding investment in research, and efficiency concerning the cost of the intervention. In practice, little is known about the performance of an instrument in comparison to other tools. In this thesis we therefore formulate a theoretical framework for the selection of instruments supporting industry-oriented research, which contributes to the formulation of an optimal policy mix. We focus on instruments providing funding, tax measures, loans and regulations aimed at creating collaboration in research. We apply this framework for different forms of competition (i.e. Cournot and Bertrand for a market with homogeneous products, and with differentiated products). We extend the potential application of our results by analyzing the effectiveness of collaboration in R&D for a hybrid market form of perfect and monopolistic competition. We also apply different decision models to describe the behavior of firms concerning their investment in research, in order to assess the efficiency of instruments providing financial contribution to research projects.

Marcel J.L. de Heide obtained a Master's degree in Industrial Design Engineering from the Delft University of Technology. He subsequently worked for various international consultancy agencies, advising national and supra-national governments on research and innovation policy. He was furthermore employed as a policy advisor for the Directorate-General for Innovation of the Dutch Ministry of Economic Affairs. He conducted his doctoral research in Economics at the Tinbergen Institute, Erasmus University Rotterdam.

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