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Recent Evolutions in the Funding of Public Research : Theoretical and Applied Analyses

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À mes grands parents

À mes parents

À Saba

À Guillaume

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RESUME EN FRANCAIS

EVOLUTIONS RECENTES DU FINANCEMENT DE LA RECHERCHE PUBLIQUE: ANALYSES THEORIQUES ET EMPRIQUES

Cette thèse analyse les conséquences de certaines évolutions récentes de la structure de financement des acteurs de la recherche publique (université et organisme public de recherche) survenues dans les années 2000, et notamment la diversification des sources de financement et la création de l'Agence Nationale pour la Recherche (ANR).

L'économie de la science a connu des développments particulierement importants ces dernière décennies. Il existe deux raisons principales à cet intérêt croissant.

En premier lieu, l'impact de la recherche sur la croissance économique n'est plus contesté. En second lieu, les résultats de la recherche possèdent les caractéristiques d'un bien public[1] (Nelson, 1959; Arrow, 1962) et les mécanismes de marché ne permettent donc pas d'atteindre le niveau d'investissement socialement optimal. De nombreux instruments politiques (brevet, crédit d'impôt *etc.*) ont été développés afin de permettre d'accroître le niveau d'investissements privés.

Ces outils politiques ne permettent cependant pas d'atteindre le niveau d'investissement souhaitable en recherche fondamentale. En effet, la recherche fondamentale est definie, selon le manuel de Frascati, comme les travaux menés dans l'unique but d'acquérir de nouvelles connaissances et n'impliquant aucune volonté d'application immédiate ou de commercialisation. De plus, les résultats ainsi que les revenus potentiels de la recherche fondamentale -menée

[1] Les caractéristiques d'un bien public sont la non exclusion et la non rivalité. La non exclusion implique que l'inventeur ne peut pas interdire l'utilisation de sa découverte aux autres. La non rivalité correspond au fait que l'utilisation des résultats par un agent n'a aucun effet sur la valeur ou la quantité disponible de ce bien pour les autres individus. Ces propriété sont développées en détail dans la sous section 1.2.1.

dans l'unique but de mieux appréhender les phénomènes scientifiques- sont, par définition, extrêmement variables et rarement prévisibles. L'absence de finalité économique immédiate et cette incertitude font que les mécanismes de marché ne permettent pas d'atteindre le niveau d'investissement optimal en recherche fondamentale, d'où la nécessité de la recherche publique.

En France, traditionnellement, les chercheurs sont financés indirectement par l'intermédiaire de leurs laboratoires. Toutefois, depuis quelques années, les fonds récurrents ont diminué au profit des subventions données directement au chercheur, ainsi qu'au profit fonds privés octroyés par les entreprises et les fonds européens.

Cette thèse est composée de quatre chapitres portant chacun sur une thématique spécifique. Le premier chapitre est une revue de littérature en économie de la science. Dans le deuxième chapitre, nous présentons les principales caractéristiques de la situation actuelle en France et les évolutions récentes qui ont affectée les laboratoires des universités françaises. Dans le troisième chapitre, nous analysons les relations entre les financements publics et privés mis à disposition des laboratoires universitaires. Le dernier chapitre est consacré spécifiquement aux fonds attribués par l'ANR. Après une présentation des principales caractéristiques du dispositif au niveau national, nous analysons de manière plus approfondie les comportements de candidature des chercheurs et le processus de sélection de l'agence. Une application est faite sur les données de l'Université Louis Pasteur.

Le deuxième chapitre présente un panorama au niveau des établissements français, appuyé par des indicateurs statistiques synthétiques, de l'évolution des financements contractuels ainsi que des outputs de la recherche (les publications et les brevets). L'analyse porte sur 28 universités françaises sur la période allant de 2000 à 2007 pour les financements et les brevets, et de 2003 à 2007 pour les publications. Alors que nous observons une augmentation des fonds contractuels, l'évolution n'est homogène ni pour les différentes sources de financements, ni pour les différents types d'établissement. En effet, alors que les financements internationaux augmentent jusqu'en 2004 et décroissent par la suite, nous observons une augmentation des fonds en provenance des collectivités locales ainsi que des organismes de recherche et entreprises qui compensent partiellement ce recul. Durant la même période, nous observons une augmentation du nombre de brevets détenus ou co-détenus par les universités, ainsi qu'une baisse du nombre de brevets cédés. Les publications ont particulièrement augmenté pour les écoles d'ingénieurs durant la période d'analyse. Après la présentation de l'évolution des financements contractuels, des activités de dépôt de brevets et de publications, nous conduisons une analyse de cluster afin d'identifier différents types de comportements ou de politiques d'universités. Ainsi nous avons pu observer entre autre une relation positive entre l'obtention de fonds privés et de fonds de l'ANR.

Le troisième chapitre de cette thèse traite de la question de la complémentarité ou de la substituabilité des différents financements accordés aux acteurs de la recherche publique. Malgré l'importance d'une meilleure compréhension des relations régissant les différents types de financement, les travaux antérieurs sont encore très rares. Ce chapitre est constitué d'une partie théorique et d'une partie empirique. Dans la partie théorique, nous développons un modèle microéconomique de maximisation de l'output du laboratoire. La fonction de 'production' de connaissance utilisée est de type CES (Constant Elasticity Substitution), ce qui permet de modéliser différents degrés de substituabilité entre les différentes sources de financements; allant de la substitution brute à la complémentarité brute. Ce modèle nous permet d'analyser les conséquences sur les choix d'un laboratoire d'une modification de la disponibilité d'une des sources de financement, avec des niveaux très variés de complémentarité ou de substituabilité entre les financements. Nous montrons notamment que la réaction optimale à un choc dépend du niveau de substituabilité entre les différentes sources de financement. Une augmentation des dotations engendre une augmentation de financement privés, et produit ainsi un effet cumulatif (crowding-in). Dans ce contexte, une politique en faveur des dotations va augmenter le budget des laboratoires via deux canaux : les dotations et les financements privés. Au contraire, les financements contractuels publics vont engendrer un effet d'éviction des financements privés, sauf lorsque les sources de financement sont quasiment parfaitement complémentaire. Les financements privés ont différents impacts selon le degré de substituabilité. Nous observons un effet d'accumulation avec les fonds publics lorsqu'ils sont complémentaires, et un effet d'éviction lorsqu'ils sont substituables. La fonction de production CES analysée dans la partie théorique a été estimée dans la partie empirique en utilisant la base de données EcS-BETA. A cause des difficultés connues de convergence de la méthode des moindres carrées non linéaire lorsque la fonction objectif est relativement plate, ainsi que des limites associés à l'approximation de Kmenta (Kmenta, 1967) basée sur une linéarisation, nous employons une méthode de balayage sur le domaine de définition du paramètre mesurant la substituabilité pour estimer notre modèle théorique. Un premier résultat de notre analyse est que les fonds publics sont le principal facteur, bien avant les fonds privés, intervenant dans la production des outputs de recherche. Ceci résulte vraisemblablement de la relativement faible proportion des financements privés dans le budget total des laboratoires (moins de 11% des ressources pour 50% des laboratoires). Notre second résultat concerne les estimations du paramètre mesurant la substituabilité des financements publics et privés. Nos résultats indiquent en effet que financements publics et financements privés sont imparfaitement substituables.

Après cette analyse de la relation entre les différentes sources de financement de la recherche publique, nous nous intéressons plus particulièrement aux financements contractuels publics. Le développement des agences de moyens chargées d'attribuer les financements contractuels publics sur un mode concurrentiel constitue un des aspects les plus marquants de l'évolution du système de financement de la recherche publique en France. Alors que de nombreux travaux théoriques analysent cette évolution en se basant sur la théorie du principal agent (Braun, 1998; Guston, 1996; Van Der Meulen, 1998), très peu d'analyses empiriques sont menées sur les bénéficiaires des financements contractuels publics attribués sur un mode concurrentiel. Ces travaux théoriques mettent en évidence le rôle de médiateur des agences de moyen entre les orientations souhaités par les gouvernements et celles des chercheurs (Braun, 1993). Elles peuvent de plus développer leurs propres stratégies selon qu'elles sont financées par un seul ministère ou plusieurs, ou encore selon qu'elles sont spécialisées sur une seule discipline ou pluridisciplinaires (Slipersaeter *et al.*, 2007). Caswill (2003) souligne l'importance de la création d'une relation de confiance entre les agences de moyen et les chercheurs.

Dans le chapitre 4 nous intéressons aux financements attribués par l'ANR sur le site de Strasbourg en particulier. L'ANR est une agence publique de financement de projets de recherche créée le 07 février 2005 dans l'esprit du National Science Foundation (NSF). L'ANR a deux fonctions principales: la première est la promotion de la création de connaissances fondamentales, et la seconde est la promotion de partenariats public/privé. Pour cela, l'ANR vise à financer des projets pour leur excellence scientifique ainsi que des projets susceptibles d'avoir un impact économique significatif.

Le quatrième chapitre, propose une modélisation du processus d'attribution de financements ANR. Dans une première étape nous expliquons la décision du chercheur de candidater ou non aux appels d'offre de l'ANR. Dans une seconde étape, l'ANR sélectionne les projets financés. La première partie du modèle se focalise sur la capacité d'une agence de moyens à créer les incitations permettant d'attirer les meilleurs projets ou encore les projets ayant une applicabilité industrielle parmi les plus prometteuses. La seconde étape met l'accent sur la sélection des projets parmi ceux qui ont été proposés. Ces modèles sont estimés en utilisant un modèle Probit bivarié. Celui-ci permet d'expliciter les comportements de candidature et de sélection grâce à une première équation expliquant la participation des chercheurs et à une seconde équation permettant d'expliquer la décision de l'ANR. Afin de rendre ce travail possible, nous avons obtenu auprès de l'ANR et de l'Université de Strasbourg les informations relatives aux propositions de recherche, financées ou non. Puis nous les avons fusionnées à la base EcS-BETA. Notre analyse met en évidence l'existence d'un effet d'auto-sélection au sein des chercheurs dans leurs décisions de candidater à un appel d'offre de l'ANR. En conséquence, la qualité scientifique des postulants à un financement de l'ANR n'est que faiblement significative, à la seconde étape, celle de la sélection des projets financés.

Ce travail est une contribution à la dimension financière de l'économie de la science. Il examine de manière théorique mais surtout empirique les implications des évolutions récentes des modes de financement des laboratoires de recherche sur leur production scientifique.

Introduction

0.1. Introduction

Since a few decades, first sociologists and later economists have devoted a particular attention to the studies of Science. Two reasons explain the focus of economists. First, the impact of advances in science on economic growth is not contested. Second, because results of scientific research have the characteristics of public goods[2](Nelson, 1959; Arrow, 1962), economists analyse the reward system involved in science. Market incentives are insufficient, even with the intervention of the State, to promote private investment in basic research to the optimal level. Indeed, basic research is the activity that is performed without any application in mind, without directly patentable outcome as well as a higher level of uncertainty on its outcome. It thus requires for a dedicated reward system that addresses the public good problem in basic research. The reward system based on priority solves the public good problem (Stephan, 1996). Merton (1968) established the importance of priority in science. Indeed, he argued that the goal of researchers was to establish the priority of a discovery in order to get the recognition of the scientific community for being the first. Recognition awards can take several forms: eponymy, other non material advantages as well as financial ones. It is important to stress the winner-take-all nature of science where publication is the principal way to establish the priority. Thus this award system based on priority solves the public good problem because it encourages the

[2]The characteristics of a public good are non-rivalry and non-excludability. Non-rivalry corresponds to the fact that the consumption of a good by an individual does not affect its value or the supply available to the others. Non-excludability corresponds to the fact that an individual cannot prevent others from consuming the good (knowledge), whether they pay or not. Those properties are discussed in detail in subsection 1.2.1.

production of new knowledge by the desire of priority. It also encourages the sharing of the discoveries because it is the principal way to establish priority (Stephan, 1996). In addition to solving the public good problem, this award system based on priority solves also the problem of monitoring (Dasgupta and David, 1994). Indeed it is difficult to the principal to base the payment of researchers on their research efforts, because the efforts are difficult to observe. Thus with a reward system based on priority, in other words on achievement rather than efforts, the monitoring problem is solve. Government solves partially the problem of underinvestment of firms in science with the creation of public research laboratories (labs). Those labs integrate a particular reward system as described.

Funding are key inputs of scientific research as underlined by Stephan (2010b):

> The overwhelming importance of equipment to the research process and the associated costs of equipment mean that in most fields access to resources is a necessary condition for doing research. It is not enough to decide to do research, as a standard human capital model might assume. One must also have access to research inputs.

In France, traditionally, researchers are funded indirectly via their labs. However since a few years, recurrent funds have decreased in favor of grants given to the researchers as well as private funds granted by firms and European funds.

This thesis analyses the ongoing evolutions of the funding of

universities and public research organizations (PROs). We first document and analyse these evolutions. They point toward an increase in the mix of public and private funds, and the development of new external funding. We thus investigate theoretically how public and private funds are combined in the production of knowledge. We study thoroughly the questions of substitutability and complementarity between the different types of funds, and the consequences of shocks in the availability of those funding on the labs behaviour. We are also willing to assess the design of competitive public fund policies, through the set of incentives they create. We investigate this question in an empirical analysis on the *Agence Nationale de la Recherche* (ANR), where we portray the types of researchers who apply, as well as the selection made by the ANR.

The thesis is organized as follows: the first chapter is a survey of the literature. In a second chapter, we present the main characteristics of the funding of the French universities and its evolutions. The third chapter analyses the relationships between the different existing types of funds. In the fourth and last chapter, we focus on the behaviour of the ANR since its creation. ANR is a national funding agency, and more precisely we investigate the applications of the researchers as well as the selection process of the agency.

In the second chapter, we present a general view of the inputs and outputs of the French universities. Using descriptive statistics, we show the evolution of the contractual funds received, as well as publications and patents produced. The analysis is performed on a sample of 28 French universities over the time period 2000-2007 as regards the funding and the patents, and 2003-2007 as regards the publications. The observed increase of contractual funds is not homogeneous among the funding. Indeed, we observe an increase of the international funds since 2004 followed by a strong decrease. Conversely, funds from private sources, public research organizations and local authorities increase steadily over the whole time period. The outputs also increase, because precisely the progression of the number of patents owned or co-owned by the universities cancels the decrease of patents with ownership left to others. We further observe an increase in the number of publications, especially for the engineering schools. We also perform cluster analyses to identify different types of behaviours at the level of the universities. We observe a positive relationship between ANR and private funds.

In a third chapter, we analyse the substitutability of private and public funds in the production of public research output. We first develop a theoretical model of maximization of the output at the level of the labs. We specify a Constant Elasticity Substitution (CES) production function, to allow for different levels of substitutability between the funds. We then investigate the consequences of different types of shocks under different assumptions in the levels of substitutability. We show that the optimal behaviour depends on the level of substitutability. There is a crowding-in relationship between recurrent and private funds whatever the substitutability level. However, contractual public funds crowd-in private funds only when they are greatly gross complements. In other cases, there is a crowding-out relationship. Contractual private funds have two different effects on the total of public funds, depending on the level of substitutability. There is a crowding-in when both public and private funds are gross complements, and crowding-out when both are gross substitutes. This theoretical part is followed by an application using a singular database on the University of Louis Pasteur (ULP). We use a grid search method over the set of possible values for the substitutability parameter to avoid the well-known numerical problems of the usual optimization routines. A first result indicates that the output is far more sensitive to public funds than to private funds. Our results further point to a gross substitutability between contractual public and private funds.

In the fourth chapter, we focus on the contractual funds allocated by the ANR. In a first step, we explain the decision of a researcher to apply to an ANR call. In a second step, the funding agency selects the projects that will be funded. The first part of the model focuses on the capacity of the funding agency to attract best proposals. The second step focuses on the selection process of the funding agency. The two steps lead us to a reduced form model of bivariate Probit type. We estimate this model on data on the ULP. Our results support the assertion that the sample of applicants is not a random sample drawn from the whole staff of the university. The researchers with a high score of publication and patenting activities apply more frequently, as well as those belonging to highly ranked labs. There is here a selection that can be explained by differences in the capability of the researchers or by a self-selection mechanism. Further we do not find evidence that the researchers with the highest publication scores who are funded.

This thesis contributes to both the theoretical and applied literature. From the **theoretical** view point, we provide a model at the labs level allowing to investigate consequences of shocks on availability of funds on labs time allocation decision. Further more we also provide a theoretical model of the application behaviour of a researcher to an ANR call. From an **empirical** viewpoint we document the recent evolution of funding of public research. We estimate a CES production function of the labs, and thus provide estimates of the substitutability parameters between different types of funds. We also estimate a type-II Tobit model describing the application behaviour of researchers as well as the selection process of the ANR.

Chapter 1

Survey of the literature

1.1. Introduction

Public research exists as an answer to market failure to reach the optimal level of investment in research. Indeed, due to the incomplete appropriation of information and the uncertainty inherent to a research activity, private investments are below their optimal level. The State can influence the level of private investment through the creation of a dedicated property right system and tax credit among others. However those incentives are still insufficient to reach the optimal level of private expenditure in basic research. These are the reasons why, there is a need for further investment in research made by the State. The priority reward system integrated in science creates an appropriate set of incentives.

Since the 60s, sociologists and economists have focused on the incentives of researchers to produce knowledge (Merton, 1968; Stephan, 1996, 2010a). They first focused on individual factors explaining the productivity of a researcher and a few studies on collective factors. Later on, a few studies were dedicated to the analysis of the production functions of knowledge. These analyses focus mainly on the characteristics of researchers.

The production of knowledge typically involves funding as input, but analyses of the role of funding on the output are surprisingly few. Furthermore, the landscape of the funding of public research incurred deep changes over the last decades. Over the last 20 years, we observe an increase of funds coming from private and European sources as well as changes in the way public funds are allocated. Nowadays, PROs and universities collect several types of funding : European contractual, private contractual and public contractual funds, among others. Against this background, we focus on public research in this thesis.

This evolution raises several questions: does the increase of private funds influence the level of the research output? the type of output? the research agenda? What are the consequences of the increases of competitive funds? How are they allocated? We provide a survey of the answers already available in the literature in the following.

The survey is organised as follows. Section 1.2 discusses the rationale behind the existence of public research. The following three sections focus on different types of contractual funds: Section 1.3 on European contractual funds, Section 1.4 on private contractual funds and Section 1.5 on public contractual funds. In Section 1.6 we present factors explaining the productivity.

1.2. Why public research?

In this section we develop the rationale behind public support to research. We first describe the reason of public support of research in subsection 1.2.1. In subsection 1.2.2 we develop the tools available for promoting private investment level and in subsection 1.2.3 the support to public research.

1.2.1 Why public support of research?

The importance of innovation as a driving force of economic growth is not challenged. However the social rate of return of expenditure in RD is higher than the private rate because of incomplete appropriation of results of RD and uncertainty on results of RD. Thus, the level of private investment in RD is suboptimal and as a consequence, governments support RD activities in several ways. We first discuss the two issues of incomplete appropriation and uncertainty of the results. We then turn to public tools to promote private investment in RD.

Incomplete appropriation

Nelson (1959) and Arrow (1962) show that knowledge can be assimilated to information. As a consequence, it has the characteristics of a pure public good: non-rivalry and non-excludability.

Non-rivalry, also referred to as non depletable, corresponds to the fact that consumption of a good by an individual does not affect its value or the supply available to the others.

Non-excludability corresponds to the fact that an individual cannot prevent others from consuming the good (knowledge), whether they pay or not. This second characteristic has important consequences. When companies invest in RD and create new knowledge (for example a pharmaceutical firm who discovers a new molecule) they cannot prevent other companies from accessing this innovation and producing the same molecule. The other companies can sell drugs, resulting from this molecule cheaper than the one who invested in RD. As a consequence, if firms cannot appropriate results of their RD, they will have limited incentives to do it. The level of investment in RD depends on the return the firms can obtain and not on the social value of the possible results.

Uncertainty of the results

Results and the potential payoff of RD are extremely variable and unpredictable. Those characteristics are more pronounced in the domain of basic research. Because basic research aims at understanding principles, to gain fuller knowledge without any application in mind. On the other hand, applied research aim at meeting needs. Thus basic research has a lower private rate of return and a higher associated risk (Dasgupta and David, 1994; Guellec, 1999). For those reasons, private firms are less prone to invest in basic research. However, social return of basic research is higher as it leads to a multitude of applications.

1.2.2 Public tools to promote private investment in RD

Government has a large number of policies to promote private investment in RD and reach the optimal level. Government introduces a property right system to increase the appropriability of the results of RD. Government can also support firms' investments with direct subsidies or with indirect channels such as RD tax credit.

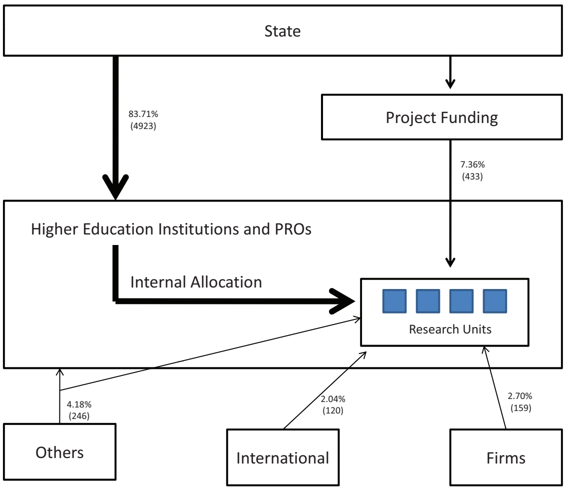
Government can partially solve the problem of non-excludability and promote private investment in RD by introducing a property right system. Indeed, one of the reasons of the market failure to reach the optimal level of investment is the difficulty for firms to appropriate the results of the RD they managed. Thus, a property right system which allows firms to appropriate results of their RD and to exclude others will improve private investment.

Government can also boost firms' RD expenditure with an RD tax credit. The implementation of an RD tax credit system differs among countries and over time. The common core is that a fraction of RD expenditure of firms is deducted from their taxes. In France tax deduction can reach 30% of firms' RD expenditure. Tax credit leaves the choice of how to conduct projects in the hands of the private sector, thus it is a market oriented response to the underinvestment of firms (Hall and Van Reenen, 1999). Numerous studies analyse the impact of tax credit on RD investements at the level of firms. For a detailed survey see Hall and Van Reenen (1999). Since the 2000s, studies on tax credit have focused on their impact on attracting and keeping potential RD investment in a country (Atkinson, 2007; Paff, 2005; Wilson, 2009). Indeed, the choice of the location where the RD is done depends on the costs, thus RD tax credit would play an important role in the country competitiveness to attract firms (Atkinson, 2007).

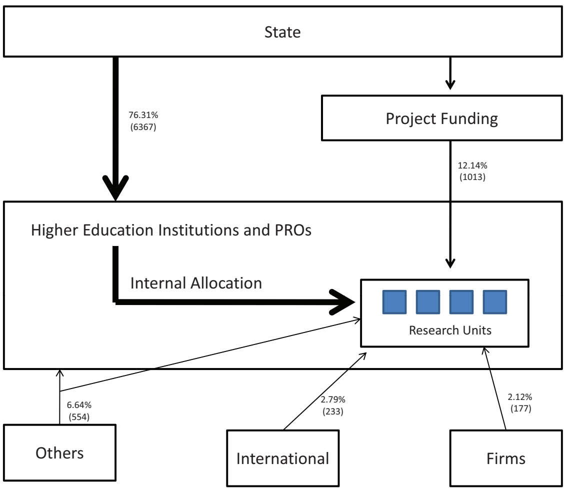
1.2.3 Support to public research

The after World War II rationale led to government funding of basic research (in a more or less centralized way) to develop education and research quality. The funding regimes differ among countries and over time. In opposition to the U.S., many countries among which France do not support scientists directly but their research institutes.

Figure 1.1 maps the state of the funding of the higher education institutions and PROs in 2000 and 2008 in France. In 2008, most of the funds come from the national state (88%), whereas international and firm funding



(a) 2000



(b) 2008

Figure 1.1: Maps of the funding.
Source : MEN-DPD C3

represent around 5% of the whole budget of the research units. Among funds from the State, 76% are recurrent and 12% are attributed on projects. Despite recent evolutions, recurrent funding is still by far the most important type of funding for the research units.

However this evolution can hide disparities among universities. The purpose of the next chapter will be to document the evolution of funding among French universities. We assess whether there is a specialization of universities in one type of fund raising.

Braun (2003) analysed the evolution of funding of public research by looking at the relationship between government and scientists as a delegation problem. The delegation occurs because the state asks scientists to do something that the state cannot perform because of lack of competences or knowledge (Coleman, 1990). To select which scientists to fund and to encourage them to act as asked within a context of asymmetry of information, different kinds of delegation mechanisms have been designed. Braun (2003) identifies five delegation modes in the course of history. Here we develop four of them [1]. The first one, "blind delegation", has occurred since the beginning of science policy and is based on no intervention of the state in the science world. States trust scientists, thus give them the power to define public research orientations, to establish their own control systems based on peer-review. The second type of delegation is "incentive delegation". Since the 60s, governments have juxtaposed it with blind delegation and have chosen the research areas to which additional funds are given. Therefore, the State can define priority research topics. After a period defined as "austerity" corresponding to the economic crisis of the 70s, research policy has changed

[1] The fifth one which is not developed here is in fact as "incentive delegation" but with a difference in the the relative importance of global and directed funding.

to a more directive type and two new modes of delegation have appeared and juxtaposed with previous ones: “delegation by contract” and “delegation by network” . The former can be defined when the State establishes contracts with institutions in charge of dispatching funds among scientists and of defining science policies. “Delegation by network” has appeared when the State sets the frame to create networks between scientists from public research labs and from private companies. Those last two types of delegation have reflected the wish of the State to lead the researchers to working on societal oriented research. Of course all those systems can co-exist.

We identified previously three main contractual fund providers: private sector, national government and European institutions. We focus on each one in the following sections.

1.3. European contractual funding

We first present in this Section a brief history of European contractual funding. Then we present analyses carried out on this evolution.

1.3.1 A brief history

In the 70s, the idea of promoting European research became high on the policy agenda. In 1971, an instrument, European Cooperation in Science and Technology (COST) in favor of cooperation among scientists and researchers across Europe was created. “COST is an intergovernmental framework for European Cooperation in Science and Technology, allowing the coordination of nationally-funded research on a European level. [...] COST does not fund research itself but provides a platform for European scientists to cooperate on a particular project and exchange expertise." In 1972, during the Paris meeting, governments indicated their wish to develop a common science and technology policy. In January 1974, the European Council voted resolution number 31974Y0129(03) in favor of a common policy in science and technology [2]. The foundations of RD policies at the European Union (EU) level were thus laid in the 70s. In 1975 the European Space Agency (ESA) was created. ESA is composed today of 18 countries and its purpose is to develop European space policy, the cooperation among European countries in space research and to coordinate European and national space programmes. In 1984, with the creation of the first Framework Programme for research and technological development (FP), a new step was achieved. The FP has been used by the European Commission to fund European research. FPs followed one another and the 7^{th} edition of the FP has been ongoing since 2007 until 2013. FP is one of the principal instrument for funding research. At the same time European structural funds are also an important instrument used to develop regional RD. [3]

Further, in 2000, the European Council set out the Lisbon strategy, also called the Lisbon agenda to make the EU "the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion" and launched the European Research Area (ERA). In addition to FPs which should support the creation of ERA, several initiatives like the European

[2] The resolution number 31974Y0129(03) is accessible with: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31974Y0129(03):EN:HTML

[3] The sets of agencies and instruments presented are not exhaustive.

Technology Platforms, were launched to improve the coordination of RD activities and programmes. The EU expenditure for RD increased from 678 to 4953 million euros in 11 years, between 1985 and 2006.

1.3.2 Analysis of this evolution

Since a few years, the importance of European funding for research has started to be well documented (Lepori *et al.*, 2007; Dinges and Lepori, 2006; Geuna, 1998). Indeed, Lepori *et al.* (2007) showed clearly an increase of the share of funds provided by European funding agencies in Austria, France, Italy, the Netherlands, Norway, and Switzerland.

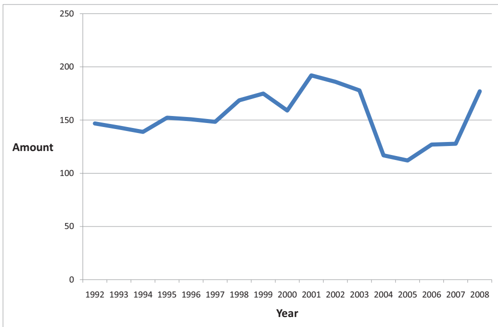
Several papers focused on the decision of firms to participate in an EU-funded cooperative RD project (Marin and Siotis, 2008; Hernan *et al.*, 2003) and on the impact of participation on their performances (Benfratello and Sembenelli, 2002). Benfratello and Sembenelli (2002) did not find evidence of a positive impact of FPs on the performances of participating firms. Geuna (1998) focused on the university side. He used a two-equation model to explain first the participation of universities in EU funded RD cooperative projects. He also analysed the frequency of participation of universities in EU funded RD cooperative projects. He concluded to the importance of scientific research productivity on the probability to take part in a project and on the frequency to participate. He also observed country and size effects on frequency of participation. Another type of analysis on European project funding focused on how European funding fit with national funding systems (Dinges and Lepori, 2006).

1.4. Private contractual funding

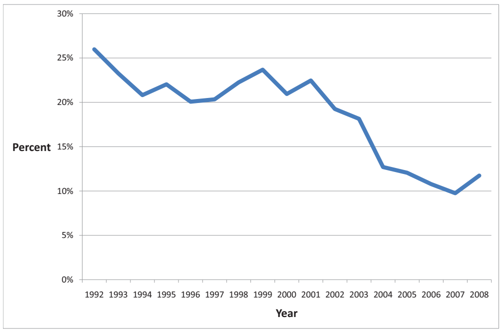
Since the 90s, universities and PROs have raised more private funds. Few studies tried to analyse the increase of sponsored research and industrial funding of PROs (see Cassier (2002), for France and Gulbrandsen and Smeby (2005), for Norway).

Figure 1.2a shows the evolution of the amount of private contractual funds and Figure 1.2b the evolution of the share of private contractual funds among total contractual funds raised by universities and PROs in France over the period 1992-2008. Until 2003, the private contractual amount increased steadily over time and decreased later. However the share of private contractual funds among contractual funds decreased during the whole time period. This result is driven by the increase of the total contractual funds of universities and PROs in their budget. However private funds remained the second most important source of contractual funds behind public contractual funds. The importance of private funds was analysed in three ways in the literature.

A first trend in this literature investigated the impact of private funding on the research agenda (Van Looy *et al.*, 2004; Blumenthal *et al.*, 1996) and the risk to switch from basic to more applied research (Florida and Cohen, 1999). Indeed researchers may change twice research agenda to get more private funds (Florida and Cohen, 1999). Further, industry involvement and basic research can require different sets of skills and organizational capabilities (Bercovitz and Feldman, 2008). It is therefore important to understand the impacts of private funding. Using different methodologies, studies con-



(a) Amount (in million euros)



(b) Share among total contractual funds

Figure 1.2: Evolution of private contractual funds between 1992-2008.
Source : MEN-DPD C3

cluded that there was an overlap of the valorization activity within basic research topics and an absence of a significant impact of private funding on research topics. Gulbrandsen and Smeby (2005) observed that Norwegian professors involved in private research contracts published more. The same result was obtained for researchers of KU Leuven in Belgium (Van Looy *et al.*, 2004), for Canadian biotechnology researchers (Beaudry and Clerk-lamalice, 2010) and for researchers of engineering departments in the UK (Banal-Estanol *et al.*, 2010). The latter underlined also that a collaboration had a negative impact on the number of basic research articles and a positive one on publications of a more applied type. Blumenthal *et al.* (1996) observe an increase of publications with private funds and a decreases when more than two-thirds of the funds were private. A curvilinear, concave relationship was also found between publications and collaborations with firms by Larsen (2005) who used data on professors of the Technical University of Denmark and Manjarrés-Henríquez *et al.* (2009) whose analysis is based on

2 Spanish universities.

A second trend of studies investigated the characteristics explaining the commitment of faculty to collaborative research with firms. The idea of top researchers receiving grants was rejected in Goldfarb's (2001) analysis of NASA grants. Mansfield (1995) showed that firms traded off between research quality and geographical proximity for decisions of who financed. The more basic the research, the more important the research quality and vice versa. Boumahdi and Carayol (2005) study at the laboratory level showed that publications positively impacted public funding and negatively private funding.

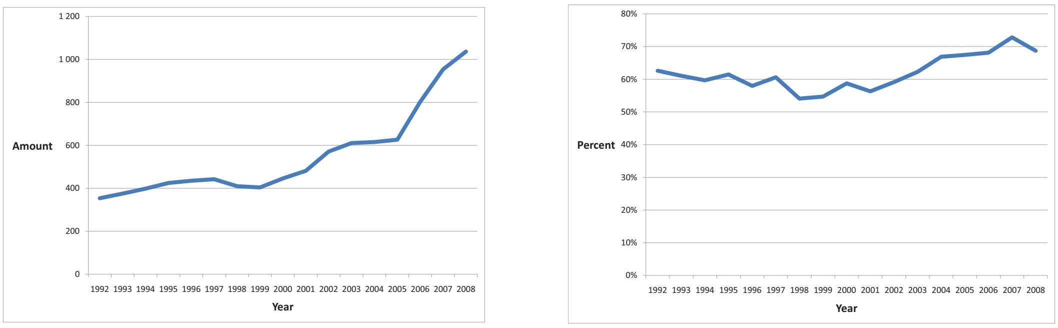
The last type of studies investigated the question of whether public and private funding were substitutes or complements (see among others Diamond, 1999; Payne, 2001; Gaughan and Bozeman, 2002; Boumahdi and Carayol, 2005). Diamond's (1999) analysis on US data showed the existence of a crowding-in effect between federal and industry spendings. Gaughan and Bozeman (2002) and Blume-Kohout *et al.* (2009) also found evidence of a crowding-in relationship. The former analysis was based on relationships between NSF research center grants and industry funding whereas the latter investigated the relationship between federal and non federal funding in life science. All those previous analyses were at university level. Boumahdi and Carayol (2005) went one step further by introducing the researchers' efforts to raise funds in their model at the laboratory level. Their analysis of the University Louis Pasteur concluded that there was a crowding-out effect between public and private funding. We investigate this issue in the third chapter. We extend Boumahdi and Carayol (2005) model to allow for more flexibility in the production function of knowledge. We show that crowding-out does not necessarily occur and that crowding-in solutions are also feasible. The relationship between the two types of funds depends on the form of the production function as well as on the variable impacted by the shock.

1.5. Public funding

In this Section we focus on public funding. First we present the recent evolution of the way public funds are attributed. This evolution shows an increase of competitive funds; thus in the following section we focus on the literature devoted to competitive funds. We focus first on the principal-agent approach, and later on the application and evaluation process of grants. Finally, we focus on the empirical analysis.

1.5.1 Recent evolutions

There is increased pressure to use scarce resources in a more efficient way to get a better return on public investment in research. This pressure entailed an increase of public contractual funds and a decrease of recurrent funds (see Geuna, 2001, among others). In France, the level of public contractual funds increased until the 90s. The increase slowed down until 2000 and has increased more quickly since. This evolution of the amount of public contractual funds raised by PROs and universities is displayed in Figure 1.3a. Figure 1.3b shows the evolution of the share of public contractual funds. We observe a small decrease of the share until 2000 and later an increase from 55% to 69%. Figure 1.4a displays for universitites and Figure 1.4b for PROs the evolution of the share of recurrent funds and public contractual funds in their total budgets. We observe a decrease of the share of the recurrent funds from 82% to 75% for the universities and from 88% to 80% for the PROs. During the same time period, we observe an increase of the share of public contractual funds of 10% to 15% for universities and from 2% to 7% for PROs.



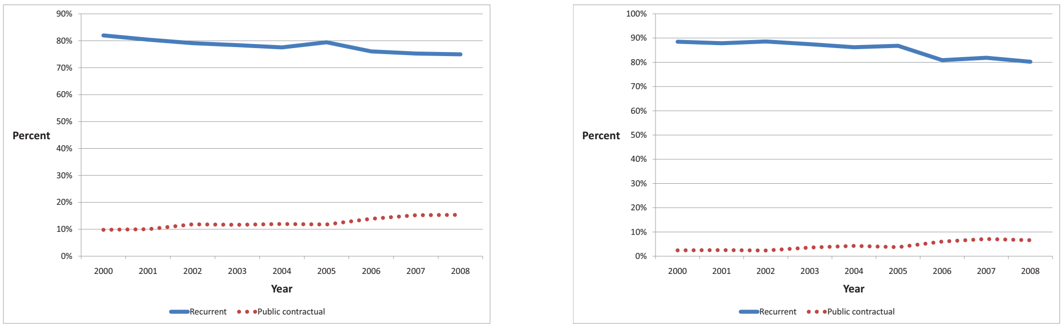
(a) Amount (in million euros)

(b) Share among total contractual funds

Figure 1.3: Evolution of public contractual funds between 1992-2008. Source : MEN-DPD C3

Research Councils (RCs, also called funding agencies) have been one important element in this whole evolution through their project funding. Indeed project funding, also called competitive funding allocated by RCs is supposed to provide for an increase in the efficiency of public expenditure. By targeting the recipient, funds can be attributed to the most productive laboratory, or support the promotion of a subject of primary interest.

The development of project funding raises fundamental theoretical questions: how to decide to whom to allocate a grant? Which research question needs to be supported? How to ensure that researchers did what they were



(a) Universities (b) PRO

Figure 1.4: Share of recurrent and of public contractual funds among total funds. Source : MEN-DPD C3

asked to? At the same time, researchers should decide on the time and effort to be allocated to their research and to the fund-raising activity.

As we will see in the next subsection 1.5.2, a large part of the literature is based on an extension of the principal-agent theory for capturing simultaneously the relationship between State, RCs and scientists. In this theoretical framework, a few studies analyze how ministries delegate to agencies, and how agencies select the recipients and check the efficiency of the investment (Braun, 1998; Guston, 1996; Van Der Meulen, 1998) among others. In subsection 1.5.3 we present the grant application and evaluation process.

1.5.2 Modeling using principal-agent approach

The principal-agent theory was developed within the framework of the "new institutional economics" (Williamson, 1975, 1985; Moe, 1984; Miller, 1992). The main idea is to describe and analyze the relationship between agents (principal and agent) with asymmetric information. The principal wants to urge the agent to act in his interest (Peterson 1993). However the agents want to maximize their own welfare. Thus, problems such as "moral hazard"[4] and "adverse selection"[5] occur.

The principal-agent theory was extended to analyze simultaneously the relationship between three agents: government, RCs and researchers. Indeed the usual dyadic approach cannot account for the importance of a third party (scientist) in the relationship between state and "intermediary funding agency" thus asking for a triadic approach (Braun, 1993). On the one side, studies focus on the relationship between State and research councils (Slipersaeter *et al.*, 2007; Braun, 1993) and on the other side between research institutions (or researchers) and the research councils (Guston, 1996; Van Der Meulen, 1998; Braun, 2003; Braun and Guston, 2003; Caswill, 2003; Van Der Meulen, 2003; Gulbrandsen, 2005; Slipersaeter *et al.*, 2007). Several studies conclude to a dual role of RCs between State and scientists (Caswill, 2003; Van Der Meulen, 2003; Gulbrandsen, 2005; Slipersaeter *et al.*, 2007; Braun and Benninghoff, 2003). Research councils have to respond to state and researchers, who have diverging interests as well as their own weaknesses and strengths, and have to develop their own strategies (Caswill, 2003; Van Der Meulen and Rip, 1998; Slipersaeter *et al.*, 2007). The capacities of RCs to develop their own strategies depend for example on whether they are funded by a single ministry or several, or whether they are specialized in one field. In this case, they depend on the recognition of the members in this field (Slipersaeter *et al.*, 2007). In addition, the response of RCs to State depends on the

[4]The principal does not know if the agent will act in the principals' interest.

[5]The principal does not have enough information about the capabilities of agents. Thus, he has difficulties to select the best for the task.

composition of their board. If the majority of the members of RCs are scientists, they are less receptive to science policy orientations than if they are composed of politicians and industrialists (Slipersaeter *et al.*, 2007). Caswill (2003) underlined the importance of trust between RCs and researchers. Researchers have to give advice to define the science policy and to monitor scientific progress. Morris (2003) focused on the behavior of researchers as agents and tried to determine if the principal-agent relationship can explain scientists' behaviors or give them tools to guide their strategies.

New developments show the limits of the principal-agent theory related to the dual function of research councils (as principal for researchers and agent for state). As underlined by Caswill (2003), it is possible for the RCs to exclude the principal (the state) from the contract. Furthermore, the principal-agent theory is not able to capture the cumulative and collective consequences of the programs (Shove, 2003).

1.5.3 Grant application and evaluation process

We describe here the general elements of the funding agencies' decision processes to distribute grants. A few times each year, funding agencies invite researchers to submit proposals to accomplish a specific program. In these cases, we are dealing with targeted research. Funding agencies can also request Investigator-Initiated Research. Generally, all applications are subject to peer review evaluation, involving specialists organized in groups around topics. Reviewers evaluate proposals on the basis of different criteria depending on the priority of the funding agency. Here a set of common criteria frequently used :

- Significance: if the project addresses important problems or critical barriers to progress in the field. The impact on the development of the scientific knowledge, technical capability, methods and technologies;
- Investigators: if the principal investigator (PI) and researchers involved in the project are well suited to the project;
- Approach: if the approach and methodology are appropriate for a successful completion;
- Environment: if the institutions where the research will be carried out can contribute to a successful achievement of the project. Are the equipments and other physical resources required to achieve the project available.

Based on a peer review recommendation of the scientific and technical merit and/or the appropriateness of budget requests, funding agencies negotiate with PI and award grant or not projects.

1.5.4 Empirical analysis

This increase of project funding expresses the State's wish to increase the efficiency of each unity of fund. The impact of funding on research output is evaluated in a few studies. However, the evaluation of treatment effect has to deal with self-selection and unobserved heterogeneity problems. Therefore the literature focuses on the selection process. We present first the studies on the impact of being granted and second the literature analysing the selection process.

Few analyses investigated the impact of being granted on the publications of researchers. Numerous analyses found a limited impact of research grants on the output production, measured as publications or citations. Arora and Gambardella's (1998) analysis was based on NSF grants in economics. They found that the effect of a grant was declining with the seniority of the principal investigator. The same results were obtained for NIH postdoctoral grants and standard research grants between 1980 and 2000 (Jacob and Lefgren, 2007). Indeed, in their analysis based on 13 462 applications to NIH postdoctoral grants and 54 742 applications to standard research grants between 1980 and 2000, they concluded that the effect of NIH standard grants was very limited and the effect of postdoctoral grants on publications was positive. The same results were obtained for research grants in Argentina (Chudnovsky *et al.*, 2006). Beaudry and Clerk-lamalice's (2010) analysis was based on Canadian data, and showed a positive effect of grants on publications.

Another set of studies focused on factors explaining the decision of the funding agencies to support a project. Arora and Gambardella (1998) analyzed factors influencing NSF decisions to grant a project in economics. They used data on all applications to the NSF between 1985-1990, whether they were awarded the grant or not. First, they observed a positive relationship between the probability of a project to be selected and the score attributed to the project by the NSF reviewers. They also observed a positive impact of the past publication activity of the principal investigator of the project on the probability to be selected. This impact was much more important for senior principal investigators than junior ones. The authors also found a positive effect of belonging to an elite institution and to be located in the West, Mid-West and North-East. They interpreted these last results as the existence of social networks. Feinberg and Price's (2004) analysis was based on the applicants to NSF grants in economics programs. They investigated the influence of social networks on the decisions of the NSF. They concluded that there was a positive effect of NBER affiliation on success. The authors interpreted this result as a proof of the existence of a social capital effect. However, their results were less clear-cut than they seemed to be. First, they did not control for the quality of the project. Second, belonging to the NBER was likely to be also the outcome of previous important publications, and the NBER indicator was thus collinear with the variables measuring past publications. Disentangling the influence of both variables was thus complex, and a careful discussion of this issue would be helpful to assess their results. Arora *et al.*'s (1998) analysis was based on grants awarded by the Italian National Research Council, CNR, in biotechnology and bio-instrumentation. They showed a positive impact of "variables correlated with scientific merit" like quality adjusted publications of the principal investigator, during the five year preceding the period of analysis and listed in the application form, like the number of past collaborations with foreign non profit institutions.

As we saw above, the literature focuses only on the selection process. This means that the authors use data on the set of applicants to explain who is selected by the funding agency. In this thesis, we go one step further and analyse who is applying among the whole population of researchers. This allows us to assess whether there is a self-selection already at the stage of application to a grant.

1.6. Modeling the research production function

Numerous studies focus on the determinants of scientific output and productivity. First, sociologists led by Merton (1968) focused on the determinants of scientific output at researcher level and few economist focused on collective determinants. Later, economists investigated the relationships between research investment and output production, usually at university level. We survey their works in this Section, where we devote particular attention to the determinants of scientific output in subsection 1.6.1 and to the functional form in subsection 1.6.2.

1.6.1 Determinants of scientific output

After the seminal work of Lotka (1926) who showed that a minority of researchers published the majority of publications, numerous authors tried to determine the factors explaining the productivity of researchers. This effect is known as Lotka's law. Since the 60s, sociologist led by Merton (1968) tried to explain this phenomenon and more generally the productivity of researchers. They focused on individual characteristics such as gender or age.

A first group of studies focused on the effect of age on the productivity of researchers. Studies by Lehman (1953, 1958, 1960) showed that the main publications appear during the late thirties, early forties. For fundamental science it is at a younger age. Later, Cole (1979) concluded to the existence of a curvilinear relationship between age and mean number of publications with a peak in the forties. Others concluded to the existence of 2 peaks, a first one at (30-40) and another one at 50 (Bayer and Dutton, 1977). Based on utility functions, several studies confirmed the conclusions of previous analyses, that is an increase of the productivity of researchers followed by a decrease (Levin and Stephan, 1991; Weiss and Lillard, 1982; Diamond, 1984, 1986) with a peak depending on the field (Levin and Stephan, 1991; Weiss and Lillard, 1982). All those analyses used US data. A couple of studies focused on the effect of age on the productivity of researchers in Europe. Mairesse and Turner (2005) analyses on French physicist reached similar conclusions . However Carayol and Matt (2006) did not find a clear impact of age on researchers productivity. The main difficulty of those studies is to distinguish the age effect from the cohort effect. Numerous developments tried to overcome this difficulty (Hall, 1971; Berndt and Griliches, 1990). More recently Hall *et al.* (2005) concluded to the quasi-impossibility to estimate the impact of age without important restrictions in the model.

Gender analysis shows that women publish less, receive less citations, are promoted more slowly and get lower wages (Fox, 1983; Long, 1992; Long *et al.*, 1993; Levin and Stephan, 1998; Mairesse and Turner, 2005). However Long (1992) and Levin and Stephan (1998) underlined the importance of using panel data to study the gender effect and the former showed that if we excluded women who never published then women would receive more citations and the latter showed that gender had no impact on the wage level.

Few studies focused on the collective determinants of productivity of researchers. Those studies defined collective variables such as elements related to the composition of labs: mean age, percentage of full time professors, size, reputation of laboratories and etc.

Bonaccorsi and Daraio (2003) developed the idea that a positive complementarity can be obtained in a laboratory composed of researchers of different generations. Their analysis on Italian National Research Council showed a negative relationship between mean age and productivity indicators. Carayol and Matt (2004b) analysis based on Louis Pasteur University showed a positive impact of non-permanent researchers on publication performance of permanent researchers. Furthermore, they also point to a positive impact of the colleagues publications on the performance of researchers. This last result is coherent with the conclusion of previous research in France concerning physicist conducted by Mairesse and Turner (2005). Studies on U.S. data show that a positive impact on publication of a researchers to join prestigious laboratories (Long and McGinnis, 1981; Allison and Long, 1990). Concerning the effect of the size of labs, Carayol and Matt (2004a) concluded to a negative relationship between size and productivity and Mairesse and Turner (2005) to the quasi absence of size effect.

1.6.2 Research production function

Only a few papers focus on universities production function by opposition to firms. The principal contribution is by Adams and Griliches (1998), who developed a research production function that they estimated using data on about 30 universities over the period 1981-1989. The expression they used for the knowledge production function was as follows:

$$y = \alpha + \beta W(r) + \gamma X + u,$$

where y is the logarithm of research output (papers or citations), $W(r)$ is the logarithm of a distributed lag function of real past RD expenditure, and X is a vector of control variables. X can include year dummies to control for changes in the research production function over time.

They focused mainly on the elasticity of research output to research input, β. They found evidence of diminishing return to scale at the university level. Crespi and Geuna (2008) who extended Adams and Griliches (1998) knowledge production by using Polynomial Distributed Lag structure using data on 14 countries[6] found a diminishing return to scale at the country level and a higher elasticity for citations than for publications.

[6] The 14 countries are: Australia, Belgium, Canada, Finland, Denmark, France, Germany, Netherlands, Spain, Italy, Switzerland, Sweden, UK and USA

Chapter 2

Funding and Output of French Universities

Abstract

This paper discusses the evolution of funding, publications and patenting activities at the level of the universities. The data come from the VALO surveys conducted over 28 French universities from 2000 to 2008, and the *observatoire des sciences et Techniques.* We observe first a huge heterogeneity in the evolution of the different types of funds, with an important decrease of the international funding balanced by an increase of funds provided by the local authorities and the ANR. We further observe an increased specialization over time of the universities in a few particular sources of funding, especially in firms and ANR funding. Turning to the output, the patenting activity increases over the whole time period. Publications remain globally stable over the years 2000. Descriptive statistics seems to point a negative relationship between publications and ANR funding.

2.1. Introduction

Deep changes occurred in the inputs and outputs of the universities in the 2000s. There are now multiple rankings of the establishments at the international level, depending in part on the publications of the labs belonging to universities. Those rankings come along with a focus on university patenting. On the side of the inputs, there is a decrease of recurrent funds and an increase of contractual types among which project based funding grant by funding agencies like *Agence Nationale de la Recherche* (ANR)[1]. All in all, the full landscape of the funding, the publication and the patenting activities changed.

There are now numerous fund providers, each one with its own objectives. An increase of contractual funds does not mean an increase of each type homogeneously, and the importance of the different actors did not evolve in the same way in the 2000s. As we will see, the increase of contractual funds hides fairly heterogeneous evolutions.

Two types of outputs, patents and publications are usually analysed in the literature. Publication is the traditional criterion measuring how researchers perform and the personal rankings of researchers are based on the number of papers they issued as well as on the impact of those papers and on the impact of the journals in which the papers are published. Patents have further become an important output as such. We observe an increase of both publications and patenting activities over the 2000s.

Our purpose is to document these evolutions. In this paper, we use a

[1] *Agence Nationale de la Recherche* can be translated into National Research Agency.

database on 28 French universities and higher education establishments over the years 2000 to compute a set of descriptive statistics on the evolution of the funding, the outputs and their interactions. We first describe the general evolution of the funding, patenting activity and publication activity. To contrast the evolutions between the different types of universities, we investigate these evolutions by type of establishment. For each input and output, we perform cluster analyses to group the universities. This allows us to assess the underlying behaviours of the universities, e.g. in terms of specialization. We use cluster analyses to investigate the correlations between inputs and outputs.

The paper is organized as follows. First we describe the data used in our study in Section 2.2. We present the evolutions of funding in Section 2.3, of patents in Section 2.4 and of publications in Section 2.5. The cluster analyses between funding and patenting are presented in Section 2.6, and the cluster analyses between funding and publication in Section 2.7.

2.2. Data

The data are the result of the merges of 3 waves of the Valo survey, as well as data on publications. The first wave of the survey was conducted between 2005-06, with questions covering the time period 2000-04. The second one covers the time period 2005-06 and was conducted in 2007. For the time period 2006-07, the study ran in 2008. The valo survey is a questionnaire answered by the principal valorization structures of French universities about their budgets, staffs, patenting and licensing activities and contracts. Thus we get data on contractual funds and patenting activities of universities. However we have a partial vision of only the main structure, because universities can have several structures in charge of different types of contracts. The Valo survey is financed by the Ministry of higher education and research and result from the collaboration of several entities involving the Ministry of higher education and research, the Curie network[2], the *conférence des présidents d'universités*[3], the *conférence des directeurs des écoles françaises d'ingénieurs*[4] and the *Bureau d'Economie Théorique et Appliquée* (BETA). The BETA, a research lab of the University Louis Pasteur and CNRS, was mainly in charge of collecting the data and of their analysis. [5] [6]

The data on publications are available for the time period 2003-2007. They were provided by the OST[7]. We have for each university the total number of publication corrected for the number of co-authors per year.

We retain in our sample the universities that answer to the 3 waves of the survey fully and universities of social science and humanities are excluded from our analysis. This leads us to a sample of 28 universities observed over 7 years. Among them, 6 are comprehensive universities without medicine (*Universités Polyvalentes sans Médecine*, UPSM), 8 are comprehensive universities with medicine (*Universités Polyvalentes Avec Médecine*, UPAM), 7

[2]The CURIE network has for mission to improve valorization of the research.

[3]*Conférence des présidents d'universités* gather the presidents of universities and directors of certain high schools.

[4]*Conférence des directeurs des écoles françaises d'ingénieurs* gather the directors of engineering schools.

[5]Reports produce at the end of each wave provide detailed information on each wave (Bach and Llerena, 2010, 2008, 2006).

[6]We are grateful to Laurent Bach and to all persons who contributed to the construction of the database and to the Ministry of Higher Education and Research.

[7]*Observatoire des Sciences et des Techniques* (OST) can be translated into Observatory on sciences and techniques.

are scientific universities (*Universités Scientifiques*, USc) and 7 are engineering schools (*Ecole d'Ingénieur*, Ing).

2.3. Funding

We analyse the evolution of the contractual public and private funding. Public funding involves research contracts with ministries (Min), public research organisations (PROs), local authorities (LocAuth) and international funding[8] (Int). Private funding involves research contracts with firms and associations (Asso).

2.3.1 Descriptive statistics

Figure 2.1 displays a kernel density estimate of the distribution of the total amount of contractual funds and grants received at the level of the universities over the whole time period. We observe a skewed distribution of the total amount of contractual funds among universities. The median is about 2.4 million Euros. Differences over the median are wide, as nearly 30% of the universities collect more than 5 millions, and 10 % more than 10 millions. This observation indicates that a few universities concentrate the biggest part of contractual funds.

The dynamics of the amounts raised is plotted in Figure 2.2a. After a period of stagnation between 2000 and 2005, the total amount increases clearly, so that it shifts from 30 millions to 80 millions over the whole time period. It should be noted that the ANR was created in 2005 and that it

[8] International funding is mainly European funds.

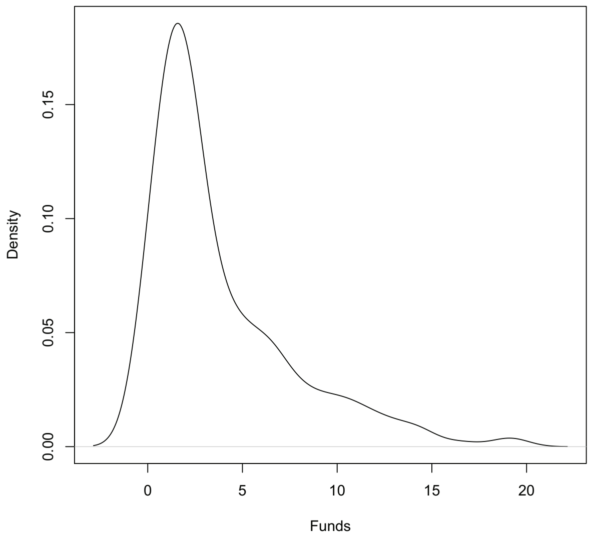


Figure 2.1: Estimated density of the amount of funds (in million Euros)

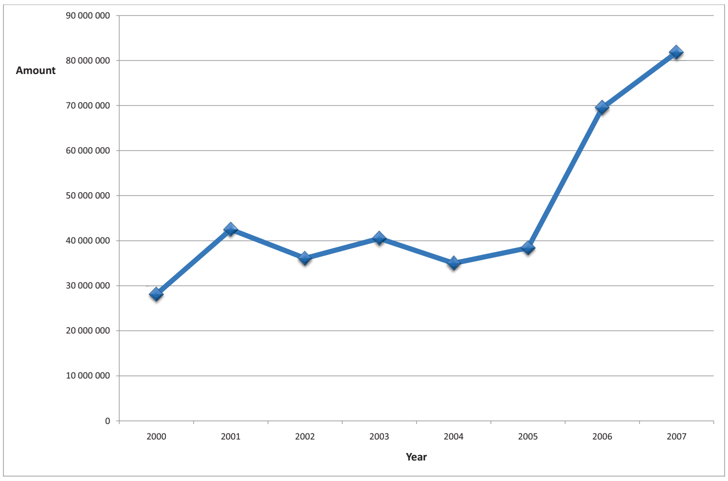
provided around 30 millions in both years 2006 and 2007.

The sources of the funds raised evolved over time, as displayed in Figure 2.2b. We observe that funds from associations represent a very low level (less than 6% in each time period) and the amount raised is constant around two million euros. The total amount of contracts with ministries increased between 2000 and 2002, and decreased slowly since. We also observe a slow upward trend of the funds provided by firms and PROs. Similarly, international contracts increased between 2000-2004 and decreased later. Conversely, it is interesting to note an important increase since 2004 of funds from local authorities. To have a full picture of the evolution of the funds over this time period, we should recall that the ANR was created in 2005 and became immediately the second most important source of funds, with nearly 30 millions transferred to the universities every year. Beside the increase of funding over the whole time period, driven by the local authorities and the ANR, there was a decrease of international and ministerial funds. The whole evolution hides fairly heterogeneous evolutions per funding, with huge changes in the importance of the different actors of the funding landscape.

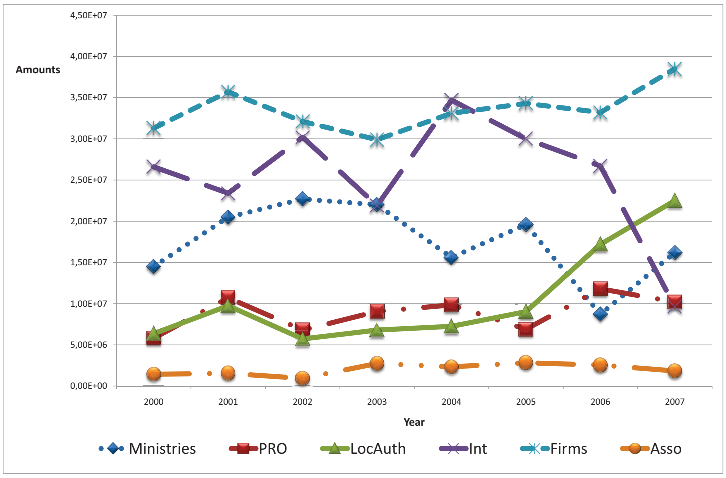
Figure 2.3 presents the evolutions of the average level of contractual funds received by types of universities from different sources. We analyse whether the importance and the evolution of the different types of funds are similar or not for the different types of universities. We observe first a convergence in the evolution of funds from ministries between the different types of universities. More specifically, the amounts collected by the USc and Ing evolved from fairly different situations in 2002 to similar levels nowadays. The same phenomenon is observed for UPSM and UPAM. International funding exhibits a stronger convergence pattern because all the types of universities earn the same amount of funds at the end of time period. The reduction of ministry and international funding is particularly concentrated on the USc.

The increase of funds from firms, PROs and local authorities is globally equally shared among all types of establishments. However there is still a decrease of firm funding toward the USc.

Table 2.1 displays the shares of the different types of funds in the total of the contractual amounts in 2000 and 2007. In 2007 firm funding was the most important type for UPSM, the other types are of equal importance. The UPSM, the UPAM and Ing present similar rankings of the different types of funding in 2007.

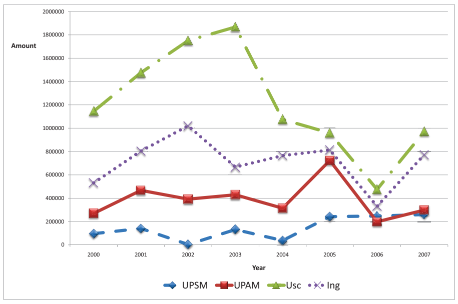


(a) All sources

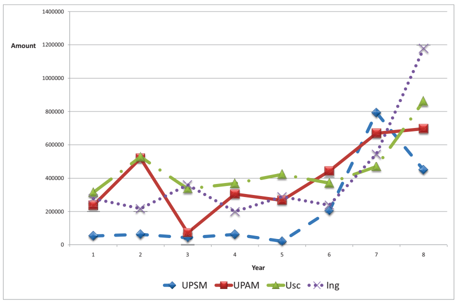


(b) Depending on source of funds

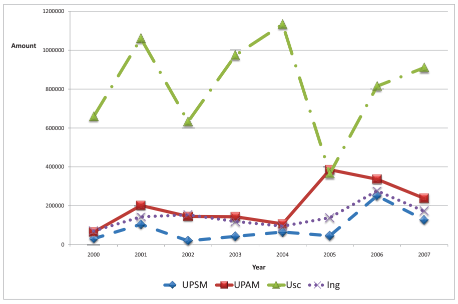
Figure 2.2: Evolution of total contractual funds (in euros). Source: EcS-BETA database



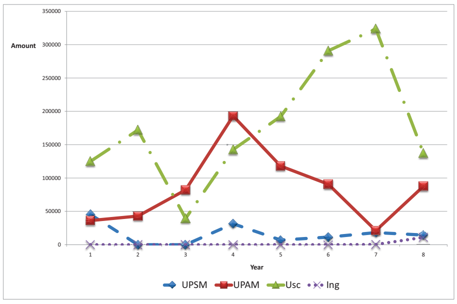
(a) Ministries



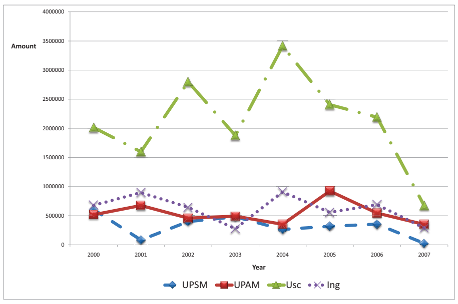
(b) Local authorities



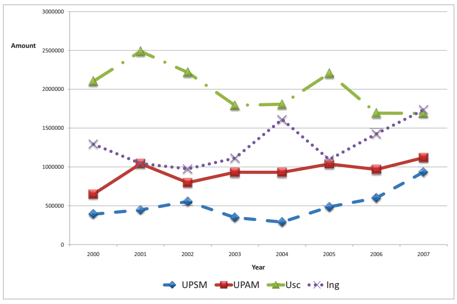
(c) PRO



(d) Associations



(e) International funds



(f) Firms

Figure 2.3: Evolution of mean contractual amount, per establishment from different sources (in million euros). Source: EcS-BETA database

2.3.2 Cluster analysis

We use cluster analysis to identify groups among the observations, and more specifically model-based clustering methods. In model based clustering, it

Table 2.1: Share of funds among the different types of universities

Types of univ	**Min**		**PRO**		**LocAuth**		**Inter**		**Asso**		**Firms**		**ANR**
Year	2000	2007	2000	2007	2000	2007	2000	2007	2000	2007	2000	2007	2007
UPSM	7.9	11.6	2.5	5.7	4.4	20	49.4	1.1	3.7	0.7	32.1	41.7	19.4
UPAM	15.2	7.5	3.6	6	13.4	17.5	29.2	8.8	2	2.2	36.6	28.1	29.9
USc	18.0	15.2	10.4	14.2	4.9	13.5	31.7	10.4	2	2.1	33	26.3	18.3
Ing	18.6	13.7	2.5	3	9.7	20.8	23.8	5.1	0	0.2	45.4	30.5	26.7

Source: EcS-BETA database

is assumed the data come from a population composed of several subpopulations. Each subpopulation (component) is modeled separately and the density of the population is a mixture where each component of the mixture represents a cluster. The distribution of each component is frequently modeled using the normal distribution, characterized by its mean and covariance matrix. Fraley and Raftery (1998, 2007) showed that the model can be estimated with the Expectation-Maximization (EM) algorithm (Dempster *et al.*, 1977). Indeed, the EM algorithm is a procedure used to approach maximum likelihood estimates of parameters in statistical models where the likelihood involves integrals in its expression, and the likelihood of mixture models involves such an integral over the realizations of the mixing distribution.

We use the R software (R Development Core Team, 2010) and the mclust package (Fraley and Raftery, 2007) to perform our analysis. The mclust package allows for numerous parameterizations of the multivariate mixture model. Selection among models, and thus the number of clusters, is performed using the bayesian information criterion developed by Schwarz (1978).

Clusters of universities by funding in 2000

We determine 4 clusters, the averages of which are presented in Table 2.2 and pairwise scatter plots in Figure 2.4. Clusters 1 and 2 are the more numerous and collect the less funds. Cluster 1 has more funds, especially international and from firms, than Cluster 2 which has the lowest average of funds, but the general level of funds remains low. Clusters 3 and 4 regroup the universities raising the most important amounts of funds. Both clusters are quite heterogeneous. Cluster 4 raises on average the most important levels of funds, especially international and ministries funding. There is however a huge variability in the collection of the other types of funds. Cluster 3 collects slightly less funds than Cluster 4, especially from the ministries, and is comparatively more specialized in private funding.

Table 2.2: Descriptives of clusters based on funding in 2000

Cluster	**1**	**2**	**3**	**4**
Average amounts				
Ministries	228 677	38 815	1 040 300	1 335 118
PRO	55 620	5 326	594 640	447 127
LocAuth	58 224	1 880	249 929	903 382
International	837 230	105 205	722 923	2 753 577
Firms	751 322	59 640	3 300 004	1 363 267
Associations	39 396	20 929	7 441	167 512
Nb. of establishments	10	8	5	5

Source: EcS-BETA database

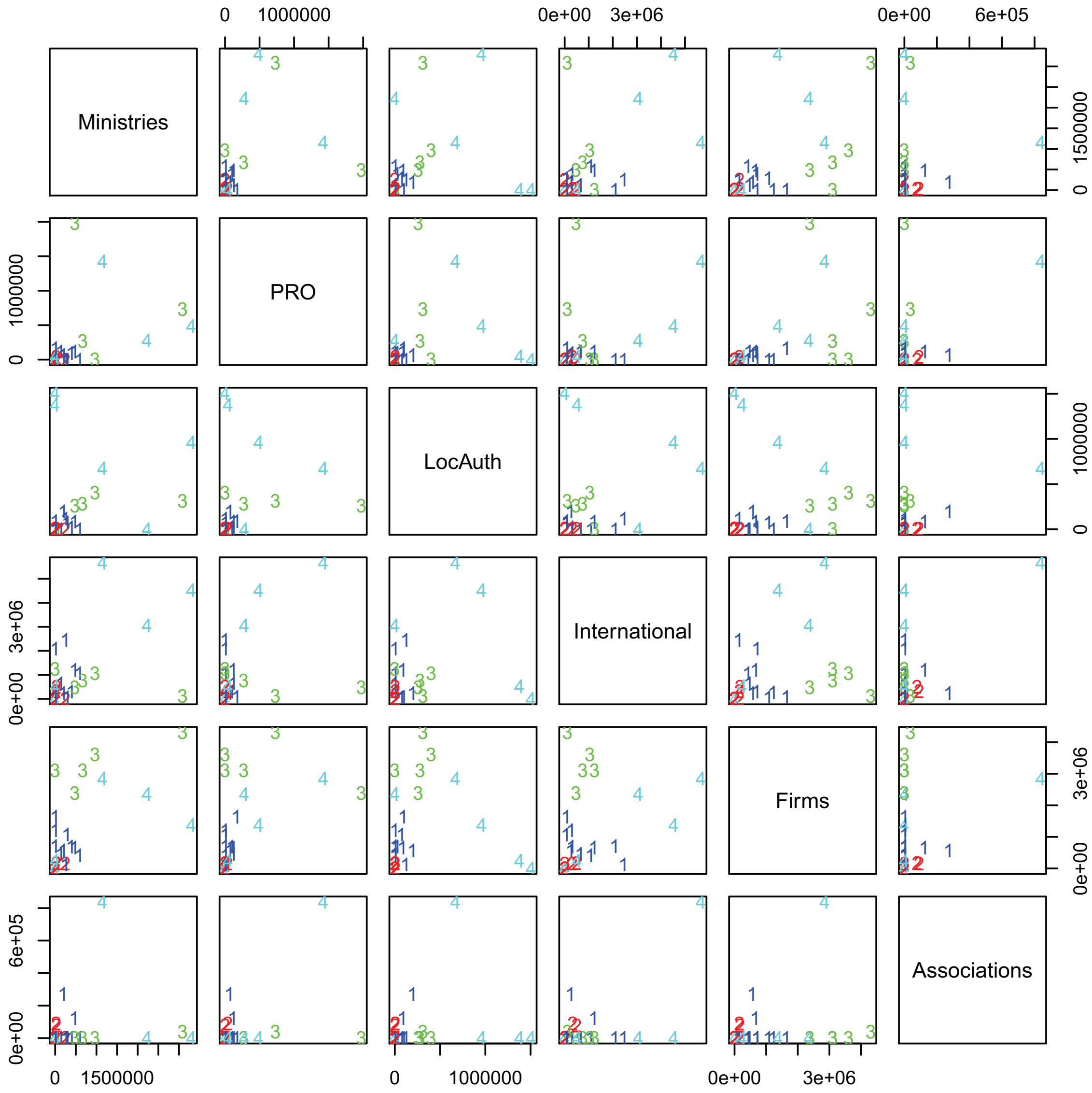


Figure 2.4: Clusters of universities by funding in 2000.
Source: EcS-BETA database

Clusters of universities by funding in 2007

We get 4 clusters again. Their averages are presented in Table 2.3 and pair-wise scatter plots in Figure 2.5. In 2007, clusters are of more equal sizes. As in 2000, Clusters 1 and 2 raise a low level of funds. Cluster 1 distinguishes from Cluster 2 by a higher level of private funds, and for some establishments by a higher level of funds from PROs. Clusters 3 and 4 still collect the most important amounts. They have the highest average of funds from all providers. Both groups are however more homogeneous than in 2000. The level of funds raised from firms is nearly the same for both groups. Cluster 4 is however specialized in huge ANR funding and to a lesser extent in firm funding, whereas they collect only very few funds from other sources. Cluster 3, on the other hand, collects more funds from the ministries as well as local authorities.

Table 2.3: Descriptives of clusters based on funding in 2007

Cluster	**1**	**2**	**3**	**4**
Average amounts				
Ministries	185 065	176 132	1 419 239	379 878
PRO	340 711	207 508	392 938	544 162
LocAuth	282 608	238 629	1 840 263	696 220
International	38 383	261 063	691 522	338 554
Firms	1 188 644	243 147	2 048 594	2 022 500
Associations	10 643	112 625	95 398	33 333
ANR	367 351	495 811	984 508	2 843 301
Nb. of establishments	7	7	8	6

Source: EcS-BETA database

The clusters of 2007 collected more funds than in 2000, even the two groups with the lowest raised amounts. At the other extreme, the two groups characterized by the highest amounts are more specialized in 2007 than in 2000. The joint specialization in firm and ANR funding in 2007, indicated by a concentration of points in the north-east part of the corresponding pairwise scatter plot is to be noted. This explained by the fact that the ANR can provide grants conditionally on partnerships with private firms. Finally, only

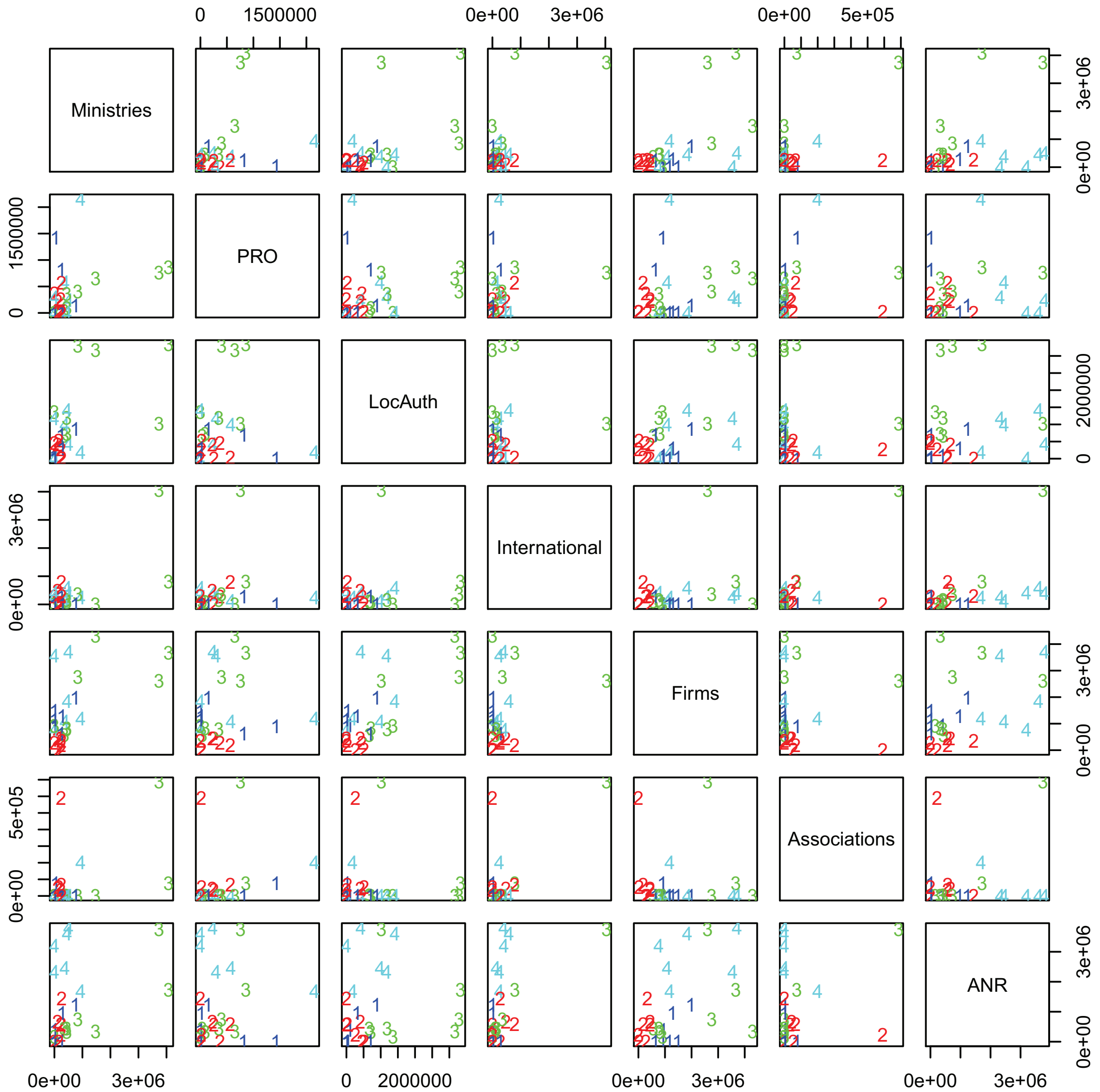


Figure 2.5: Clusters of universities by funding in 2007. Source: EcS-BETA database

one single university collects important amounts of international funds in 2007, contrary to the year 2000 where they were around 3. This is likely to be related to the decrease of international funds over the time period.

2.4. Patents

We analyse in this Section the evolution of the patenting activity of universities. We distinguish 3 types of patents : (i) university owned patents (UOP), where the university is the single owner of the patent, (ii) university co-owned patents (UCOP), where the university is among the owners but not the only one, (iii) other patents (OthP), where researchers from the university are involved but the university is not among the owners.

2.4.1 Evolution of patenting behaviours

Nonparametric kernel density estimates of the distribution of the total number of patents are plotted in Figure 2.6. The distribution is right skewed, with a small number of universities patenting a lot. The median is of 3 patents. Nearly 20% of the universities do not patent at all, and 15% of the universities have more than 10 patents.

Figure 2.7 presents the evolution of the different types of patents over the period 2000-2007. The total number of new patents per year increases, shifting from around 120 in 2000 to 210 in 2007. The number of patents added to the portfolio of the universities (UPPf), which includes only the UOP and UCOP, progresses steadily over time. This is mostly driven by the increase in the number of UCOP, which has been multiplied by more than 2 over the eight years. This expresses probably the increased pressure on universities to co-own patents in which they are involved. The number of UOP remains stationary with even a slight decrease. The evolution of the other patents displays more variability, with however a global increase over

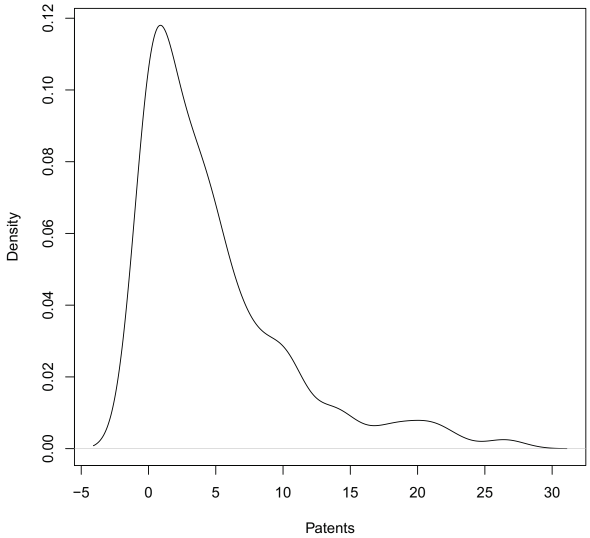


Figure 2.6: Estimated density of the number of patents

the whole time period.

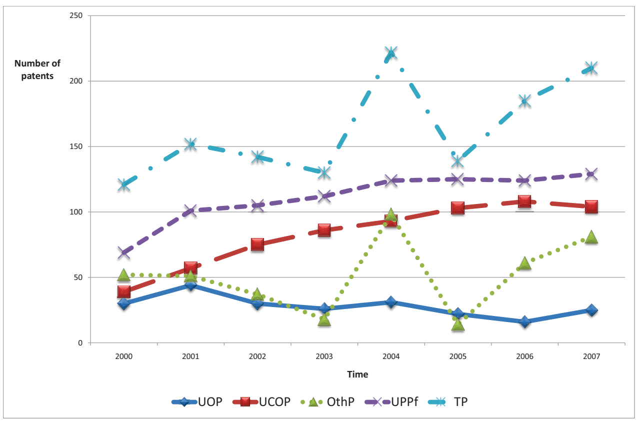
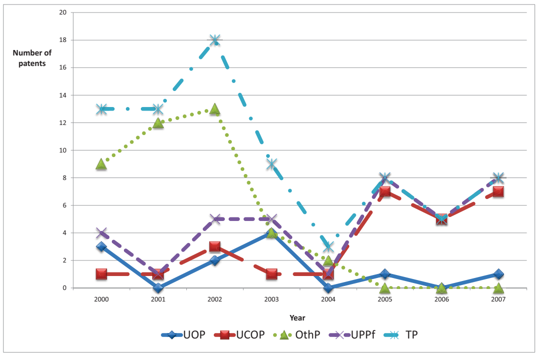
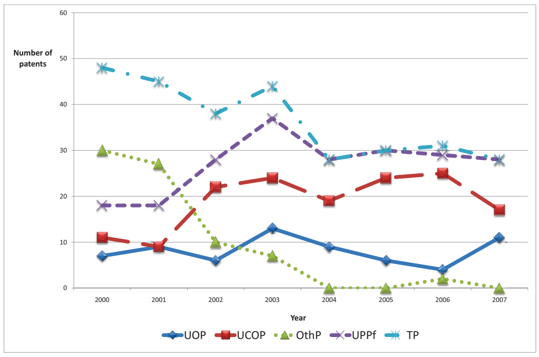


Figure 2.7: Evolution of patenting activities. Source: EcS-BETA database

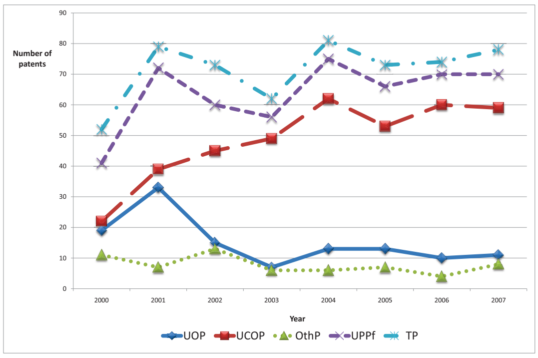
The evolutions of the types of ownership in the different types of universities are displayed in Figure 2.8. There is a similarity in the evolution of the UPSM and UPAM on the one hand and, on the other hand, between the USc and Ing. The total number of new patents decreases for the UPAM and UPSM. However the number of patents added to establishment portfolios still increases. This is due to an important increase of co-owned patents and the decrease of patent ownership left to others (Fig: 2.8a, 2.8b). As regards scientific universities and engineering schools, we observe an increase in both the total of new patents every year and the number of patents added to the establishment portfolio. The co-ownership of patents progressed a lot. On the other hand, there is a slight decrease as regards the UOP and OthP. This corresponds probably to the increased pressure on universities to co-own patents in which the are involved for all types of establishments.



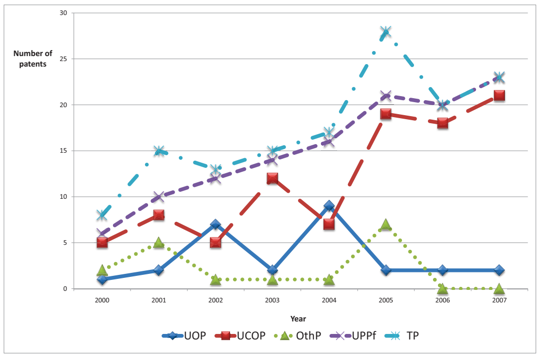
(a) UPSM



(b) UPAM



(c) USc



(d) Ing

Figure 2.8: Evolution of patenting activities in different types of establishments Source: EcS-BETA database

2.4.2 Cluster analysis of patenting behaviour

We perform cluster analysis on patenting behaviour in 2000 and 2007. We use the same methodology as previously for the funding.

Clusters of universities by patents in 2000

For 2000, we determine 3 clusters. In Table 2.4 we present their average and the pairwise scatter plots is presented in Figure 2.9. Clusters 1 and 2 represent more than 70% of the whole population, with a very low number of patents. More specifically, universities belonging to Cluster 2 do not patent at all and those belonging to Cluster 1 patent rarely in all types of patent ownership without distinction. Cluster 3 regroups the universities with the most important patenting activity. Universities belonging to Cluster 3 prefer principally co-patenting and leaving ownership to others. More specifically, except one university which chooses to own alone or to co-own patents, universities belonging to this cluster are specialized in one type of behaviour, co-patenting or leaving the ownership. This can be seen as all the points are located close to one of the axes.

Table 2.4: Descriptives of clusters based on patenting in 2000

Cluster	**1**	**2**	**3**
Average nb. of patents			
UOP	1	0	2
UCOP	1	0	4
OthP	1	0	4
Nb. of establishments	11	9	8

Source: EcS-BETA database

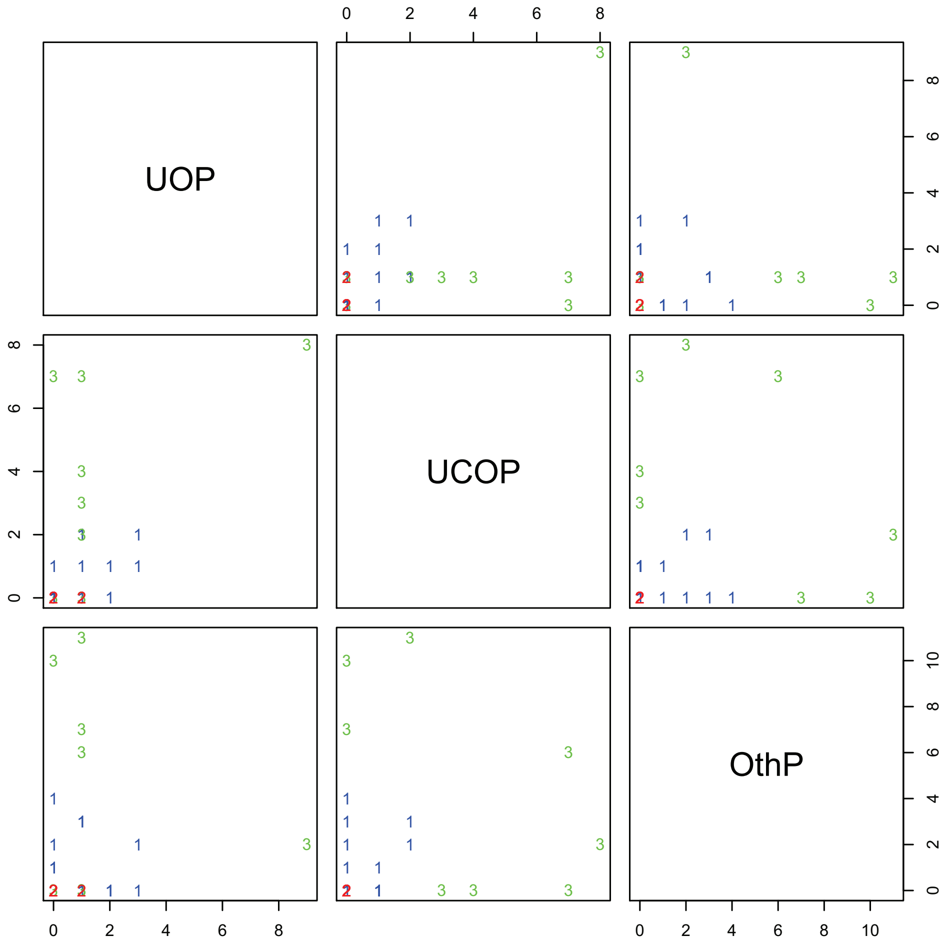


Figure 2.9: Clusters of universities by patents in 2000.
Source: EcS-BETA database

Clusters of universities by patents in 2007

For 2007, we get 3 clusters, the averages of which are presented in Table 2.5 and pairwise scatter plots in Figure 2.10. Cluster 1 is composed of 23 establishments patenting rarely and preferring co-ownership. They do not leave the ownership to others. The second cluster is made of 3 establishments with a higher level of patenting, and they prefer co-patenting. Cluster 3 is composed of the two most prolific establishments, preferring to be co-applicants either by keeping the ownership or by leaving the ownership.

Table 2.5: Descriptives of clusters based on patenting in 2007

Cluster	**1**	**2**	**3**
Average number of patents			
UOP	1	0	4
UCOP	2	9	16
OthP	0	1	3
Number of establishments	23	3	2

Source: EcS-BETA database

78% of the universities belonging to clusters 1 or 2 in 2000 moved to cluster 1 in 2007. This means that a vast majority of the universities in 2007 patent a little, but the most important change is that they do no longer leave the ownership. In fact, they prefer co-ownership.

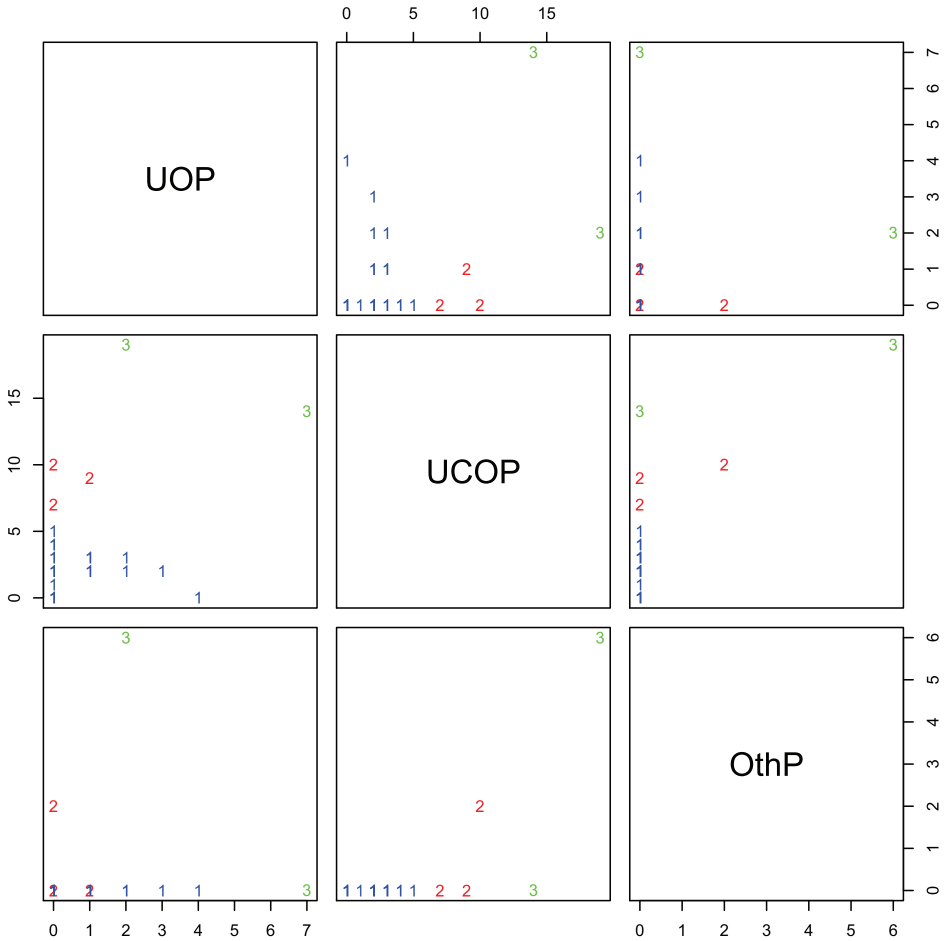


Figure 2.10: Clusters of universities by patents in 2007. Source: EcS-BETA database

2.5. Publications

We observe the total number of publications corrected for co-authorship in each university between 2003 and 2007. We analyse the evolution of the publication activities of the universities over this time period. We distinguish 9 research areas : fundamental biology (FunBio), medical research (Med), applied biology and ecology (AppBioEco), chemistry (Chem), physics (Phy), earth science and astronomy (EarthSc), engineering science (EngSc), mathematics (Math) and multi disciplinary (MultiDisc).

Figure 2.11 displays a kernel density estimate of the distribution of the total publications per university over the whole time period. As for funds and patents, we observe a right skewed distribution, with a small number of universities publishing a lot. The distribution is multimodal, with a major mode at 140 corrected publications in one year, a first minor mode at 1540 and a second minor mode at 3030.

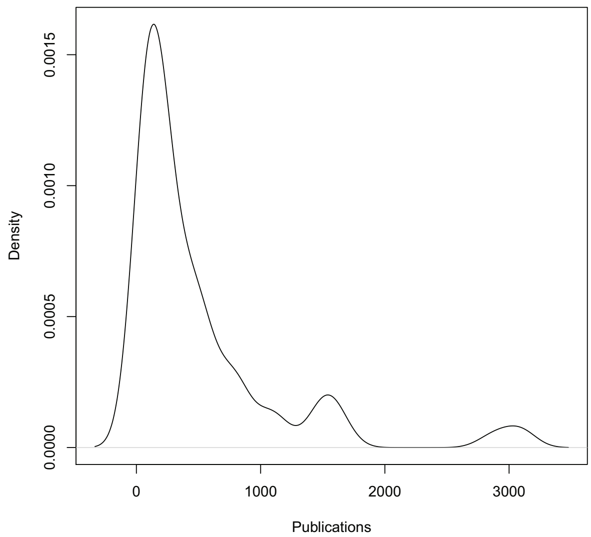


Figure 2.11: Estimated density of the total number of publications

The dynamics of the total number of publications by type of establishment is plotted in Figure 2.12. We observe that the publication level is constant for UPSM. Concerning the UPAM and the USc we observe a decrease followed by an increase, but the whole pattern is globally flat. Ing publications increase slowly during the whole time period. All in all, the variations are of a low magnitude and USc publish 3 to 9 times more than the others. This last result is obtained without controlling for the size of the universities.

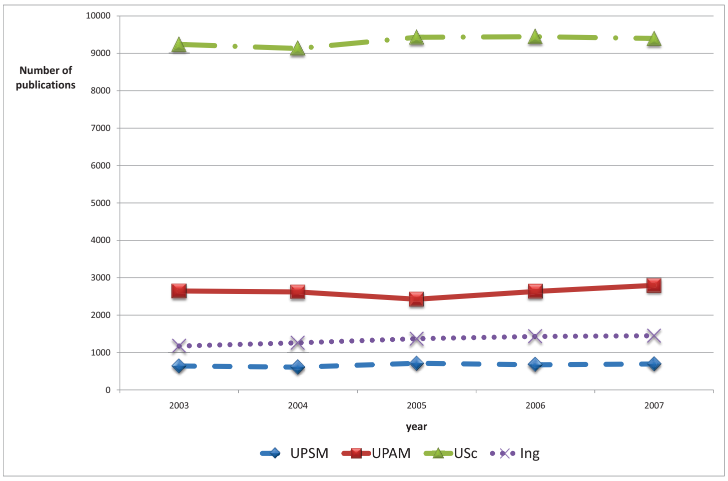


Figure 2.12: Evolution of publications activities by university types. Source: OST

Figure 2.13 displays the evolution of the number of publications in different fields. We observe that publications in the medical research area are the most numerous and constant, with more than 3000 publications each year. We observe a decrease followed by an increase in engineering sciences and earth science and astronomy. Conversely the publication level decreases and increases in fundamental biology and chemistry. The observed variations are not of an important magnitude. For all disciplines except for the multi disciplinary publications, the level in 2007 is higher than the level in 2003.

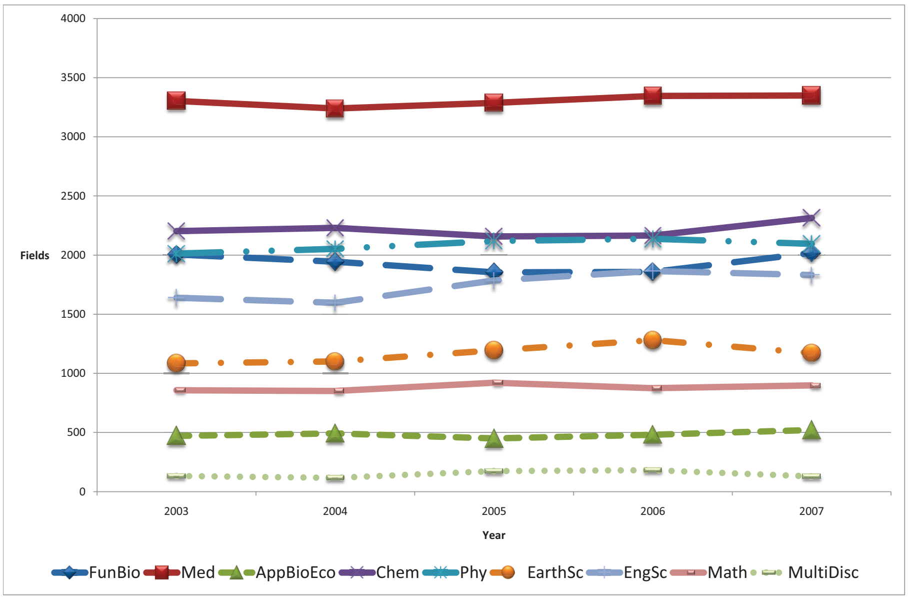


Figure 2.13: Evolution of publications activities by disciplines. Source: OST

2.6. Cluster analysis by funding and patenting profile

We use cluster analysis to identify groups of universities, with different behaviours in patenting and funds raising activities.

2.6.1 Cluster analysis by funding and patenting profile in 2000

We get 3 clusters in 2000. We presented in Table 2.6 their average and in Figure 2.14 their pairwise scatter plots. Cluster 2 has the lowest average contractual funds, and the lowest average number of patents. We note that all the universities belonging to this cluster have a very low amount of contractual funds. However, two of them co-patent a lot and increase the average number of patents of the whole cluster, whereas the others do not patent much. Cluster 1 raises a higher amount of funds, principally private funding. They also prefer leaving the patent ownership. It seems that there is a correlation between the number of the patents left and the amount of private funds raised. Cluster 3 is composed of establishments patenting frequently, with a specialization in different types of patent ownership. This cluster raises funds from all sources.

Table 2.6: Descriptives of clusters based on funding and patenting in 2000

Cluster	**1**	**2**	**3**
Average nb. of patents			
UOP	1	0	2
UCOP	0	2	2
OthP	3	1	2
Average amounts			
Ministries	230 068	39 873	1 010 388
PRO	61 800	6 087	434 070
LocAuth	51 905	1 712	490 392
International	481 765	48 847	1 826 552
Firms	761 603	43 951	2 012 050
Associations	52 352	12 890	72 897
Nb. of establishments	9	7	12

Source: EcS-BETA database

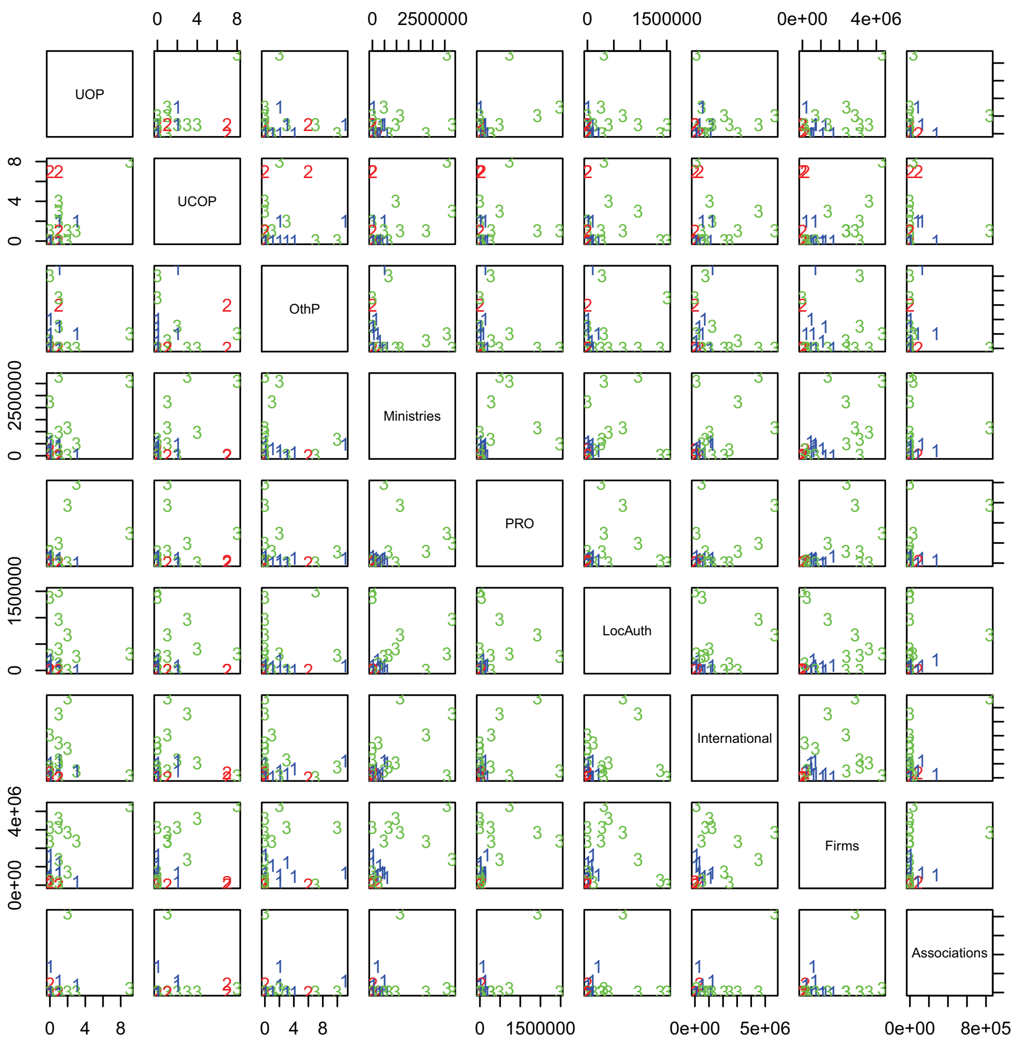


Figure 2.14: Clusters of universities by funding and patenting in 2000. Source: EcS-BETA database

2.6.2 Cluster analysis by funding and patenting profile in 2007

For 2007, we get 3 clusters. Their averages are presented in Table 2.7 and pairwise scatter plots in Figure 2.15. Cluster 1 has the lowest average contractual funding and patenting level. Their principal fund providers in decreasing order are: firms, local authorities and ANR. Cluster 2 is specialized in funds provided by the ANR and firms, and has an intermediate level of patents in co-ownership. This cluster is heterogeneous in terms of funding profile. Cluster 3 raises the most important average amount of funds of all types. Made of 2 universities, it has the highest patenting score. Those two universities have a similar level of funds provided by the ministries, PROs, firms. They diverge concerning funds provided by local authorities, international sources, associations and the ANR. One establishment is specialized in funds provided by local authorities and the second in the others (international, associations and ANR).

Table 2.7: Descriptives of clusters based on funding and patenting 2007

Cluster	**1**	**2**	**3**
Average nb. of patents			
UOP	1	1	2
UCOP	1	5	14
OthP	0	0	3
Average amounts			
Ministries	196 210	467 012	3 905 233
PRO	195 415	491 303	807 280
LocAuth	460 040	980 006	2 173 727
International	173 788	198 975	2 419 439
Firms	647 380	1 934 410	3 135 025
Associations	14 275	72 086	380 590
ANR	423 714	1 631 648	2 733 115
Nb. of establishments	14	12	2

Source: EcS-BETA database

The cluster with the lowest patenting activity gets more funds in 2007 than in 2000. The cluster specialized in private funds prefers co-ownership in 2007 as opposed to 2000 when they preferred to leave the ownership. In

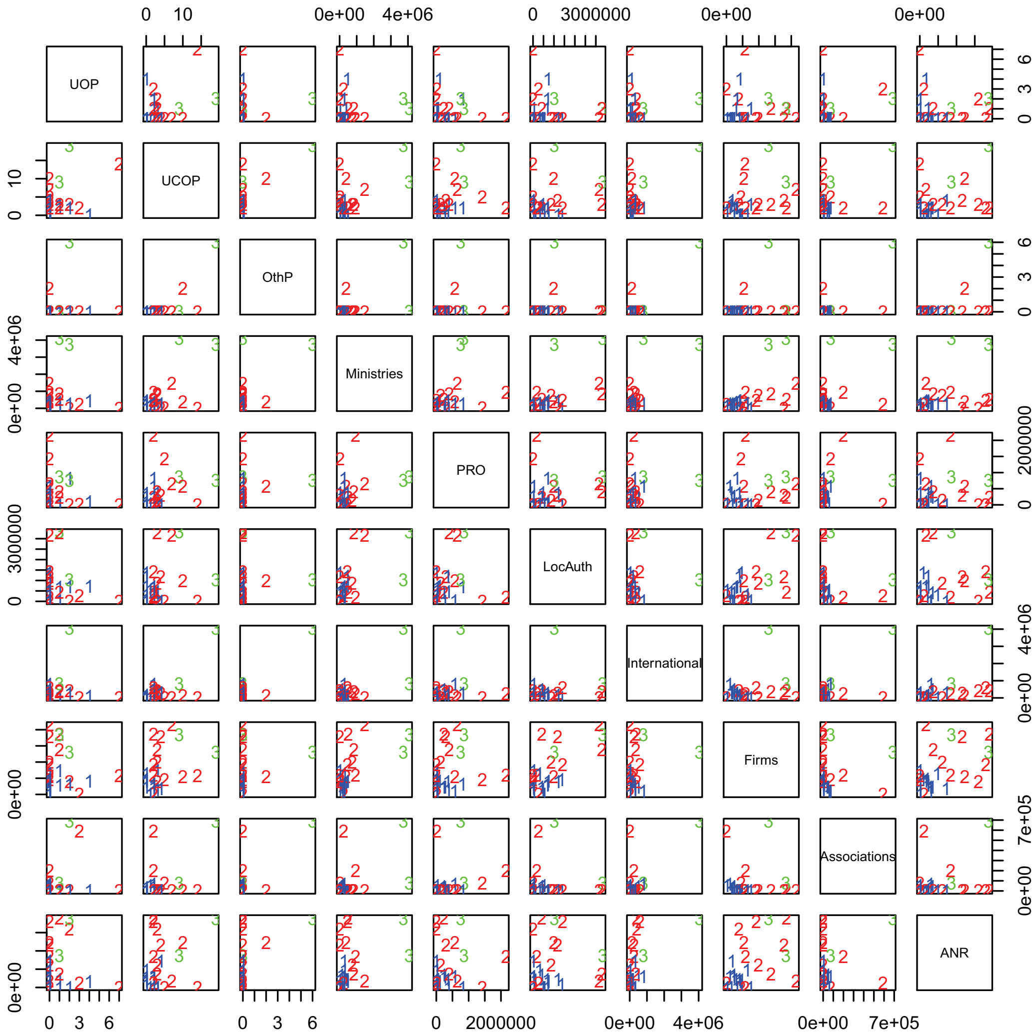


Figure 2.15: Clusters of universities by funding and patenting in 2007. Source: EcS-BETA database

addition, they get on average twice more private funds in 2007, with the ANR as the principal source of funding.

2.7. Cluster analysis by funding and publication profile

We use cluster analysis to identify groups among universities, presenting different types of relationship between publication and fund raising activities.

2.7.1 Cluster analysis by funding and publication profile in 2003

We get 4 clusters in 2003. Their averages are presented in Table 2.8 and pairwise scatter plots in Figure 2.16. Cluster 1 is composed of 6 universities with the lowest average publication level and also the lowest average amount of contractual funds. It is a very homogeneous group in terms of publications and funding, as opposed to the other clusters. Cluster 3, composed of 9 universities, has the highest publication average and the highest average contractual funds level. Their contractual funds profile is heterogeneous. Two universities raise a large amount of international funds, one university raises funds from PROs, and another one from private providers. Their publication level is also very heterogeneous. Clusters 2 and 4 have an intermediate number of publications. Moreover, Cluster 4 has a very low level of contractual funds with a peak for two universities on funds from associations. Cluster 2 collects a high average amount of contractual funds. More specifically, they are specialized in funds provided by firms and raise also high amounts from the ministries, local authorities and international sources.

Table 2.8: Descriptives of clusters based on funding and publications in 2003

Cluster	**1**	**2**	**3**	**4**
Average nb. of publications				
Publications	152	530	704	458
Average amounts				
Ministries	110 151	743 755	1 564 619	335935
PRO	77 294	294 032	669 609	85323
LocAuth	105 479	536 890	141 292	187216
International	154 917	519 196	1 395 448	794748
Firms	170 256	1 971 324	1 497 345	264442
Associations	50 174	23 294	36 738	322725
Nb. of establishments	6	7	9	6

Source: EcS-BETA database and OST

2.7.2 Cluster analysis by funding and publication profile in 2007

For 2007 we identify three clusters. In Table 2.9 we present their averages and the pairwise scatter plots is presented in Figure 2.17. Cluster 1 has the lowest publication and contractual funding level. The main fund providers of cluster 1 are firms. They also raise an intermediate level of funds from research organizations and local authorities. However compared to the other groups, the amount collected is still fairly low. Cluster 2 is ranked second in terms of average number of publications. This cluster is extremely heterogeneous in terms of both publication levels and funding profiles. Some establishments present a specialization on funds provided by the ANR and firms. We observe also a negative relationship between the publication level and the level of funds provided from those 2 sources, particularly for the ANR. In Cluster 3 publications and funds are extremely high. Composed of 3 universities, they have the highest averages of publications and funding from the min-

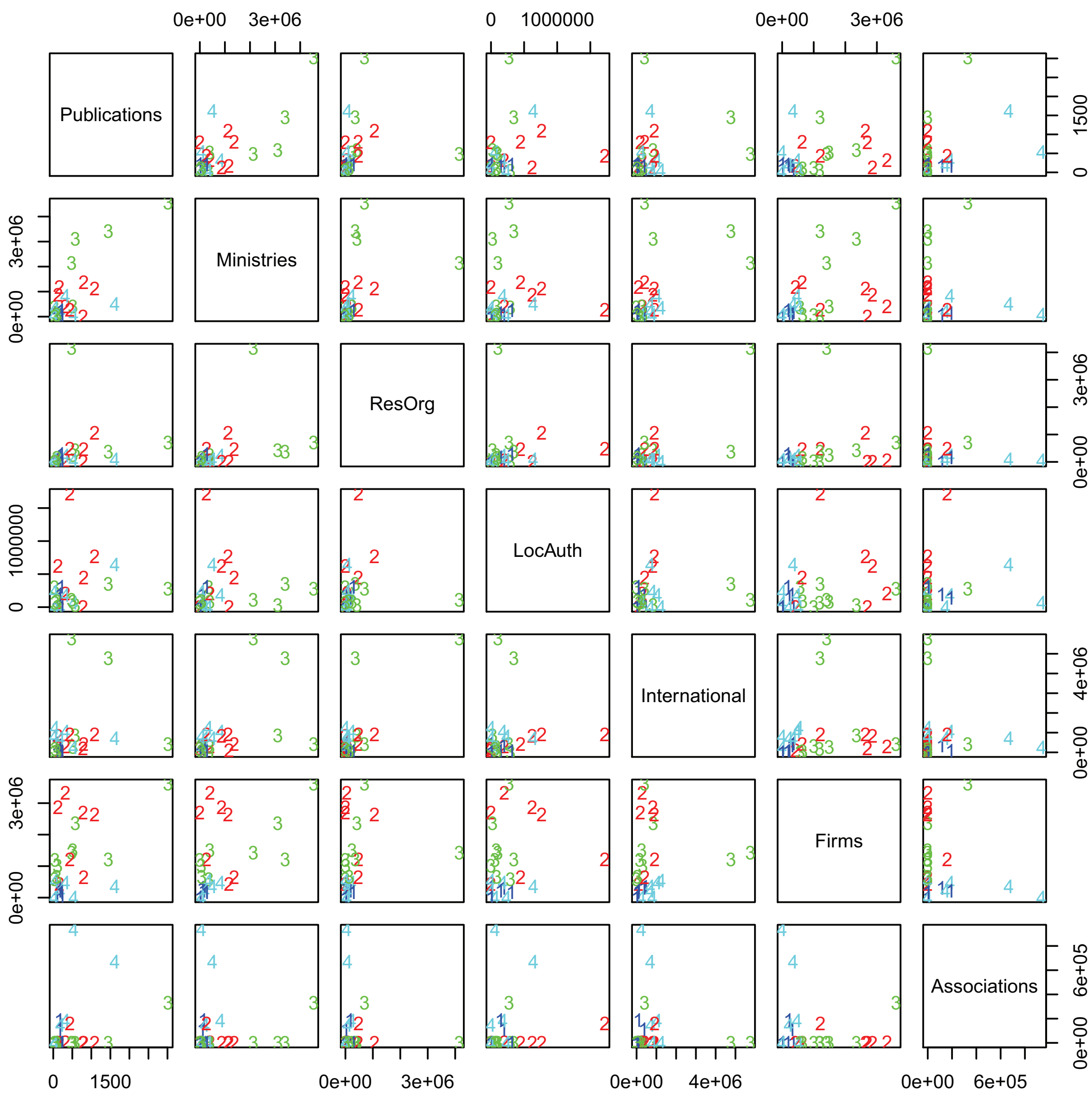


Figure 2.16: Clusters of universities by funding and publication in 2003. Source: EcS-BETA database and OST

istries, PROs, international organizations, firms, associations and the ANR. However, the publication level of two universities of this cluster is not high, and the average is actually driven by only one university. Each university in this group of 3 is the principal fund recipient among universities for one type of funds: (i) international organizations, associations and ANR for the most prolific university in terms of publications, (ii) ministry and local authorities for the second one (iii) and associations for the last one.

Table 2.9: Descriptives of clusters based on funding and publications in 2007

Cluster	**1**	**2**	**3**
Average nb. of publications			
Publication	138	687	1250
Average amounts			
Ministries	187 796	450 667	2 683 110
PRO	113 193	558 185	543 761
LocAuth	477 201	939 167	1 537 501
International	114 827	264 832	1 612 959
Firms	688 266	1 847 465	2 090 017
Associations	11 030	26 307	450 570
ANR	446 256	1 533 311	1 896 630
Nb. of establishments	12	13	3

Source: EcS-BETA database and OST

The clusters in 2007 collected more funds than in 2003, even the two clusters (1 and 4) with the lowest amounts raised in 2007. The cluster specialized in private funding is more numerous in 2007 than in 2003. Furthermore, firm funding is combined with ANR funding.

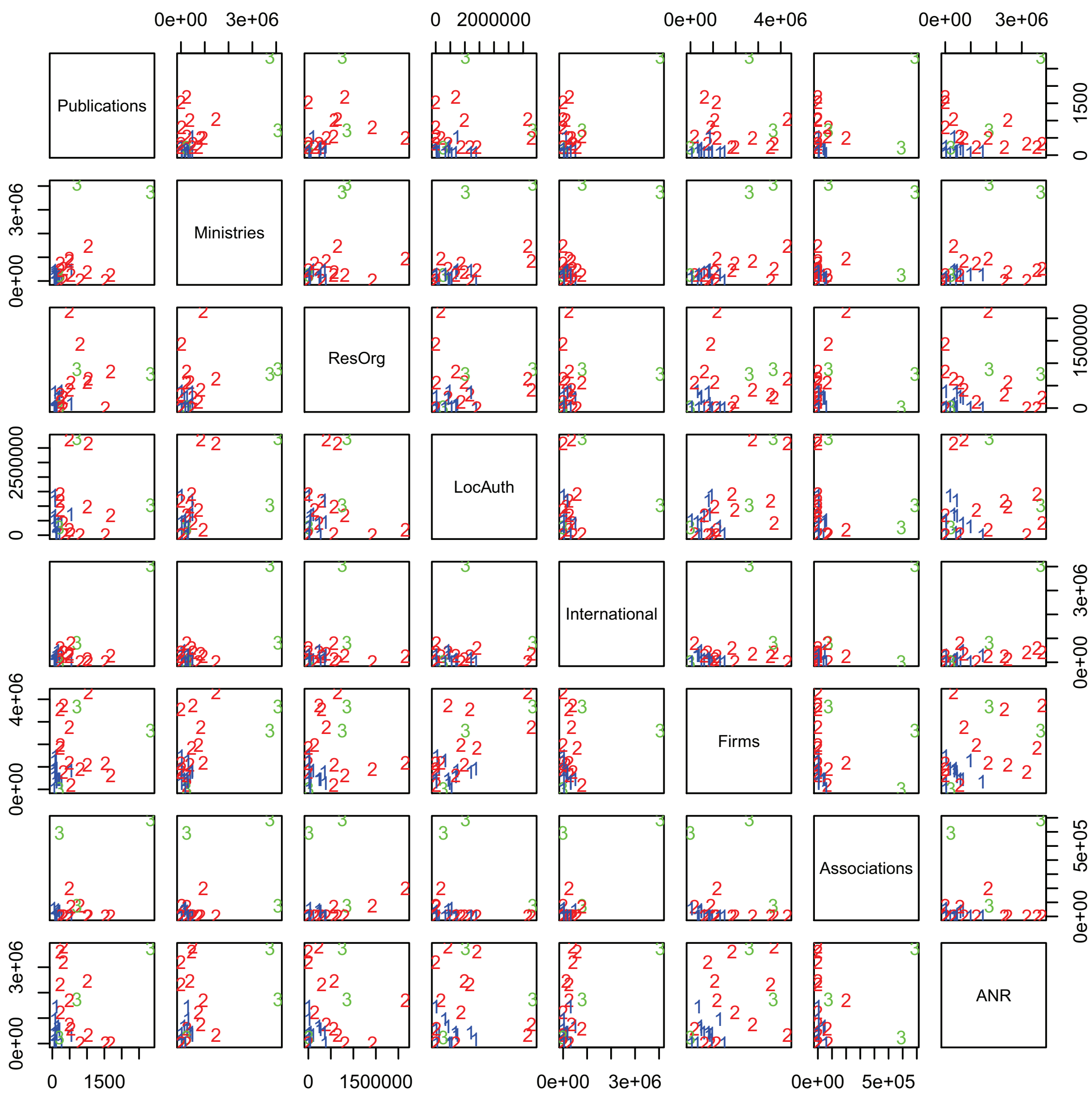


Figure 2.17: Clusters of universities by funding and publication in 2007. Source: EcS-BETA database and OST

2.8. Conclusion

In this paper we focus on the evolution of funding, publications and patenting activities of 28 French universities. We observe first a huge heterogeneity in the evolution of the different types of funds, with an important decrease of international funding balanced by an increase of funds provided by local authorities and the ANR. We further observe an increase in the specialization in a few particular sources of funding, with a notable specialization in firms and ANR funding.

We investigate the evolutions of two types of outputs. The patenting activity increased over the whole time period. This increase is also heterogeneous across universities, with a decrease for the UPAM and UPSM and an increase for the Usc and Ing. All the universities nowadays have a patenting activity, and keep the ownership partially or totally. Publications remain globally stable over the years 2000.

The joint analysis of the inputs and outputs seems to indicate a negative relationship between publications and ANR funding and a positive relationship between patenting ownership lets and firms funding.

These results raise several questions. First, the multiplication of the types of funds raises the issue of the complementarity or substitutability between the new types and the preexisting ones. Second, it seems there is a negative relationship between the ANR and publications in a given year. This raises some questions on the way the ANR provides funds. This point clearly deserves some more investigations as the ANR is currently the most important project based funding agency in France.

Chapter 3

Complementarity-Substitutability of Funding of Public Research

Abstract

In this paper, we analyse the substitutability of private and public funds in the production of public research. The output is measured by publications. We first provide a theoretical model of research production, and deduce the consequences of a shock on the availability of funds on the optimal behaviour of labs under different levels of substitutability between funds. Optimal reactions depend on the substitutability level between funds. There is a crowding-in relationship between recurrent and private funds whatever the substitutability level. However, public contractual funds crowd-in private funds only when they are greatly gross complement. In other cases, there is a crowding-out relationship. Private contractual funds have two different effects on the total of public funds, depending on the level of substitutability. There is a crowding-in effect when both public and private funds are gross complements, and a crowding-out effect when both are gross substitutes.

We further estimate a constant elasticity of substitution production function, based on a singular database on the University of Louis Pasteur. Our results reject hypothesis of perfect substitutability and complementarity between public and private funds. They also indicate a higher contribution of public funds to production. In addition, the results indicate a gross substitutability between public contractual and private funds.

3.1. Introduction

Few studies investigate the relationship between public and industrial funding or private donations of PROs. Those analyses focus on the question of whether public and private funds are substitutes or complements. Diamond (1999) is one of the first analyses, using annual aggregated data from 1953 to 1995. He focused on the impact of a change in expenditure at the federal level on spending of (a) non-profit organization and (b) private firms. He concluded to crowding-in effect between federal and industry spending. More recently, Payne (2001) developed a research production function made of a composite set of goods and allowed for a spillover effect of federal public funding on private donations. To control for endogeneity and an omitted variables bias resulting from an OLS estimation, she performed an instrumental variables estimation. She found a positive relationship between federal research funding and private donations. An increase of one dollar of federal funding induced an increase of private donation of 0.65 cents. Gaughan and Bozeman (2002) showed that NSF research centers grants increased the probability to obtain grants from industry. Blume-Kohout *et al.* (2009) analysis based on 272 U.S. universities found evidence of a positive relation between federal and non-federal funding (private, state, local government and others). An increase of 1$ in federal funding induced an increase of 0.33$ in non-federal funding. They also showed that the impact was higher for universities ranked low and universities receiving less funding historically. This result was interpreted as a possibility that non federal funders considered federal spending as a signal of quality of the recipient. Boumahdi and Carayol (2005) developed a theoretical model which predicted a crowding-out effect between public and private funding. As far as we know, their work was the first and the only attempt to introduce agents' strategies. However, the specification of the research output as an additive function of funds, naturally leads to the the crowding-out conclusion between public and private funds. Their analysis at laboratory level based on 76 labs of ULP between 1993-2000 concluded to a crowding-out effect between public and private funds.

Those analyses, except the last one, do not take into account the fact that researchers should put efforts and time to collect funds. The complementarity or substitutability between different kinds of funds does not just depend on funders but also on the decision of the researchers to spend time applying and collecting funds. It depends also on their perception of how funds are combined to reach their objectives.

We propose here a model describing the production of research output using two different types of funds.[1] We distinguish two sources of funds in our model: public and private funds. Indeed public and private funds exhibit different eligibility, monitoring criteria and do not give access necessarily to the same consumables and machinery. We specify a Constant Elasticity of Substitution (CES) production function developed by Arrow *et al.* (1961), so that our model allows for extreme cases from gross complementarity to gross substitutability between public and private funds. We assume that the time available for research or to raising funds is finite. Thus the laboratories (labs) maximize their research output subject to a time constraint. We study how

[1] Indeed to produce research output, labs need to put efforts on research. These efforts can be made more efficient with an access to consumables. To finance additional equipments and/or staff labs have to raise funds.

time is re-allocated after a shock on the availability of the different types of funds between the efforts dedicated to raise funds (whether they are public or private) and research. We estimate our model using a database on labs of the Louis Pasteur University of Strasbourg (France).

The paper is organized as follows. In section 3.2, we present the theoretical model and the consequences of a shock on the availability of funds. Section 3.3 describes the data used in our study. The results are discussed in Section 3.4.

3.2. A model for research output

We first present the theoretical model in subsection 3.2.1 and in subsection 3.2.2 we present the optimum and analyze the consequences of shocks on the availability of funds.

3.2.1 Research production function

Our theoretical model analyzes the production of research output. Labs maximize the research output under the following production function:

$$R = \delta h(e_r) f(x, y), \tag{3.1}$$

where R is the research output[2], δ ($\delta > 0$) is the quality of the lab and h a function of the research effort e_r. Function h is assumed to be continuous, twice differentiable, increasing weakly and concave over $\mathbb{R}_+$: $(h^{'}(e_r) > 0, h^{"}(e_r) \leq 0, \forall e_r \geq 0)$. Function $f(.)$ depends on the total amount of funds received from public organizations, denoted by x, and the total amount of funds raised from the private sector, denoted by y. Function f is of the CES family. Function f can be written as follows:

$$f(x,y) = \left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}}. \tag{3.2}$$

Or equivalently, with $-\rho \equiv \frac{\sigma-1}{\sigma}$:

$$f(x,y) = \left[\alpha x^{-\rho} + (1-\alpha)y^{-\rho}\right]^{\frac{-\omega}{\rho}}, \tag{3.3}$$

Parameter $\alpha \in (0,1)$ determines the distribution of inputs, $\omega \in (0,\infty)$ measures the return to scale and $\sigma \in (0,+\infty)$ is the elasticity of substitution between the two inputs. This functional form allows us to model different levels of substitutability, from gross complementarity ($\sigma \in (0,1)$) to gross substitutability ($\sigma > 1$).

One can rewrite equation (3.1) as:

$$R = \delta h(e_r)\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}}. \tag{3.4}$$

[2]The scientific process produces several research outputs generally classified into three categories. The first one is new knowledge the second is highly qualified human resources and the third is new technologies (Crespi and Geuna, 2006). In this paper we focus on the first type of research output, the knowledge production which is the most closely related to the funding of research.

Therefore, the research output depends on a function h of the research effort and on a function f of financial inputs.

Public funds

The lab members share their time between research and fund raising activities. The time, also called effort, devoted to raising public contractual funds is denoted by e_x, whereas the parameter φ_x denotes the relative availability of public contractual funds and a the level of recurrent public funds. The amount of public funds received is defined as follows:

$$x \equiv x(e_x; a, \varphi_x) = a + \varphi_x e_x^{\eta}. \tag{3.5}$$

The amount of funds received from public actors increases concavely with the effort e_x spent to raise public funds ($\frac{dx}{de_x} > 0, \frac{d^2x}{de_x^2} < 0$). This is due to the fact that the more lab members invest efforts to raise public contractual funds, the more funds they will get. The marginal return of the fund raising effort is decreasing.

The relative availability of national public funds measures the easiness to obtain public funds. The amounts received from public actors increase with their availability ($\frac{dx}{d\varphi_x} > 0$) and the effort ($\frac{d^2x}{d\varphi_x de_x} > 0$). In other words, the more funds are available and the more researchers put efforts for raising funds, the more they will get.

Private funds

Researchers use a part e_y, of their time to raise an amount y of private funds. We assume that y is a function of the effort e_y, and of the distance between the private fund provider's research interests and the lab research issues denoted by φ_y. In other words parameter φ_y measures the relative abundance or accessibility of private funds to the laboratory.

$$y \equiv y(e_y; \varphi_y) = \varphi_y e_y^{\mu}. \tag{3.6}$$

The amount received from private firms increases concavely with effort e_y ($\frac{dy}{de_y} > 0, \frac{d^2y}{de_y^2} \leq 0$), increases with their availability ($\frac{dy}{d\varphi_y} > 0$) and with the effort ($\frac{d^2y}{d\varphi_y de_y} > 0$). The marginal return of the fund raising effort is decreasing.

3.2.2 Characterisation of the optimum

We will analyses the optimum and consequences of a shock, a variation on the availability of different types of funds on the behaviour of the labs.

We maximize the production function of labs subject to a time constraint. Members of labs maximize their research output by using the time allocated to raise public and private contractual funds and the time used to do research. Time is finite and the time constraint is normalized to one ($e_x + e_y + e_r = 1$). The program of labs is therefore given by:

$$\max_{e_x,e_y,e_r} \delta h(e_r)\left[\alpha x^{\frac{\sigma-1}{\sigma}} + (1-\alpha)y^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\omega\sigma}{\sigma-1}}, \tag{3.7}$$
$$sc \quad : \quad e_x + e_y + e_r = 1.$$

Computation of the First Order Conditions (FOC) is given in Appendix A1. After some simplifications, the FOC gives us the following set of conditions:

$$\alpha\frac{x'}{x^{(\frac{1}{\sigma})}} = (1-\alpha)\frac{y'}{y^{(\frac{1}{\sigma})}}, \tag{3.8}$$

$$\omega\alpha\frac{x'}{x^{(\frac{1}{\sigma})}}\frac{1}{\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]} = \frac{h'(e_r)}{h(e_r)}, \tag{3.9}$$

$$\omega(1-\alpha)\frac{y'}{y^{(\frac{1}{\sigma})}}\frac{1}{\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]} = \frac{h'(e_r)}{h(e_r)}. \tag{3.10}$$

From this set of constraints, we obtain the optimal amount (x^*, y^*) of funds raised. We study how shocks on the availability of each type of funds affect the time allocation. The analysis is performed under different levels of substitutability of the funds. We will first focus on gross complementarity between public and private funds ($\sigma \in (0,1)$). Then we focus on the Cobb-Douglas case ($\sigma = 1$). Finally, we focus on gross substitutability ($\sigma > 1$).

Consequences of a shock when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

We focus here on the case of gross complementarity ($\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$) between public and private funds. Labs need both to produce output. FOC are given by sets of equations (3.8), (3.9) and (3.10). When public and private funds are gross complements, a positive (negative) shock on the availability of public contractual funds φ_x induces two types of reactions. Because of complementarity in the use of the two types of funds, the two feasible reactions include an increase in the level of efforts to get private funds and, because of the time constraint, a decrease (increase) in the research effort e_r. The two feasible equilibria are:

- In a first setting corresponding to solution 2 in Appendix A2.1, labs keep e_x constant, increase e_y and decrease e_r. More specifically, the time constraint $e_x + e_y + e_r = 1$ induces $\Delta e_y = -\Delta e_r$. To sum up, the increase in the availability of public contractual funds induces an increase in the time allocated to gather private funds, and finally a decrease of the research effort. As a consequence the total amount of public and private funds raise increases. It should be noted that the overall impact on the research output depends on functions h and f. Research activities asking for huge material investment are expected to still increase their research output.

- In a second setting corresponding to solution 3 in Appendix A2.1, labs decrease e_x, increase e_y and decrease e_r. The total amount of public funds still increases due to the positive shock, but less than in the previous case. This equilibrium comes with an increase of e_y, and thus an increase in the total amount of private funds raised. However, the variation of e_y is smaller than in the previous case : it does not need to "compensate" exactly the increase in public funds. In the end, the research effort is still reduced but less than in the previous case. When the research production relies more on research efforts than on funds, this strategy is expected to be more appropriate than the preceding one.

Proof. (Appendix A2.1) ■

Consequences and reactions to a shock on the availability of recurrent funds a are the same as shocks on the availability of public contractual funding: an increase of recurrent public funds induces an increase of efforts to raise private funds and a decrease of research efforts. The effort to raise public funds remains constant or decreases. In the second case the decrease of the research effort is smaller.

Proof. (Appendix A2.2) ■

Consequences and reactions to a shock on the availability of private funds are symmetric to consequences of a shock on the availability of public funds (whether on contractual or recurrent funds). Thus when a positive shock occurs on the availability of private funds, there are two possible cases.

The first reaction is when one faces research activities asking for huge material investment. To maximize the research output, an increase of the availability of private funds induces an increase of the effort to raise the complementary type of funds, public funds, and thus a decrease of the time allocated to the research effort.

The second type of reaction is connected to a research production relying more on research efforts than on funds, comparatively to the previous case. Thus after a positive shock on the availability of private funds, the research effort decreases less and the total amount gets a lesser increase as well.

Proof. (Appendix A2.3) ■

To sum up, when ($\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$), the optimal reaction on the reallocation of time after a shock on the availability of funds induce a crowding-in effect between public and private funds.

Consequences of a shock when $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$

We are here still in the gross complementarity setting, with however more substitutability than in the preceding settings.

Consequences and reactions to a shock on the availability of contractual public funds induce two types of reactions. The two feasible reactions include an increase of the effort to get contractual public funds, and because of the time constraint, a decrease of the research effort, e_r. The two feasible reactions are:

- In a first setting corresponding to solution 1 in Appendix A3.1, labs increase e_x, keep e_y constant, increase e_x and decrease e_r. More specifically, the time constraint $e_x+e_y+e_r = 1$ induces $\Delta e_x = -\Delta e_r$. To sum up, the increase in the availability of contractual public funds induces an increase in the time allocated to gather public funds, and finally a decrease of the research effort. As the overall impact on the research production depends on functions h and f. Research activities asking for huge material investments are expected to still increase their research output.

- In a second setting corresponding to solution 3 in Appendix A3.1, labs increase e_x decrease e_y and e_r. The total amount of public funds increases but less than previously and the total amount of private funds decreases. In the end, the research effort is still reduced but less than in the previous case. When research production relies more on efforts than on funds, this strategy is expected to be more appropriate than the preceding one.

Proof. (Appendix A3.1) ■

Thus when ($\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$), the appropriate reaction to an increase in the availability of public contractual funds induces a crowding-out of private funds.

When $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$, the consequences and reactions to the shocks on the availability of recurrent public and private funds are the same as when public and private funds are gross complements ($\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$). Thus when a positive shock occurs on the availability of recurrent public funds a, labs react by increasing the effort they make to get contractual private funds e_y, they decrease their research effort e_r and keep constant or decrease, e_x, the time allocated to raising public funds.

If the shock is on the availability of private funds in the two feasible cases labs will increase their efforts to get contractual public funds e_x. The effort to raise private funds e_y remains constant or decreases. Thus the level of public and private funds raised will increase in the two cases but more in the first case. The research effort e_r decreases in the two cases but more in the first one.

Proof. (Appendix A3.2) ■

When ($\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$), an increase in availability of recurrent public funds (respectively contractual private funds) induces an increase of the level of private (respectively public) funds. In this case there is a crowding-in effect between public recurrent and private funds.

To sum up, we can observe crowding-in or crowding-out effect. A shock on recurrent public funds or private funds induces a crowding-in effect. Conversely a shock on public contractual funds induces a crowding-out effect. In this case it is more efficient to promote public research with recurrent public funds than contractual public funds.

Consequences of a shock when $\sigma = 1$ (Cobb-Douglas case)

When the elasticity between public and private funds is equal to one ($\sigma = 1$), we have a Cobb-Douglas production function. In this case the FOC can be written:

$$\omega\alpha\frac{x'_{e_x}}{x} = \omega(1-\alpha)\frac{y'_{e_y}}{y} = \frac{h'_{(e_r)}}{h_{(e_r)}} \tag{3.11}$$

An increase in the availability of contractual public funds will induce one type of reaction. This is an increase of the effort dedicated to raising public funds e_x. Thus the total amount of public funds raise increases. Because of the imperfect substitutability between public and private funds, the increase of the level of effort to raise public contractual funds is combined with a decrease of the effort to raise private funds e_y and the research effort e_r.

Proof. (Appendix A4.1) ■

The reactions of labs are different when a shock occurs on the availability of recurrent public funds a. When labs encounter a positive shock on the availability of recurrent public funds a, the level of public funds increases. Because the availability of contractual public and private funds has not changed and because public and private funds are imperfect substitutes, labs decrease their efforts to raise contractual public funds e_x and increase their efforts to raise private funds e_y, and research effort e_r. Tu sum up, in the case of a Cobb-Douglas production function, an increase of recurrent funds will induce an increase of the level of public funds, private funds and of research efforts.
Proof. (Appendix A4.2) ■

In the Cobb-Douglas case, when there is a shock on the availability of contractual private funds, the time devoted to raising different types of funds and doing research does not change. Thus increases in the availability of private funds lead to an increase of the total amount of private funds raised without inducing any change in the behaviour of researchers. Respectively, when a negative shock occurs on the availability of private funds, the level of private funds decreases because of the decrease of the availability of private funds.
Proof. (Appendix A4.3) ■

To sum up, in Cobb-Douglas cases, labs do not change their time allocation between funds raising activities and research efforts when there is a variation in the availability of private contractual funds. However their reactions change when there is a variation in the availability of public contractual and recurrent funds. An increase in public contractual funds causes a decrease in the level of the private funds raised (crowd-out).On the other hand, an increase in the level of public recurrent funds causes an increase in the private funds raised, thus a crowding-in effect. With a Cobb-Douglas production function, it is more efficient to increase public recurrent funds than public contractual funds.

Consequences of a shock when $\sigma > 1$ (gross substitute)

When public and private funds are gross substitutes, they give access almost to the same consumables with the same advantages and constraints. In other words when public and private money are gross substitutes, they can almost not be differentiated in their use. In this case, a positive shock on the availability of public funds φ_x, induces three types of reaction. Because of the gross substitutability between public and private funds, the three feasible reactions include a decrease of the effort to raise private funds e_y.

- In a first setting corresponding to solution 2 in Appendix A5.1, labs keep e_x constant, decrease e_y and increase e_r. More specifically, the time constraint $e_x + e_y + e_r = 1$ induces $\Delta e_y = -\Delta e_r$. To sum up, the increase in the availability of public contractual funds induces a decrease in the time allocated to raise private funds, and finally an increase of the research effort. As the total impact on the research output depends on functions h and f, this reaction is adopted by labs which need additional research efforts more than additional funds.
- In a second setting corresponding to solution 3 in Appendix A5.1, labs increase e_x, decrease e_y and increase e_r. This time the total amount

of public funds increases more than in the previous case. The decrease of e_y is of smaller magnitude. Thus the total amount of private funds still decreases but less. When the research production relies more on funds than on research efforts, comparatively to the previous case, this strategy is expected to be more appropriate.

- In a third setting corresponding to solution 4 in Appendix A5.1, labs increase e_x, decrease e_y and e_r. This time the total amount of public funds increases more than in the two previous cases. The research effort e_r and the effort to raise private funds e_y decrease. When the research production relies more on funds than on research efforts, comparatively to the previous cases, this strategy is expected to be more appropriate than the preceding ones.

To sum up, in this three settings we observe a decrease of the level of efforts to do research and an increase of the level of funds raised. This evolution is more pronounced as we move from the first setting to the third one.

Proof. (Appendix A5.1) ∎

However, the reactions of labs are different when a shock occurs on the availability of recurrent public funds. A positive shock on the availability of recurrent public funds induces two types of reaction. Because of the gross substitutability between public and private funds, in the two cases, labs decrease the efforts spent on raising contractual public funds and increase their research efforts.

- In a first setting corresponding to solution 1 in Appendix A5.2, labs decrease e_x, keep e_y constant and increase e_r. More specifically, the time constraint $e_x + e_y + e_r = 1$ induces $\Delta e_x = -\Delta e_r$. To sum up, the increase in the availability of recurrent public funds induces a decrease in the time allocated to raise public contractual funds, and an increase of the research effort. To get an increase of research production, as the overall impact depends on functions h and f, this reaction is adopted by labs which need more additional research efforts than additional funds.

- In a second setting corresponding to solution 4 in Appendix A5.2, labs decrease e_x, increase e_y and e_r. This time the total amount of public funds increases less than in the previous case. The increase of e_y induces an increase of the amount of private funds raised. When the research production relies more on funds than on research efforts compared to the previous case this strategy is expected to be more appropriate than the preceding one.

Proof. (Appendix A5.2) ■

When public and private money are gross substitute in their uses, the laboratory can react in three different ways to an increase of availability of private funds φ_y. Because of the gross substitutability between public and private funds, the three feasible reactions include a decrease of the effort to raise public contractual funds e_x. The three feasible equilibria are:

- In a first setting corresponding to solution 2 in Appendix A5.3, labs decrease e_x, keep e_y constant and increase e_r. More specifically, the time constraint $e_x + e_y + e_r = 1$ induces $\Delta e_x = -\Delta e_r$. To sum up, the increase in the availability of private funds induces a decrease in the time allocated to raise contractual public funds, and finally an increase of the research effort. This reaction is adapted to research activities which do not need additional or huge investments.

- In a second setting corresponding to solution 3 in Appendix A5.3, labs decrease e_x, increase e_y and e_r. This time the total amount of private funds increases more than in the previous case. The decrease of e_x is of smaller magnitude. Thus the total amount of public funds still decreases but less. When research production relies more on funds than on efforts compared to the previous case this strategy is expected to be more appropriate than the preceding one.

- In a third setting corresponding to solution 4 in Appendix A5.3, labs decrease e_x, increase e_y and e_r. This time the total amount of public funds increases more than in the two previous cases. The research effort e_r and the effort to raise private funds e_y decrease. When the research production relies more on funds than on efforts compared to the previous case this strategy is expected to be more appropriate than the preceding ones.

To sum up, in this three settings we observe a decrease of the level of efforts to do research and an increase of the level of funds raised. This evolution is more pronounced as we move from the first setting to the third one.

Proof. (Appendix A5.3) ■

To conclude, a positive shock on either contractual public or private funds causes a mutual crowding-out effect. However an increase of the availability of public recurrent founds will not impact the level of private funds or increase it.

Results are summarized in the following Figure 3.1. As one can observe an increase in recurrent funds leads to an increase in private funds whatever the level of substitutability between funds. Conversely to recurrent funds, public contractual funds crowd-out (CO) private funds generally except when public and private funds are greatly gross complement. Private funds crowd-in (CI) public funds when they are gross complements and crowd them out when they are gross substitutes.

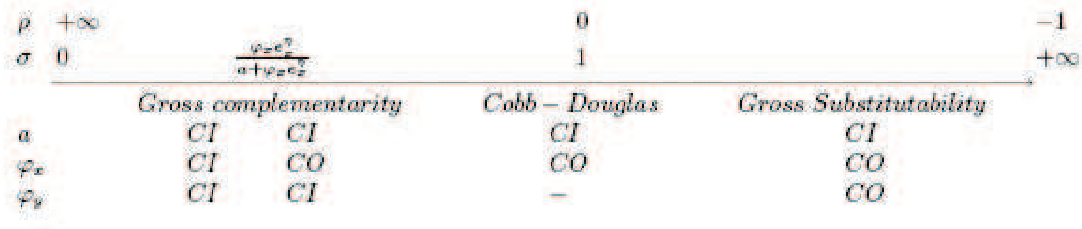


Figure 3.1: Results of theoretical model

3.3. Data

We use data collected over 10 years by a team of researchers at Beta [3] on the ULP of Strasbourg (France). ULP was one of the most important French research universities in terms of research impact, with around 80 laborato-

[3] We are grateful to all present and previous members of the lab, Nicolas Carayol, Rachel Levy, Mireille Matt, Ami Marxer, Karine Pellier among others for their contribution to the construction of the database.

ries. ULP had a strong tradition of fundamental research and researchers of the university received numerous national and international honours[4]. The third European report on science and technology indicators ranked ULP first among French university in terms of impact and Shanghai 2010 ranked ULP fourth among French universities. Those good results were driven by chemistry. ULP, in this discipline, was the first among French universities and fourteenth in the world.

Our analysis bears on 53 labs of ULP. The scientific discipline distribution among labs is displayed in Table 3.1. ULP showed a specialization on life science and medicine.

Table 3.1: Discipline distribution among labs

Disciplines	**Nb of labs**
Life science	17
Medicine	14
Chemistry	9
Physics	4
Earth sc and Astr	3
Engineering Sc	5
Mathematics	1

Source: EcS-BETA database

Our application requires data on research output and research input. As underlined this paper focuses on production of new knowledge. There exists no direct measure of new knowledge, however several proxies like publications are usually used in studies. Thus we consider as output the publications in peer refereed journals. The inputs are measured by public and private funds raised by the labs.

[4]One Nobel Prize among ULP researchers and seventeen nobel prize laureates who studied or worked at ULP.

3.3.1 Publication information

Information on publications of permanent researchers are collected using SCI (Science Citation Index) data from the Institute for Scientific Information. Thus we have information on publications of permanent researchers between 2001-2004. For all publications we have information on the number of co-authors. We divide each publication by the number of co-authors to get a normalized scientific contribution for each researcher. We sum over the members of the labs to compute the number of publications corrected for co-authors, that is the yearly publication outcome of a lab.

3.3.2 Information on funds

Data on financial resources raised by the labs involve two different sources: administrative reports and the Technology Transfer Office (TTO). From the administrative reports, we get information related to recurrent funds allocated to the labs by the Ministry of research and also by CNRS and INSERM [5]. From the TTO, we get information on public and private contractual funds raised by lab members. We do not have information related to the wages of employees (researchers etc.) and the infrastructure available to each lab. For each contract, we know the year it was signed, its duration, the amount of the contract, the identity of the labs receiving the funds and the fund providers. Thus, we are able to distinguish three principal types of funds in our analysis: the recurrent public funds, the contractual public funds and the private

[5] Centre National de la Recherche Scientifique (CNRS) can be translated into National Centre for Scientific Research and Institut National de la Santé et de la Recherche Médicale (INSERM) can be translated into National Institute for Health and Medical Research.

funds. The details of the different types of sources are summarized in Table 3.2.

Table 3.2: Different sources of funds

Type of fund	**Aggregate level**	**Funding organization**
Public grant	Public grant	Ministry of research CNRS INSERM ...
Contractual public funds	Local government	Regional council City of Strasbourg ...
	European Union	PCRD FEDER EUREKA COST ...
	Various French public funds	CNRS by project French university ...
	Various international public funds	Foreign university ...
Contractual private funds	French private funds	Firms Foundations Associations ...
	International private funds	Firms Foundations Associations ...

Source: EcS-BETA database

Figure 3.2 displays the evolution of the funds raised over the years. We observe a U-shaped evolution of contractual public funds, whereas contractual private funds decrease over time.

The assumption that all the financial means obtained are consumed in the first year after a contract is signed is not realistic. Thus we use three differ-

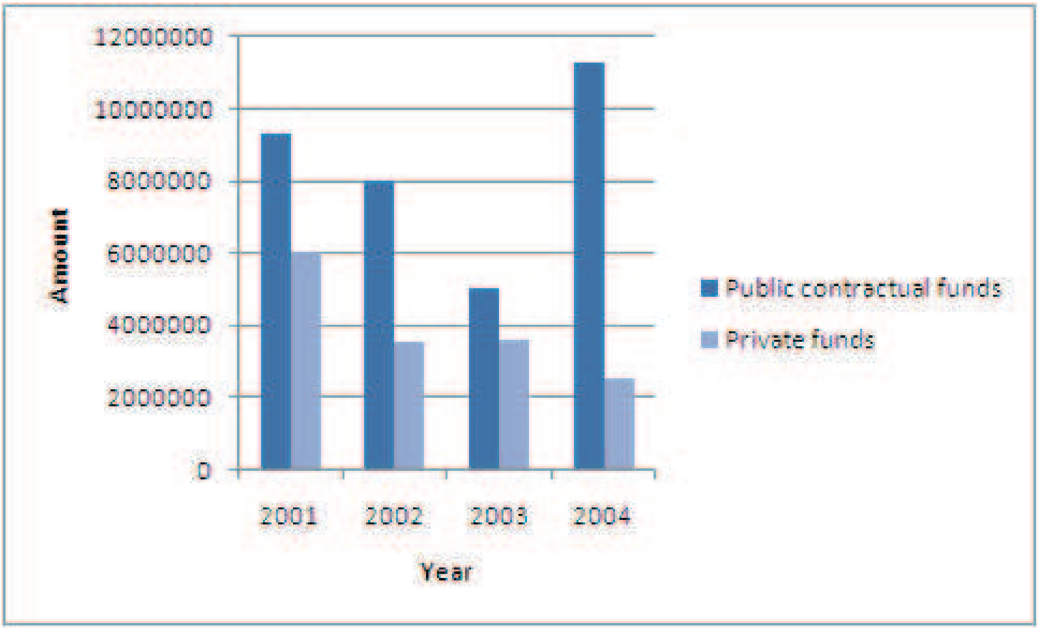


Figure 3.2: Evolution over time of funds raised

ent ways of sharing out resources over time: constant allocation, degressive allocation and mixed allocation.

We define first a constant allocation for all types of funds over time. Thus labs consume an equal amount of the contract each year. More formally, let us denote by Z the amount of a contract in euros and T the duration of the contract in years. We assume that each year $t < T$ the lab spends $Z_t = \frac{Z}{T}$. The amount are computed for each contract and we sum them up for each lab over the years.

Subsequently, we define a degressive use of funds. In this case, we assume that labs spend more at the beginning of the project, and the expenses decrease over time. A degressive use of funds is formalized as follows: for each year $t < T$, the lab outlay is $z_t = \frac{Z(T-t+1)}{\sum_{t=0}^{T} t}$. After computation for each contract, we sum up the amounts for each lab over the years.

In the last specification of the spending of funds over time, we distinguish recurrent funds from contractual funds (either public and private). Recurrent funds are generally used for operating expenses, thus we use the constant allocation method for them. Contractual funds are more often spent for investment, thus degressive use is applied to them. After computation for each contract, we sum up the amounts for each lab over the years.

It is possible there is a simultaneity between the production of output and the collection of inputs. Indeed a forthcoming publication in a top journal can increase the probability to sign a contract. A detailed examination of this issue involves instrumental variables. However defining good instruments is problematic and their use in a non linear models does not follow a unique general procedure. We tackle the endogeneity issue in estimating models using the current value of the explanatory variables or they lagged values over one period.

3.4. Results

3.4.1 Methodology

The CES function is non-linear in parameters, thus it cannot be estimated with the usual linear estimation techniques. Two main estimation techniques are used in the literature. The first one is the so-called "Kmenta Approximation" (Kmenta, 1967) which relies on a linearization. The second one is the estimation by non-linear-least-squares (NLS) using different optimization algorithms. Those two methods have important limits.

The "Kmenta Approximation" (Kmenta, 1967) is the first one introduced in the literature using Taylor's expansion around $\rho = 0$. This methodology allows the linearization of the CES function and thus its estimation using standard regression analysis. Using Monte Carlo studies, Maddala and Kadane (1967) showed that the Kmenta procedure "does not give reliables estimates of σ". They explain that the the omission in the Taylor's expansion of third and further order terms could explain the bias in the estimation of σ (Maddala and Kadane, 1967). Thursby and Lovell (1978) investigated the sources of bias and inconsistency of estimation of CES parameters with Kmenta approximation. They concluded also, under mild conditions, to the existence of bias in the estimation of σ and they underlined further the difficulty for the Kmenta approximation to reject a false Cobb-Douglas hypothesis. The only case where results are reliable is when $\rho \to 0$, and thus $\sigma \to 1$ (Henningsen and Henningsen, 2010b). Thus using Kmenta Approximation in a context where ρ is the principal variable of interest is not judicious.

The NLS estimation uses different algorithms to minimize the sum of squared residuals. Henningsen and Henningsen (2010b) compared the performance of different methods such as: Levenberg-Marquardt algorithm (Marquardt, 1963), gradient-based methods like "conjugated Gradient" method (Fletcher and Reeves, 1964), and global optimisation algorithms. They concluded that the Levenberg-Marquard algorithms (Marquardt, 1963) performed poorly in estimating σ (Thursby, 1980; Henningsen and Henningsen, 2010b). The gradients-based algorithms was not appropriate because it did not converge because of flat surface (Henningsen and Henningsen, 2010b). All these studies and others concluded that those procedures exhibited poor performances when it came to estimating ρ.

For all these reasons, we prefer to use the grid one-dimensional search method. A sequence of values for ρ is pre-selected and the remaining parameters are estimated by non-linear least-squares holding ρ fixed at each of the pre-defined values. This method estimates parameters by NLS for fixed values of iteratively selected over a given interval. We use Levenberg-Marquardt algorithm (Marquardt1963) to estimate the remaining parameters. The corresponding sum of squared residuals is computed, and the model with the least one is preferred (Henningsen and Henningsen, 2010b). The whole procedure is implemented in the minEconCES package (Henningsen and Henningsen, 2010a) for R sofware (R Development Core Team, 2010).

We will first estimate the relationship between public and private funds in subsection 3.4.2, and then the relationship between contractual public and private funds in subsection 3.4.3.

3.4.2 Estimation with total public and private funds

We present here the results obtained with both contractual and recurrent public funds and contractual private funds. The plots of the sums of squared residuals as functions of ρ are in Appendix B and results are summarized in Table 3.3 below.

As can be observed in Table 3.3, the estimates of the parameters are very similar between different types of sharing out of the funds, and also between current and lagged values.

The value of α shows that public funds are the most important resources

Table 3.3: Results of the estimation

	Current values			Lagged values		
Covariates	Degressive	Constant	Combined	Degressive	Constant	Combined
$\delta h(e_r)$	7.836e-04*	3.301e-04*	2.784e-04*	7.854e-04	7.452e-04	3.449e-04
	(4.455e-04)	(.940e-04)	(1.685e-04)	(4.859e-04)	(4.914e-04)	(2.274e-04)
α	1***	1***	1***	1***	1***	1***
	(2.274e-04)	(1.425e-08)	(1.467e-08)	(4.126e-07)	(1.745e-07)	(1.089e-09)
ω	0.77***	0.83***	0.84***	0.76***	0.77***	0.82***
	(4.079e-02)	(4.225e-02)	(4.341e-02)	(4.407e-02)	(4.746e-02)	(4.714e-02)
ρ	1.3	1.5	1.5	1.2	1.3	1.7
	1.054	1.361	1.405	1.152	1.537	1.958

* p<0.1, ** p<0.05, *** p<0.001
Notes: Std. error are in parentheses below estimates.

for production. This can be explained by the fact that public funds are the predominant funding. Indeed, as displayed in Table 3.4, a high percentage of labs have a very low share of private funds in their budgets. Private funds represent less than 36% of the resources for more than 75% of the labs and less than 11% for more than 50% of the labs. This result is in line with those obtained by Adams and Griliches (1998) who found that the effect of federal spending on research output (measured by the number of publications and citations) is higher than the effect of non-federal spending (state and local government, firms and foundations).

Table 3.4: Distribution of private/public fund ratio

Percentage	Ratio
5	5.21e-06
10	6.77e-06
25	.0091797
50	.1071231
75	.3540893
90	1.013177
95	3.075112

Source: EcS-BETA database

Second, the value of ω shows evidence of decreasing returns to scale. This result is coherent with the finding of Adams and Griliches (1998) in US data and of Crespi and Geuna (2004) in data based on fourteen countries [6].

Lastly, a confidence interval at a 5% level for ρ goes from $-0,77$ to $3,37$. We therefore reject both the assumptions of perfect complementarity and perfect substitutability. Thus it is impossible to conclude in favor of crowding-in or crowding-out effect between public and private funds. Indeed it depends on the level of elasticity.

The estimate of α is equal to one. It is likely that this result is driven by the prominence of public recurrent funds. In the next section we analyse the crowding-in and crowding-out effects between contractual funds whose origin can be private or public.

3.4.3 Estimation with contractual public and private funds

We now focus on whether public contractual and private contractual funds are substitutes or complements. Indeed both are obtained in a competitive way but differ in the way they can be employed and in their availability. In other words, we now estimate a variant of our model without recurrent funds. Technical points concerning this simplification are develop in Appendix C. To summarize there is a crowding-out relationship between public and private funds when they are gross complements and crowding-in when there are gross substitute as show in the Figure below 3.3

[6] Australia, Belgium, Canada, Finland, Denmark, France, Germany, Netherlands, Spain, Italy, Switzerland, Sweden, UK and USA.

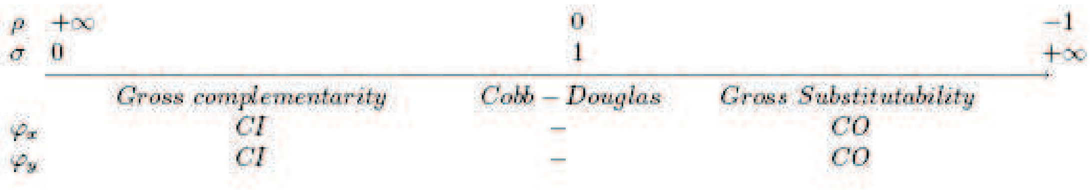


Figure 3.3: Results of theoretical model for contractual public and private funds

We estimate the model with the same methodology as previously. The estimates are in Appendix D and summarized in Table 3.5 below.

Table 3.5: Results of the estimation

	Degressive	Constant	Degressive	Constant
$\delta h(e_r)$	0.05	0.04	0.02	0.02
	(0.05)	(0.03)	(0.02)	(0.03)
α	0.78***	0.78***	0.76***	0.75***
	(0.11)	(0.10)	(0.09)	(0.09)
ω	0.49***	0.51***	0.57***	0.56***
	(0.07)	(0.07)	(0.08)	(0.08)
ρ	-0.7*	-0.7*	-0.7**	-0.6**
	(0.4)	(0.38)	(0.35)	(0.29)

* p<0.1, ** p<0.05, *** p<0.001
Notes: Std. error are in parentheses below estimates.

First, the share of public contractual funds in the production of research output is less important than before and drops by nearly a quarter. A possible explanation is that the ratio of private contractual funds to public contractual ones is closer to one for most of the labs. Another result is that the returns to scale are now decreasing more quickly. Finally, ρ differs significantly from 0 and the two types of funds are gross substitutes. Thus contractual public and private funds crowd-out each other.

3.5. Conclusion

In this paper, we study the optimal behaviour of public labs producing research output. We analyse the consequences of different kinds of shocks on the optimal behaviour under different levels of substitutability between funds. Our main results indicate that the optimal reaction to a shock depends on the level of substitutability of the different types of funds. Increased recurrent funds lead to increased level of private funds, whatever the level of substitutability (crowding-in). Policies in favor of recurrent funds will thus increase the budget of the labs via two channels: recurrent funds and private funds. Conversely, public contractual funds generally crowd-out private contractual funds. The only exception occurs when public and private funds are greatly gross complements. Private contractual funds have two different effects, depending on the level of substitutability with public contractual funds. We observe a crowding-in when both are gross complements, and crowding-out when both are gross substitutes.

In a second part of the paper, we turn to the estimation of a CES production function using a singular database on the ULP. Our results reject the perfect substitutability and complementarity between total public, involving recurrent and contractual funds, and private funds. The contribution of public contractual funds in the knowledge production is higher than the private funds. Turning to contractual funds, we observe gross substitutability between contractual public and private funds. Thus there is a crowding-out effect.

The application can be extended with data over a longer time period.

Few studies show the necessity to have a lag of 5 years to capture the effect of funds on output (Crespi and Geuna, 2005). The effect of past funds on knowledge production thus is underestimated.

Our theoretical model is based on a short term assumption, stating that the level of effort a lab can provide is constant over time. However, a lab can use part of the funds raised to hire contractual workers. Therefore, the amount of time a lab can invest in the production of research output and the activity of raising funds is itself a function of its budget. A positive shock on the availability of contractual funds therefore does not necessarily imply a decrease in the research effort. This is likely to balance the influence of recurrent funds with respect to contractual funds in the production of knowledge. An interesting extension would thus be to analyze the consequence of the relaxation of this assumption on the optimal behaviour of the labs.

Appendix

A. Analysis of the consequences of a shock on the availability of funds

A1 The program of the Labs

The program of the labs is:

$$\max_{e_x,e_y,e_r} \delta h(e_r)\Big[\alpha x(e_x;a,\varphi_x)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)y(e_y;\varphi_y)^{\frac{\sigma-1}{\sigma}}\Big]^{\frac{\omega\sigma}{\sigma-1}} \quad \text{(A1)}$$

$$st \ : \ e_x + e_y + e_r = 1$$

The Lagrangien can be written:

$$L = \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}} + \lambda(e_x + e_y + e_r - 1) \quad \text{(A2)}$$

$$\begin{aligned}\frac{\partial L}{\partial e_x} &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\frac{\omega\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}\alpha x'_{e_x}x^{(\frac{\sigma-1}{\sigma}-1)} + \lambda \\ &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\omega\alpha x'_{e_x}x^{\frac{-1}{\sigma}} + \lambda \quad \text{(A3)}\end{aligned}$$

$$\begin{aligned}\frac{\partial L}{\partial e_y} &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\frac{\omega\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}(1-\alpha)y'_{e_y}y^{(\frac{\sigma-1}{\sigma}-1)} + \lambda \\ &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\omega(1-\alpha)y'_{e_y}y^{\frac{-1}{\sigma}} + \lambda \quad \text{(A4)}\end{aligned}$$

$$\frac{\partial L}{\partial e_r} = \delta h'(e_r)\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}} + \lambda \tag{A5}$$

Equating the FOC, we get:

$$\delta h(e_r)\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}-1} \omega\alpha x'_{e_x} x^{\frac{-1}{\sigma}} \tag{A6}$$

$$= \delta h(e_r)\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}-1} \omega(1-\alpha) y'_{e_y} y^{\frac{-1}{\sigma}} \tag{A7}$$

$$= \delta h'(e_r)\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}} \tag{A8}$$

After some simplifications of (A6) and (A7), we have:

$$\alpha \frac{x'_{e_x}}{x^{\frac{1}{\sigma}}} = (1-\alpha)\frac{y'_{e_y}}{y^{\frac{1}{\sigma}}} \tag{A9}$$

Equations (A6) and (A8) give us:

$$\omega\alpha \frac{x'_{e_x}}{x^{\frac{1}{\sigma}}} \frac{1}{\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]} = \frac{h'(e_r)}{h(e_r)} \tag{A10}$$

From (A7) and (A8), we have:

$$\omega(1-\alpha) \frac{y'_{e_y}}{y^{\frac{1}{\sigma}}} \frac{1}{\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]} = \frac{h'(e_r)}{h(e_r)} \tag{A11}$$

The quantities $\left(\frac{x'}{x^{(\frac{1}{\sigma})}}\right)$, $\left(\frac{y'}{y^{(\frac{1}{\sigma})}}\right)$ appear in the FOC. In order to be able to do the comparative analysis, we focus on how those expressions vary with a, e_x, φ_x, e_y and φ_y. The different cases are presented in Table A1 below.

Here we just develop how we get the first column.

Table A1: Variation of expression of FOC with parameters

	$\frac{\partial\left[\frac{x'_{e_x}(e_x;a,\varphi_x)}{x^{1/\sigma}_{(e_x;a,\varphi_x)}}\right]}{\partial e_x}$	$\frac{\partial\left[\frac{x'_{e_x}(e_x;a,\varphi_x)}{x^{1/\sigma}_{(e_x;a,\varphi_x)}}\right]}{\partial \varphi_x}$	$\frac{\partial\left[\frac{x'_{e_x}(e_x;a,\varphi_x)}{x^{1/\sigma}_{(e_x;a,\varphi_x)}}\right]}{\partial a}$	$\frac{\partial\left[\frac{y'_{\theta y}(e_y;\varphi_y)}{y^{1/\sigma}_{(e_y;\varphi_y)}}\right]}{\partial e_y}$	$\frac{\partial\left[\frac{y'_{\theta y}(e_y;\varphi_y)}{y^{1/\sigma}_{(e_y;\varphi_y)}}\right]}{\partial \varphi_y}$
$\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$	<0	<0	<0	<0	<0
$\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$	<0	>0	<0	<0	<0
$\sigma = 1$	<0	>0	<0	<0	$=0$
$\sigma > 1$	<0	>0	<0	<0	>0

$$\frac{\partial x}{\partial e_x} = x' = \eta \varphi_x e_x^{\eta-1} \tag{A12}$$

Thus we have

$$\frac{x'}{x^{1/\sigma}} = \frac{\eta \varphi_x e_x^{\eta-1}}{(a+\varphi_x e_x^\eta)^{1/\sigma}} \tag{A13}$$

$$\begin{aligned}
\frac{\partial(\frac{x'}{x^{1/\sigma}})}{\partial e_x} &= \frac{\eta(\eta-1)\varphi_x e_x^{\eta-2}(a+\varphi_x e_x^\eta)^{1/\sigma} - \left(\frac{1}{\sigma}(a+\varphi_x e_x^\eta)^{\frac{1}{\sigma}-1}\eta\varphi_x e_x^{\eta-1}\eta\varphi_x e_x^{\eta-1}\right)}{(a+\varphi_x e_x^\eta)^{2/\sigma}} \\
&= \frac{(a+\varphi_x e_x^\eta)^{1/\sigma}\left(\eta(\eta-1)\varphi_x e_x^{\eta-2} - \left(\frac{1}{\sigma(a+\varphi_x e_x^\eta)}\eta^2\varphi_x^2 e_x^{2(\eta-1)}\right)\right)}{(a+\varphi_x e_x^\eta)^{2/\sigma}} \\
&= \frac{\eta(\eta-1)\varphi_x e_x^{\eta-2} - \left(\frac{1}{\sigma(a+\varphi_x e_x^\eta)}\eta^2\varphi_x^2 e_x^{2(\eta-1)}\right)}{(a+\varphi_x e_x^\eta)^{1/\sigma}}
\end{aligned} \tag{A14}$$

Because for each value of σ we have $\eta(\eta-1)\varphi_x e_x^{\eta-2} < 0$, $(\frac{1}{\sigma(a+\varphi_x e_x^\eta)}\eta^2\varphi_x^2 e_x^{2(\eta-1)}) > 0$ and $(a+\varphi_x e_x^\eta)^{1/\sigma} > 0$ thus $\frac{\partial \frac{x'}{x^{1/\sigma}}}{\partial e_x} < 0$

A2 When $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

We analyze the consequences of shocks on the availability of different types of funds on time allocation decisions of the when public and private funds are gross complements $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$. We first consider a positive shock on the availability of public contractual funds in Appendix A2.1, then we focus on a shock on public recurrent funds in Appendix A2.2 and lastly on a shock on availability of private funds in Appendix A2.3.

A2.1 Shock on the availability of public contractual funds φ_x when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

A positive shock on the availability of public contractual funds, that is an increase of φ_x up to $\varphi'_x(\varphi'_x > \varphi_x)$, induces a deviation from the equality of the FOC given by equations (A9), (A10) and (A11). The labs return to the optimum by changing either e_x, e_y or e_r.

The different possibilities are given in the Table A2 below. We analyze them one by one and exclude those which are incompatible with an optimum, as defined by equations (A9), (A10) and (A11).

Table A2: After a shock on φ_x when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

	e_x	e_y	e_r	A/R*
possibility 1	↘	cst	↗	R
possibility 2	cst	↗	↘	A
possibility 3	↘	↗	↘	A
possibility 4	↘	↗	↗	R

* A/R means Accepted / Rejected

Possibility 1: We consider the first possibility where e_x decreases, e_y remains constant and e_r increases. As one can observe in Table A1, $x'_{e_x}/x^{1/\sigma}$

decreases when φ_x increases and increases when e_x decreases. Therefore an increase of φ_x and a decrease of e_x can lead to a constant $\alpha x'_{e_x}/x^{1/\sigma}$, the first term of equation (A9). The second term of equation (A9) does not change when e_y remains constant whereas e_x and φ_x do not. The result of all of this is that the equality given by (A9) still holds. As we see, the first terms of equations (A10) and (A11), $\omega\alpha x'_{e_x}/x^{1/\sigma}$ and $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$ do not change. The second part of the left side terms of equations (A10) and (A11), $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$, increases because x increases. Thus the left hand of those equations increases. However, the time constraint given by ($e_r = 1 - e_x - e_y$) implies an increase of the research effort thus a decrease of $h'(e_r)/h(e_r)$ the term on the right side of equations (A10) and (A11). Hence, while the right hand of equations (A10) and (A11) decreases, the left hand side increases. Thus the first possibility is rejected.

Possibility 2: Now we will check the second possibility when e_x remains constant, e_y increases and e_r decreases. The increase of φ_x induces a decrease of the left term of equation (A9). By increasing e_y we can decrease the right side term of the equation so that the first equality is respected. Because of the increase of e_y, the time constraint induces a decrease of e_r and thus an increase of the right term of equations (A10) and (A11). However, keeping e_x constant and increasing e_y induces a decrease of $\omega\alpha x'_{e_x}/x^{1/\sigma}$ and $\omega(1-\alpha)y'/y^{1/\sigma}$ and an increase of $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$, the right hand side term of the FOC given by equations (A10), (A11). Hence the second solution is feasible.

Possibilities 3 and 4: We consider the third and fourth solutions, made of a decrease of e_x as in solution 1 and an increase of e_y as in solution 2. However the decrease of e_x is of a lesser magnitude, so $x'_{e_x}/x^{1/\sigma}$ still decreases. Increasing e_y causes a decrease of the right hand side of equation (A9) hence the equality is respected. Thus, the increase of φ_x, decrease of e_x and increase of e_y induce a decrease of $\omega\alpha x'_{e_x}/x^{1/\sigma}$ and $\omega(1-\alpha)y'/y^{1/\sigma}$ and an increase of $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$ the right hand side term of FOC given by equations (A10), (A11). Because of time constraint and the result of possibility one, the third solution is feasible and the fourth one rejected.

A2.2 Shock on the availability of public recurrent funds a when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

Because of the signs in Table A1, this time the decrease of $x'_{e_x}/x^{1/\sigma}$ is caused by the increase of a instead of φ_x. With exactly the same reasoning we get the same results as previously.

A2.3 Shock on the availability of private contractual funds when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

This time we have a decrease of $y'_{e_y}/y^{1/\sigma}$, caused by the increase of φ_y. With a symmetric reasoning to the case with a shock on φ_x, which induces a decrease of $x'_{e_x}/x^{1/\sigma}$, we get symmetric results to when a shock occurs on φ_x. The results we obtain for e_x (respectively for e_y) are similar to those obtained previously for e_y (respectively for e_x). They are depicted in the Table A3:

Table A3: After a shock on φ_y when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$

	e_x	e_y	e_r	A/R
possibility 1	cst	↘	↗	R
possibility 2	↗	cst	↘	A
possibility 3	↗	↘	↘	A
possibility 4	↗	↘	↗	R

A3 When $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$

We analyze the consequences of shocks on the availability of different types of funds on time allocation decisions of the labs when public and private funds are gross complements $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$, that mean the level of complementarity is lower than the previous case. We first consider a positive shock on the availability of public contractual funds in Appendix A3.1, then we focus on a shock on public recurrent funds and on availability of private funds in Appendix A3.2.

A3.1 Shock on the availability of public contractual funds φ_x when $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$

We consider now shocks on the availability of public contractual funds, that is an increase of φ_x up to $\varphi_x'(\varphi_x' > \varphi_x)$. This induces a deviation from the equality of the FOC given by equations (A9), (A10) and (A11). The lab can react by changing either e_x, e_y or e_r.

The different possibilities are given in the Table A4 below. We analyze them one by one and exclude those which are incompatible with an optimum, as defined by equations (A9), (A10) and (A11).

Possibility 1: We consider the first possibility where e_x increases, e_y re-

Table A4: After a shock on φ_x when $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$

	e_x	e_y	e_r	A/R
possibility 1	↗	cst	↘	A
possibility 2	cst	↘	↗	R
possibility 3	↗	↘	↘	A
possibility 4	↗	↘	↗	R

mains constant and e_r decreases. As one can observe in Table A1, $x'_{e_x}/x^{1/\sigma}$ increases with φ_x and decreases with e_x. Therefore an increase of φ_x and of e_x can lead to a constant $\alpha x'_{e_x}/x^{1/\sigma}$, the first term of equation (A9). The second term of equation (A9), $(1-\alpha)y'_{e_y}/y^{1/\sigma}$, does not change when e_y remains constant and does not depends on e_x and φ_x. The result is that the equality given by (A9) still holds. As we see, the first terms of equations (A10) and (A11), $\omega\alpha x'_{e_x}/x^{1/\sigma}$ and $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$, do not change. The second part of left hand side of equations (A10) and (A11), $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$, increase. Thus the left hand side of those equations increase. In addition, the time constraint given by $e_r = 1-e_x-e_y$ implies a decrease of e_r, the research effort thus an increase of $h'(e_r)/h(e_r)$, the right side term of equations (A10) and (A11), which is compatible with the increase of the left hand. The first possibility is feasible.

Possibility 2: Now we check the second possibility where e_x remains constant, e_y decreases and e_r increases. As a result of the positive shock on φ_x and because we keep e_x constant, the first term of equation (A9) increases. By decreasing e_y, an increase of the right term of equation (A9) is obtained. Consequently the first equality can still hold. The time constraint induces an increase of e_r and thus a decrease of the right hand side term of equations

(A10) and (A11), $h'(e_r)/h(e_r)$. However keeping e_x constant and decreasing e_y induce an increase of $\omega\alpha x'_{e_x}/x^{1/\sigma}$, $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$ and the effect on $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$ is not determined. Thus the total effect on the left term of FOC given by equations (A10), (A11) is not determined. Consequently the second solution is feasible

Possibilities 3 and 4: The two solutions are made of an increase of e_x, as in possibility 1 and a decrease of e_y as in possibility 2. In those cases, the increase of e_x is however of a smaller magnitude than in possibility 1, so that $\alpha x'_{e_x}/x^{1/\sigma}$ still increases due to the shock. The decrease of e_y leads to an increase of the second term of (A9). The equality given by equation (A9) can thus hold. In addition, the increase of φ_x, e_x and the decrease of e_y induce an increase of $\omega\alpha x'_{e_x}/x^{1/\sigma}$, $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$, their total effect on $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$ is not determined. Thus the total effect on the left term of FOC given by equations (A10), (A11) is not determined. Thus the third and fourth solutions are feasible.

A3.2 Shock on the availability of private contractual funds φ_y and recurrent funds a when $\sigma \in]\frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}, 1[$

Because of the signs in Table A1 the consequences of shocks on the availability of recurrent funds a and on private contractual funds y are exactly the same as when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$ (cf Appendix A2.2 for shock on the availability of public recurrent funds and Appendix A2.3 for shock on the availability of private contractual funds).

A4 Appendix : $\sigma = 1$

We analyze the consequences of shocks on the availability of different types in the Cobb-Douglas case ($\sigma = 1$). After simplifications the FOC given by equations (A9), (A10) and (A11) can be written:

$$\omega\alpha\frac{x'_{e_x}}{x} = \omega(1-\alpha)\frac{y'_{e_y}}{y} = \frac{h'_{(e_r)}}{h_{(e_r)}}. \tag{A15}$$

We first consider a positive shock on the availability of public contractual funds, that is an increase of φ_x up to $\varphi'_x(\varphi'_x > \varphi_x)$ in Appendix A4.1. Second, we focus on a shock on recurrent public funds in Appendix A4.2, and third on a shock on the availability of private funds in Appendix A4.3.

A4.1 Shock on the availability of public contractual funds φ_x when $\sigma = 1$

We first consider a positive shock on the availability of public contractual funds, that is an increase of φ_x up to $\varphi'_x(\varphi'_x > \varphi_x)$. This induces a deviation of x'_{e_x}/x from its previous value thus the equality of the FOC given by equation (A15) does not hold. A return to optimum is possible by changing either e_x, e_y or e_r.

The different possibilities are in Table A5. We analyze them one by one and exclude those incompatible with an optimum, as defined by equation (A15).

Possibility 1: The term x'_{e_x}/x increases with φ_x and decreases with e_x (Table A1). Therefore $\omega\alpha x'_{e_x}/x$ comes back to its initial value when φ_x and

Table A5: After a shock on e_x when $\sigma = 1$

	e_x	e_y	e_r	A/R
possibility 1	$\nearrow$	cst	$\searrow$	R
possibility 2	cst	$\searrow$	$\nearrow$	R
possibility 3	$\nearrow$	$\searrow$	$\searrow$	A
possibility 4	$\nearrow$	$\searrow$	$\nearrow$	R

e_x increase. The second term, $\omega(1-\alpha)y'_{e_y}/y$, does not change when e_x, φ_x and e_r change whereas e_y remains constant. Equation (A15) implies that the third term, $h'_{(e_r)}/h_{(e_r)}$ must stay constant. However it is not possible because the time constraint given by $(e_x + e_y + e_r = 1)$ induces a decreases in e_r and thus an increase of the last term. The first possibility is thus rejected.

Possibility 2: Now we check the possibility where e_x remains constant, e_y is decreasing and e_r is increasing. As a result of the increase of φ_x and because we keep e_x constant,the first term of equation (A15) increases. By decreasing e_y, an increase of the second term of the FOC $\omega(1-\alpha)y'_{e_y}/y$ is obtained. However keeping e_x constant and decreasing e_y induce an increase of e_r (because $e_r = 1 - e_x - e_y$) thus a decrease of the last term of equation (A15). The FOC does not hold and the second solution is rejected too.

Possibilities 3 and 4: Now we check the third and fourth solutions. The two solutions are made of an increase of e_x, as in possibility 1 and a decrease of e_y. In those cases, the increase of e_x is however limited, so that $\omega\alpha x'_{e_x}/x$ is still increasing due to the shock. The decrease of e_y leads to an increase of the second term of (A15). The FOC implies an increase of the last term of (A15), thus a decrease of e_r. Hence, only the third solution is feasible whereas the fourth one is rejected.

A4.2 Shock on the availability of public recurrent funds a when $\sigma = 1$

The effect on $\omega \alpha x'_{e_x}/x$ of a shock on a is the opposite of when the shock is on φ_x. Thus reactions are reverted, leading to 4 possibilities resumed in Table A6. As for the preceding section, the only adjustment leading to an optimum is the third one.

Table A6: After a shock on a when $\sigma = 1$

	e_x	e_y	e_r	A/R
Possibility 1	↘	cst	↗	R
Possibility 2	cst	↗	↘	R
Possibility 3	↘	↗	↗	A
possibility 4	↘	↗	↘	R

A4.3 Appendix: Shock on the availability of private contractual funds φ_y when $\sigma = 1$

As can be observed in Table (A1), $\frac{\partial\left[\frac{y'_{e_y}(e_y;\varphi_y)}{y^{1/\sigma}_{(e_y;\varphi_y)}}\right]}{\partial \varphi_y} = 0$, thus, when a change occurs on the availability of private funds φ_y, the FOC given by equation (A15) continues to hold and labs do not change their behaviors.

A5 Analysis of the consequences of a shock when public and private funds are gross substitutes ($\sigma > 1$)

We analyze the consequences of shocks on the availability of different types of funds when public and private funds are gross substitutes ($\sigma > 1$). We first consider in Appendix A5.1 a positive shock on the availability of public contractual funds. Then, we focus on a shock on public recurrent funds in Appendix A5.2 and lastly on a shock on the availability of private funds Appendix A5.3.

A5.1 Shock on the availability of public contractual funds φ_x when $\sigma > 1$

We first consider a positive shock on the availability of public contractual funds, that is an increase of φ_x up to $\varphi'_x(\varphi'_x > \varphi_x)$. This induces a deviation from the equality of the FOC given by equations (A9), (A10) and (A11). The lab can react by changing either e_x, e_y or e_r.

The different possibilities are in the Table A7 below. We analyze them one by one and exclude those incompatible with an optimum.

Table A7: After a shock on φ_x when $\sigma > 1$

	e_x	e_y	e_r	A/R
possibility 1	$\nearrow$	cst	$\searrow$	R
possibility 2	cst	$\searrow$	$\nearrow$	A
possibility 3	$\nearrow$	$\searrow$	$\nearrow$	A
possibility 4	$\nearrow$	$\searrow$	$\searrow$	A

Possibility 1: We consider the first possibility where e_x increases, e_y remains constant and e_r decreases. As can be observed in Table A1, $x'_{e_x}/x^{1/\sigma}$ increases with φ_x and decreases with e_x. Therefore, an increase of φ_x and of e_x can lead to a constant $\alpha x'_{e_x}/x^{1/\sigma}$, the first term of equation (A9). The second term of equation (A9),$(1-\alpha)y'_{e_y}/y^{1/\sigma}$, does not change when e_y remains constant whereas e_x and φ_x do not. The result of that is that the equality given by (A9) still holds. The first term of equations (A10) and (A11), $\omega\alpha x'_{e_x}/x^{1/\sigma}$ and $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$, does not change, the second part of left

hand of equations (A10) and (A11), $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha) y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$, decreases. Thus the left hand side of equation (A10) and (A11) decreases. However the time constraint given by $e_r = 1 - e_x - e_y$ implies a decrease of the research effort and thus an increase of $h'(e_r)/h(e_r)$, the term on the right hand side of equations (A10) and (A11). This is not compatible with the decrease of the left hand side terms. As a consequence, the first possibility is rejected.

Possibility 2: We check now the second possibility where e_x remains constant, e_y decreases and e_r increases. As a result of the increase of φ_x and because we keep e_x constant, the term $\alpha x'_{e_x}/x^{1/\sigma}$, in equation (A9) increases. The increase of $(1-\alpha)y'_{e_y}/y^{1/\sigma}$ in equation (A9) is obtained with an appropriate decease of e_y. Consequently the first equality can hold. The time constraint induces an increase of e_r, thus a decrease of $h'(e_r)/h(e_r)$, the right hand side term of equations (A10) and (A11). The left hand side term of equations (A10) and (A11) can also decrease when e_x remains constant and e_y decreases because of an increase of $\omega\alpha x'_{e_x}/x^{1/\sigma}$, $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$ and a decrease of $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha) y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$. As a consequence, the second solution is feasible.

Possibilities 3 and 4: The two solutions are made of an increase of e_x, as in possibility 1, and a decrease of e_y, as in possibility 2. In those cases, the increase of e_x is however of a smaller magnitude than in possibility 1, so that $\alpha x'_{e_x}/x^{1/\sigma}$ still increases due to the increase of φ_y. The decrease of e_y leads to an increase of the second term of (A9). The equality given by equation (A9) is thus respected. The increase of φ_x and of e_x, the decrease of e_y induce an increase of $\omega\alpha x'_{e_x}/x^{1/\sigma}$ and $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$ and their effect on

$\left[\alpha x^{(\frac{\sigma-1}{\sigma})}+(1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$ is not determined thus the effect on the left term of FOC given by equations (A10), (A11) is not determined either. consequently, the third and fourth solutions are feasible.

A5.2 Shock on the availability of public recurrent funds a when $\sigma > 1$

We consider a positive shock on the availability of public recurrent funds, that is an increase of a up to $a'(a' > a)$. This induces an instability on the equality of FOC given by equations (A9), (A10) and (A11). The lab can react by changing either e_x, e_y or e_r.

The different possibilities are given in Table A8 below. We analyze them one by one and exclude those which are not compatible with an optimum, as defined by equations (A9), (A10) and (A11).

Table A8: After a shock on a when $\sigma > 1$

	e_x	e_y	e_r	A/R
possibility 1	$\searrow$	cst	$\nearrow$	A
possibility 2	cst	$\nearrow$	$\searrow$	R
possibility 3	$\searrow$	$\nearrow$	$\searrow$	R
possibility 4	$\searrow$	$\nearrow$	$\nearrow$	A

Possibility 1: We consider the first possibility (where e_x decreases, e_y remains constant and e_r increases). As can be observed in Table A1, $x'_{e_x}/x^{1/\sigma}$ decreases when a increases and increases when e_x decreases. Therefore an increase of a and a decrease of e_x lead to maintaining constant $\alpha x'_{e_x}/x^{1/\sigma}$, the first term of equation (A9). The second term of equation (A9), $(1-\alpha)y'/y^{1/\sigma}$, does not change when e_y remains constant whereas e_x and a do not. As a result the equality given by (A9) is respected. As we see, the first terms of

equations (A10) and (A11) do not change, the second part of the left hand of equations (A10) and (A11) decrease thus the left hand of those equations decreases. In addition time constraints given by ($e_r = 1 - e_x - e_y$) imply an increase of e_r the research effort thus a decrease of $h'(e_r)/h(e_r)$ the term on the right side of equations (A10) and (A11). Thus the first possibility is feasible.

Possibility 2: Now we check the second possibility (keeping e_x constant, increasing e_y and decreasing e_r). The increase of a induces a decrease of the left term of equation (A9). By increasing e_y we decrease the second term of the equation consequently the first equality is respected. Time constraints induce a decrease of e_r thus an increase of the right term of equations (A10) and (A11). However keeping e_x constant and increasing e_y induce a decrease of $\omega\alpha x'_{e_x}/x^{1/\sigma}$, $\omega(1-\alpha)y'_{e_y}/y^{1/\sigma}$ and of $\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\right]^{-1}$ the left term of FOC given by equations (A10), (A11). Consequently while the right hand side of equations (A10) and (A11) increases the left hand side decreases. Thus the second solution is rejected.

Possibilities 3 and 4: We consider the third and fourth solutions. The two solutions are made of a decrease of e_x as in solution one and an increase of e_y as in solution two. However the decrease of e_x is smaller, so $x'_{e_x}/x^{1/\sigma}$ still decreases. Increasing e_y causes a decrease of the right side of equation (A9) thus the equality is respected. In addition the increase of a, decrease of e_x, increase of e_y induce a decrease of the left term of FOC given by equations (A10), (A11). The FOC implies a decrease of the right term of equations (A10), (A11), thus an increase of e_r. As a consequence the third solution is feasible whereas the fourth one similar to the third one with a decrease of e_r

is rejected.

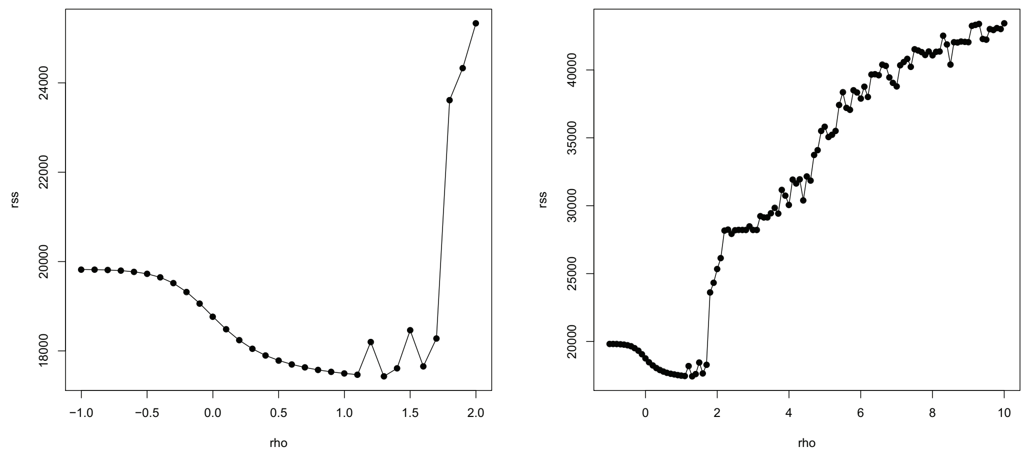
A5.3 Shock on the availability of private contractual funds φ_y when $\sigma > 1$

This time we have an increase of the second term of equation (A9), $y'_{e_y}/y^{(1/\sigma)}$, caused by the increase of φ_y. With a reasoning symmetric to the case with a shock on φ_x, which induces an increase of $x'_{e_x}/x^{(1/\sigma)}$, we get symmetric results to when a shock occurs on φ_x. The results we obtain for e_x (respectively for e_y) are similar to those obtained previously for e_y (respectively for e_x). They are depicted in Table A9:

Table A9: After a shock on φ_y when $\sigma > 1$

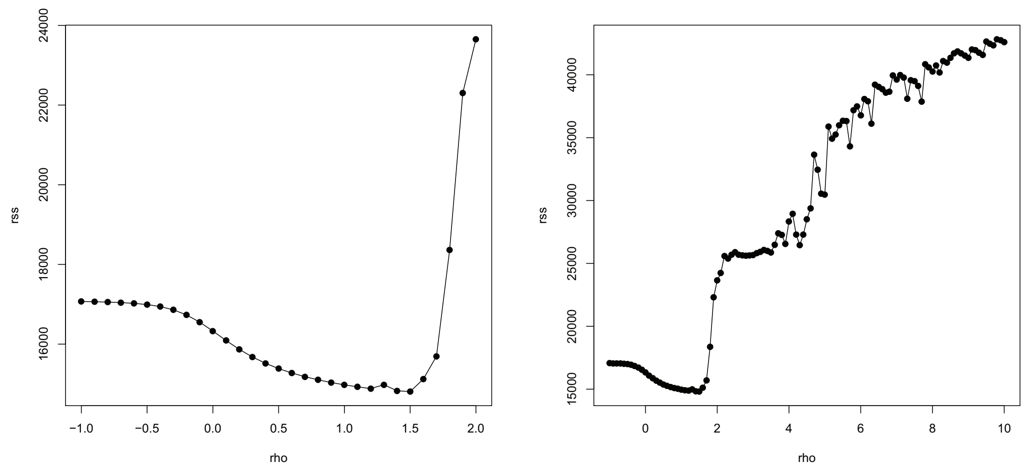
	e_x	e_y	e_r	A/R
possibility 1	*cst*	↗	↘	R
possibility 2	↘	*cst*	↗	A
possibility 3	↘	↗	↗	A
possibility 4	↘	↗	↘	A

B. Models fit for different value of ρ



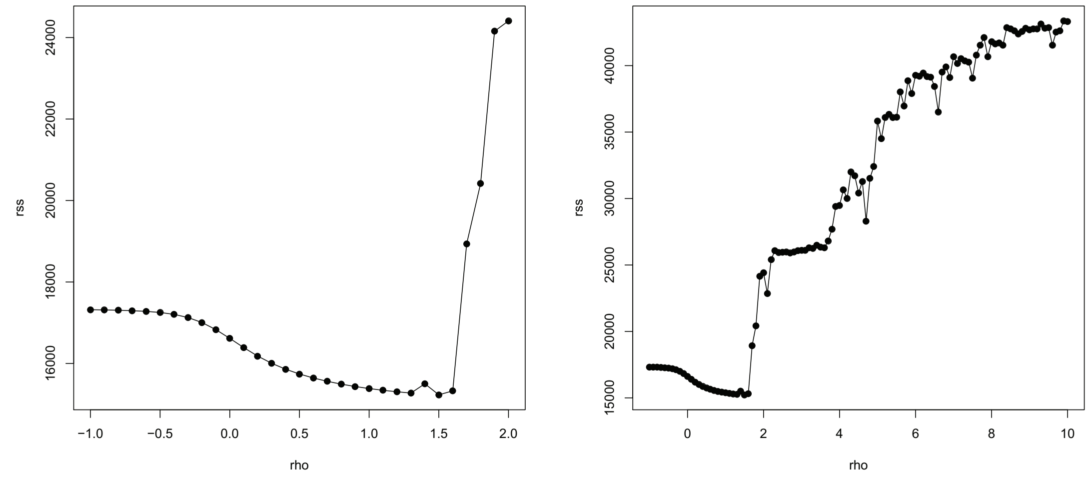
(a) ($\rho \in (-1, 2)$)   (b) ($\rho \in (-1, 10)$)

Figure B1: Root of the sum of squared residuals, public and private funds with degressive use of funds



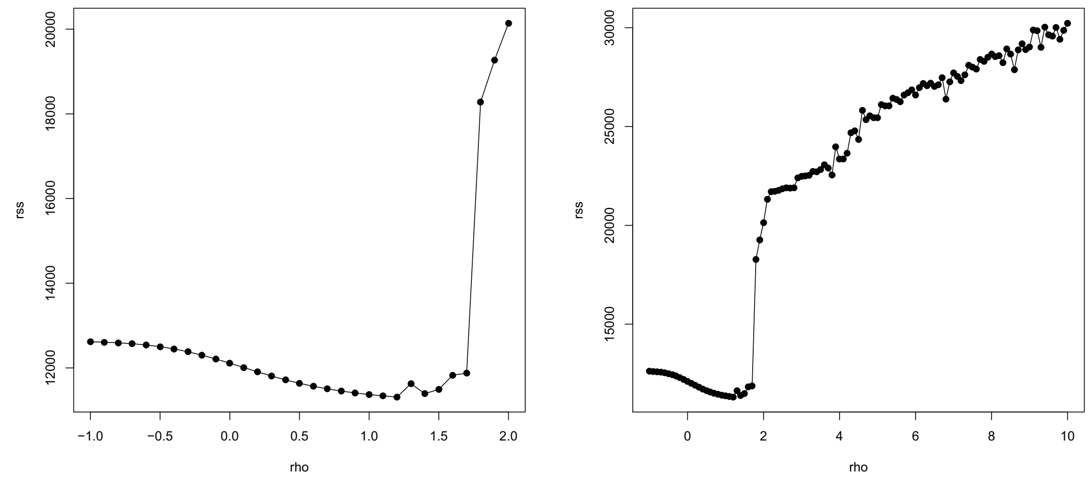
(a) $\rho \in (-1, 2)$ (b) $\rho \in (-1, 10)$

Figure B2: Root of the sum of squared residuals, public and private funds with constant use of funds



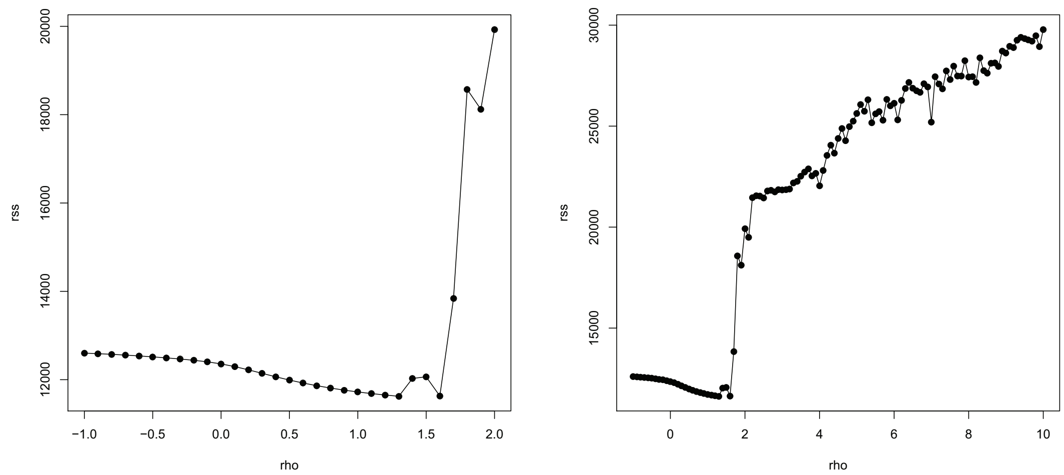
(a) $\rho \in (-1, 2)$ (b) $\rho \in (-1, 10)$

Figure B3: Root of the sum of squared residuals, public and private funds with constant use of recurrent funds and degressive use of contractual funds



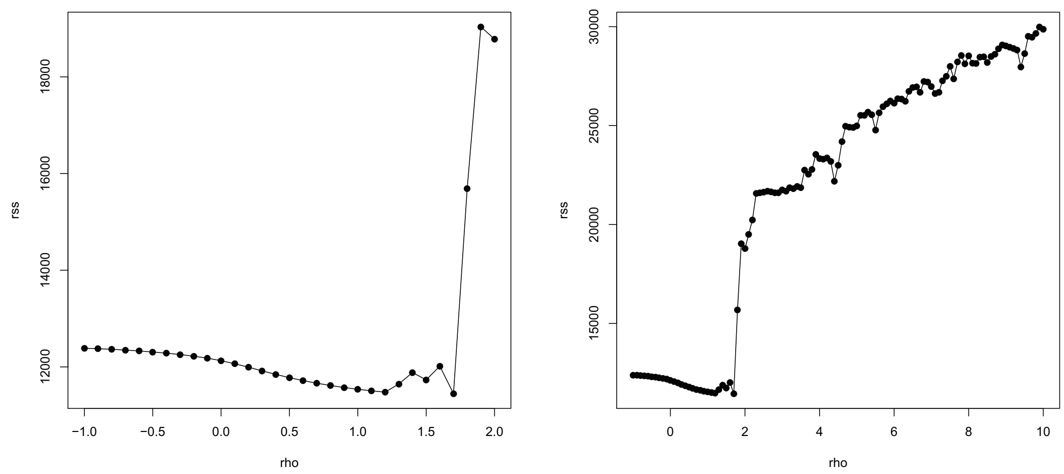
(a) ($\rho \in (-1, 2)$) (b) ($\rho \in (-1, 10)$)

Figure B4: Root of the sum of squared residuals, public and private funds with degressive use of funds and lag



(a) $\rho \in (-1, 2)$ (b) $\rho \in (-1, 10)$

Figure B5: Root of the sum of squared residuals, public and private funds with constant use of funds and lag



(a) $\rho \in (-1, 2)$ (b) $\rho \in (-1, 10)$

Figure B6: Root of the sum of squared residuals, public and private funds with constant use of recurrent funds and degressive use of contractual funds and lag

C. Theoretical model of the relationship between contractual public and private funds

As in the principal model we have

$$f(x,y) = \left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha) y^{(\frac{\sigma-1}{\sigma})}\right]^{\frac{\omega\sigma}{\sigma-1}}, \tag{C1}$$

and

$$y = y(e_y; \varphi_y) = \varphi_y e_y^{\mu}. \tag{C2}$$

However we focus on public contractual funds, thus we have:

$$x = x(e_x; \varphi_x) = \varphi_x e_x^{\eta}. \tag{C3}$$

C1 Optimum

The program of the labs is:

$$\max_{e_x, e_y, e_r} \delta h(e_r) \left[\alpha x(e_x; \varphi_x)^{\frac{\sigma-1}{\sigma}} + (1-\alpha) y(e_y; \varphi_y)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\omega\sigma}{\sigma-1}} \tag{C4}$$

$$st \quad : \quad e_x + e_y + e_r = 1$$

The Lagrangien can be written:

$$L = \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}} + \lambda(e_x + e_y + e_r - 1) \tag{C5}$$

$$\begin{aligned}\frac{\partial L}{\partial e_x} &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\frac{\omega\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}\alpha x'_{e_x} x^{(\frac{\sigma-1}{\sigma}-1)} + \lambda \\ &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\omega\alpha x'_{e_x} x^{\frac{-1}{\sigma}} + \lambda \qquad \text{(C6)}\end{aligned}$$

$$\begin{aligned}\frac{\partial L}{\partial e_y} &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\frac{\omega\sigma}{\sigma-1}\frac{\sigma-1}{\sigma}(1-\alpha)y'_{e_y} y^{(\frac{\sigma-1}{\sigma}-1)} + \lambda \\ &= \delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\omega(1-\alpha)y'_{e_y} y^{\frac{-1}{\sigma}} + \lambda \qquad \text{(C7)}\end{aligned}$$

$$\frac{\partial L}{\partial e_r} = \delta h'(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}} + \lambda \tag{C8}$$

Equating the FOC, we get:

$$\begin{aligned} &\delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\omega\alpha x'_{e_x} x^{\frac{-1}{\sigma}} && \text{(C9)} \\ = \; &\delta h(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}-1}\omega(1-\alpha)y'_{e_y} y^{\frac{-1}{\sigma}} && \text{(C10)} \\ = \; &\delta h'(e_r)\Big[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha)y^{(\frac{\sigma-1}{\sigma})}\Big]^{\frac{\omega\sigma}{\sigma-1}} && \text{(C11)}\end{aligned}$$

After some simplifications of (C9) and (C10), we have:

$$\alpha \frac{x'_{e_x}}{x^{\frac{1}{\sigma}}} = (1-\alpha)\frac{y'_{e_y}}{y^{\frac{1}{\sigma}}} \tag{C12}$$

Equations (C9) and (C11) give us:

$$\omega\alpha \frac{x'_{e_x}}{x^{\frac{1}{\sigma}}} \frac{1}{\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha) y^{(\frac{\sigma-1}{\sigma})}\right]} = \frac{h'(e_r)}{h(e_r)} \tag{C13}$$

From (C10) and (C11), we have:

$$\omega(1-\alpha) \frac{y'_{e_y}}{y^{\frac{1}{\sigma}}} \frac{1}{\left[\alpha x^{(\frac{\sigma-1}{\sigma})} + (1-\alpha) y^{(\frac{\sigma-1}{\sigma})}\right]} = \frac{h'(e_r)}{h(e_r)} \tag{C14}$$

The quantities $\left(\frac{x'}{x^{(\frac{1}{\sigma})}}\right)$, $\left(\frac{y'}{y^{(\frac{1}{\sigma})}}\right)$ appear in the FOC. In order to be able to do the comparative analysis, we focus on how those expressions vary with e_x, φ_x, e_y and φ_y. The different cases are presented in Table C1 below.

Table C1: Variation of expression of FOC with parameters

	$\frac{\partial\left[\frac{x'_{e_x}(e_x;\varphi_x)}{x^{1/\sigma}_{(e_x;\varphi_x)}}\right]}{\partial e_x}$	$\frac{\partial\left[\frac{x'_{e_x}(e_x;\varphi_x)}{x^{1/\sigma}_{(e_x;\varphi_x)}}\right]}{\partial \varphi_x}$	$\frac{\partial\left[\frac{y'_{\theta y}(e_y;\varphi_y)}{y^{1/\sigma}_{(e_y;\varphi_y)}}\right]}{\partial e_y}$	$\frac{\partial\left[\frac{y'_{\theta y}(e_y;\varphi_y)}{y^{1/\sigma}_{(e_y;\varphi_y)}}\right]}{\partial \varphi_y}$
$\sigma \in]0,1[$	<0	<0	<0	<0
$\sigma = 1$	<0	$=0$	<0	$=0$
$\sigma > 1$	<0	>0	<0	>0

C2 Analysis of shocks

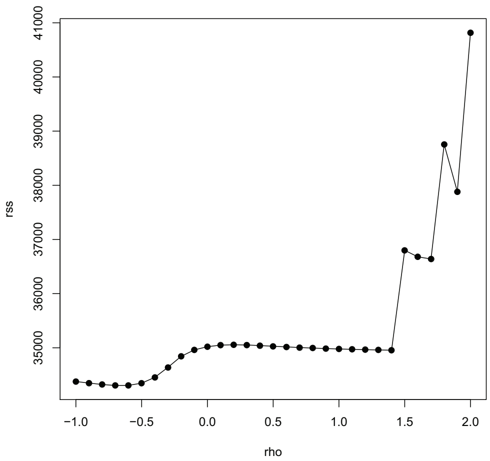
Because of the sign in Table C1 and in Table A1 for the general cases, the conclusion concerning the analysis of impact on the availability of different types of fund is as follows:

- When contractual public and private funds are gross complements ($\sigma \in]0,1[$), consequences of a shock on the availability of contractual public φ_x and private φ_y funds are exactly the same as when $\sigma \in]0, \frac{\varphi_x e_x^\eta}{a+\varphi_x e_x^\eta}[$ presented in Appendix A2. Thus there is a crowding in relationship between contractual public and private funds.

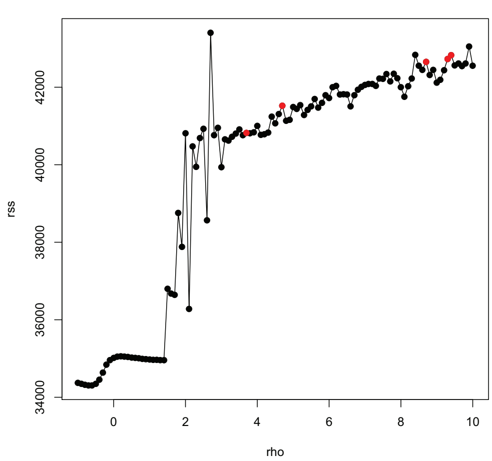
- When we are in the Cobb-Douglas case ($\sigma = 1$), because of the sign of Table C1, labs do not react to change on the availability of contractual public φ_x and private φ_y funds.

- When contractual public and private funds are gross substitutes ($\sigma > 1$), then reactions to changing occur on the availability of contractual public φ_x and private φ_y funds are exactly the same as in the general cases, presented in Appendix A5. Thus there is a crowding out relationship between contractual public and private funds.

D. Models fit for different value of ρ

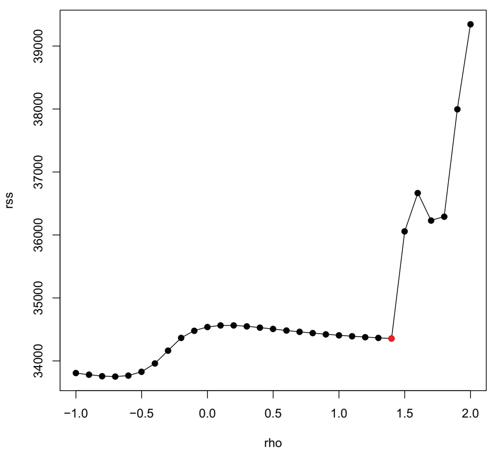


(a) $\rho \in (-1, 2)$

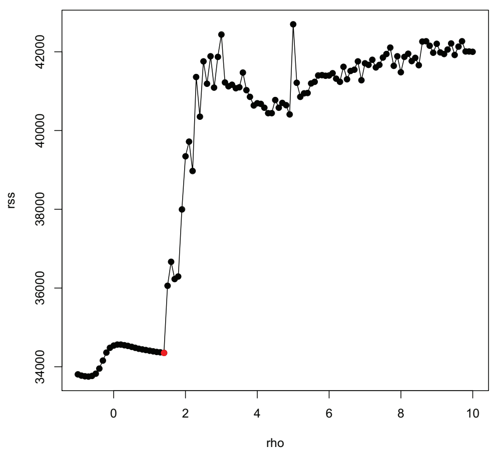


(b) $\rho \in (-1, 10)$

Figure D1: Root of the sum of squared residuals, contractual public and private funds with degressive use of funds

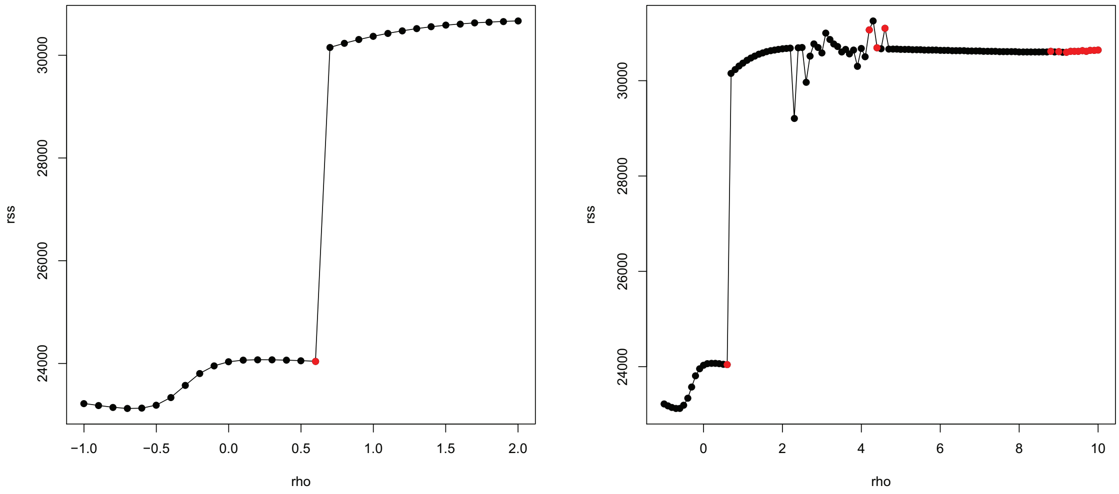


(a) $\rho \in (-1, 2)$



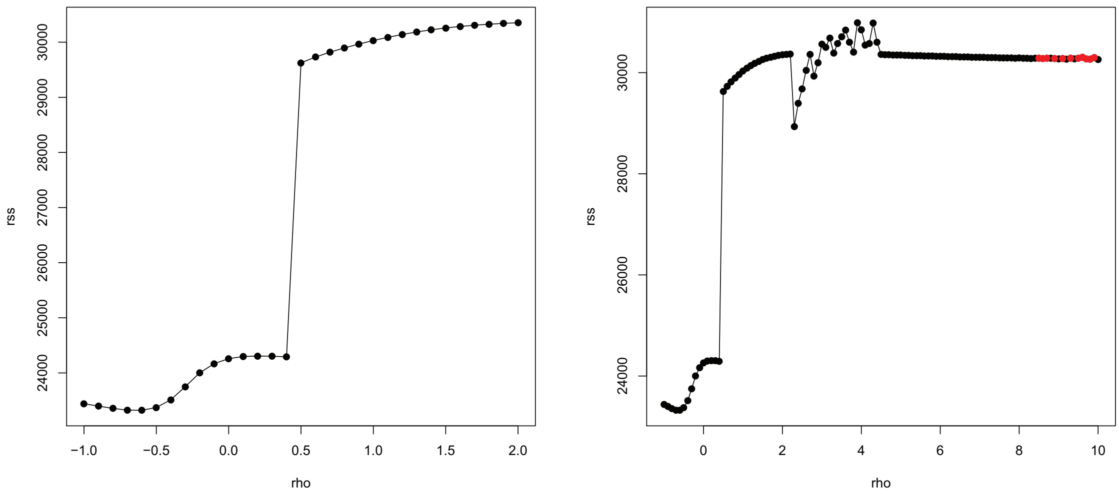
(b) $\rho \in (-1, 10)$

Figure D2: Root of the sum of squared residuals, contractual public and private funds with constant use of funds



(a) $\rho \in (-1, 2)$ (b) $\rho \in (-1, 10)$

Figure D3: Root of the sum of squared residuals, contractual public and private funds with degressive use of funds and lag



(a) $\rho \in (-1, 2)$ (b) $\rho \in (-1, 10)$

Figure D4: Root of the sum of squared residuals, contractual public and private funds with constant use of funds and lag

E. Variables

Table E1: The variables

Variables	Explications
x	Total amount of fund received from public sources
y	Total amount of fund received from private sectors
a	Recurrent public funding
e_x	Effort for raising public contractual funds
φ_x	Availability of public contractual funds
e_y	Effort for raising private contractual funds
φ_x	Availability of private contractual funds
e_r	Research effort
α	Distribution parameter
σ	Elasticity of substitution

Chapter 4

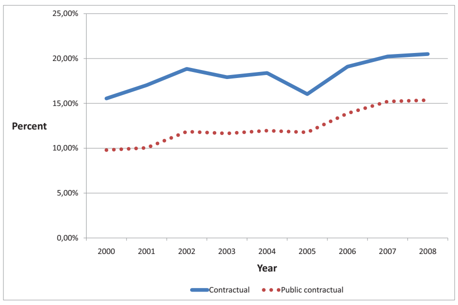
Obtaining Competitive Funds From a Public Agency: The Case of the ANR

Abstract

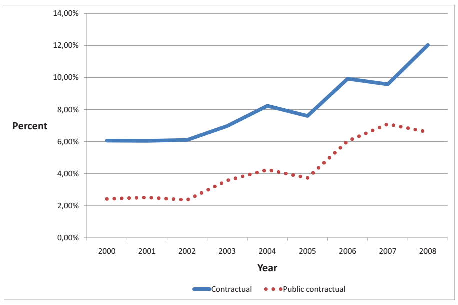
We analyse the process of getting competitive funds from a public agency. We model the decision of the researcher to apply and the decision of the funding agency to select a project. The model is estimated using a singular database on the Louis Pasteur University. Our results show evidence of self selection in the researchers' applications. Those with the highest scores of publication and patenting activities are applying more frequently. Contrary to other studies using data on public agencies from different countries, we do not find a clear influence of the score of publications on the decisions of the ANR. Our results point instead to the importance of being professors instead of associate professor and the ranks of the laboratories.

4.1. Introduction

For most economists, state support for PROs and universities is based on the expectation of future contributions to economic growth and social welfare. Since the 70s, we observe changes in the funding of PROs and universities, a decrease of stable and recurrent types of funds in favor of competitive and project-based types (Geuna, 2001). In France we observe an increase of the share of total contractual and public contractual funds in the total budget of universities and PROs as displayed in Figure 4.1 and an increase of the share of public contractual funds among contractual funds for PROs and universities as displayed in Figures 4.2.



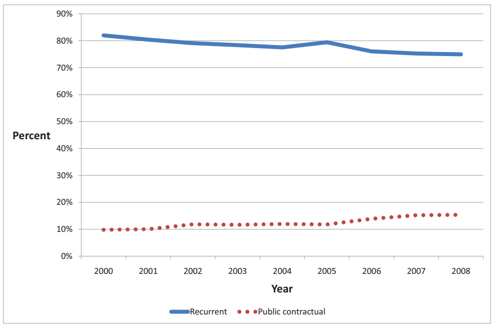
(a) Universities



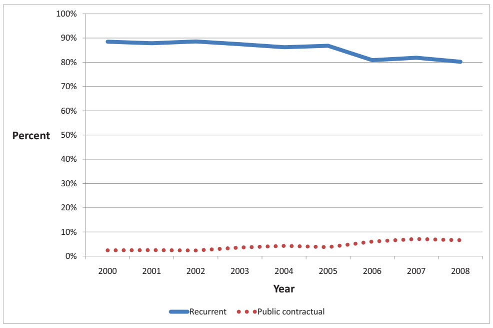
(b) PROs

Figure 4.1: Share of contractual and of public contractual funds among total funds. Source : MEN-DPD C3

This change occurs with the desire of using scarce resources in a more efficient way by targeting the recipient, and it reflects the wish of the State to obtain better returns of its investment in research. Thus, funds should support the most productive groups of researchers or/and the promotion of a topic of prior interest. Nowadays, public funds allocated in a competitive



(a) Universities



(b) PROs

Figure 4.2: Share of recurrent and of public contractual funds among total funds Source : MEN-DPD C3

way represent a non-negligible source of funds for the labs (Millar and Senker, 2000; Geuna, 2001; Lepori *et al.*, 2006, 2007). A key element of this evolution was the creation of Research Councils (RCs), called also funding agencies. Their mission is to elaborate calls for proposals, analyse the proposals and select the ones that should be funded in priority. In this spirit, the ANR, was founded on February 7^{th}, 2005. The ANR is a public funding agency for public or private research projects, created in the spirit of the National Science Foundation (NSF) in the USA. The ANR has a dual function explicitly written in its status : promoting first the production of new basic knowledge and second the interaction between public laboratories and industries through the development of partnerships. Based on two selection processes, ANR funds research projects based on their scientific excellence and their economic relevance for industry.

Few studies focus on factors explaining the decision of the funding agencies to grant a project. Based on all applications to the NSF between 1985-

1990, Arora and Gambardella (1998) analysed factors explaining the decision of NSF to grant a project in economics. They observed a positive relationship between the score of the project attributed by NSF reviewers and the probability to be selected and also between the past publications of the principal investigator of the project and the probability of the project to be selected. The authors also found a positive effect of belonging to an elite institution. Feinberg and Price (2004) concluded that there was a positive impact of NBER affiliation on success of getting NSF grants in economics programs. Arora *et al.* (1998) concluded also to a positive impact of variables related to scientific merit on grants awarded by the Italian research council.

In this paper, we develop a theoretical model of the behaviour of the researchers explaining their decision to apply or not, as well as the decision of the funding agency to select and finance a project. Our model is derived from the literature on labor market participation, and more precisely on the works of Heckman (1979) and Blundell *et al.* (2002). It leads us to a reduced form model, that we estimate using a database on researchers of the Louis Pasteur University of Strasbourg (France). This singular database contains information on the whole population of researchers working at the university, and enables us to identify precisely, among those who applied, the ones who were rejected and the ones who were funded. We are thus able to analyse separately the decision to apply at the level of the researcher and the decision to finance a project at the level of the ANR. As far as we know, this is the first empirical analysis at these two levels since the creation of the ANR.

The paper is organized as follows. Section 4.2 describes Institutional setting. In Section 4.3 we present the theoretical model explaining both the decision of the researchers to apply and the decision of the ANR to finance a project. Section 4.4 describes the data used in our study. The resulting empirical strategy is developed in Section 4.5 and results are discussed in Section 4.6.

4.2. Institutional setting

The ANR is a public funding agency for research projects. The ANR has a dual function: promoting the production of new basic knowledge, as well as the interaction between public laboratories and industry through the development of partnerships. Thus ANR supports research projects based on their scientific excellence and their economic relevance for industry.

The organizational and selection process of the ANR is as follows. First, the ANR determines its long term strategic plans in several domains. Sectoral committees (*comité scientifique sectoriel*) are constituted for each main research area. In 2010 the main domains are : sustainable energy, environment and urban system, ecosystem and sustainable development, biology and health, social science, engineering process and security, information and communication science and last but not least nano-science and nano-technology. The ANR asks sectoral committees made of scientists from universities and firms, and also representatives of the ministry to produce a research program proposal. The sectoral committees put forward an opinion on future research programs based on national government policies, advice of the committee for forecasting (*conseil de prospective*), the report of the workshop of forward thinking (*atelier de réflexion prospective*) and take stock of past programs.

After collecting the opinions of ministries in charge of the different research organizations, the board of directors votes research programs and so sets the scientific orientations. Thus for each research program, a set of topics corresponding to national priorities as defined by the ANR and the government is agreed upon. For each research program a steering committee is set up. Steering committees contribute to the elaboration of the calls for applications, they also contribute to the determination of grantees and to the monitoring of the projects. With the contribution of the steering committees, the ANR prepares public calls for applications. The funding agency then collects the applications and proceeds to a two-step evaluation of the applications.

In a first step, all applications are evaluated through the ANR peer review system by the evaluation committees. The evaluation committees are made of researchers from the relevant fields. Reviewers provide recommendations on the scientific and technical relevance of the applications, using a rating scale between A and C. Only the projects with A and B are presented to the steering committee. Based on the recommendations of the evaluation committees on the long term priorities of the ANR as well as the financial constraints, the steering committee provides a list of potential awardees and eventually a complementary list. The steering committee can also produce a document for realignment of the purpose of projects and/or on the appropriateness of the requested budgets. All those documents are submitted to the board and selected projects are announced but not yet funded. The Principal Investigator (PI) is informed and, if necessary, additional information are requested. The PI can also be requested to amend the proposal or the budget. At this stage, a negotiation between the PI and the ANR can occur. After the completion of the negotiations, PIs are asked to submit a final proposal, which documents all costs and technical agreements reached during the negotiations. At this point, the final decision is taken and the selected project funded.

Some descriptive statistics on the ANR are provided in Table 4.1. During our time period analysis, 2005-2007, we observe an increase of the percentage of foreign experts in the evaluation committee, a decrease of the percentage of the budget allocated to investigator oriented research projects called blue sky (*programme blanc*). We also observe an increase of the mean duration, mean amount by project and the number of partners of a standard project. The ANR presents these last results as a wish to concentrate its budget on important projects instead of numerous smaller projects.

Table 4.1: ANR funding characteristics

Year	**2005**	**2006**	**2007**
Percentage of foreign researchers in evaluation committees	9.8	12.6	15.2
Selection percentage	25.3	25.7	26.51
Percentage of budget allocated to investigator oriented research	29.96	28.03	25.1
Standard project			
Duration (months)	32	35.5	37
Amount (euros)	370840	382603	425093
Nbr of partner	3.2	3.1	3.1
Amount by partner	115887	123794	138594

Source: ANR Annual report

4.3. Model

We used a Heckman type approach, introduced first by Heckman (1979) to model the labor supply of women. This model led to several extensions. We follow an approach in line with Blundell *et al.* (2003), adapted to our setting. We first model the determinants of the decision of researchers to apply in subsection 4.3.1. In subsection 4.3.2, we model the evaluation of the applications by the ANR, and its decision to select a project.

4.3.1 Researchers' applications

The ANR calls are public, and we focus here on the decision of researchers to apply. We assume that each researcher i invests H_{it} level of human capital (skill) at time t in a project. Human capital is differentiated by field, thus it commands a price per field r_d.

Researcher i at time t in the field d proposes a project that he is evaluating w^s_{idt}:

$$w^s_{idt} = r_d H_{it}. \tag{4.1}$$

The evaluation of the project depends on the human capital invested in the project H_{it} and on the price of human capital r_d. We assume $\ln H_{it}$ can be approximated using a set of explanatory variables A^s_{it}, that we do not specify yet. Thus the log-project-value equation has the following additive form:

$$\ln w^s_{idt} = \ln r_d + A^s_{it} + \varsigma^s_{it}, \tag{4.2}$$

where ς^s_{it} is a normal error term($\varsigma^s_{it} \sim \mathcal{N}(0, \sigma^2_{A^s})$).

The reservation value of the project depends on the other resources available to the researcher i at time t. The reservation value also depends on the scientific importance of the project. Indeed, if a researcher considers his project as scientifically very relevant, he expects high quality publications and thus an increase of his reputation. Therefore, he is willing to work more easily for a project of high scientific relevance than for another one. Therefore, we specify:

$$w_{it}^r = B_{it}^{\psi^r} H_{it}^r, \tag{4.3}$$

where B_{it} measures the other resources available to the researcher and H_{it}^r denotes the importance given by the researcher to the project. We assume $\ln H_{it}^r$can be approximated using a set of explanatory variables A_{it}^r , that we do not specify yet.

Allowing for non informative measurement error we obtain the following equation for the reservation value:

$$\ln w_{it}^r = \psi^r \ln B_{it} + A_{it}^r + \varsigma_{it}^r, \tag{4.4}$$

with $\varsigma_{it}^r \sim \mathcal{N}(0, \sigma_{Ar}^2)$

A researcher applies if the gain of doing so is more important than the reservation value of the project. Let us denote by C_{it} a dummy variable indicating the application of researcher i at time t. The decision of the researcher is thus:

$$C_{it} = 1[\ln r_d - \psi^r \ln B_{it} + A_{it}^s - A_{it}^r + \varsigma_{it}^s - \varsigma_{it}^r \geq 0]. \tag{4.5}$$

We can rewrite equation (4.5) as follows:

$$C_{it} = 1[\ln r_d - \psi^r \ln B_{it} + X_{it} + u_{it} \geq 0], \tag{4.6}$$

where $X_{it} = A^s_{it} - A^r_{it}$ and $u_{it} = \varsigma^s_{it} - \varsigma^r_{it}$. We will connect X_{it} to observable in subsection (4.5.1).

4.3.2 Funding agency

The funding agency collects the applications and proceeds to a two step evaluation of applications. The evaluation of the project depends on: (i) the recommendation of the evaluation committee, which focuses on scientific and technical relevance of the applications, (ii) the evaluation by the steering committee of the quality of the project, (iii) the financial capacity of the agency measured by its budget.

Thus the evaluation depends on the budget M_t of the agency. Indeed, the agency can at most finance projects up to a total of M_t. The evaluation also depends on the priority of the discipline for the ANR denoted ψ_d. Finally the value of the project is related to the evaluation of the human capital invested in the project H^d_{it}. We thus write the ANR evaluation of the project as follows:

$$w^d_{idt} = \psi_d H^d_{it} M_t. \tag{4.7}$$

Variable H^d_{it} is approximated using a set A^d_{it} of explanatory variables. We thus have:

$$\ln w_{idt}^d = \ln \psi_d + \ln M_t + A_{it}^d + \varsigma_{it}^d, \tag{4.8}$$

where $\varsigma_{it}^d \sim \mathcal{N}(0, \sigma^2_{A^d})$

Because we do not have information on the negotiations occurring at the last step before the final decision, we assume that a project which reaches this step is fully funded. Thus the agency decides to finance a project if its own evaluation is higher than the price w_{idt}^s asked for the project. The dummy variable S_{it} indicating the decision to finance project presented by researcher i at time t is thus equal to one if the difference between w_{idt}^d and w_{idt}^s is greater than zero:

$$S_{it} = 1[\ln \psi_d - \ln r_d + \ln M_t + A_{it}^d - A_{it}^s + \varsigma_{it}^d - \varsigma_{it}^s \geq 0]. \tag{4.9}$$

We can thus rewrite:

$$S_{it} = 1[\ln G_d + \ln M_t + Z_{it} + v_{it} \geq 0], \tag{4.10}$$

where $\ln G_d = \ln \psi_d - \ln r_d$, $Z_{it} = A_{it}^d - A_{it}^s$ $v_{it} = \varsigma_{it}^d - \varsigma_{it}^s$. We will connect Z_{it} to observable in subsection (4.5.2).

4.4. Data

We use data on the ULP, Strasbourg. ULP is one of the most important French research universities, with around 80 laboratories (labs). ULP has a strong tradition of fundamental science and researchers of the university receive numerous national and international honours[1]. The third European report on science and technology indicators ranks ULP first among French universities in terms of impact and Shanghai 2010 ranks ULP as fourth among French universities. In chemistry ULP is the first among French universities and fourteenth in the world. We use data collected since a decade by a team of researchers at Beta[2] We first present application and selection data in subsection 4.4.1. In subsection 4.4.2 we present data on Labs and in subsection 4.4.3 on researchers. An overview of the characteristics of the applicants is presented in subsection 4.4.4 .

4.4.1 Application and selection data

The data on applications and selection involve two different sources: ULP and ANR.

ANR provided us with information on the projects they financed between 2005 and 2007. For each project they financed, we have information on the date, the amount and the researchers involved in the project and their institutions.

To be able to analyse the application process, we need to complement this data with information on the rejected applications. At ULP, it is mandatory for every application to be notified to the University before it is submitted to the ANR. ULP thus provided us with the complementary data on the researchers who applied and were not funded by the ANR. Using both sets

[1] One Nobel Prize among ULP researchers and seventeen nobel prize laureates who studied or worked at ULP.

[2] We are grateful to all present and previous members of the lab, Laurence Frank, Gabrielle Genet, Nicolas Carayol, Mireille Matt, Rachel Levy and Karine Pellier among others for their contribution to the construction of the database.

of data, we were able to construct the list of all the applications to the ANR calls coming from ULP, and to identify the funded projects as well as the rejected ones.

Our model is static and depicts the behaviour of the researchers at different points in time. However we observe in the data that some researchers applied with several projects during the same year. Only 31 researchers among the 1 237 researchers of ULP had multiple applications during one period. Therefore, we need sometimes to map several projects to a unique researcher for a given year in a single observation. We consider that a project of a researcher is selected in a period if at least one project of the researcher is selected.[3] When several applications from the same researcher are selected, we compute the sum of the amounts provided by the ANR to him.

Table 4.1 presents the number of researchers applying over the period 2005-2007. We observe an increase of the number of researcher applying during this period. However, the number of grantees is more or less constant over time. Thus the selection rate decreases.

Table 4.1: Number of researchers who applied to an ANR call and were selected

Year	**Nb of researchers who applied**	**Nb of selected researchers**	**Proportion**
2005	74	57	77%
2006	80	63	79%
2007	103	62	60%

Source: EcS-BETA database

[3]This hypothesis is not so restrictive because in 78 percent of the cases their rate of success is equal or superior to 50 percent.

4.4.2 Information on labs

In France, each research unit is evaluated by the AERES[4], a national agency every four years. This evaluation is based on knowledge production activities, national and international attractiveness of the unit, its strategies and future projects. This evaluation is based on past publications as well as future expected activities, and leads to the attribution of a rating: A^+, A, B or C. Table 4.2 displays ranking distribution among researchers and labs. We observe that more than 70 percent of the researchers working at ULP are members of labs rated A or A+, whereas labs rated C or D involve less than 6% of the researchers.

Table 4.2: Mark distribution among researchers and labs

Marks	Nb of researchers	Nb of labs
A+	402	23
A	478	10
B	285	26
C and D	72	8

Source: EcS-BETA database

The scientific discipline of a researcher is defined as the discipline of his lab. Disciplinary distribution among researchers and labs is presented in Table 4.3. Life science and medicine are more important with 50 percent of researchers working in these disciplines

We have information on funds raised by the labs from public and private sources. In our analysis we distinguish three types of funds: the recurrent

[4] *Agence d'Evaluation de la Recherche et de l'Enseignement Supérieur* (AERES) can be translated into Evaluation Agency for Research and Higher Education. The AERES was created by the law of 2006 and has been running since March 2007. The AERES mission is to evaluate research organisations and institutions, research and higher education institutions, scientific cooperation foundations and institutions as well as the French National Research Agency by taking account of all their missions and activities.

Table 4.3: Discipline distribution among researchers and labs

Disciplines	**Nb of researchers**	**Nb of labs**
Life science	430	21
Medicine	188	23
Chemistry	125	9
Physics	191	4
Earth sc and Astr	87	3
Engineering Sc	139	6
Mathematics	77	1

Source: EcS-BETA database

public funds and both public and private contractual funds. The details of the different types of sources are summarized below in Table 4.4. By recurrent funds we mean the block funding attributed to the university by the ministry and also by the CNRS and INSERM [5]. Public contractual funds encompass national and international contractual funds. Similarly private contractual funds include funds from national ant foreign private companies. For each contract, public or private, we observe the year of signature, the duration, the amount of the contract, the identity of the lab receiving the funds for each contract and the fund providers. In our analysis, each public and private contractual fund is attributed to the year the contract was signed. The recurrent public funds are distributed uniformly over time.

4.4.3 Information on researchers

We got information on researchers from administrative reports prepared by research unit every four years. Using the administrative reports produced

[5] *Centre National de la Recherche Scientifique* (CNRS) can be translated into National Centre for Scientific Research and *Institut National de la Santé et de la Recherche Médicale* (INSERM) can be translated into National Institute for Health and Medical Research.

Table 4.4: Different sources of funds

Type of fund	Aggregate level	Funding organization
Public grant	Public grant	Ministry of research CNRS INSERM ...
Contractual public funds	Local government	Regional council City of Strasbourg ...
	European Union	PCRD FEDER EUREKA COST ...
	Various French public funds	CNRS by project French university ...
	Various international public funds	Foreign university ...
Contractual private funds	French private funds	Firms Foundations Associations ...
	International private funds	Firms Foundations Associations ...

Source: EcS-BETA database

for the period 2004-08, we got information on 1237 researchers across 67 labs. Among them, 574 were full time researchers working for PROs (243 professors[6], 162 Associate Professors[7] with HDR[8] and 169 without HDR) and 663 for universities (270 professors, 137 Associate Professors with HDR and 256 without HDR).

[6]Professors correspond to *directeur de recerche.*

[7]Associate professor correspond to *chargé de recherche.*

[8]*Habilitation à Diriger des Recherches* (HDR) can be translated into the right to supervise phd students and research activities.

Information on publications of permanent researchers are collected using SCI (Science Citation Index) data from the Institute for Scientific Information. Because several studies show the impact of past publication activities on the success of an application (Arora and Gambardella, 1998; Arora *et al.*, 1998), we compute past publication scores using publications of researchers between 2002 and 2004. We have information on the number of co-authors, for each publication between 2002 and 2004, for which a researcher of ULP appears as one of the co-author. We hence divide each publication by the number of co-authors to get normalized scientific contribution per publication. We finally sum over the years for each researcher to obtain a publication score for each researcher.

We also compute a patenting score using the same time period (2002-2004). The database also incorporates patents which have been invented by at least one of the ULP permanent researcher. Numerous studies show that in Europe, patents involving university researchers are not owned by the university (Lissoni *et al.*, 2008; Verspagen, 2006). Thus in our analysis, we analyse patents for which researchers appear as one of the inventors, whatever the identity of the owner of the patent. For each researcher, we sum the number of patents in which he appears as one of the inventors. We then sum over the years for each researcher to get patenting scores (statistics are summarized in Table 4.5).

Table 4.5: Statistics on publication and patenting score

Variables	**Number of observations**	**Mean**	**s.d.**	**Min**	**Max**
Sum of patents	1237	0.35	1.53	0	25
Sum of publications	1237	6.36	8.25	0	77
Sum of publications adjusted for co-authorship	1237	1.34	1.71	0	17.17

Source: EcS-BETA database

4.4.4 Overview of the characteristics of the applicants

Table 4.6 summarizes the statistics on the full sample and the sample of applicants. The comparison of the averages computed over the full sample or the sample of applicants provides us with information on the application process. The applicants have 3 times more patents and twice more publications than the average staff. They are also more often full professors than associate professors. The average age is however 1 year younger in favor of the applicants. Discrepancies at the level of the lab indicate that the applicants belong to labs with slightly less public funds, whether recurrent or contractual, and slightly more private funds. The average rating of the labs is also slightly higher in the sample of the applicants than in the full sample. The main difference is in terms of discipline : labs in life science are far more represented among the applicants than in the full sample. Those labs are more often rated A+ (54%) than on average in the sample of applicants (35%). Furthermore, they receive less private (3.24) and public contractual funds (6.28) than the average applicant, who receives on average 3.79 private funds and 6.38 public funds. The increase of the average amount of private funds received by the labs is thus not related to a change in the composition of the sample by discipline.

Table 4.6: Descriptive statistics on data

	All population		Applicant	
Variables	Mean	S.d.	Mean	S.d.
Researcher level				
Sum of patents	0.35	1.53	1.11	2.77
Sum of publications	1.34	1.71	2.49	2.43
Age	48.99	9.96	48.08	8.32
Rank:				
Prof	0.22	0.41	0.28	0.45
Full time prof	0.20	0.40	0.34	0.47
Ass prof with HDR	0.11	0.31	0.07	0.25
Ass prof without HDR	0.21	0.41	0.10	0.30
Full time ass prof with HDR	0.13	0.34	0.13	0.36
Full time ass prof without HDR	0.13	0.34	0.09	0.28
Lab level				
Funds:				
Log private funds*	3.66	3.89	3.79	3.97
Log public funds*	6.40	3.93	6.38	4.01
Log recurrent funds*	7.26	3.67	7.21	3.88
Mark:				
A+	0.32	0.47	0.35	0.48
A	0.37	0.49	0.43	0.50
B	0.23	0.42	0.19	0.40
C and D	0.06	0.23	0.02	0.15
Size:				
$[0, 10]$	0.13	0.34	0.14	0.35
$[11, 25]$	0.35	0.48	0.35	0.48
$[25, 60]$	0.27	0.44	0.23	0.42
> 61	0.25	0.43	0.28	0.45
Research topics:				
Life science	0.35	0.48	0.49	0.50
Medicine	0.15	0.36	0.09	0.29
Chemistry	0.10	0.30	0.13	0.34
Physics	0.15	0.36	0.13	0.34
Earth sc and Astr	0.07	0.26	0.03	0.16
Engineering Sc	0.11	0.32	0.09	0.28
Mathematics	0.06	0.24	0.03	0.18
Time dummies				
Year 2005	0.33	0.47	0.29	0.45
Year 2006	0.33	0.47	0.31	0.47
Year 2007	0.33	0.47	0.40	0.49
Observations	3711		257	

Source: EcS-BETA database

*:the funds are expressed in millions euros before taking the natural logarithm.

4.5. Empirical strategy

We first investigate the researchers' applications in subsection 4.5.1. We then turn to the decision of the ANR in subsection 4.5.2.

4.5.1 Researchers' decisions

Explaining the decisions of the researchers:

The decision to apply is observed through the dummy variable C_{it} defined such as:

$$C_{it} = \begin{cases} 1 & \text{if } C^*_{it} > 0 \text{ if researcher } i \text{ applies to a call at time } t, \\ 0 & \text{if } C^*_{it} \leq 0 \text{ otherwise.} \end{cases} \tag{4.11}$$

$$C^*_{it} = \alpha^1 K^c_d + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it} + u_{it} \tag{4.12}$$

where K^c_d is a set of dummies indicating the research topic, $\ln B_{it}$ the budget of the researchers' lab divided by the number of researchers in the lab and X_{it} a vector of covariates including:

- year dummies,
- indicator of the rating of the lab, as a proxy of quality of the project it,
- score of the publication activity of the researcher,
- score of the patenting activity of the researcher,

- age and age squared of the researcher,
- dummies indicating the status of the researcher: associate professor without HDR, associate professor with HDR, full professor. A set of dummies is defined symmetrically for the researchers of PROs.
- indicator of the size of the lab.

The likelihood function is the one of a standard Probit model, given by the following relation:

$$L(C,\theta^c) = \prod_{t=1}^{T}\prod_{i=1}^{N}\left(\Phi\Big(\frac{\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}}{\sigma_u}\Big)\right)^{C_i} \left(1 - \Phi(\frac{\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}}{\sigma_u})\right)^{(1-C_i)}, \tag{4.13}$$

where $\Phi(.)$ is the cumulative univariate standardized normal distribution and $\theta^c = (\alpha^1, \alpha^2, \alpha^{3'}, \sigma_u^2)$ is the set of parameters of the model.

4.5.2 Decision of the funding agency

The decision of the funding agency about the applications is modeled as follows:

$$S_{it} = \begin{cases} 1 & \text{if } S_{it}^* > 0 \text{ if the agency decides to grant,} \\ 0 & \text{if } S_{it}^* \leq 0 \text{ otherwise.} \end{cases} \tag{4.14}$$

$$S_{it}^* = \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s + v_{it}, \tag{4.15}$$

where K_d^s is a set of dummies indicating the research topic, $\ln M_t$ the budget of the funding agency and Z_{it}^s a vector of covariates including:

- year dummies,
- indicators of the rating of the lab, to control for the heterogeneity of the labs the researchers belong to and as a proxy of quality of the project it,
- score of the publication activity of the researcher,
- score of the patenting activity of the researcher,
- age and age squared of the researcher,
- dummies indicating the status of the researchers : associate professor without HDR, associate professor with HDR, full professor. A set of dummies is defined symmetrically for the researchers of PROs.
- indicator of the size of the lab.

The likelihood function of the decision of the funding agency is the one of a standard Probit model, defined as follows:

$$L(S,\theta^s) = \prod_{t=1}^{T}\prod_{i=1}^{N}\left(\Phi\Big(\frac{\beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s}{\sigma_v}\Big)\right)^{S_i} \left(1-\Phi(\frac{\beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s}{\sigma_v})\right)^{(1-S_i)}, \tag{4.16}$$

where $\Phi(.)$ is the cumulative univariate distribution standardized normal distribution and $\theta^s = (\beta^1, \beta^2, \beta^{3'}, \sigma_v^2)$ is the set of parameters. In a first stage, we assume u_{it} and v_{it} to follow independent gaussien distributions with variances σ_u^2 and σ_v^2. This leads us to two independent Probit models defined by the equations (4.11), (4.12), (4.14), (4.15).

4.5.3 Joint model

We allow for u_{it} and v_{it} to follow a bivariate normal distribution. Indeed it is likely that shocks on the evaluation of the project by the researcher are correlated with the evaluation made by the ANR:

$$\begin{pmatrix} u_{it} \\ v_{it} \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix} \right) \tag{4.17}$$

This model is estimated with maximum likelihood (ML). There are three types of observations in the sample with the following probabilities (details are in Appendix C):

$$\begin{aligned}
\Pr(C_{it}=0) &= \Phi\big(-(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it})\big) \\
\Pr(C_{it}=1, S_{it}=1) &= \Phi_2(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}, \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s; \rho) \\
\Pr(C_{it}=1, S_{it}=0) &= \Phi(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}) \\
&\quad -\Phi_2(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}, \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s; \rho).
\end{aligned}$$

where, $\Phi(.)$ is the cumulative standardized univariate normal distribution and $\Phi_2(.)$ the cumulative standardized bivariate normal distribution. From these probabilities we can determine the following log-likelihood equation:

$$
\begin{aligned}
\ln L(C,S,\theta^{BP}) \quad = \quad & \sum_{i=0}^{N}\sum_{t=0}^{T}(1-C_{it})\ln\Phi\big(-(\alpha^1 K_d^c+\alpha^2\ln B_{it}+\alpha^{3'}X_{it})\big) \\
& +C_{it}S_{it}\ln\Phi_2\big(\alpha^1 K_d^c+\alpha^2\ln B_{it}+\alpha^{3'}X_{it}, \\
& \beta^1 K_d^s+\beta^2\ln M_t+\beta^{3'}Z_{it}^s;\rho\big) \\
& +C_{it}(1-S_{it})\ln\big[\Phi(\alpha^1 K_d^c+\alpha^2\ln B_{it}+\alpha^{3'}X_{it}) \\
& -\Phi_2(\alpha^1 K_d^c+\alpha^2\ln B_{it}+\alpha^{3'}X_{it},\beta^1 K_d^s+\beta^2\ln M_t+\beta^{3'}Z_{it}^s;\rho)\big],
\end{aligned}
$$

where, $\theta^{BP}=(\alpha^1,\alpha^2,\alpha^{3'},\beta^1,\beta^2,\beta^{3'},\sigma_u^2,\sigma_v^2,\rho)$ is the set of parameters of the bivariate Probit model.

4.6. Results

We present here the estimates of the equations describing the decision of the researcher to apply as well as the decision of the funding agency. Table 4.1 displays the estimated marginal effects of the equations (4.11), (4.12), (4.14) and (4.15). The first two columns present the results obtained assuming two independent Probit models, and the last columns the results obtained assuming a Probit with sample selection.[9] Results are notably close for both models. A likelihood ratio test reject the null hypothesis of dependence between the two equations, and thus concludes in favor of the two independent Probit models.

As regards the researchers applications, we observe that researchers with numerous publications and a high patenting score over the last 3 years are more likely to apply for ANR funds. It should be noted that the publication of one paper with a single author increases the number of publications of the author by one, yielding an increase in the probability to apply of 1%. This result can be viewed as the result of a self selection as researchers with the most visible and the most numerous output can expect to be more likely to be selected by the agency. Parameters related to the age of the researcher are significant in both models. The probability to apply is an inverted U-shaped function of the age, leading to an optimal age of 34 years and 6 months so that the relationship is essentially increasing and concave.[10] The ranking

[9] The marginal effects deduced from the second equation of the bivariate Probit are those of the conditional probability of a selection given an application, that is $\Pr[S = 1|C = 1]$.

[10] The optimal age is computed using the coefficients reported in Table D1 in Appendix D. The applicants are on average 49 year old, suggesting that this variable evolves jointly with others such as the rank of the researcher. One has thus to be careful when interpreting the coefficients of this variable separately from the others.

Table 4.1: Estimated marginal effects of the decision equation of the researchers and labs

Model	Probit	Probit	Bivariate Probit	
	Researcher application	ANR decision	Researcher application	ANR decision
Researcher level				
Sum of patents	0.005***	-0.010	0.005***	-0.001
Sum of publications	0.011***	0.013	0.011***	0.021
Age	0.008*	0.095**	0.008*	0.121**
Age square	-0.000**	-0.001**	-0.000**	-0.001**
Rank:				
Prof	0.091***	-0.070	0.090***	-0.106
Full time prof	0.101***	0.039	0.101***	0.022
Ass prof with HDR	0.018	-0.221	0.018	-0.277
Full time ass prof with HDR	0.049***	0.014	0.049**	-0.007
Full time ass prof without HDR	-0.010	0.126	-0.010	0.134
Lab level				
Funds:				
Log private funds	0.001		0.001	
Log public funds	-0.001		-0.001	
Log recurrent funds	0.002		0.002	
Mark:				
A+	-0.004	-0.076	-0.002	-0.080
B	-0.009	-0.290***	-0.009	-0.293**
C and D	-0.032**	0.008	-0.031**	0.044
Size:				
$[0, 10]$	-0.005	-0.094	-0.005	-0.147
$[11, 25]$	-0.015	-0.058	-0.016	-0.081
$[25, 60]$	-0.019	0.033	-0.017	0.031
Research topics:				
Medicine	-0.030***	-0.296**	-0.030***	-0.366**
Chemistry	-0.015	-0.323**	-0.014	-0.365**
Physics	-0.034***	-0.456***	-0.034***	-0.532***
Earth sc and Astr	-0.039***	-0.548***	-0.038***	-0.583***
Engineering Sc	-0.023*	-0.630***	-0.022*	-0.650***
Mathematics	-0.041***	-0.208	-0.041***	-0.278
Time dummies				
Year 2006	0.006	0.046	0.006	0.061
Year 2007	0.028***	-0.058	0.027***	-0.061
Observations	3711	257	3711	257
Log likelihood	-811.83709	-115.60219	-926.78631	
LR test chi2(1) = 1.31 Prob > chi2 = 0.2531				

*** p<0.01, ** p<0.05, * p<0.1

of the researcher is important, as professors, whether they depend on the university or on a research center, are more likely to apply.

Surprisingly, none of the variables related to the funding of the lab is a significant parameter. It should be recalled that we have informations on funds at lab level, thus it is likely that these variables are only broad measures of the financial constraints faced by the researchers at the individual level. Labs with the worst evaluations are also less likely to have researchers who apply. This can be seen as indicating self selection, as researchers might expect to be rejected based on the bad signal caused by the evaluation of the whole lab. There is furthermore a strong heterogeneity among disciplines, and researchers working in life science, chemistry and engineering science have a higher probability to apply than medicine researchers, physicist, earth science and astronomy.

The ANR decision depends on the rating of the lab of the researcher. Researchers belonging to labs with the highest ratings (A and $A+$) have a higher probability to be selected than the ones belonging to labs rated B. Surprisingly, researchers of labs with marks C and D do not have a significantly different probability to be selected than researchers of labs A and $A+$. This last result is not surprising considering the data. Actually, 5 researchers belonging to labs with mark of C and D applied, and 4 were selected. It should be noted that those 4 researchers are among the 11.5 % of the researchers with the highest publication scores, and the rejected one has a far lower publication score. At the same time, the coefficients of the variables measuring publication and patenting activities are not significant. This result, along with the previous estimated coefficients of these variables in the equation explaining the decision to apply, may indicate that most of the selection on publication and patenting activities is self-selection rather than selection by the ANR. This result is in contradiction with the ones of Arora *et al.* (1998) and Arora and Gambardella (1998), who concluded that there was a positive impact of past publications on the decision of the funding agency using respectively data on the NSF only in economics and on the CNR in the field of biotechnologies. An interpretation is that the ANR studies closely the different proposals, and bases its decision on the whole project rather than on a single indicator of academic activities. One should also remember that the dummy variables indicating the rating of the lab capture part of the effect of the publication score for researchers belonging to labs rated C or D. Hence, we cannot exclude that the coefficients of the publication and patenting activities are not significant because of a lack of empirical identification. Another explanation is that a three year window is not long enough to measure PI career. As before, parameters related to the age of the researcher are significant in both models. The probability to be selected is also an inverted U-shaped function of the age, leading to an optimal age of 57 years so that the relationship is essentially increasing and concave. Researchers working in medicine, chemistry, physics, earth science and astronomy and engineering science have a lower probability to be selected than mathematicians and life scientists. This can be interpreted as indicating the disciplines prioritized by the ANR. It should be recalled also that ULP is recognized as a top research university in life science.

4.7. Conclusion

In this paper, we model the decision of the researcher to apply to a call for proposals of a public funding agency, and the decision of the funding agency to fund a project. The empirical analysis is based on a singular database on the ULP, a French university with a leading scientific role in chemistry and life sciences in the world.

Our results show first that the sample of applicants is not a random sample drawn from the whole staff of the university. The researchers with a high score of publication and patenting activities apply more frequently, as well as those belonging to highly ranked labs. There is here a selection, that can be explained by differences in the capability of the researchers or by a self-selection mechanism. Second, our results do not indicate a clear impact of the funds gathered by the lab from other sources on the decision to apply. There is thus no evidence of spillovers, whether positive or negative, between the ANR and the other types of funding. The results on the equation explaining the decision of the ANR show an impact of the evaluation of the labs as well as a strong heterogeneity by disciplines. All in all, it seems that the projects are assessed individually, and selected in line with the fields prioritized by the agency. It is thus not necessarily the researchers with the highest publication scores who are funded.

Our results indicate that the agency attracts the scientists with the most activities, and select their projects. A few years after its creation, the ANR seems to be perceived as a project funding agency, and not as funding narrowly a set of top researchers without clear projects. This study can be enriched, by adding to the study the evaluation of the project and by broadening it to the national level.

In addition, the purpose of the ANR is to improve the research output. An issue that remains to be analysed is that of the impact of the ANR funding on knowledge production. It will be interesting to compare the publications or citations of researchers who were supported and those who were not.

Appendix

A. Definition of the variables of the theoretical model

Table A1: Variables of the theoretical model

Variables	**Definition**
H_{it}	Level of human capital invested by researcher i at time t to a project
r_d	Price of the human capital per field d
w^s_{idt}	Value for the researcher i of the project he proposed at time t in the field d
A^s_{it}	Set of explanatory variables used for approximate H_{it}
H^r_{it}	Importance given by researcher i at time t to a project or to the fund given by ANR
B_{it}	Other resources available in the lab of the researcher i at time t
w^r_{idt}	Reservation value of a project for the researcher i at time t
H^d_{it}	ANR evaluation of the human capital invested in the project
ψ^d	Importance given to the field d by the funding agency
M_t	Budget of the funding agency at time t
w^s_{idt}	Value given by the funding agency to the project proposed by researcher i at time t in the field d

B. Definition of the variables

Table B1: Variables of the estimated models

Sum of patent	Quality-adjusted number of patent in the 3 year window (2003 2005)
Sum of publication corrected	Quality-adjusted number of publications in the 3 year window (2003 2005)
Age	Age of the researcher
Age square	Square age of the researcher
Prof	Dummy equal to 1 if the researcher is a university professor
Full time prof	Dummy equal to 1 if the researcher is professor at a PRO
Ass prof with HDR	Dummy equal to 1 if the researcher is associate professor at university with right to supervise phd Student
Full time ass prof with HDR	Dummy equal to 1 if the researcher is associate professor at a PRO with right to supervise phd Student
Full time ass prof without HDR	Dummy equal to 1 if the researcher is associate professor at a PRO without right to supervise phd Student
Ln private fund	Natural log of private contractual funds get by the lab
Ln public fund	Natural log of public contractual funds get by the lab
Ln recurrent fund	Natural log of recurrent funds get by the lab
Mark A+	Dummy equal to 1 if the lab get as mark A+
Mark A	Dummy equal to 1 if the lab get as mark A
Mark B	Dummy equal to 1 if the lab get as mark B
Mark C and D	Dummy equal to 1 if the lab get as mark C and D
Size [0,10]	Number of research at the lab between 0 and 10
Size [11,25]	Number of research at the lab between 11 and 25
Size [26,60]	Number of research at the lab between 26 and 60
Medicine	Dummy equal to 1 if the field of researcher is the Medicine
Chemistry	Dummy equal to 1 if the field of researcher is the Chemistry
Physics	Dummy equal to 1 if the field of researcher is the Physics
Earth sc and Astr	Dummy equal to 1 if the field of researcher is the Earth Science and Astronomy
Engineering Sc	Dummy equal to 1 if the field of researcher is the Engineering Science
Mathematics	Dummy equal to 1 if the field of researcher is the Mathematics
Year 2006	Dummy equal to 1 if year = 2006
Year 2007	Dummy equal to 1 if year = 2007
Industry	Dummy equal to 1 of a firm involve in the project

C. Maximum likelihood of bivariate Probit model

The decision of the researcher to apply is measured by the dummy variable defined such as:

$$C_{it} = \begin{cases} 1 & \text{if } C_{it}^{*} > 0 \text{ if researcher } i \text{ applies to a call at time } t, \\ 0 & \text{if } C_{it}^{*} \leq 0 \text{ otherwise.} \end{cases} \tag{C1}$$

$$C_{it}^{*} = \alpha^{1} K_{d}^{c} + \alpha^{2} \ln B_{it} + \alpha^{3'} X_{it} + u_{it} \tag{C2}$$

The decision of the funding agency among applications is modeled as follows:

$$S_{it} = \begin{cases} 1 & \text{if } S_{it}^{*} > 0 \text{ if the agency decides to grant,} \\ 0 & \text{if } S_{it}^{*} \leq 0 \text{ otherwise.} \end{cases} \tag{C3}$$

$$S_{it}^{*} = \beta^{1} K_{d}^{s} + \beta^{2} \ln M_{t} + \beta^{3'} Z_{it}^{s} + v_{it} \tag{C4}$$

There are three types of observations in the sample with the following probabilities:

$$\begin{aligned}
\Pr(C_{it}=0) &= \Phi\big(-(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it})\big) \\
\Pr(C_{it}=1, S_{it}=1) &= \Phi_2(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}, \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s; \rho) \\
\Pr(C_{it}=1, S_{it}=0) &= \Pr(C_{it}=1) - \Pr(C_{it}=1, S_{it}=1) \\
&= \Phi(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}) \\
&\quad -\Phi_2(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}, \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s; \rho),
\end{aligned}$$

where, $\Phi(.)$ is the cumulative standardized univariate normal distribution and $\Phi_2(.)$ the cumulative standardized bivariate normal distribution. From these probabilities we can determine the following log-likelihood equation:

$$\begin{aligned}
\ln L(C, S, \theta^{BP}) &= \sum_{i=0}^{N}\sum_{t=0}^{T}(1-C_{it}) \ln \Phi\big(-(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it})\big) \\
&\quad + C_{it} S_{it} \ln \Phi_2(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}, \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s; \rho), \\
&\quad + C_{it}(1-S_{it}) \ln[\Phi(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}) \\
&\quad - \Phi_2(\alpha^1 K_d^c + \alpha^2 \ln B_{it} + \alpha^{3'} X_{it}, \beta^1 K_d^s + \beta^2 \ln M_t + \beta^{3'} Z_{it}^s; \rho)]
\end{aligned} \quad \text{(C5)}$$

where, $\theta^{BP} = (\alpha^1, \alpha^2, \alpha^{3'}, \beta^1, \beta^2, \beta^{3'} \sigma_u^2, \sigma_v^2, \rho)$ is the set of parameters of the bivariate Probit model.

D. Estimated Coefficients

Table D1: Estimated coefficients of the decision equation of the researchers and funding agency

Model	Probit Researcher application	Probit ANR decision	Bivariate Probit Researcher application	 ANR decision
Researcher level				
Sum of patents	0.049***	-0.032	0.052***	-0.037
Sum of publications	0.111***	0.041	0.112***	-0.038
Age	0.077*	0.309**	0.078*	0.173
Age square	-0.001**	-0.003**	-0.001**	-0.001
Rank:				
Prof	0.664***	-0.219	0.663***	-0.648**
Full time prof	0.711***	0.129	0.709***	-0.437
Ass prof with HDR	0.162	-0.623	0.159	-0.586
Full time ass prof with HDR	0.386***	0.0453	0.386***	-0.278
Full time ass prof without HDR	-0.103	0.485	-0.106	0.352
Lab level				
Funds:				
Log private funds	0.009		0.006	
Log public funds	-0.011		-0.015	
Log recurrent funds	0.016		0.016	
Mark:				
A+	-0.038	-0.245	-0.022	-0.133
B	-0.097	-0.830***	-0.090	-0.448
C and D	-0.440**	0.027	-0.425**	0.383
Size:				
$[0, 10]$	-0.051	-0.287	-0.057	-0.219
$[11, 25]$	-0.161	-0.185	-0.162	-0.036
$[25, 60]$	-0.206	0.112	-0.188	0.191
Research topics:				
Medicine	-0.372***	-0.820**	-0.372***	-0.358
Chemistry	-0.170	-0.901**	-0.155	-0.507
Physics	-0.442***	-1.258***	-0.433***	-0.619
Earth sc and Astr	-0.586***	-1.503***	-0.565***	-0.641
Engineering Sc	-0.277*	-1.792***	-0.264*	-1.038*
Mathematics	-0.673***	-0.583	-0.673***	0.021
Time dummies				
Year 2006	0.058	0.152	0.058	0.076
Year 2007	0.258***	-0.186	0.254***	-0.290
Constant	-2.902***	-6.799**	-2.913***	-2.458
Observations	3711	257	3711	257
Log likelihood	-811.83709	-115.60219	-926.78631	
LR test chi2(1) = 1.31 Prob > chi2 = 0.2531				

*** p<0.01, ** p<0.05, * p<0.1

Chapter 5

Conclusion

Science is at the center of many economic and political questions, due to its central role in economic growth. We saw in the first chapter why there is a need for public support to improve private investment and why the usual incentives are not sufficient for private investment to reach the optimal level in basic research. Therefore, the solution adopted by developed economies is to fund public labs according to the priority award system. However, since few decades we have observed a change in the funding structure of labs. Numerous studies focus on the impact of this evolution. However literature is still scarce on several issues.

In Chapter 2 we discussed the evolution of funding, publications and patenting activities at the level of the universities. First, we observe a huge heterogeneity in the evolution of the different types of funds, with an important decrease of international funding balanced by an increase of funds provided by local authorities and the ANR. We also observe an increased specialization over time of the universities in a few particular sources of funding, especially in firms and ANR funding. Turning to the output, we investigate the evolutions of two types of outputs, publications and patenting. The patenting activity increased over the whole time period. This increase is also heterogeneous across universities, with a decrease for the UPAM and UPSM and an increase for the Usc and Ing. All the universities nowadays have a patenting activity, and keep the ownership partially or totally. Publications remain globally stable over the years 2000. The joint analysis, based on cluster analysis of the inputs and outputs, seems to indicate a negative relationship between publications and ANR funding, as well as a positive one between the decision to leave the patent ownership to others and the amount of private funds raised.

In Chapter 3 we analysed the optimal behavior of public labs producing research outputs, measured by publications. We focus on the consequences of different kinds of shocks on the optimal behaviour of labs under different levels of substitutability between funds. Our main results indicate that the optimal reaction to a shock depends on the level of substitutability of the different types of funds. There is a crowding-in relationship between recurrent and private funds whatever the substitutability level. Policies in favor of recurrent funds will thus increase the budget of the labs via two channels: recurrent funds and private funds. Conversely, public contractual funds generally crowd-out private contractual funds. In this last case, the only exception occurs when public and private funds are greatly gross complements. Private contractual funds have two different effects, depending on the level of substitutability with public funds. We observe a crowding-in when both are gross complements, and crowding-out when both are gross substitutes. In a second part of the paper, we turn to the estimation of a CES production function. Our results reject the assumption of perfect substitutability as well as of perfect complementarity between total public, involving recurrent and contractual funds, and private funds. The contribution of public funds in the knowledge production is higher than the private funds. Turning to contractual funds, we observe gross substitutability between contractual public and private funds. Thus there is a crowding-out relationship between contractual public and private funds and which can lead to a specialization of labs on contractual public or private funds.

In Chapter 4 we analysed the process of getting competitive funds from a public agency. Thus we model the decision of the researcher to apply to a call for proposals of a public funding agency, and the decision of the funding agency to fund a project. This leads us to a Tobit-II type model. First, our results show that the sample of applicants is not a random sample drawn from the whole staff of the university. The researchers with a high score of publication and patenting activities apply more frequently, as well as those belonging to highly ranked labs. There is here a selection, that can be explained by differences in the capability of the researchers or by a self-selection mechanism. Second, our results do not indicate a clear impact of the funds gathered by the lab from other sources on the decision to apply. There is thus no evidence of spillovers, whether positive or negative, between the ANR and the other types of funding. The results on the equation explaining the decision of the ANR show a positive impact of the evaluation of the labs as well as a strong heterogeneity by disciplines. All in all, it seems that the projects are assessed individually, and selected in line with the fields prioritized by the agency. It is thus not necessarily the researchers with the highest publication scores who are funded.

Against his background, several further investigations are possible. In Chapter 2 we observed that there is perhaps a crowding-out relationship between international funds and funds of the ANR and local authorities. An interesting research question would be to perform complementarity or substitutability analysis in order to determine if the creation ANR did not crowd-out international funds (which are principally European funds). Indeed both types of funds are allocated in a competitive way, with the difference that European funds ask for collaborations between labs of several countries to be implemented. Therefore, one can wonder whether the ANR attracts the projects that can be developed at a national level, and there is in this case a complementarity between the ANR and the European funds and thus a crowding-in effect. Conversely, one can wonder whether the ANR discourages international cooperations, or simply if it is perceived as less binding. In those cases, there would be a substitutability between both funding and a crowding-out effect.

In Chapter 3 we did a short term assumption of constant level of efforts over time. However, the total level of the effort (time) that labs can invest in the production of research output and the activity of raising funds is itself a function of its budget. Indeed labs can use part of the funds raised to hire contractual workers. Thus a positive shock on the availability of contractual funds does not necessarily imply a decrease in the research effort. This is likely to balance the influence of recurrent funds with respect to contractual funds in the production of knowledge. A future research question would be relax this assumption. Therefore, the amount of time a lab can invest in the production of research output and the activity of raising funds is itself a function of its budget. Another possible extension of our analysis would be to use data over a longer time period. This point is important, because several studies show the necessity to have a lag of 5 years to capture the effect of funds on output. The effect of past funds on knowledge production thus is likely to be underestimated.

Chapter 4 raises several questions. First, our results suggest that the ANR funds projects. However this relation should be confirmed by adding to our database the marks received by projects. Second, it would be interesting to assess the causal effect of the ANR on knowledge output. One possibility would be to use the discontinuity in the ANR funding introduced by the rating of the projects. For some projects every year, minor differences in the mark lead to some of them being funded whereas the others are rejected. This discontinuity can be used to assess the causal effect of an ANR grant on the production of knowledge, using regression discontinuity techniques as surveyed in (Imbens and Lemieux, 2007).

Bibliography

Adams, J. D. and Griliches, Z. (1998). Research productivity in a system of universities. (49/50), 127–162.

Allison, P. D. and Long, J. S. (1990). Departmental effects on scientific productivity. *American Sociological Review*, 55 (4), 469–478.

Arora, A., David, P. and Gambardella, A. (1998). Reputation and competence in publicly funded science: Estimating the effects on research group productivity. *Annales d'économie et de statistique*, (49/50), 163–198.

Arora, A. and Gambardella, A. (1998). The impact of NSF support for basic research in economics. *SSRN eLibrary*.

Arrow, K. J. (1962). *Economic welfare and the allocation of resources to invention*. Princeton University Press.

Arrow, K. J., Chenery, H. B., Minhas, B. S. and Solow, R. M. (1961). Capital-labor substitution and economic efficiency. *The Review of Economics and Statistics*, 43 (3), 225–250.

Atkinson, R. D. (2007). Expanding the R and E tax credit to drive innovation, competitiveness and prosperity. *The Journal of Technology Transfer*, 32 (6), 617 – 628.

Bach, L. and Llerena, P. (2006). *Rapport final: les activités de valorisation dans les établissements universitaires français.* Beta, Ministère de l'enseignement supérieur et de la recherche.

Bach, L. and Llerena, P. (2008). *Rapport final: les activités de recherche contractuelle et de transfert se technologie dans les établissements français d'enseignement supérieur.* Beta, Ministère de l'enseignement supérieur et de la recherche.

Bach, L. and Llerena, P. (2010). *Rapport final: les activités de recherche contractuelle et de transfert se technologie dans les établissements français d'enseignement supérieur.* Beta, Ministère de l'enseignement supérieur et de la recherche.

Banal-Estanol, A., Jofre-Bonet, M. and Meissner, C. (2010). The impact of industry collaboration on research: Evidence from engineering academics in the UK. Working Paper 1190.

Bayer, A. E. and Dutton, J. E. (1977). Career age and research-professional activities of academic scientists: Tests of alternative nonlinear models and some implications for higher education faculty policies. *The Journal of Higher Education*, 48 (3), 259–282.

Beaudry, C. and Clerk-lamalice, M. (2010). Grants, contract and networks: What influences biotechnology scientific production? In *DRUID Summer Conference*.

Benfratello, L. and Sembenelli, A. (2002). Research joint ventures and firm level performance. *Research Policy*, 31 (4), 493 – 507.

Bercovitz, J. and Feldman, M. (2008). Academic entrepreneurs: Organizational change at the individual level. *Organization Sience*, 19 (1), 69–89.

Berndt, E. R. and Griliches, Z. (1990). Price indexes for microcomputers: An exploratory study. Working Paper 3378, National Bureau of Economic Research.

Blume-Kohout, M., Kumar, K. and Sood, N. (2009). Federal Life Sciences Funding and University R and D. *SSRN eLibrary*.

Blumenthal, D., Campbell, E. G., Causino, N. and Seashore Louis, K. (1996). Participation of life-science faculty in research relationships with industry. *The New England Journal of Medicine*, 335 (23), 1734–1739.

Blundell, R., Griffith, R. and Windmeijer, F. (2002). Individual effects and dynamics in count data models. *Journal of Econometrics*, 108, 113–131.

Blundell, R., Reed, H. and Stoker, T. M. (2003). Interpreting aggregate wage growth: The role of labor market participation. *The American Economic Review*, 93 (4), 1114–1131.

Bonaccorsi, A. and Daraio, C. (2003). Age effects in scientific productivity. *Scientometrics*, 58, 49–90. 10.1023/A:1025427507552.

Boumahdi, R. and Carayol, N. (2005). Public and private funding of academic laboratories: Crowding out evidence from a large european research university. *Mimeo*.

Braun, D. (1993). Who governs intermediary agencies? principal-agent relations in research policy-making. *Journal of Public Policy*, 13 (2), 135–162.

Braun, D. (1998). The role of funding agencies in the cognitive development of science. *Research Policy*, 27, 807–821.

Braun, D. (2003). Lasting tensions in research policy-making - a delegation problem. *Science and Public Policy*, 30 (5), 309–321.

Braun, D. and Benninghoff, M. (2003). Policy learning in swiss research policy - the case of the national centres of competence in research. *Research Policy*, 32 (10), 1849–1863.

Braun, D. and Guston, D. (2003). Principal–agent theory and research policy: An introduction. *Science and Public Policy*, 30 (5), 302–308.

Carayol, N. and Matt, M. (2004a). Does research organization influence academic production?: Laboratory level evidence from a large European university. *Research Policy*, 33 (8), 1081 – 1102.

Carayol, N. and Matt, M. (2004b). The exploitation of complementarities in scientific production process at the laboratory level. *Technovation*, 24 (6), 455 – 465.

Carayol, N. and Matt, M. (2006). Individual and collective determinants of academic scientists' productivity. *Information Economics and Policy*, 18, 55–72.

Cassier, M. (2002). L'appropriation des connaissances dans les partenariats de recherche entre laboratoires publics et entreprises: Quelques tendances recentes. Working paper, IMRI.

Caswill, C. (2003). Principals, agents and contracts. *Science and public policy*, 30 (5), 337–346.

Chudnovsky, D., López, A., Rossi, M. and Ubfal, D. (2006). Evaluating a program of public funding of scientific activity. A case study of FONCYT in Argentina. OVE Working Papers 1206, Inter-American Development Bank, Office of Evaluation and Oversight (OVE).

Cole, S. (1979). Age and scientific performance. *American Journal of Sociology*, 84, 958–977.

Coleman, J. (1990). *Foundations of social theory*. Belknap press of Harvard University Press, Cambridge MA/London.

Crespi, G. and Geuna, A. (2008). The productivity of UK universities. In Albert, M., Voigt, S. and Schmidtchen, D., editors : *Conferences* *on New Political Economy*, volume 25 in *Conferences on New Political Economy*, pages 71 – 95.

Crespi, G. A. and Geuna, A. (2004). The productivity of science. Report prepared for the Office of Science and Technology (OST), Department of Trade and Industry (DTI), UK.

Crespi, G. A. and Geuna, A. (2005). Modelling and measuring scientific production: Results for a panel of OECD countries. SPRU Electronic Working Paper Series 133, University of Sussex, SPRU - Science and Technology Policy Research.

Crespi, G. A. and Geuna, A. (2006). The productvity of UK universities. SPRU Electronic Working Paper Series 147, University of Sussex, SPRU - Science and Technology Policy Research.

Dasgupta, P. and David, P. A. (1994). Toward a new economics of science. *Research Policy*, 23, 487–521.

Dempster, A. P., Laird, N. M. and Rubin, D. B. (1977). Maximum likelihood from incomplete data via the em algorithm. *Journal of the Royal Statistical Society. Series B (Methodological)*, 39 (1), 1–38.

Diamond, A. M. (1984). An economic model of the life-cycle research productivity of scientists. *Scientometrics*, 6, 189–196.

Diamond, A. M. (1986). The Life-cycle Research Productivity of Mathematicians and Scientists. *Journal of Gerontology*, 41 (4), 520–525.

DIAMOND, J. A. M. (1999). Does federal funding ”crowd in” private funding of science. *Contemporary Aconomic Journal*, 17 (4), 423–431.

DINGES, M. and LEPORI, B. (2006). Public project funding of research activities: National differences and implications for the creation of a european research council. In *paper be presented at the Conference New Frontiers in Evaluation*.

FEINBERG, R. M. and PRICE, G. N. (2004). The funding of economics research: Does social capital matter for success at the national science foundation. *The Review of Economics and Statistics*, 86 (1), 245–252.

FLETCHER, R. and REEVES, C. (1964). Function minimization by conjugate gradients. *Computer Journal*, 7, 48–154.

FLORIDA, R. and COHEN, W. M. (1999). Engine or infrastructure? the university role in economic development. In BRANSCOMB, L.M., K. F. F. R., editor : *Industrializing Knowledge: University-Industry Linkages in Japan and the United States.*, MIT Press, London, pages 589 – 610.

FOX, M. F. (1983). Publication Productivity among Scientists: A Critical Review. *Social Studies of Science*, 13 (2), 285–305.

FRALEY, C. and RAFTERY, A. E. (1998). How many clusters? which clustering method? answers via model-based cluster analysis. *The Computer Journal*, 41, 578–588.

Fraley, C. and Raftery, A. E. (2007). Model-based methods of classification: Using the mclust software in chemometrics. *Journal of Statistical Software*, 18.

Gaughan, M. and Bozeman, B. (2002). Using curriculum vitae to compare some impacts of nsf research grants with research center funding. *Research Evaluation*, 11 (1), 17–26.

Geuna, A. (1998). Determinants of university participation in EU-funded R and D cooperative projects. *Research Policy*, 26 (6), 677 – 687.

Geuna, A. (2001). The changing rationale for European university research funding: Are there negative unintended consequences? *Journal of Economic Issues*, 35 (3), 607–632.

Guellec, D. (1999). *L'économie de l'innovation*. Repères, Paris.

Gulbrandsen, J. (2005). Tensions in the research council-research community relationship. *Science and Public Policy*, 32 (3), 199–209.

Gulbrandsen, M. and Smeby, J. (2005). Industry funding and university professors' research performance. *Research Policy*, 34, 932–950.

Guston, D. (1996). Principal-agent theory and the structure of science policy. *Science and Public Policy*, 23 (4), 229–240.

Hall, B. H., Mairesse, J. and Turner, L. (2005). Identifying age, cohort and period effects in scientific research productivity: Discussion and illustration using simulated and actual data on French physicists. Working Paper 11739, National Bureau of Economic Research.

HALL, B. H. and VAN REENEN, J. (1999). How effective are fiscal incentives for R and D? A new review of the evidence. Working Paper 7098, National Bureau of Economic Research.

HALL, R. E. (1971). The measurement of quality change from vintage price data. In GRILICHES, Z., editor : *Price Indexes and Quality Change: Studies in New Methods of Measuremet*, pages 240–271.

HECKMAN, J. J. (1979). Sample selection bias as a specification error. *Econometrica*, 47 (1), 153–161.

HENNINGSEN, A. and HENNINGSEN, G. (2010a). *micEconCES: Analysis with the Constant Elasticity of Scale (CES) function.* R package version 0.6-8.

HENNINGSEN, G. and HENNINGSEN, A. (2010b). Estimating the CES function in R:Package minEconCES.

HERNAN, R., MARIN, P. and SIOTIS, G. (2003). An empirical evaluation of the determinants of research joint venture formation. *Journal of Industrial Economics*, 1, 75–89.

IMBENS, G. and LEMIEUX, T. (2007). Regression discontinuity designs: A guide to practice. Working Paper 337, National Bureau of Economic Research.

JACOB, B. and LEFGREN, L. (2007). The impact of research grant on scientific productivity. *NBER Working Paper Series*, (13519).

KMENTA, J. (1967). On estimation of the ces production function. *International Economic Review*, 8 (2), 180–189.

Larsen, M. T. (2005). Does industrial relevance in public science come at the expense of basic research? revisiting tradeoffs in university research. In *DRUID Winter Conference*.

Lehman, H. (1958). The chemist's most creative years. *Science*, 127, 1213–1222.

Lehman, H. (1960). The decrement on scientific productivity. *American psychologist*, 15, 128–134.

Lehman, H. C. (1953). Age and achievement. In *Aging: concepts and controversies*. Pine Forge Press.

Lepori, B., Dinges, M., Mamphuis, R., Poti, B., Reale, E., Slipersaeter, S., Theves, J. and Van Der Meulen, B. (2006). Convergence versus national specificities in research policies. an empirical study on public project funding. In *Indicators on Science, Technology and Innovation. History and New Perspectives.*

Lepori, B., Van den Besselaar, P., Dinges, M., Poti, B., Reale, E., Slipersaeter, S., Theves, J. and Van Der Meulen, B. (2007). Comparing the evolution of national research policies: what patterns of change? *Science and Public Policy*, 34 (6), 372–388.

Levin, S. G. and Stephan, P. E. (1991). Research productivity over the life cycle: Evidence for academic scientists. *The American Economic Review*, 81 (1), 114–132.

LEVIN, S. G. and STEPHAN, P. E. (1998). Gender differences in the rewards to publishing in academe: Science in the 1970s. *Sex Roles*, 38, 1049–1064. 10.1023/A:1018882711314.

LISSONI, F., LLERENA, P., MCKELVEY, M. and SANDITOV, B. (2008). Academic patenting in Europe: New evidence from the KEINS database. *Research Evaluation*, 17, 87–102(16).

LONG, J. S. (1992). Measures of sex differences in scientific productivity. *Social Forces*, 71 (1), 159–178.

LONG, J. S., ALLISON, P. D. and MCGINNIS, R. (1993). Rank advancement in academic careers: Sex differences and the effects of productivity. *American Sociological Review*, 58 (5), 703–722.

LONG, J. S. and MCGINNIS, R. (1981). Organizational context and scientific productivity. *American Sociological Review*, 46 (4), pp. 422–442.

LOTKA, A. J. (1926). The frequency distribution of scientific productivity. *J Washington Acad Sci*, 16, 317–324.

MADDALA, G. S. and KADANE, J. B. (1967). Estimation of returns to scale and the elasticity of substitution. *Econometrica*, 35 (3/4), 419–423.

MAIRESSE, J. and TURNER, L. (2005). Individual productivity differences in public research : How important are non-individual determinants? An econometric study of French physicists' publications and citations (1986-1997). *Cahiers de la MSE.Série Verte. V02066.*

Manjarrés-Henríquez, L., Gutiérrez-Gracia, A., Carrión-García, A. and Vega-Jurado, J. (2009). The effects of university–industry relationships and academic research on scientific performance: Synergy or substitution? *Research in Higher Education*, 50, 795–811. 10.1007/s11162-009-9142-y.

Mansfield, E. (1995). Academic research underlying industrial innovations: Sources, characteristics, and financing. *The Review of Economics and Statistics*, 77 (1), 55–65.

Marin, P. and Siotis, G. (2008). Public policies towards research joint venture: Institutional design and participants' characteristics. *Research Policy*, 37, 1057–1065.

Marquardt, D. (1963). An algorithm for least-squares estimation of non-linear parameters. *Journal of the Society for Industrial and Applied Mathematics*, 11, 431–444.

Merton, R. K. (1968). The Matthew Effect in Science: The reward and communication systems of science are considered. *Science*, 159 (3810), 56–63.

Millar, J. and Senker, J. (2000). International approaches to research policy and funding: University research policy in different national contexts. *Final report. Sussex : Science and Technology Policy Research.*

Miller, G. (1992). *Managerial Dilemmas. The political economy of hierarchy.* Cambridge University Press, Cambridge.

Moe, T. (1984). The new economics of organization. *American Journal of Political Science*, 28 (4), 739–777.

Morris, N. (2003). Academic researchers as 'agents' of science policy. *Science and public policy*, 30 (5), 359–370.

Nelson, R. R. (1959). The simple economics of basic scientific research. *The Journal of Political Economy*, 67 (3), 297–306.

Paff, L. A. (2005). State-level R and D tax credits: A firm-level analysis. *Economic Analysis and Policy*, 5, Article 17.

Payne, A. (2001). Measuring the effect of federal research funding on private donations at research universities: Is federal research funding more than a substitute for private donations? *International Tax and Public Finance*, 8, 731–751.

R Development Core Team (2010). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

Schwarz, G. (1978). Estimating the dimension of a model. *The Annals of Statistics*, 6 (2), 461–464.

Shove, A. (2003). Principals, agents and research programmes. *science and Public Policy*, 30 (5), 371–381.

Slipersaeter, S., Lepori, B. and Dinges, M. (2007). Between policy and science: Research councils' responsiveness in Austria, Norway and Switzerland. *Science and Public Policy*, 34 (6), 401–415.

STEPHAN, P. (2010a). The economics of science. In HALL, B. and ROSENBERG, N., editors : *Handbook of the Economics of Innovation*, pages 244–273.

STEPHAN, P. (2010b). The economics of science funding for research. ICER Working Paper Series 12/2010, University of Sussex, SPRU - Science and Technology Policy Research.

STEPHAN, P. E. (1996). The economics of science. *Journal of Economic Literature*, 34 (3), 1199–1235.

THURSBY, J. (1980). Alternative ces estimation techniques. *The Review of Economics and Statistics*, 62 (2), 295–299.

THURSBY, J. G. and LOVELL, C. A. K. (1978). An investigation of the kmenta approximation to the ces function. *International Economic Review*, 19 (2), 363–377.

VAN DER MEULEN, B. (1998). Science policies as principal-agent games - institutionalization and path dependency in the relation between government and science. *Research Policy*, 27 (4), 397–414.

VAN DER MEULEN, B. (2003). New roles and strategies of a research council: Intermediation of the principal–agent relationship. *Science and public policy*, 30 (5), 323–336.

VAN DER MEULEN, B. and RIP, A. (1998). Mediation in the Dutch science system. *Research Policy*, 27 (8), 757–769.

Van Looy, B., Ranga, M., Callaert, J., Debackere, K. and Zimmermann, E. (2004). Combining entrepreneurial and scientific performance in academia: Towards a compounded and reciprocal Matthew-effect? *Research Policy*, 33, 425–441.

Verspagen, B. (2006). University research, intellectual property rights and european innovation systems. *Journal of Economic Surveys*, 20 (4), 607–632.

Weiss, Y. and Lillard, L. A. (1982). Output variability, academic labor contracts, and waiting times for promotion. *Research in labor economics*, 5, 157–188.

Williamson, O. (1975). *Markets and Hierarchies*. New York: Free Press.

Williamson, O. (1985). *The Economic Institutions of Capitalism. Firms, Markets, Relational Contracting*. New York: Free Press.

Wilson, D. (2009). Beggar thy neighbor? The in-state, out-of-state, and aggregate effects of R and D tax credits. *The Review of Economics and Statistics*, 91 (2), 431–436.