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Cooperation with Public Research Institutions and Success in Innovation: Evidence from France and Germany

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Abstract

We evaluate the impact of cooperation with public research institutions on firms' innovative activities in France and Germany, using data from the fourth Community Innovation Survey (CIS4). We propose an original econometric methodology, which explicitly takes into account potential estimation biases arising from self-selection and endogeneity, and apply it to both process and product innovation. We find a positive effect of cooperation on both types of innovation. This effect is significant in both countries, but much higher in Germany than in France. Drawing on a comparison of the institutional context of cooperation across both countries, we interpret this difference as a consequence of the more diffusion-oriented German science policy. Finally, our robustness checks confirm the importance of controlling for selection and endogeneity. We show that these problems can be serious, and may lead to inconsistent estimates if neglected.

Keywords: Public/private research partnerships; University/industry linkages; Innovativeness; Heckit procedure with endogenous regressors.

JEL Codes: O31 - O33 - O38

1 Introduction

Modern societies supposedly base their wealth on a steadily increasing and widely accessible knowledge base. This implies that new knowledge needs not only to be discovered, but also to be diffused, i.e. it ought to be made readily available to the society, which will then be able to generate value from it. Most lines of research agree on the fact that interactions between industry and science are among the most prominent institutional interfaces for knowledge diffusion. This paper focuses on formal collaborations between firms and public research institutions, and examines their impact on the innovativeness of firms using French and German data from the Fourth Community Innovation Survey (CIS4).

Our contribution to the literature is threefold. First, we propose an econometric methodology that tackles both selection and endogeneity issues. The fact that both issues may arise when estimating the effect of cooperation was left out of the focus of previous studies. Second, we extend our analysis to process innovation, whereas most of the previous studies focused on product innovation only. Last but not least, we are aware that any analysis of the interactions between different social actors (in our case scientific and economic ones) requires a detailed knowledge of the relevant institutional interfaces. We therefore develop a detailed comparison of the institutional contexts of cooperation with science in France and in Germany. This comparison will inform the interpretation of our econometric results.

The remainder of the paper is organised as follows: in Section 2, we state the objective of our research, and discuss the interest and feasibility of a comparison between France and Germany. In Section 3, we sketch our conceptual framework and present our econometric methodology. Section 4 is dedicated to the presentation and discussion of the results. We derive policy implications and conclude in a final section.

2 Cooperation with science and success in innovation: a comparative approach

2.1 Objective of the research

There is a fairly large consensus on the fact that modern societies base their wealth on the creation and diffusion of new knowledge. Seminal articles in the endogenous growth literature (Romer, 1990; Aghion and Howitt, 1992) focus on the expansion of the knowledge base and show its importance for economic growth. In a similar vein, Grossman and Helpman (1993) have shown that diffusion of new knowledge is a prerequisite for long-term increases in production and wealth. To favour diffusion, the organisational setting should allow knowledge to move freely across institutional borders, and not to be stuck where it was created. Accordingly, the innovation systems approach argues that relationships and linkages between societal actors are central to their innovation behaviour. Extending this approach, the Triple Helix literature highlighted the importance of university-industry-government relations (Etzkowitz and Leydesdorff, 1998, 2000; Leydesdorff, 2000). The interaction between industry and science is one of the most prominent institutional interfaces for knowledge diffusion. Although knowledge transfer can occur through a variety of channels (see Schartinger *et al*., 2002, for an overview), we will focus in this article on formal collaborations between firms and public research institutions. The reason is that they play a key role in science and technology policy: they are often seen by governments as the best way to create strong links between industry and public research (Hagedoorn *et al.*, 2000).

Despite large differences in issues and methodological approaches, several studies show that collaboration with public research entails positive outcomes for firms. Monjon and Waelbroeck (2003) find that highly innovative firms benefit from official collaboration projects with universities, whereas imitating firms benefit from spillovers. Lööf and Brostrom (2008) find positive impacts for large manufacturing firms. Similarly, Miozzo and Dewick (2004) focus on the question of whether inter-organisational cooperation enhances firm performance in construction industry and find that in some European countries there are positive effects from collaboration with universities. In the case of US-firms, Darby *et al.* (2004) find that firms participating in the Advanced Technology Program of the Commerce Department patent more frequently when a university also participates.

In an effort to estimate the so-called ‘innovation function' across seven European countries, Mohnen *et al.* (2006) observe that the effect of "proximity to basic research [is] quite sizeable in the high-tech sectors, much less so in the low-tech sectors" (Mohnen *et al.*, 2006, p. 31). Although this observation is not their main result, it seems nevertheless to be consistent across countries and period, and other studies tend to corroborate it. Using data from the Dutch component of the 2nd and 3rd Community Innovation Surveys, Belderbos *et al.* (2004) provide evidence that cooperation with universities boosts the sales of new or significantly improved products. In line with this, Nieto and Santamaria (2007) find that technological cooperation networks are crucial in achieving a higher degree of novelty in product development.

In this paper, we examine the impact of cooperation with public research on firms' success in innovation, using the most recent ‘complete' wave of the Community Innovation Survey[1], and adding three new contributions to the literature. First, we adopt an econometric methodology that addresses both self-selection and endogeneity issues in the innovation function. This was left out of the focus of previous studies. Second, we extend our analysis to process innovation, whereas most of the previous studies focused on product innovation only. Third, we explicitly follow an international comparison approach. We concentrate on two countries, France and Germany, which allows us not only to compare our econometric results, but also to examine in some depth the conditions of firms' cooperation with science in each country.

2.2 Institutional background: the French and German technology transfer systems

A comparison between France and Germany is both extremely relevant and very informative to anyone interested in studying university-industry relationships in the European context. Historically, both countries are among the founding members of the European Union (EU). As far as European countries are concerned, France and Germany are large-scale economies, which have kept for many years a leading position but are now facing similar difficulties (e.g., relative slowdown in economic growth, lingering unemployment, etc.). They are also (together with Italy and the U.K.) among the four European countries whose investments in R&D are the highest in absolute terms (Hagedoorn *et al.*, 2000).

France and Germany also share similarities in their intellectual tradition, which has been instrumental in shaping their academic systems. Even today the French and German academic systems still differ in a number of ways from the international standards set by the New Public Management paradigm, as applied in North American and British universities. For instance, in France, academic careers are not driven by the "up or out" model that prevails in most universities worldwide. Tenure occurs at a very early stage, and the "publish or perish" rule is therefore far less drastic than in other countries (although publications play a key role at different stages in the career). And although Germany is gradually adopting the international standard, academic careers are

1 We use CIS4, which covers the years 2002-2004. At the time of this writing, CIS5 (2006-2008) is not available for research yet, while the ‘intermediary’ CIS covering 2004-2006 has only a very limited scope (in France, for instance, it only samples manufacturing firms and foregoes some of the usual questions).

still largely shaped by the traditional system of academic self-governance and strong State regulations (compare Schubert, 2009).

In France as well as in Germany, public research institutions include both universities and research institutes. In France, besides university laboratories, there are four public research institutes: (1) the CNRS, which conducts basic research in most scientific disciplines, (2) the INRA, which focuses on life sciences and their agronomic applications, (3) the INRIA, dedicated to applied computer sciences, and (4) the INSERM, which is concerned by medical research and public health. These four institutes all have headquarters located in the capital, and research centres spread all over the national territory. These research centres either function as autonomous, standalone units, or are integrated within universities. Even in the latter case, researchers in the public institutes are evaluated on the basis of their academic publications only and have no teaching obligation.

Two other public institutions, the CEA and the Institut Pasteur, must also be mentioned, if only because (together with the CNRS) they represent 90% of the income generated from intellectual property rights in the French public sector (IGF, 2007). The CEA, whose initial mission was to develop the French nuclear program, now conducts basic and applied research in several disciplines, from quantum physics to molecular biology. The research conducted at the CEA is generally related, even if only remotely or indirectly, to nuclear research. The Institut Pasteur is focusing on biological and medical research, with therapeutic applications. The French public research system is completed by a number of smaller institutes, with more narrowly defined missions (research on environmental resources, marine research, etc.).

In Germany, the public research system consists of (1) universities, (2) universities of applied sciences (*Fachhochschulen*), which are in majority run by the governments of the *Länder*, and (3) extra-university research. Most extra-university research institutes belong either to the Max Planck Society, the Helmholtz Association, the Fraunhofer Gesellschaft, or the Leibniz Society. Apart from these, there are other smaller institutes, either government-run or completely independent. Altogether, the extra-university research institutes command budgets which account for one third of the German public science budget. As in France, the personnel doing research in extra-university institutes have no teaching obligations. However, some of them do have explicit technology transfer missions. This is especially true for the Fraunhofer Gesellschaft with its about 17,000 employees and 60 research centres. These centres primarily engage in applied research and development, a large part of which is conducted in collaboration with firms.

All these similarities between France and Germany suggest that university-industry relationships may have the same determinants, and may face the same difficulties in both countries. However, in spite of those similarities, Hagedoorn *et al.* (2000) emphasise some fundamental differences in the implementation of science policies in France and in Germany. In France, science and technology policies are more mission-oriented[2], where the missions are defined at the national level by a strongly centralized State. By contrast, in Germany, science and technology policies are more diffusion-oriented, and are defined within a decentralized, federal political system where States (*Länder*) are given a very large degree of autonomy. In fact, the Constitution of the Federal Republic of Germany (especially Article 70 and Articles 72 to 74) puts university policy almost completely into the hands of the *Länder*.

In France, the policy instruments designed to encourage knowledge transfers from public research institutions are comprised in the Act of Law of July 12th, 1999 (a testimony to the centralized, mission-oriented French approach to science policy). A substantial part of this Act is specifically dedicated to the cooperation between firms and public research. It allows universities and research institutes (CNRS, INRA, INRIA and INSERM) to create in-house knowledge and technology transfer offices. Their task is to manage research contracts with other organisations, and especially contracts with private firms. In spite of this Act, research contracts still represent a very small fraction of public research funding: in 2007, the ratio of revenue from research contracts to total research expenditures was equal to 2% on average in CNRS and universities, although it could rise to 6% in some universities (IGF, 2007).

In the recent period, a number of instruments were added to the Act of Law of July 12th, 1999. Since 2006, the National Research Agency (ANR) can bring financial support to collaborative research projects between public research institutions and private firms. This support targets specific fields of research with a comparatively low private R&D effort, and considered as strategic by the French government, such as nanotechnologies. The government has also created clusters (known as *pôles de compétitivité*) in order to foster scientific collaborations at the regional level. These clusters regroup in a same area universities, research institutes and private firms, generally around a common topic or research field. In order to give firms an incentive to cooperate, the government offers tax credits to those that settle down in these areas. In addition, a decen-

2 For instance, cooperating with public institutions and private firms is defined in France as the "Third Mission of the University", the first two being teaching and doing academic research.

tralized organisation (OSEO) was created in 2005 (through a merger of existing institutions), in order to help SMEs collaborate with public research labs at the regional level[3]. Note, however, that these additional instruments did not exist during the period of analysis considered in the present paper (2002-2004).

In Germany, knowledge and technology transfers (KTT) have been a central concern for the German federal government since the 1980s. German governments have followed a three-dimensional approach to the promotion of KTT. These three dimensions are: (1) reducing the costs of KTT, (2) increasing the incentives of universities and other research institutions to engage in KTT, and (3) increasing the incentives of enterprises to engage in KTT. In Germany, however, science (and especially university) policy is generally a competency of the local States (the *Länder*). Since this also includes policies related to KTT, the result is that policy measures are widely scattered. Therefore, giving more than short examples of the aforementioned three dimensions would go beyond the scope of this paper.

As an example of the first dimension, technology transfer offices (*Technologietransferstelle*) form a widespread policy instrument, common to all *Länder*. Technology transfer offices are considered as a key element for a successful KTT policy, since they should help reducing the high costs associated with the search for partners. Many German universities thus have their own technology transfer offices. Their task is to establish and reinforce contacts between university labs on the one hand, and private firms on the other. However, their effectiveness is often constrained by a chronic lack of manpower. Indeed, a technology transfer office often consists of only two or three employees, with a variable amount of work experience.

Until recently, German universities could not keep the surpluses generated by research contracts with private firms. This gave them little incentive to engage in KTT. Recent policy changes, following the second of the above-mentioned dimensions, have altered that situation in many *Länder*. These *Länder* now allow universities to keep the financial surpluses of their research contracts, and to use them for their own purposes (such as purchasing equipment or hiring temporary personnel). In addition to these measures, the federal government has recently launched the "Research Bonus", which can be seen as an example of both the second and third dimensions. It is a temporary policy measure, which aims at giving additional incentives to cooperate to both universities

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3 The scope of OSEO’s action has been enlarged in 2008, when it incorporated the Agency for Industrial Innovation (AII), which has a similar mission but targets large firms.

and firms (and in particular to SMEs). Organisations wishing to start a collaborative research project may apply for this bonus, which is added to the proposed value of the contract, and can be shared between the firm and the public research institution. If the bonus is granted (which only occurs if the research proposal passes an external review process), it can amount to up to 25% of the value of the contract, with an upper bound of 100,000 euros.

To put it in a nutshell, our examination reveals two inverse trends. In Germany, strengthening partnerships between industry and science has traditionally been the task of the regional governments (the *Länder*). However, the recent creation of the "Research Bonus" may illustrate the need for a stronger – even if temporary – involvement of the federal government. In France, over the last decade, the central government has expressed its willingness to encourage public-private research partnerships. However, the need to give more autonomy to the local and regional actors of innovation has gradually emerged. As an answer to this need, the French government has created clusters and the decentralized agency OSEO. Time alone will tell if these policies measures have been fruitful. Meanwhile, we can expect, from these observations, that the returns to public-private research collaborations may be quite different in France and in Germany.

2.3 Data sources: CIS4 data for France and Germany

To conduct our empirical analysis, we use data from the French and German CIS4, which cover the years 2002-2004. The CIS is a harmonised survey conducted in every EU Member State by the national statistical agency, under the coordination of Eurostat. It consists of two parts: (1) a core questionnaire common to all EU countries, and (2) a complementary questionnaire, the contents of which can vary across countries. The core questionnaire gives firm-level information on innovative activities, including R&D, product and process innovations, innovation protection, and abandoned innovations. It also contains information on the environment of the innovation process (such as market conditions, public subsidies, and hampering factors), as well as firm specific details such as size and turnover. The complementary questionnaire provides additional information on specific topics, defined at the national level. These topics may vary across countries, according to their degree of importance in the eye of each national government.

By its very nature, the CIS lends itself well to international comparisons. The CIS4 survey provides in each EU country a representative sample of manufacturing and services firms with 20 employees or more. However, in spite of the large degree of harmonisation of the CIS, two difficulties in comparing France and Germany remain. The first concerns the status of the survey: it is mandatory in France (firms that refuse to answer have to pay a fine), but not in Germany. This entails a much lower response rate in the latter country. The CIS4 survey obtained a response rate of about 80% in France, yielding a sample size of 20,672 firms, and a response rate of about 20% in Germany, yielding a sample of 5,200 firms. Because of the smaller size of the German sample, it is difficult to make international comparisons on a specific industry or group of industries (e.g., high-tech industries). Our comparative analysis will therefore concern the whole sample in each country, and we will control for inter-industry heterogeneity by including industry fixed-effects in the econometric models.

A second difficulty is that the German CIS4 contains additional questions which are neither part of the harmonised survey, nor included in the French complementary survey. These questions provide variables that may be interesting for our analysis (e.g. variables describing market structure). We tried to find reasonable substitutes for these variables in the French survey, but this was not always possible. To overcome this difficulty, we had to allow for some flexibility in the specification of the econometric model. This means we will rely, as far as possible, on variables that are common to both surveys. But we will also include, in the model estimated on the German data, variables that are not available in the French data.

3 Conceptual framework and econometric modelling

3.1 The conceptual framework of the innovation production function

The concept of a production function is essential to economic theory. It is usually applied to production processes that result in marketable goods or services. A production function is simply a functional relationship defining a mathematical mapping of the input space into the output space. Although the distinction between innovation inputs and innovation output goes further back in time, Griliches (1979) was among the first to propose a formal representation of the so-called "knowledge production function"[4]. In Griliches (1979)'s conceptual framework, knowledge actually appears both as an input (in the usual production function), and as the output of a specific production process:

4 See also Kohn and Scott (1982) for the inclusion of a formal "R&D production function" in a theoretical framework.

the knowledge production process, which can be seen as a more general representation of the innovation process.

Mairesse and Mohnen (2002) focus on the latter, and explain how it can be represented using an "innovation production function", linking innovation outputs to innovation inputs (some of them being control variables rather than direct inputs). Unfortunately, the mere statement of the existence of an innovation production function gives little guidance on what it may look like. Leaving aside the problem of the specification of a functional form, once an indicator for innovative performance or innovation output has been chosen, the hardest task is to find the relevant input and control variables. This requires a solid understanding of innovation processes occurring within firms. Since Schumpeter (1934), many branches of the economic literature have given valuable ideas on this topic. Most notably, the determinants of the innovation process may be divided into external and internal factors (external and internal being defined here with respect to the boundaries of the firm).

The most prominent external factors are certainly market structure (Schumpeter, 1934, 1943; Scherer, 1965; Kamien and Schwartz, 1982) and technological opportunities (Schumpeter, 1934; Crépon *et al.*, 1998). The latter definitely should, *ceteris paribus*, raise innovative performance, because the costs of discovering knowledge should decrease with larger technological opportunities, while the pay-offs should increase. The direction of the influence of the market structure is an oft-discussed topic. There is not much agreement in the literature, regarding whether innovation is higher in a monopolistic, oligopolistic or competitive market – although firm-level studies (e.g., Baldwin *et al.*, 2002; Schubert, 2010) often find that a moderate amount of competition is associated with a higher degree of innovation. In any case, no matter how heterogeneous the opinions on the direction of its effect, almost all studies agree that market structure is a decisive factor.

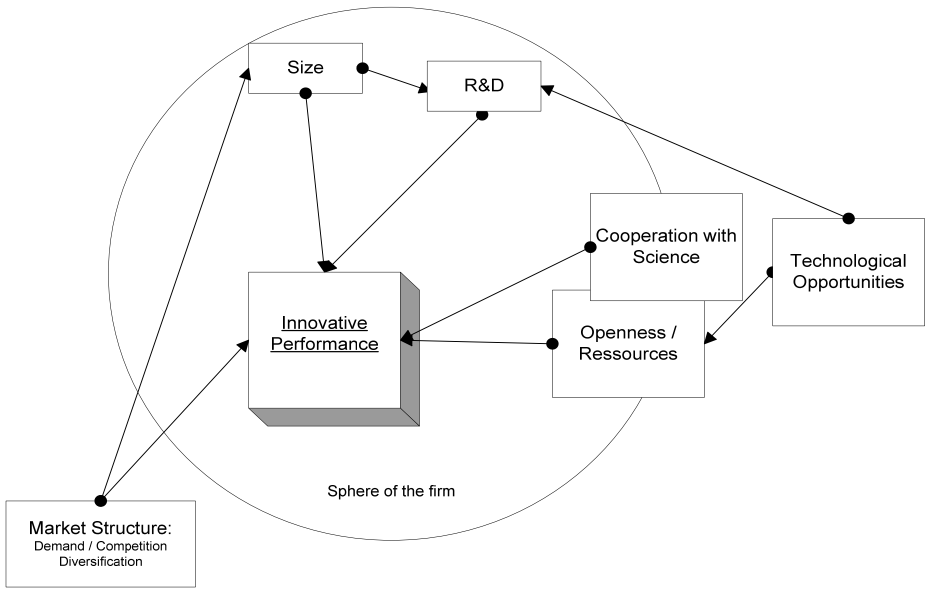
Among internal factors, the most prominent is firm size, presented as a key determinant of innovation since Schumpeter (1934). The relationship between innovation and firm size has been the object of a large body of empirical literature, which often uses R&D as a proxy for innovation. Kohn and Scott (1982) propose a theoretical justification of why a test of the relationship between firm size and an innovation input such as R&D is a good proxy for a test of the relationship between firm size and innovation output. Whether they use R&D or an output measure, most empirical studies (e.g., Scherer, 1965; Link 1981; Acs and Audretsch 1987; Cohen et al. 1987; Cohen and Klepper 1996a, b; Chang and Robin, 2006) find an inverted-u relationship between firm size and innovation. It must be noted, however, that studies using CIS-type data (e.g., Baldwin, 2002; Griffith *et al.*, 2006) sometimes find that innovation output strictly increases with firm size. Again, whatever the exact nature of the relationship, firm size is definitely a factor that must be accounted for when estimating the innovation production function.

The other internal factors liable to affect innovative performance can be summed up as the ‘resources' of a firm. In this sense, the generic term ‘resources' include, among others, human capital, management capabilities and financial resources (Penrose, 1959; Wernerfelt, 1984). Increasing the quality of any of these resources should lead to a larger innovation output, especially if they are explicitly dedicated to the innovation process. Indeed, innovation output is not the mere by-product of the usual production process, but results from an intentional activity. Therefore, some of the aforementioned resources should be used as direct innovation inputs. The amount (and quality) of resources devoted to innovation may increase a firm's chances to find technological opportunities. But finding technological opportunities also depends on how efficient the search process is.

Nelson and Winter (1982) actually understood a firm's innovation process as a search process where some degree of mistake would be inevitable. The quality of this search process clearly reflects a form of resource or capability (Eisenhardt and Martin, 2001), since ‘quality' here means nothing more than seeking out a technological opportunity and correctly predicting its commercial relevance. The broader this strategy is, the more technological opportunities will be discovered and the more precisely the prospective value will be predicted (Nelson and Winter, 1982; Teece, 1986; March, 1991; Katila, 2002; Laursen and Salter, 2004). In this context, collaboration with science (the effect of which is at the core of this paper) can be understood as a special way of engaging in the search process. Indeed, science commands valuable and additional knowledge resources, in which firms usually cannot readily tap.

The above arguments are schematically summarised in Figure 1, where the arrows primarily have an expository meaning. They do not reflect a complete model of the innovation process: to do so, many of them should be bidirectional. For instance, in Figure 1, size influences innovation performance. But a higher innovation performance may in turn help a firm grow, i.e. increase in size. The model depicted in Figure 1 could also be completed with additional arrows. For instance, one could place an arrow between cooperation with science and R&D, to take into account a firm's absorptive capacity (Cohen and Levinthal, 1989, 1990): leading firms also do R&D because it gives them the capacity to absorb new scientific knowledge. The innovation production function approach does not capture all of the relationships depicted (or potentially depicted) in Figure 1. However, it does capture key elements of Figure 1, and in this respect may be a powerful tool to help us answer the question of how cooperation with science affects firms innovation output.

Figure 1: A schematic overview on factors affecting the process of firm innovation



Source: Authors' own representation.

3.2 Econometric modelling

3.2.1 Estimation strategy and model specification

The aim of our econometric analysis is to estimate the impact of cooperation between public research institutions and private firms on the latter's innovation activities. To do so, we follow the innovation production function approach described in Section 3.1, adopting and extending the framework proposed by Mairesse and Mohnen (2002). Since non-responses to innovation-related questions in the CIS are unlikely to be random, these authors specify the innovation production function as a two-equation Generalized Tobit model. The first equation (selection equation) explains the propensity to innovate and the second equation (intensity equation) explains the intensity of innovation activities within the firm.

In the selection equation, the dependent variable is an indicator of whether a firm has done product innovation over a period of reference. In the intensity equation, the dependent variable is a measure of the share of sales due to new or innovative products.

The latter equation includes a measure of proximity to basic research, which has a significantly positive impact on innovation intensity[5].

Due to the filtering methodology of CIS that guides non-innovators around questions that provide details about its innovation activities, the intensity equation can only be estimated for firms that have indicated that they innovate. It can be shown that it is impossible (except for pathological cases) to estimate consistently the intensity equation without looking at the selection equation.

However, because Mairesse's and Mohnen's main purpose is elsewhere, they do not take into account the fact that proximity to science on the one hand, and innovation intensity on the other, may be determined by common (unobserved) variables. This can occur because cooperating with public research institutions makes more sense for companies actively engaged in innovation. In econometric terms, this means that proximity to science could be an endogenous explanatory variable in Mairesse and Mohnen (2002)'s model. In an content-related perspective not controlling for endogeneity finding a positive "effect" of collaborations with science on the innovation intensity (e.g. turnover with new products) is indicative of situation where otherwise innovative firms simply choose to innovate with universities. It does not ensure any kind of causality in the sense that the collaboration has made the firm more innovative. To find out whether there is any causal effect, we have to take possible endogeneity into account.

Since, in the present paper, the focus is on the effect of cooperation with public research, we extend Mairesse and Mohnen (2002)'s framework in two directions. First, in addition to controlling for selectivity into innovation, we account for the potential endogeneity of cooperation with science. Second, we extend the analysis to process innovation. The first extension leads us to estimate a Heckit model with endogenous explanatory variables (rather than a Generalized Tobit model with all explanatory variables treated as exogenous). We first apply this model to product innovation, and then apply it to process innovation, experimenting with different proxies to depict the latter.

The Heckit model with endogenous explanatory variables is an extension of the Heckman procedure, accounting for the potential endogeneity of some of the explana-

5 This result is not mentioned in the core of Mairesse and Mohnen (2002)'s paper, but can be observed in the Appendix mentioned in Footnote 8 on page 228. It has been confirmed in discussions with the authors, and also appears in Mohnen *et al.* (2006), who apply a similar model to the same dataset.

tory variables. It can be specified as a three-equation model, which, following Wooldridge (2002, p. 567), we can write as follows:

(1)
$$\begin{cases} y_{i1} = z_{i1}\delta_1 + \alpha_1 y_{i2} + u_{i1} \\ y_{i2} = z_i\delta_2 + u_{i2} \\ y_{i3} = 1(z_i\delta_3 + u_{i3}) \end{cases}$$

where the δ's and α_1 are parameters to be estimated and where the u_i's are random errors.

In Model (1), y_{i1} is the variable of interest (here a measure of innovation intensity in firm *i*) and y_{i2} a potentially endogenous explanatory variable (here an indicator of a cooperation between firm *i* and a public research institution). The third equation, where 1(.) denotes the indicator function (equal to 1 if its argument is true, and to 0 otherwise), is the selection equation, as in the standard Heckman model. The role of this equation (generally specified as a Probit model) is to correct for the selection bias: in CIS4 non-innovating firms do not have to provide answers on more detailed innovation-related questions (such as turnover with new products, patents, knowledge sources) and thus drop out, leaving only innovative firms to answer the relevant questions. If this selection is not random, it will induce estimation bias. It must therefore be taken into account in the econometric model.

To estimate Model (1), we follow the standard three-step procedure described in Wooldridge (2002, 567-570). First, we obtain the predicted value of δ_3 by estimating the selection equation (linking y_{i3} to z) on the whole sample. Second, we compute the inverse Mills ratio:

(2)
$$\hat{\lambda}_{i3} = \lambda(z_i\hat{\delta}_3)$$

Third, we estimate, on the sub-sample of innovating firms, the following model:

(3)
$$\begin{cases} y_{i1} = z_{i1}\delta_1 + \alpha_1 y_{i2} + \gamma_1\hat{\lambda}_{i3} + v_{i1} \\ y_{i2} = z_i\delta_2 + \gamma_2\hat{\lambda}_{i3} + v_{i2} \end{cases},$$

which is specified as an Instrumental Variable (IV) regression and estimated by 2 Stages Least Squares (2SLS). Given proper instruments, the effect of cooperation with public research, measured by α_1, will be net of endogeneity and selection biases. That is controlling for selection, it can be interpreted as the causal effect of collaboration with science on innovativeness.

For confidentiality reasons, the access to each national CIS is restricted to researchers working in the relevant country. We thus had to conduct our estimations separately, in France and in Germany respectively. In what follows, we will therefore sometimes refer, for the sake of convenience, to the "French model" or to the "German model". Nevertheless, the reader should keep it mind that it is the basically the same econometric model, with a similar structure applied in both countries[6].

When the model is applied to product innovation, our measure of innovation intensity y_1 is the share of sales related to new products (or "share of innovative sales"), as in Mairesse and Mohnen (2002)[7]. When the model is applied to process innovation, we experiment with four alternative explained variables, which respectively measure: (1) the extent of unit cost reductions, (2) the extent of cost reductions in materials, (3) the increase in production flexibility, and (4) the increase in production capacity. All these variables are ordered categorical variables, but, in a first approximation, we treat them as continuous. In all applications of the model (i.e. for both product and process innovation), our endogenous explanatory variable y_2 is a binary variable indicating whether, between 2002 and 2004, firm *i* has cooperated with a university or another public research institution. The *z* vector includes all other explanatory variables, i.e. the z_1 vector of explanatory variables used in the intensity equation plus the exclusion variables used in the selection equation. The later variables are also used as instruments in Model (2), which is why *z* appears twice in Model (1).

6 The only differences come from the additional explanatory variables that were included when estimating the model on the German sample. As explained in 2.3, these variables are not available in the French sample.

7 As in Mairesse and Mohnen (2002), we actually use the log-transform of this variable, $\ln[y_1/(1-y_1)]$. The reason is that the share of innovative sales is by definition a truncated variable that is always positive. This may bias the regression, whereas the log-transform is allowed to vary from $-\infty$ to $+\infty$.

Table 1.a: Summary statistics

	France		Germany	
	Mean	*(Std Dev).*	*Mean*	*(Std Dev.)*
EXPLANATORY VARIABLES:				
Number of employees	287.79	(1945.60)	545.46	(5744.92)
Sales to 3 main customers (as % of total sales)	—		40.82	(28.43)
Obstacles to innovation linked to competition (yes/no)	0.14	(0.35)	—	
Obstacles to innovation linked to demand (yes/no)	0.15	(0.35)	—	
Importance of quality competition [(a)]	—		2.00	(1.03)
Importance of price competition[(a)]	—		1.85	(1.12)
Relative size of main competitors[(b)]	—		2.29	(1.23)
Suppliers as source of information[(c)]	0.23	(0.42)	1.18	(1.07)
Customers as source of information[(c)]	0.23	(0.42)	1.45	(1.23)
Group as source of information[(c)]	0.15	(0.36)	1.66	(1.30)
Competitors as source of information[(c)]	0.37	(0.48)	1.05	(1.01)
Industry (coded using OECD technological levels):				
Manufacturing – high technological intensity	0.03	(0.16)	0.09	(0.08)
Manufacturing – high/medium tech.	0.09	(0.29)	0.15	(0.36)
Manufacturing – medium/low tech.	0.08	(0.28)	0.15	(0.36)
Manufacturing – low technological intensity	0.16	(0.37)	0.13	(0.34)
Knowledge intensive businesses and services	0.23	(0.42)	0.26	(0.44)
Other services	0.41	(0.49)	0.21	(0.41)
Innovation expenditures in Euros	1906.98	(36927.09)	11084.63	(217167.00)
East Germany (yes/no)	—		0.33	(0.47)
Part of a group (yes/no)	0.56	(0.50)	0.59	(0.49)
ENDOGENOUS EXPLANATORY VARIABLE:				
Cooperation with public research institutions (yes/no)	0.07	(0.26)	0.06	(0.25)
EXCLUSION VARIABLES/INSTRUMENTS:				
Firm uses secrecy to protect innovation (yes/no)	0.14	(0.35)	0.38	(0.49)
Total profit in 2003 in Euros	—		1007.58	(9430.51)
Total sales in 2002 in Euros	64005.89	(553248.00)	—	

	France		Germany	
	Mean	*(Std Dev).*	*Mean*	*(Std Dev.)*
Lack technological know-how to innovate[(c)]	0.04	(0.19)	0.93	(0.92)
Lack of skilled personnel to innovate[(c)]	0.12	(0.32)	0.67	(0.74)
Costs of innovation too high[(c)]	0.20	(0.40)	1.66	(1.13)
Lack of partners to innovate[(c)]	0.07	(0.26)	0.73	(0.87)
Number of CRITT in the region	7.19	(3.64)	—	
CRITT covering several industries	0.69	(0.46)	—	
Universities / 1000 km²	—		1.58	(3.17)
DEPENDENT VARIABLES:				
Firm introduced a product innovation (yes/no)	0.27	(0.44)	0.52	(0.50)
% of total sales due to new products	0.06	(0.17)	17.55	(25.25)
Proxy for process #1: Extent of unit cost reduction	1.78	(1.16)	0.89	(1.01)
Proxy for process #2: Extent of cost reduction in materials	1.25	(1.11)	0.72	(0.92)
Proxy for process #3: Increase in production flexibility	1.68	(1.14)	1.21	(1.14)
Proxy for process #4: Increase in production capacity	1.68	(1.14)	1.00	(1.07)

(a) Measured on a Likkert scale from 1 (most important) to 6 (least important).

(b) Measured on a Likkert scale from 1 (largest) to 4 (smallest).

(c) For France, indicator equal to 1 if medium/high importance and to 0 otherwise; for Germany, measured on Likkert scale from 0 (no importance) to 3 (high importance).

In accordance with the discussion summarised in Figure 1, the z_1 vector includes the following explanatory variables: the log of firm size (measured by the number of employees), indicators of demand-size constraints on the firm's output market, indicators of various sources of information used to innovate, industry dummies, innovation expenditures[8] per employee, and a variable indicating whether a firm is part of a group. In the German model, z_1 also includes additional variables which describe a firm's degree of diversification, market shares, and whether a firm is located in West or East Germany. Diversification is represented by the share of sales to the three main customers of a firm, while market shares are measured by the relative size of the main competitors of a firm. As was said above, we do not have equivalent variables in the French component of CIS4. Note, that, for a similar reason, demand constraints are

8 I.e. R&D expenditures plus expenditures on other innovation inputs.

represented by different variables in the French and German models: in the German model, we use indicators of the relative importance of price competition and quality competition. Lacking similar indicators in the French survey, we replace them in the French model by two indicators of "hampering factors", the first indicating obstacles linked to competition and the second obstacles related to an insufficient demand.

In both models, the variables describing the sources of information used in the innovation process can be interpreted as indicators of the openness of the firm, in the sense of Laursen and Salter (2006). As explained in 3.1, innovation is a process in which a firm must seek the relevant internal and external resources to innovate. Laursen and Salter (2004, 2006) suggest that more ‘open' firms might not only be more innovative, but also more prone to cooperate with universities. Finally, our industry dummies should allows us to capture technological opportunities, as emphasised by Mairesse and Mohnen (2002). For this reason, we have recoded the 2-digit industry codes (NACE codes) available in CIS4 into the "technological levels" classification proposed by the OECD. The different categories used in this classification are presented in Table 1.a.

Our exclusion variables (i.e. those included in z, but excluded from z_1) are an indicator of the use of secrecy as a mean to protect inventions, a measure of past profits (for Germany) or past sales (for France), as well as indicators of factors liable to hamper the innovation process. These factors include high innovation costs, lack of technological knowledge, lack of qualified personnel, and lack of innovation partners. We add to our list of exclusion variables regional indicators acquired from external statistical sources. The rationale for the choice of these indicators will be explained in Section 3.2.2.

Table 1.a gives summary statistics for the explanatory and exclusion variables in the French and German samples. Table 1.b presents the distribution of the key explanatory variable (our potentially endogenous indicator of cooperation with public research), by industry and with respect to firm size. Both distributions appear to be quite similar in France and in Germany: the proportion of collaborations with public research institutions is more important among large firms and in high-tech industries.

Table 1.b: Proportion of firms cooperating with public research institutions (by industry and by size)

	France		Germany	
	Mean	*Std Dev.*	*Mean*	*Std Dev.*
INDUSTRY (OECD technological levels):				
Manufacturing – High technological intensity	0.10	0.30	0.12	0.32
Manufacturing – High/Medium tech.	0.10	0.30	0.10	0.29
Manufacturing – Medium/Low tech.	0.04	0.20	0.06	0.23
Manufacturing – Low technological intensity	0.02	0.15	0.02	0.14
Knowledge intensive businesses and services	0.03	0.18	0.06	0.23
Other services	0.01	0.09	0.02	0.13
FIRM SIZE:				
49 employees or less	0.01	0.12	0.03	0.18
50-99 employees	0.04	0.19	0.04	0.21
100-249 employees	0.06	0.23	0.04	0.19
250-499 employees	0.11	0.31	0.06	0.24
500 employees or more	0.21	0.41	0.15	0.36

Example: in France, in high technology industries, the proportion of firms that have cooperated with a university or public research institution between 2002 and 2004 is 0.10. In other words, 10% of firms operating in high technology industries have cooperated with public research institutions.

3.2.2 Choice of instruments

As was said above, we suspect our indicator of cooperation with public research may be endogenous. The econometric model presented in 3.2.1 account for a potential endogeneity bias by combining a standard Heckman procedure with an IV approach. In this model, the exclusion variables used in the selection equation are also used as instruments in the IV regression. By definition, in our model, good instruments are variables which are likely to be correlated with cooperation, without having a direct effect on innovation intensity. Finding good instruments is never an easy task, and our application is no exception to this rule. Since their quality is crucial for an unbiased estimation of our model, our choice of instruments deserves to be discussed more extensively. To find instrument candidates in the CIS4 samples, we first tried to identify variables that may give public research institutions an incentive (or disincentive) to cooperate with a firm. We then tried to ensure that these variables were not necessarily directly correlated with a firm's innovation intensity.

Let us first consider the role of firms' financial resources as an instrument candidate. Accessing additional financial resources is a strong incentive to cooperate for public research institutions. Therefore, a firm having a large amount of financial resources will be more likely to attract academic partners. We thus include in our list of instruments a measure of firms' *past* financial resources. This measure is the value of total profits observed in 2003 for Germany, and the value of total sales observed in 2002 for France (as total profits are not available in the French CIS4 sample). This choice of variable as an instrument candidate is justified by the fact that high financial resources in the past do not necessarily entail more innovation in the current period.

However, public research institutions have sources of motivations that go beyond the sole financial incentives. These institutions (and researchers themselves) are primarily interested in publishing new and interesting results in international scientific journals, because this is the usual way to maintain their scientific reputation and academic visibility. Research institutions may therefore be reluctant to start partnerships or cooperative agreements with firms that rely on secrecy to protect their inventions. Secrecy associated to a research project might mean fewer opportunities to publish in good scientific journals. From the viewpoint of the firm, secrecy is not systematically associated to a lower innovation intensity, which makes an indicator of secrecy a good candidate for an instrument. The CIS4 samples explicitly provide such an indicator, which we included in our list of instruments.

Finally, our list of instruments includes four indicators, already presented in 3.2.1, of obstacles that may hamper innovation. Three of them (lack of technological know-how, lack of qualified personnel, and lack of partners to innovate with) correspond to difficulties that may be overcome through cooperation with a public research institution. These three variables may then be associated with a higher probability to cooperate. By contrast, the indicator of high innovation costs could be associated with a lower propensity to cooperate, because cooperation induces additional costs for a firm. These four indicators are quite likely to be correlated with the probability to cooperate. We cannot say that they are always associated with less innovation: sometimes the most innovative firms report high difficulties to innovate, since innovating becomes more difficult when they get closer to the technological frontier. This qualifies our four indicators as instruments candidates, although they may well be weak instruments: they still might be correlated with innovation intensity.

Whether all the variables described above are truly valid instruments remains a debatable issue, as in any study relying on a similar methodology. A first element pleading for these variables is that, compared to the main determinants of innovation reviewed in Section 3.1, their direct effect on innovation intensity is presumably inexistent or negligible. We also tested for the empirical relevance of these instruments candidates. Although the tests[9] were reassuring regarding the validity of the instruments listed above, we felt compelled to scan other statistical sources for additional candidates, in order to enrich our list of instruments and to be able to test for alternative specifications, if need be.

This led us to regional indicators describing the opportunities for cooperation in research offered by the region or area where a firm is located. In addition to being readily available, these variables are good potential instruments. Indeed, a firm located in a region with higher cooperation opportunities will be more likely (everything else being equal) to develop research partnerships with public institutions. However, the existence of cooperation opportunities at the regional level is unlikely to have a direct impact on the innovation intensity of a specific firm.

In France, we used the list of the Regional Centres for Innovation and Technology Transfer (hereafter denoted by the French acronym CRITT) to build two measures of regional opportunities for cooperation with public research[10]. A CRITT is a public centre whose task is to provide firms with R&D services. To do so, it is backed by a public research institution such as a university or a public research laboratory. A CRITT is generally associated with a specific industry or market, but can also propose services across a wider scope of industries. The list of CRITT is available online. It is published by the Ministry of Higher Education and Research[11]. Our first measure based on this list is the number of CRITT in the region where a firm is located. The second measure is a binary variable which indicates whether there exists, in this region, a CRITT whose activities cover several industries. These regional indicators were easily matched to the CIS4 data, since the latter informs us of the region where each surveyed firm is located, and of the industry in which it operates.

In Germany, sources of regional indicators were harder to come by. However, we were able to retain one variable: the number of universities per thousand of square kilometres. This variable is observed for each *Land* (there is a total of 16 *Länder* in Germany). Since the German CIS4 informs us about the *Land* in which a firm is located, adding

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9 In Section 4, we detail and comment upon these tests, implemented on our full list of instruments.

10 The geographic level is that of the 26 administrative regions of France (both mainland and overseas).

11 http://wwww.enseignementsup-recherche.gouv.fr/technologie/critt/index.htm

this variable to the CIS4 data was quite straightforward. Even though the German *Land* is a more aggregated geographic level than the French administrative region, the number of universities per thousand of square kilometres is a good proxy variable for cooperation opportunities at a regional level. Table 1.a provides summary statistics for our various indicators of regional cooperation opportunities (which are featured at the end of the list of exclusion variables).

4 Results

4.1 Product innovation

4.1.1 Detailed discussion of the Heckit estimates

Since the model we estimate for product innovation builds on Mohnen and Mairesse (2002)'s seminal framework, it deserves to be commented in detail (if only for the sake of comparison). To start with, we briefly comment the estimates of the Probit model, used to specified the selection equation in Model (1). We then thoroughly discuss our main results, obtained by estimating Model (2)[12].

The results of the selection equation (which models the probability to be a product innovator) are presented in Table 2. This table shows that, in France as in Germany, the Schumpeterian determinants of innovation (firm size and market structure) play an important role. A larger size (as measured by the log of the number of employees) is associated with a higher probability to introduce a new product on the market. In Germany, market power has a significant impact: a smaller market share (as measured by a larger relative size, in terms of sales, of the main competitors) is associated with a lower probability to innovate. It is all the more unfortunate that we miss a similar variable in the French CIS. We also find, in both countries, that a higher level of innovation expenditures (per employee) is associated with a higher probability to innovate. This result is consistent with the framework of an "innovation production function", in which the main inputs are innovation expenditures (which mostly, but not exclusively, comprise R&D expenditures).

12 Model (1) and Model (2) refer to the general multi-equation models presented in Section 3.2.1.

Table 2: Endogenous Heckit procedure: selection equation (probability to be a product innovator)

	France		Germany	
	Coefficient	*Std Error*	*Coefficient*	*Std Error*
Constant term	-1.75	(0.09)***	-2.14	(0.19)***
FIRM SIZE (Log-number of employees)	0.06	(0.01)***	0.06	(0.02)***
DIVERSIFICATION				
Turnover w/ 3 main customers	—		0.13	(0.03)***
DEMAND				
Obstacles to innovation due to competition	0.03	(0.04)	—	
Obstacles to innovation due to demand	0.15	(0.04)***	—	
Importance of quality competition	—		-0.03	(0.03)
Importance of price competition	—		0.08	(0.03)***
MARKET SHARE				
Relative size of main competitors	—		-0.05	(0.03)**
OPENNESS OF THE COMPANY				
Suppliers as source of information	0.17	(0.03)***	-0.01	(0.03)
Customers as source of information	0.71	(0.03)***	0.34	(0.04)***
Group as source of information	1.61	(0.03)***	0.44	(0.03)***
Competitors as source of information	0.23	(0.04)***	0.07	(0.02)**
INDUSTRY (*ref.: Hi-Tech Manufacturing*)				
Hi-/Med-Tech Manufacturing	-0.15	(0.08)*	0.07	(0.12)
Med-/Low-Tech Manufacturing	-0.35	(0.09)***	-0.31	(0.12)***
Low-Tech Manufacturing	-0.38	(0.08)***	-0.23	(0.12)*
Knowledge Intensive Businesses and Services	-0.42	(0.08)***	-0.15	(0.11)
Other Services	-0.83	(0.08)***	-0.41	(0.12)***
OTHER CHARACTERISTICS				
Innovation expenditures per employee	0.00	(0.00)***	2.41	(0.72)***
Company is part of a group	0.06	(0.03)**	0.01	(0.06)
Eastern Germany	—		-0.02	(0.06)
EXCLUSION VARIABLES				
Use of secrecy	0.40	(0.03)***	0.44	(0.06)***
Total sales in 2002	0.00	(0.00)	—	
Total profit in 2003	—		-0.00	(0.00)

	France		Germany	
	Coefficient	*Std Error*	*Coefficient*	*Std Error*
Costs of innovation too high	0.01	(0.03)	-0.02	(0.03)
Lack of technological know-how	-0.09	(0.07)	0.02	(0.05)
Lack of skilled personnel	0.07	(0.04)	0.02	(0.04)
Lack of partners to innovate	0.06	(0.05)	0.00	(0.04)
Number of universities / 1000 km²	—		0.02	(0.01)**
Number of CRITT in the region	0.00	(0.00)	—	
CRITT covering several industries	-0.02	(0.03)	—	

Models estimated by Maximum Likelihood.
The LR test for global fit is significant at the 1% level in each country.
Significant at the: *** 1% level; ** 5% level; * 10% level.

Table 2 provides other interesting results. Thus, in France as in Germany, most of the variables measuring the openness of a firm are associated with a higher probability to be a product innovator. These results confirm those obtained by Laursen and Salter (2006) on UK data, and emphasize the increasing importance of "openness" in the innovation process. By contrast, industry effects differ significantly across countries. In France, the probability to innovate is highest in the high-technology manufacturing industries: in all other industries, the probability is always significantly lower than in this industry of reference. In Germany, high-technology manufacturing is not the only industry to be associated with a high propensity to innovate: this propensity is as high in the High/Medium-technology manufacturing industries and in the knowledge-intensive services as it is in our industry of reference. Finally, at this stage of the Heckit procedure, only one exclusion variable is significant in both countries. This variable, the use of secrecy as a mean to protect inventions, is associated with a higher probability to be a product innovator. The added regional indicator(s) of cooperation opportunities are only significant in the German model.

We now turn to the discussion of the results obtained in the final stage of the Heckit procedure – denoted by Model (2) in Section 3.2.1. Model (2) is a system of two equations estimated by 2SLS. In other words, estimating Model (2) consists in running an IV regression, using the exclusion variables of the Probit model as instruments. The results of this IV regression are presented in Table 3.a. In this table, Column (I) gives the estimates of the first equation (the linear probability model explaining cooperation with a public research institution) and column (II) those of the second equation (explaining innovation intensity).

Table 3.a: Endogenous Heckit procedure for product innovation: IV regression

	(I) Cooperation w/ research				**(II) Innovation intensity[1]**			
	France		Germany		France		Germany	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Constant term	-0.26	(0.16)*	-0.36	(0.21)*	-0.40	(0.49)	1.01	(0.90)
FIRM SIZE (Log-number of employees)	0.05	(0.00)***	0.03	(0.01)***	-0.17	(0.02)***	-0.18	(0.04)***
DIVERSIFICATION								
Turnover w/ 3 main customers	—		-0.00	(0.01)	—		-0.30	(0.06)***
DEMAND								
Obstacles to innovation due to competition	0.03	(0.02)**	—		-0.04	(0.06)	—	
Obstacles to innovation due to demand	0.02	(0.02)	—		-0.19	(0.06)***	—	
Importance of quality competition	—		-0.00	(0.01)	—		0.05	(0.04)
Importance of price competition	—		0.02	(0.01)**	—		0.10	(0.04)**
MARKET SHARE								
Relative size of main competitors	—		-0.02	(0.01)**	—		-0.05	(0.04)
OPENNESS OF THE COMPANY								
Suppliers as source of information	0.02	(0.01)*	-0.01	(0.01)	0.03	(0.04)	-0.01	(0.06)
Customers as source of information	0.07	(0.03)**	0.02	(0.02)	-0.06	(0.10)	-0.09	(0.11)
Group as source of information	0.17	(0.09)**	0.04	(0.03)	-0.43	(0.27)	-0.03	(0.13)
Competitors as source of information	0.04	(0.01)***	0.01	(0.01)	0.07	(0.05)	0.06	(0.06)
INDUSTRY[2]								
Hi-/Med-Tech Manufacturing	-0.04	(0.03)	0.01	(0.03)	-0.25	(0.10)**	-0.32	(0.16)**
Med-/Low-Tech Manufacturing	-0.10	(0.03)***	-0.03	(0.03)	-0.46	(0.11)***	-0.38	(0.18)**
Low-Tech Manufacturing	-0.17	(0.03)***	-0.07	(0.03)**	-0.45	(0.11)***	-0.19	(0.19)

	(I) Cooperation w/ research				(II) Innovation intensity(1)			
	France		Germany		France		Germany	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Knowledge Intensive Services	-0.09	(0.03)***	-0.01	(0.03)	-0.39	(0.10)***	-0.32	(0.15)**
Other Services	-0.18	(0.04)***	-0.05	(0.04)	-0.46	(0.13)***	-0.49	(0.21)**
OTHER CHARACTERISTICS								
Innovation expenditures per employee	0.00	(0.00)***	0.69	(0.15)***	0.00	(0.00)*	2.30	(0.90)**
Company is part of a group	-0.04	(0.01)***	-0.01	(0.02)	0.04	(0.05)	-0.09	(0.11)
Eastern Germany	—		0.05	(0.02)**	—		0.20	(0.11)*
SELECTIVITY CORRECTION								
Inverse Mills ratio	0.12	(0.08)	0.15	(0.10)	-0.48	(0.24)**	-1.21	(0.53)**
COOPERATION W/ PUBLIC RESEARCH					**1.13**	**(0.28)*** **	**2.13**	**(0.71)*** **
INSTRUMENTS								
Use of secrecy	0.21	(0.02)***	0.13	(0.03)***				
Total sales in 2002	0.00	(0.00)**						
Total profit in 2003			0.00	(0.00)***				
Costs of innovation too high	0.04	(0.01)***	0.01	(0.01)*				
Lack of technological know-how	-0.03	(0.03)	-0.01	(0.01)				
Lack of skilled personnel	-0.01	(0.02)	-0.00	(0.01)				
Lack of partners to innovate	0.07	(0.02)***	0.04	(0.01)***				
Number of universities / 1000 km²			0.00	(0.00)				
Number of CRITT in the region	0.00	(0.00)***						
CRITT covering several industries	-0.01	(0.01)						

(1) Dependent variable: logit transform of the % of turnover arising from new or improved products.

(2) The reference category is "Manufacturing – High technological intensity".

The Fisher test for the global fit of the IV regression is significant at the 1% level for both France and Germany.

Significant at the: *** 1% level; ** 5% level; * 10% level.

Column (I) in Table 3.a shows that France and Germany share some common determinants of the propensity to cooperate with public research. In both countries, this propensity increases with firm size, and with innovation expenditures per employee. Furthermore, firms that are facing a stronger competition are also more likely to cooperate: obstacles to innovation due to competition (in France) and the importance of price competition (in Germany) are both associated with a higher probability to cooperate.

We nevertheless observe two important differences. First, in France, firms operating in High-tech and High-/Medium-tech manufacturing industries have a significantly higher propensity to cooperate (the estimated parameters are significantly negative in all other categories of industry). By contrast, in Germany, the propensity to cooperate with a public research institution is not significantly different across sectors, except in Low-tech manufacturing industries (where it is significantly lower). It seems, therefore, that in France cooperation with public research is concentrated in the most technology-intensive industries, whereas in Germany this type of cooperation is likely to occur in almost any industry. This could be a result of the German science policy, which is more "diffusion-oriented" than its French counterpart, as was stated in Section 2.2. The second cross-country difference observed in Table 3.a, Column (I), concerns the openness of the firm. In France, firms that rely (for their innovation process) on information gathered from external sources are more likely to cooperate with public research than the other firms. This result, which corroborates some of the findings obtained by Laursen and Salter (2004) for the U.K., is not observed in the German model.

We can now comment the results of the innovation intensity equation, presented in Table 3.a, Column (II). We first observe that control variables corresponding to the usual determinants of innovation (firm size, innovation expenditures, and industry dummies controlling for technological opportunities) are significantly correlated with innovation intensity. For the sake of concision, we will not engage in a detailed discussion of these correlations, focusing instead on our main result: the effect of cooperation with public research institution. Provided that we have adequately controlled for selectivity and endogeneity, this effect can be interpreted as a causal effect. In France as in Germany, cooperation with public research entails a significant increase in the (Logit transform) of the share of innovative sales in total sales. This increase is twice as high in Germany as it is in France.

To make interpretation easier, we computed the marginal effect of cooperation on the share of innovative sales (rather than on the Logit transform) at the sample mean and at the sample median. This computation confirms the large difference observed between France and Germany: at the sample mean, the marginal effect is equal to 0.13 in France and to 0.48 in Germany. At the sample median, the marginal effect is equal to

0.17 in France and to 0.49 in Germany. These marginal effects are significant at the 1% level. They can be interpreted as follows: a marginal effect of, say, 0.13 means that (everything else being equal) cooperating with a public research institution entails a 13% increase in a firm's share of innovative sales.

4.1.2 Additional tests and robustness checks

As was said above, the effect of cooperation on innovation intensity can only be interpreted as a causal effect insofar as we properly control for selectivity and endogeneity. We therefore need to carefully examine the robustness of the estimation, and in particular the quality of the instruments. First of all, some of the results displayed in Table 3.a give us useful information regarding selectivity: thus, we see that the inverse Mills ratio (which is included as a covariate in order to control for selectivity) has a significant effect in the intensity equation (Column II), but not in the cooperation equation (Column I). This makes sense, since in our model selection occurs between innovators and non-innovators (not between cooperating and non-cooperating firms). Therefore, we need not worry about the non-significance of the inverse Mills ratio in Column (I). Furthermore, the significance of this ratio in Column (II) is reassuring: it indicates that selectivity in product innovation has been properly accounted for.

Now, regarding endogeneity, Table 3.a shows that several of our instruments have a significant effect, which is reassuring as far as the overall quality of the estimation is concerned. Among the instruments taken from the CIS4 survey itself, four are correlated with the propensity to cooperate with public research. These instruments are the same in both countries: the use of secrecy to protect inventions, past sales/profits, high innovation costs, and a lack of partners to innovate. Regarding the regional indicators used as additional instruments, we observe significance in the French model only. We find that the probability to be a product innovator gets higher when the number of CRITT in the region where the firm is located increases.

Table 3.b: Additional tests and robustness checks

	France	Germany
P-value of the Sargan test for overidentification	0.483	0.790
P-value of the test for endogeneity in the ordinary Heckit model	0.000	0.005
P-value of inverse Mills ratio in ordinary Heckit (test for selectivity)	0.033	0.015
F-statistic of the Fisher test for weak instruments	24.00***	9.25***

Significant at the: *** 1% level; ** 5% level; * 10% level.

Examining the significance of instruments candidates in the cooperation equation is not enough to let us conclude on the robustness of our results. This is why we conducted a number of additional tests and robustness checks. The outcomes of these tests (presented in Table 3.b) gave us more confidence regarding the validity of our results. The first test we conducted was a Sargan overidentification test, which can be performed when more than one instrument is used in an IV regression. As can be seen in the first line of Table 3.b, this test is never significant, neither in France nor in Germany. In the light of this test, no doubt can be cast on the validity of our list of instruments.

For the sake of comparison, we then estimated a simple Heckit model, without taking into account the fact that the cooperation variable may be endogenous[13]. In this model, the estimated parameter associated with cooperation remains significant, but its value falls down to 0.21 (with a standard error of 0.05) in France and to 0.32 (with a standard error of 0.02) in Germany. These estimates correspond to a marginal effect of cooperation on innovation intensity equal to 0.02 in France (at both the sample mean and the sample median), and to 0.07 in Germany (again at both the sample mean and the sample median). Comparing these figures to those displayed in Section 4.1.1 suggests that failing to control for endogeneity leads to severely underestimating the marginal effect of cooperation.

Given this important difference in the estimated marginal effects, we conducted a test for endogeneity in the ordinary Heckit model, thus further validating our main results. To conduct this test, we first estimated the reduced-form cooperation equation by OLS, and saved its residual. We then re-estimated the ordinary Heckit model described in the previous paragraph, this time including the residual of the cooperation equation as an additional explanatory variable. If the estimated parameter associated with this additional variable is significant, there are unobserved factors influencing both the propensity to cooperate and the intensity of innovation. In this case, the cooperation variable should be considered as endogenous, and the Heckit model with endogenous regressors presented in Section 4.1.1 should be preferred to the ordinary Heckit model. The second line of Table 3.b shows that it is indeed the case: the p-value of this simple test for endogeneity is well below 1% in both countries. Moreover, the third line of Table 3.b shows that the inverse Mills ratio of the ordinary Heckit model is significant at the 5% in both countries. Considered together, these two lines confirm that the ordinary Heckit

13 This model is an ordinary Heckit model, with jut a selection equation (probability to innovate) and an intensity equation (innovation intensity), in which the cooperation indicator is treated as an ordinary explanatory variable.

model does control for selectivity into product innovation, but not for endogeneity. Since our Heckit model with endogenous explanatory variables controls for both, it should definitely be preferred to the ordinary Heckit model.

Our final test consisted in detecting potential *weak instruments* in our list of instruments. By definition, weak instruments provide a weaker correction for endogeneity and may therefore be a source of concern when researchers try to estimate a causal effect using IV approaches. To test for weak instruments, we followed the method proposed by Cameron and Trivedi (2005, p. 105). First, we only estimated the selection equation and the cooperation equation in Model (1), thus leaving aside the intensity equation. A Fisher test then allowed us to check whether the global effect of our instruments in the cooperation equation was significant or not. Cameron and Trivedi (2005) explain that if the Fisher test is *not* significant, then some of the instruments are indeed weak instruments. Fortunately, this test was significant in France and in Germany, as can be seen in the fourth and final line of Table 3.b. Thus, we can legitimately consider that weak instruments are not a problem in our estimations.

All of the aforementioned tests therefore reinforce and confirm our main results, as stated in Section 4.1.1: in both France and Germany, firms cooperating with public research can expect a significant increase in the intensity of their product innovation. This increase is however stronger in Germany than in France. The details of all the additional estimations conducted for the purpose of tests and robustness checks are available upon request from the authors.

4.2 Process innovation

An additional contribution of the present paper is to examine whether cooperation with public research may affect firms' process innovation as well as product innovation. To do so, we implemented the same methodology as before, adapting Model (1) to address process rather than product innovation. The y_{i3} indicator in the selection equation is now an indicator of process innovation, and we use four alternative proxies in turn to capture the intensity of process innovation, y_{i1}. These proxies are (1) the extent of unit cost reduction, (2) the extent of cost reduction in materials, (3) the increase in production flexibility and (4) the increase in production capacity.

These four proxies are categorical variables, ordered from 0 (low) to 3 (high)[14]. Since the focus here is on selectivity and endogeneity, we treat them, in Model (1), as continuous variables. In the absence of selectivity and endogeneity issues, we could capture the specificity of these variable using (for instance) an ordered Probit model. In the present application, such a model would impose strong (and unrequited) distributional assumptions without handling selectivity and endogeneity in the efficient and flexible manner granted by Model (1). Since we have grounds for suspecting strong selectivity and endogeneity biases, and since ordered variables can be treated (in a first approximation) as continuous variables, it is definitely preferable to rely on Model (1).

For the sake of concision, we do not present the parameter estimates of the selection and cooperation equations (full tables of results are available on request from the authors). We assume that selection into process innovation is driven by the same determinants as selection into product innovation, including firm size, innovation expenditures, openness of the firm and technological opportunities measured at the industry level. In the light of the literature reviewed in Section 3.1, this seems to be a reasonable assumption. Empirically, the signs of the estimated parameters are the same indeed, and do not call for further comments. Similarly, the determinants of cooperation with public research institutions are the same as those commented upon in Section 4.1.1. These similarities are not surprising, since about 60% of process innovators are also product innovators and since, conversely, more than 70% of product innovators are also process innovators.

We therefore focus our comments, for the remainder of this section, on the estimates of the intensity equation. Table 4 displays the results obtained when the intensity of process innovation is measured by the extent of unit cost reduction (first column) and by the extent of cost reduction in materials (second column) respectively. Table 5 displays the results obtained when the intensity of process innovation is measured by the increase in production flexibility (first column) and by the increase in production capacity (second column) respectively.

14 Summary statistics for these variables can be found at the bottom of Table 1.a.

Table 4: Endogenous Heckit procedure, IV regression for process innovation (final equation, proxies 1 and 2)

	Proxy #1: extent of unit cost reduction				**Proxy #2: extent of cost reduction in materials**			
	France		Germany		France		Germany	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Constant term	1.85	(0.33)***	0.70	(0.20)***	0.41	(0.34)	0.99	(0.21)***
FIRM SIZE (Log-number of employ-ees)	0.05	(0.01)***	0.02	(0.02)	0.04	(0.01)***	-0.02	(0.02)
DIVERSIFICATION								
Turnover w/ 3 main customers	—		0.01	(0.03)	—		-0.01	(0.03)
DEMAND								
Obstacles to in-novation due to competition	0.12	(0.04)***	—		0.10	(0.04)***	—	
Obstacles to in-novation due to demand	0.02	(0.04)	—		0.00	(0.04)	—	
Importance of quality competi-tion	—		0.01	(0.02)	—		0.01	(0.02)
Importance of price competition	—		-0.05	(0.02)**	—		-0.09	(0.03)***
MARKET SHARE								
Relative size of main competitors	—		0.02	(0.02)	—		0.02	(0.03)
OPENNESS OF THE COMPANY								
Suppliers as source of infor-mation	0.13	(0.08)*	0.14	(0.03)***	0.28	(0.08)***	0.11	(0.03)***
Customers as source of infor-mation	0.11	(0.03)***	0.00	(0.03)	0.11	(0.03)***	-0.02	(0.03)
Group as source of information	0.12	(0.03)***	0.12	(0.03)***	0.11	(0.03)***	0.06	(0.04)
Competitors as source of infor-mation	-0.15	(0.19)	0.09	(0.03)**	0.19	(0.19)	0.08	(0.03)**
INDUSTRY[(1)]								
Hi-/Med-Tech	0.01	(0.08)	0.13	(0.11)	0.30	(0.08)***	0.03	(0.12)

	Proxy #1: extent of unit cost reduction				Proxy #2: extent of cost reduction in materials			
	France		Germany		France		Germany	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Manufacturing								
Med-/Low-Tech Manufacturing	-0.01	(0.08)	0.22	(0.11)*	0.37	(0.08)***	0.11	(0.12)
Low-Tech Manufacturing	-0.16	(0.08)**	0.14	(0.12)	0.24	(0.08)***	(0.12)	(0.13)
Knowledge Intensive Services	-0.42	(0.08)***	-0.21	(0.10)*	-0.14	(0.08)*	-0.58	(0.11)***
Other Services	-0.41	(0.08)***	0.01	(0.12)	0.10	(0.08)	-0.32	(0.13)**
OTHER CHARACTERISTICS								
Innovation expenditures per employee	0.00	(0.00)***	-1.27	(0.51)**	0.00	(0.00)***	-0.70	(0.54)
Company is part of a group	0.13	(0.03)***	-0.07	(0.06)	0.08	(0.03)**	0.02	(0.07)
Eastern Germany	—		-0.13	(0.06)**	—		-0.17	(0.07)**
COOPERATION W/ PUBLIC RESEARCH	**0.31**	**(0.15)****	**0.82**	**(0.37)****	**0.68**	**(0.16)*****	**1.88**	**(0.40)*****
SELECTIVITY CORRECTION								
Inverse Mills ratio	-0.29	(0.16)*	*Not significant*		0.07	(0.17)	*Not significant*	
Tests on instruments:								
P-value, Sargan test for overidentification	0.235		0.410		0.022		0.940	
P-value, test for endogeneity in Heckit	0.179		0.010		0.000		0.000	
P-value, test for selectivity in Heckit	0.017		0.230		0.570		0.350	
F-statistic, Fisher test for weak instruments	58.39***		11.49***		78.95***		11.51***	

(1) The reference category is "Manufacturing – High technological intensity".

The Fisher test for the global fit of the IV regression is significant at the 1% level for both France and Germany.

Significant at the: *** 1% level; ** 5% level; * 10% level.

Table 5: Endogenous Heckit procedure, IV regression for process innovation (final equation, proxies 3 and 4)

	Proxy#3: increase in production flexibility				**Proxy#3: increase in production capacity**			
	France		Germany		France		Germany	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Constant term	1.82	(0.34)***	-1.69	(1.01)*	1.69	(0.35)***	1.04	(0.23)***
FIRM SIZE (Log-number of employees)	0.00	(0.01)	0.04	(0.04)	0.00	(0.01)	-0.07	(0.02)***
DIVERSIFICATION								
Turnover w/ 3 main customers	—		0.05	(0.03)	—		0.04	(0.04)
DEMAND								
Obstacles to innovation due to competition	0.07	(0.04)*	—		0.08	(0.04)**	—	
Obstacles to innovation due to demand	0.01	(0.04)	—		-0.03	(0.04)	—	
Importance of quality competition	—		0.01	(0.03)	—		0.02	(0.03)
Importance of price competition	—		0.04	(0.04)	—		-0.08	(0.02)***
MARKET SHARE								
Relative size of main competitors	—		-0.01	(0.02)	—		0.03	(0.03)
OPENNESS OF THE COMPANY								
Suppliers as source of information	0.24	(0.08)***	0.42	(0.10)***	0.24	(0.08)***	0.15	(0.04)***
Customers as source of information	0.09	(0.03)***	0.18	(0.04)***	0.09	(0.03)***	0.01	(0.03)
Group as source of information	0.07	(0.03)**	0.34	(0.11)***	0.10	(0.03)***	0.11	(0.04)**
Competitors as source of information	-0.19	(0.19)	0.04	(0.04)	-0.07	(0.20)	0.04	(0.04)
INDUSTRY[(1)]								

	Proxy#3: increase in production flexibility				**Proxy#3: increase in production capacity**			
	France		Germany		France		Germany	
	Coef.	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*	*Coef.*	*Std. Err.*
Hi-/Med-Tech Manufacturing	-0.01	(0.08)	0.02	(0.11)	0.04	(0.08)	0.13	(0.13)
Med-/Low-Tech Manufacturing	-0.09	(0.08)	0.45	(0.13)	0.09	(0.08)	0.35	(0.13)***
Low-Tech Manufacturing	-0.05	(0.08)	0.25	(0.13)*	0.00	(0.08)	0.24	(0.14)*
Knowledge Intensive Services	-0.04	(0.08)	0.29	(0.12)**	0.01	(0.08)	-0.03	(0.12)
Other Services	-0.15	(0.08)*	0.23	(0.13)*	-0.06	(0.08)	-0.13	(0.14)
OTHER CHARACTERISTICS								
Innovation expenditures per employee	0.00	(0.00)**	-0,34	(0.54)	0.00	(0.00)*	-0.24	(0.58)
Company is part of a group	0.10	(0.03)***	-0.20	(0.07)***	0.02	(0.03)	0.01	(0.07)
Eastern Germany	—		0.05	(0.07)	—		0.04	(0.07)
COOPERATION W/ PUBLIC RESEARCH	**0.46**	**(0.15)*** **	**1.33**	**(0.46)*** **	**0.31**	**(0.15) ** **	**1.63**	**(0.43)*** **
SELECTIVITY CORRECTION								
Inverse Mills ratio	-0.24	(0.16)	1.19	(0.40)***	-0.20	(0.17)	*Not significant*	
Tests on instruments:								
P-value, Sargan test for overidentification	0.039		0.609		0.123		0.910	
P-value, test for endogeneity in Heckit	0.017		0.000		0.136		0.000	
P-value, test for selectivity in Heckit	0.037		0.000		0.024		0.750	
F-statistic, Fisher test for weak instruments	58.39***		9.75***		80.71***		11.08***	

(1) The reference category is "Manufacturing – High technological intensity".

The Fisher test for the global fit of the IV regression is significant at the 1% level for both France and Germany.

Significant at the: *** 1% level; ** 5% level; * 10% level.

Depending on which proxy we use for process innovation, the significance of the control variables may vary (for the sake of concision, we will not give detailed comments on the significance of the controls). By contrast, our main result is clear-cut and extremely consistent across all four specifications of the model and across both countries: cooperation with a public research institution always entails a significant increase in the intensity of process innovation. No matter which proxy we use for process innovation, the magnitude of the increase is always more than twice as high in Germany as it is in France. It seems therefore that the returns on cooperation (in terms of innovation intensity) are always higher in Germany than in France, not only for product, but also for process innovation.

As was the case in Section 4.1, the effect of cooperation we measure here can be interpreted as a causal effect, provided we have adequately controlled for selectivity and endogeneity. To examine the quality of this control, we conducted the same series of test as in Section 4.1.2. The outcomes of these tests are reported at the bottom of Table 4 and Table 5. We first checked the relevance of our list of instruments with a Sargan overidentification test, which, in most cases, was not significant. The two exceptions occurred for France, in the models where process innovation is measured by a cost reduction in materials, and by an increase in production flexibility, respectively. This result suggests that, in these two cases, there is at least one redundant instrument in our list. We experimented with various lists of instruments, and with dropping some of the instruments, but never managed to get the significance of the test over the 5% level. These two exceptions (out of eight estimations) should not obfuscate, however, that the Sargan test is generally not significant. This means that, overall, our list of instruments performs fairly well.

We then conducted a test for endogeneity, following the procedure described in Section 4.1.2, i.e. by estimating an ordinary Heckit model with the predicted residual from the reduced-form cooperation equation added to the regressors. In six models of out the eight we estimated, the test was significant. It means that overall the Heckit model with endogenous regressors should be preferred to the ordinary Heckit model (as was already the case in our analysis of product innovation). Again, the two exceptions occur for France, this time in the models where process innovation is measured by the extent of unit cost reduction, and by an increase in production capacity, respectively. Note, however, that in both cases, the p-value of the test is very close to the conventional level of significance of 10%, which still pleads in favour of the Heckit with endogenous explanatory variables.

Moreover, as in Section 4.1.2, we tested for selectivity in addition to testing for endogeneity. In four cases out of eight, the test was not significant, which suggests that selectivity is less of an issue when we study process innovation than it was when we studied product innovation. This is also reflected in the fact that the Inverse Mills ratio of the Heckit model with endogenous regressors is often not significant, as can be seen in Tables 4 and 5. Still, there is evidence of selectivity in several of the estimations, and we should not neglect overall to control for the potential selection bias. Taken together, these last two tests plead for the use of the Heckit model with endogenous regressors, which allows us to control for both selectivity and endogeneity.

Finally, we tested for weak instruments using the Cameron and Trivedi (2005) procedure detailed in Section 4.1.2. The Fisher test statistics reported at the bottom of Tables 4 and 5 are always significantly different from zero. This means that we do not have to fear an imperfect control for selectivity arising from weak instruments. To put it in a nutshell, the results of our series of tests are strong enough to validate our model overall (even though there are indications that the estimations may occasionally be less robust for process than they were for product innovation). We can therefore conclude that cooperation with public research entails not only more product innovation, but also more process innovation. With both types of innovation, the observed effect of cooperation is much larger in Germany than in France.

5 Summary and conclusion

In this paper, we evaluated the impact of cooperation with public research institutions on firms' innovative activities. To do so, we estimated an innovation production function on the fourth wave of the CIS (CIS4). Our contribution to the literature was threefold. First, we proposed an econometric methodology that addresses both selection and endogeneity issues. Second, our analysis encompassed not only product innovation, but also process innovation. Last but not least, we followed an international comparison approach, concentrating on two countries: France and Germany. This allowed us to draw an in-depth descriptive comparison of the national contexts of public-private collaborations in research, before examining our comparative econometric results.

These results show a positive effect of cooperation with public research on the intensity of product innovation (measured by the share of innovative sales) in both countries. This effect is however twice as high in Germany is it in France. Similarly, we find a positive effect of cooperation on the intensity of process innovation in both countries (no matter which proxy we use to measure process innovation). Again, this effect is much higher in Germany than in France. While these results answer our main interrogation, they raise a new question: how can we explain the observed difference between France and Germany?

One possible explanation lies in the differences in science policy highlighted in our comparison of the national institutional contexts. As mentioned in Section 2.2, public support to collaborations between firms and public research labs is decentralised in Germany. It relies mostly on the technology transfer offices of the German universities. By contrast, in France, different instruments coexist at different levels, from very centralized national policies to regional and local incentive structures. Although the public effort in creating and sustaining public/private partnerships in research is not less than in Germany, this proliferation of instruments generates some confusion as well as multiple costs. In this context, firms may find it difficult to identify the proper public partner for starting a collaborative research. Moreover, multiple costs can lead to a dispersion of public resources, which may result in less effective support to research partnerships. From a national policy perspective, this suggests that the innovation clusters created in France in the recent years (as mentioned in Section 2.2) might not yield the expected results, if they simply come as an additional layer in an already overly complex set of institutions.

Finally, even though our analysis highlights the positive impact of cooperation with public research on firms' innovativeness, we should refrain from jumping to conclusions as far as policy implications are concerned. In particular, since our data did not allow us to conduct a complete costs/benefits analysis (comparing private and social costs to private and social returns), we cannot say that cooperation must be encouraged at all cost. It can indeed have hidden social costs, for instance if it leads public research institutions to focus only on applied research and to forego fundamental research. Examining such issues remains an interesting topic for further research.

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