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Objectives, agreements and matching in science–industry collaborations: reassembling the pieces of the puzzle

Nicolas Carayol [a,b,*,1]

[a] LIRHE, UMR CNRS 5066, Université de Toulouse 1, Place Anatole France, F-31042 Toulouse Cedex, France
[b] BETA, UMR CNRS 7522, Université Louis Pasteur, 61, avenue de la Forêt Noire, F-67085 Strasbourg Cedex, France

Abstract

Science–industry collaborations have been the subject of a considerable attention in the last few years. The paper argues that, however, the existing studies are still restricted to a partial view of the phenomenon. In this respect, our study departs from the specialised literature by taking into consideration, for a given set of heterogeneous collaborations, information from both the academics' and the firms' side, relative to their characteristics, their aims and the collaboration settings. To do so, we constructed a database of 46 collaborations from original data we collected, in several European countries and in the US, within the SESI-TSER project. The first outcome of our study is a typology of science–industry collaborations built on a formal procedure (a multi-correspondence analysis followed by an ascendant hierarchical classification) exhibiting five coherent types of collaborations that we describe precisely. Highlighting the crucial importance of research agendas, we thus propose a simple rationale for the matching process. The latter leads us to propose an "assortative" matching hypothesis generating two polar configurations which we test and confirm. Finally, we examine the policy implications of the findings.

Keywords: Science–industry collaborations; Typology; Research agendas; Assortative matching

1. Introduction

The last two decades have seen a considerable increase in collaborations between researchers belonging to the sphere of Open Science (Merton, 1973) or academics[2] and firms, as the empirical literature has repeatedly shown (Cohen et al., 1994, 1998; Mansfield and Lee, 1996; Meyer-Krahmer and Schmoch, 1998; Mowery, 1998; OECD, 2000). If science–industry collaborations interested both scholars and policy makers so much, it is because of their expected important positive impact on economic performances. On the one hand, most scholars highlighted their social benefits (Brooks, 1994) in increasing either the performances of the collaborating firms, the productivity of their R&D processes (David et al., 1992; Zucker and Darby, 2000), their absorptive capacity (Cohen and Levinthal, 1989) or even, looking at the outcomes arising on the other side of the collaborations, by improving the economic relevance of scientific knowledge production (Gibbons et al., 1994; Gibbons, 1997). On the other hand, some others emphasised their risks and costs expressed in terms of inopportune modifications of public research agendas toward more applied research (Cohen and Randazzese, 1996; David, 2000) or on knowledge disclosure restrictions they may generate (Cohen et al., 1994; Blumenthal

* Tel.: +33-3902-42104; fax: +33-3902-42071.
E-mail address: carayol@univ-tlse1.fr (N. Carayol).
[1] Tel.: +33-561633863; fax: +33-561633860.

[2] To be interpreted in the broad sense, that is including researchers belonging to universities, and all other institutions, either public or private, being totally or partially dedicated to the advance of scientific knowledge.

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et al., 1997). The mode of funding being a critical explanatory variable for the nature of public laboratories research (Crow and Bozeman, 1987), this issue is obviously far from marginal. Indeed, as Berens and Gray (2001) suggested, the 7% of US academic research funded by industry may lead, due to leverage effects, to a share of approximately 20–25% of academic research being directly influenced by industrial funding.

However, it appears that there is no uniform way of stating this issue since there is no univocal manner for science–industry collaboration. Indeed, as Mowery (1998) clearly indicated: "[Collaboration] covers a diverse array of programs, projects, and institutional actors. No single recipe for project design, program policies, or evaluation applies to all these disparate entities. Collaboration is a means not an end". This naturally calls for a clear understanding of how the various science–industry collaborations proceed, that is including why and how different actors, belonging to spheres of human activity which have different rules and reward systems are finding it profitable to collaborate. This is indeed a necessary condition for setting up and implementing policies dedicated to support and orient them.

Thus, in this paper, we investigate issues which we put under the heading of the 'microeconomics of science–industry collaborations', by trying to answer the following questions: What are the various partners' aims and strategies for collaborating? How do these strategies match? Can we find separate and coherent types of collaborations? As a matter of fact, previous studies have indeed already examined some of these aspects and one may find presumptuous to address many of them simultaneously. Nevertheless, we argue that the numerous studies on the domain did concentrate on restricted dimensions of the issue, that is either on the point of view of only one of the partners or on contractual agreements only. That is why we might have missed so far how the different partners' strategies fit together in the different resulting collaborations. What we would like to know here can be summed up in the following questions. How do partners' goals fit and match altogether? To what collaboration settings do they lead? That can obviously only be tackled by getting, for a given set of sufficiently heterogeneous collaborations, data from and on different actors involved in the collaboration. The study on science–industry collaborations we present here is based on the idea, that we may call 'reassembling the pieces of the puzzle'.

This aim is grounded in the original data we collected within the SESI-TSER project network[3] in five countries (Austria, France, Germany, UK, US), interviewing firms of the information and telecommunication (IT) and pharmaceuticals and health related biotechnologies (Ph/Bio) sectors and some of their academic partners. We collected data on the collaborations and on the partners. An important point to be noticed is that we chose the collaborations to be the statistical individuals, informed by variables of the collaborations themselves, and by the characteristics and strategies of the partners. What we studied as the "academic partners" were the public laboratories involved. The whole firm constituted the industrial partner. The data were filled ex post thanks to an ex ante defined common procedure which allowed us to build a data base of 46 exploitable cases of science–industry collaborations. It should also be noted that all the cases of collaboration as well as partners' organisation and strategies were studied in-depth and were then also informed with comprehensive data that appeared to be very useful for supplementing formal data analyses and for interpreting the findings.

The first outcome of this study is a five set typology of collaborations obtained through a multi-correspondence analysis followed by an ascendant hierarchical classification. The interpretation of each type of collaboration is focusing on how they are practically organised, the contractual agreements, and the generic aims simultaneously followed by both academics and firms. The second outcome of the study is a rationale for understanding the matching of potential academics and firms based on the nature of the research the former perform and the nature of the research realised in common. Our hypothesis is that an "assortative" matching is at work. Becker (1973) first introduced that notion in his economic "theory of marriage". An "assortative" matching process is said to be arising when best ranked agents (on a given criterion) preferentially match together (for our purpose collaborate). The importance of such phenomena for contractual agreements has recently been

[3] SESI is a targeted socio-economic research (TSER) project funded by the European Commission DG XII (contract SOE1-1054, project 1297).

demonstrated by Ackerberg and Botticini (2002). We will test and validate this hypothesis on our sample of science–industry collaborations. Even if this result has to be taken cautiously due to the limited size of the sample, it may have important policy implications.

The paper is organised in the following manner. In the next section, we shall present a literature review of science–industry collaborations from which our study departs. This we will show in Section 3, which is mainly dedicated to the presentation of our data. In Section 4, we shall build and present the typology of science–industry collaborations. In Section 5, we will then present and test a rationale for understanding the matching of academic labs and firms suggesting that two polar forms of collaborations can be distinguished in practice. The last section concludes by discussing the public policy implications of the findings.

2. What do we know about science–industry collaborations?

Many previous empirical studies focused on collaborations between public researchers and firms. Due to several difficulties in collecting collaborative data, most of the previous empirical studies were based on one or a few monographs (Webster, 1989; Berman, 1990). However, since the mid-1990s, many scholars have tried to overcome the difficulties faced in a systematic data collection, using different methodologies and having different focuses. Reviewing these, we identified five broad categories for the previous empirical investigations: the study of the various forms of interactions (in which collaborations are a single item), the study of collaboration agreements, the analysis of the academics' aims for collaborating, the negative consequences of the collaborations on the academics behaviours and finally firms' aims for collaborating. They are presented in the remaining of this section.

2.1. The various forms and intensity of interactions

Meyer-Krahmer and Schmoch (1998) carried out a survey of more than 400 scientists "representing" German research centres belonging to five fields (Production Technology, Microelectronics, Software, Biotechnology, Chemistry). They found that the more applied fields are the ones that receive the more important share of their funding from industry. In all fields, "collaborative research" and "informal contacts" are the most important interaction types and usually, "attending conferences" receives a higher ranking than "publications reading". It is also to be noted that "service like research" tends to be ranked higher in the fields which are the more applied ones.

These results were extended and refined by a recently published and very complete study for Austria. Indeed, Schartinger and co-authors attempted to measure the sectoral pattern for different types of knowledge interactions and explored the determinants of interactions at the level of scientific fields and sectors. Their results are three-fold: first, they found that interactions are not restricted to a few industries and science fields, and that, on the contrary, a large number of scientific disciplines and almost all economic sectors interact. Secondly, there is no evidence that factors such as R&D spending in industry and a priori orientation of scientific fields towards industry needs determine the intensity of interactions. Thirdly, they evidenced that "industry and university use a large variety of channels for knowledge interaction, and there are significant differences in the orientation on certain types of interaction by industrial sectors and fields of science" (Schartinger et al., 2002).

2.2. Contractual agreements

Cassier (1997) studied 150 contracts of laboratories of the French CNRS sometimes including firms as partners. He focused on the institutional settings partners agreed on, observing different generic rationales for: (i) sharing knowledge produced before the collaborative research but used in its performing; (ii) sharing the knowledge produced through the collaborative research; and (iii) the ex ante definition of the allocation of IPRs on relevant knowledge that the collaboration may produce. He found the different rules that were used in practice, and to which situations they appeared to be relevant.

Joly and Mangematin (1996) realised a typology of laboratories belonging to a large French research institution specialised in agricultural research (INRA) and also analysed their collaborations with firms. Concerning the latter, which we are interested in, their database included 180 cases of collaborations. Even if limited to one single field, one institution and one country, their results are very interesting. They found what they called three "logics" for collaborating: a "geographical proximity logic", a "market oriented logic" and a "symbiotic" one which is grounded in a co-specialisation process of partners' knowledge, competencies, involving the co-definition of collaborative research projects.

2.3. Academic partners' objectives for collaborating

The academic partners are composite in the sense that different actors, potentially following slightly different objectives, may intervene in the settlement of a collaboration. Indeed, the objectives of the technology transfer office (TTO) managers may differ from the ones of the laboratory manager, or even of the scientists themselves. Previous empirical studies brought insights on the three of them.

Thursby et al. (2001) used data from the Association for University Technology Managers (AUTM) survey and built their own survey of 62 TTO managers. They found that the latter's objectives were, by decreasing average importance: royalties and fees generated, number of inventions commercialised, number of licenses signed, sponsored research, and finally number of patents awarded. The authors also found that royalties generated are lower and sponsored research is more likely when the new technology is licensed at an early stage of development.

In their study mentioned above, Meyer-Krahmer and Schmoch (1998) showed that academic researchers perceive that the advantages of laboratories for interacting with industry lie mainly in obtaining additional funding and exchanging knowledge, while the disadvantages primarily reside in the short term orientation of firms' agendas.

Surveying more than 100 academic scientists in the US, Lee (2000) found that the most important reasons for collaborating were, in a decreasing frequency order: to secure funds for research assistants and laboratory equipment, to gain insights in one's own academic research, to test application of a theory, to supplement funds for one's own academic research. It may be interesting to note that the preceding items are occurring much more often than the following ones: to assist university's outreach mission, to create student jobs and internships, to gain practical knowledge for teaching and to look for business opportunity.

Lee (2000), in addition to the aims of academics for collaborating mentioned above, also studied the perceptions academics have of their gains from collaborating with industry. He showed that "a large majority, over 67% [of faculty members] say that they are experiencing substantial or considerable benefit to their academic research support by acquiring fund necessary to support graduate students and purchase lab equipment. Similarly, an equally large majority, over 66%, say that from research collaboration with industry they are gaining valuable insight into their research agendas. Over 56% also agree that they find an opportunity to field-test the practical application of their own research and theory". On the other hand, "only a small percentage of faculty members (21%) believe that research collaboration with firms offer a significant window for business opportunity for them".

2.4. The "unintended consequences"

Our concern now is with the negative consequences of the collaborations on research performed by academics, what Berens and Gray (2001), somehow misleadingly, called the "unintended consequences" of the science–industry collaborations. This theme has been put forward by the *New Economics of Science*. These authors (Dasgupta and David, 1994; Stephan, 1996), highlighting the efficiency properties of collective knowledge production relying on the norms and rules of Mertonian Open Science (Merton, 1973), tend to be attentive to the various risks science–industry collaborations put on Science collective organisation. The risks treated by both the theoretical and the empirical literature are mainly related either to distortion of research agendas selection, restriction of disclosure behaviours or even decrease in research productivity.

From an empirical point of view, these phenomena were first been observed by Cohen et al. (1994), in their well-known study based on data collected surveying directors of US universities University Industry Collaborative Research Centres (UICRC). They first evidenced that collaborating with industry implied restrictions to publication, and was correlated to performing applied research. As emphasised in Cohen et al. (1998), they also found that, when directors of UICRC declare that they aim to "improve industry products and processes" then their research is more applied.

Thursby and Thursby (2000) addressed the issue whether the dramatic increase in the patenting and licensing activities in the US universities was due to an increase in the willingness to patent discoveries or if it was the consequence of a shift in the nature of their research contents, i.e. a decrease of the basicity of their research agendas. They found that the growth in licensing patented university inventions was driven primarily by an increase in professors' propensity to patent and firms' propensity to outsource R&D by licensing rather than by a shift in the average basicity of the research they perform. Gluck et al. (1987) surveyed more than 700 Ph.D. candidates at life science departments of major US universities. They found that if the Ph.D. or their supervisors were involved in science–industry collaborations, then their publishing and disclosure behaviours were altered.

Blumenthal et al. (1996) surveyed more than 2000 public researchers in the life sciences. They showed that faculty members were more productive, in terms of peer-reviewed articles published in the past 3 years, when they received industrial funds. Nevertheless, scientists are less productive when the share of industry in their funding is higher than two-thirds. Moreover, researchers receiving funding from industry are reported more often that they took "commercial considerations" into account when they choose their research agendas and acknowledged more frequently that they were involved in "trade secrets" agreements (Blumenthal et al., 1996). This result although it is confirmed, is supplemented in Blumenthal et al. (1997). Therein, it is showed through a multivariate analysis that even if involvement in science–industry collaborations is associated with data withholding, the latter is even more often correlated with having a high publication rate.

2.5. Surveying the firms side

Adams et al. (2001) surveyed the firms involved in collaborations with the UICRCs. Their results tend to indicate that collaborating with academics is more a complement to their own research than a substitute, by evidencing that interacting with a UICRC increases R&D spending and the number of patents awarded.

Hall et al. (2001) carried out a study based on a limited set[4] of contractual data from the US government ATP research program supplemented by questionnaires addressed to the leading firms of the projects. They wondered why firms included university scientists in their projects, and whether IPR issues were barriers for doing so. They found that the probability that an IPR-related "insurmountable" barrier arose in the relationship was increased when the intellectual property characteristics of the research were certain and when the research was expected to lead to less appropriate results. The authors also showed that the probabilities are much higher when the lead participant (a firm) has prior experience partnering with a university, which they interpreted as the firms being thus "aware of the difficulties they may encounter".

In another paper Hall et al. (2000) studied again ATP projects data, including now 47 cases, among which 30 involved universities. Their main conclusion was the following. The involvement of university researchers creates "research awareness" in the aims of the projects, this statement being grounded in observing that projects involving universities are less likely to be early terminating projects than the others.

Caloghirou et al. (2001) built a survey of 285 cases of collaborative projects funded through EU framework programs, including at least one university and one firm. The questionnaires were addressed to firms, asking them to indicate on a one to five Likert scale the importance of collaborating with different types of partners (public research institutions, universities, firms, . . .). In the meantime, they also asked them to express the relative importance, from their point of view, to be involved in this collaboration. They found that the intensity of the collaboration with universities was positively correlated with the declared importance of aiming (in a decreasing intensity order): to access to complementary resources and skills, to benefit from research synergies leading to cost savings or improvements in R&D productivity, to keep up with major technological developments, to obtain funding, and finally to share R&D cost.

Lee (2000), in addition to the survey of academics, built another one of 140 firms collaborating with universities. He showed that by partnering with faculty

[4] Thirty cases in all (out of the 352 ATP projects population), among which 12 involved universities.

members, firms were first "gaining increased access to new research and discoveries", second making "significant progress toward the development of new products and processes", and third helping them significantly toward a closer relationship with the university". But, on the other hand, 77% of firms felt that faculty members made only "moderate or marginal improvement of product quality", and most of them judged that faculty contribution to the firm R&D agenda is "inconsequential".

Zucker and Darby (1996) followed by Zucker and Darby (2000) while studying biotech firms, looked at the consequences of either hiring or co-publishing with "star scientists" on the firms research productivity (as indicated by the number of patents granted, the number of projects in the three phases of pharmaceutical R&D processes and finally on the market). They found a significant positive effect.

3. The data

3.1. Reassembling the pieces of the puzzle

From the preceding (non-exhaustive) exposure of empirical studies, one has to acknowledge the considerable amount of research recently dedicated to science–industry interactions and more specifically to collaborations. These studies provide us with a large amount of knowledge on nearly all dimensions of the issue, that are, the various forms of interactions, their determinants, the different contractual agreements signed, the academics' aims (for the several actors intervening at the academic side: TTO managers, laboratory managers, researchers), the possible negative modifications of their behaviours (and of Ph.D.) due to collaborating with firms, and finally firm objectives for and benefits from collaborating.

Nevertheless, one may also observe that each study is built on a partial representation of collaborations, while one may also find it interesting to combine them. Indeed, what the previous studies did tell us and what we now know better, are the lists of the different actors objectives for collaborating and of the various collaboration agreements. In the meantime, one may expect on each side potential partners to be heterogeneous, that is to have different objectives or at least to weight them differently. If so, the following three questions naturally arise. First, knowing the determinants of each objective: can we find characteristics of partners that are correlated to the stressing of specific aims? Secondly, which academics' aim "fits better" with which firms' aim and vice versa? Finally, what are the different collaboration agreements which are used to simultaneously serve these objectives? These three questions are at the very core of what science–industry collaborations really are: practical and presumably profitable solutions that "uneasy partners" (Cohen et al., 1998) find for collaborating.

To address these questions, one tractable solution is to choose the collaborations to be the "statistical individuals", being informed jointly by variables related to the collaboration itself, the characteristics of partnering agents, their opinions and their objectives. This approach requires to: (i) identify collaborating agents; (ii) define the frontiers of the relevant partnering agents; (iii) define the sphere of their collaboration; (iv) collect data about them, their opinions on the collaboration; and (v) obtain objective information on the collaborations.

Filling this bill was a hard job, which is described in the next subsection. We would like to dwell now on the problems this statistical option brings forward or, more precisely, the already existing problems it renders more accurate. Two of them seem particularly important. The first problem is related to the definition of the collaborations frontiers which are fuzzy in many respects. Some collaborations may last over a long period of time, with several agreements, one succeeding the others. In such situations, we decided to take the ongoing collaborations into consideration, as indicated by the applicable agreement(s), instead of taking the whole story as the reference.[5] When collaboration agreements involved several partners, we decided to keep this information, but we concentrated on the firm studied and the main academic involved.

Secondly, we have to determine who is the relevant actor on the academic side? This is to be considered for very different institutions and for different countries: Is it the individual researcher, the research team, the laboratory, the department, or even the institution? Some arguments can be found to support each of them.

[5] One problem could also have emerged if we had had several simultaneous and non-coordinated agreements between the same partners. Such a configuration did not occur in our sample.

We selected the research laboratory level, because it appeared to be relevant in most cases. For few cases (essentially in the US and the UK), it was not possible to find a laboratory in the full sense of the term. What we studied then as the academic partner was the research team. Even if it is a slightly different unit of observation, it still appeared to be acceptable because, in such cases, the research team was indeed the relevant unit of research organisation.

3.2. The data

The empirical evidence on which we base our analyses comes from original data collected within the framework of the SESI project.[6] We visited plants located in five different countries (Austria, France, Germany, UK, US) of companies belonging to the IT, and to the Ph/Bio. In doing so we identified and selected some of their academic partners which we also interviewed. This study thus concerns the scientific fields which have collaborations with these sectors (engineering sciences, applied maths, physics, biotechnologies, organic chemistry, etc.).

On average, around 15 interviews were carried out in each company (with heads of R&D, human resources, and technical services and researchers) and in the public laboratories involved (researchers involved and laboratory directors). By interviewing the academic partners, we also discovered cases of academic spin-offs. When they led to a close collaboration between the start-up and the lab, they did constitute cases of science–industry collaborations.

In all, out of the 24 firms visited (comprising the start-ups) and included in the study, we identified and selected 46 exploitable cases of collaboration collected in five countries.[7] Thirty-four concerned firms belonging to the IT sector and 12 to the Ph/Bio sector.[8] Nine cases of collaborations directly involved several partners. In such situations, our interviews were limited to the firm initially visited and the main academic partner. Six cases involving start-ups were selected, studied and then included in the data base.

In practice, we defined a grid for the interviews so as to permit ex post codification of the data and then comparative studies. But we also collected a large body of information through the interviews that were compiled in standardised monographs. We thus complemented the formal data with the more contextual information reported therein. Such a methodology based on case studies allows us to reconcile empirical wealth and comparability thanks to a quite substantial number of cases analysed involving partners of different fields, research institutions and countries within an integrated approach.

Concerning the normalised variables, the cases are mainly defined by means of three series of critical variables which are summed up in Table 1. The first is related to the characteristics of the two partners involved. The industrial partners are characterised by their 'type' (big multinational, national champion[9] or start-up), their sector (IT or Ph/Bio), and the country where the plants we studied are located. The academic partners are characterised by their scientific domain (biology, biochemistry, chemistry, pharmacology, physics, maths, engineering sciences, social sciences), their administrative affiliation (university, national research institute, or both), the main type of research they perform (basic, basic oriented[10] or applied), the intensity of their thematic specialisation (high or low) and the academic excellence of the institution to which they are affiliated (notably high or not).[11]

The second series focuses on the collaboration itself. The variables are: the organisational solution

[6] For a more detailed presentation of the data, one can refer to the dedicated chapter in the original report to the EC, available upon request (Carayol, 2001).

[7] The obvious advantage of international data is that they allow us to go beyond specific national features often resulting from the existence of particular institutional mechanisms and to focus attention on the essential micro variables for collaborating.

[8] The firms visited include notably: Motorola, Hewlett-Packard, Nortel Networks, Alcatel, Ericsson, Siemens, Canon, Racal, ICL, ICI, Pfizer, Aventis, Laboratoires Fabre and Boehringer Ingelheim. Some of these were visited in several countries.

[9] The term "national champion" is used to characterise a firm which is of a quite big size having the world as a market but which is mainly localised for its conception and production side in one single country.

[10] This notion was introduced in the well known Frascati Manual, relying on theoretical insights from the authors of the so-called "Finalization" thesis (Schäfer, 1983). For an example of that notion being used in the domain of science–industry collaborations, see Meyer-Krahmer and Schmoch (1998).

[11] This subjective information was filled ex post from the interviews and contextual information which could indicate that the academic institution was notably prestigious.

Table 1
Description of the variables (based on χ^2-tests)

Characteristics of the relation	
Organisational solutions	Simple contract, mixed laboratory, research platform, framework agreement, start-up creation and assistance
Consortium	Big, small (less than four partners), bilateral relation
Volume	High (more than US$ 1 million), medium (more than US$ 100,000), low (less than US$ 100,000)
Duration	Long (more than 2 years), short (less than 2 years)
Novelty of the sub-field concerned (stated from information collected interviewing the academic partners)	High, medium, low
Nature of research performed (stated interviewing both partners)	Basic, basic oriented, applied, service
Research risk (ex ante probability of success estimated from firms R&D officers)	High, low
IPRs solution	No IPRs issue concerned, owned by the firm, shared ownership, owned by the academics
Environment of the relation	
Common history	High, low, none
Distance	Same regional area, same country, other country
Significant additional public funding	Yes, none
Technology transfer institution involved	Yes, no
Strategy of the academics	Valorise expertise, increase volume of research, increase scientific excellence
Time to development (from the beginning of the collaboration and through interviews realised on the firm side)	More than 3 years, more than 1 year, less than 1 year
Firm characteristics	
Type of the firm	Big multinational, start up, national champion
Sector	Ph/Bio, IT
Country of the plant	Austria, France, Germany, UK, US
Academic partner characteristics	
Scientific domain	Biology/biochemistry, chemistry/pharmacology, physics, maths, engineering sciences, computer sciences, social sciences
Administrative affiliation	University, National Research Institute, Both
Main type of research	Basic, basic oriented, applied
Thematic specialisation	High, low
Academic excellence (of the affiliated institution, filled from the interviews and contextual information)	Notably high, not high

adopted (simple contract,[12] mixed laboratory created, research platform,[13] framework agreement,[14] start up assistance), the volume of the research collaboration in terms of the cash flow spent by the firm (more than US$ 1 million, more than US$ 100,000 or less), the duration of the collaboration (over or under than 2 years), the number of participants (big consortium, less than four partners involved or purely bilateral collaboration), the IPR solution adopted (no IPR issue concerned, IPRs owned by the firm, shared ownership, IPRs owned by the academic partner), the novelty of the sub-field concerned (high, medium or low obtained from information collected interviewing the academic partners), the degree of research risks as evaluated by the ex ante probability of success (high or low estimated from firms R&D officers), the nature of research performed within the collaboration (basic

[12] "Simple contract" means that the collaboration did not imply the settlement of any specific infrastructure.

[13] What we mean by "research platform", is an agreement that structures a partnership specifying the funding and use of instrumentation, collective rules for knowledge sharing, fields of research and rules for allocating property rights. It is most of the time realised for several partners.

[14] A "framework agreement" differs from the creation of a "mixed laboratory" in that there is no common institution created; it only specifies the nature of the collaboration (field, type of research, property rights, cost of research) and very often the amount of research that the firm will externalise through this collaboration.

research, basic oriented research, applied and service, as stated while interviewing both partners).

The last series of variables is related to what we could broadly call the environment of the collaboration and the strategies of the partners. They are: the existence of a common partnership history between the partners (strong, weak, none), the geographic distance between the two (same geographic area, same country, other country), the significant support of additional public funding to the collaboration (yes or no), the mediation of the collaborations through a technology transfer institution (yes or no), the main strategy followed by the academic partner in setting this collaboration (valorise expertise, increase research volume, increase scientific excellence),[15] and the expected time before the research results enter in the firm development process[16] (more than 3 years, more than 1 year, <1 year).

4. The diversity of science–industry collaborations: a typology

The aim of this section lies in beginning to answer the following questions: In what and why do science–industry collaborations differ? For that purposes we build a typology of collaborations which is formally grounded in the methodology exposed in the first subsection. Such a procedure is well adapted both for a limited set of cases and for qualitative data. It allows us to apprehend the diversity of science–industry relations whereas a structural model would tend to emphasise the main trends.

4.1. The methodology

The formal data analysis aims to construct a typology of the relations between academics and firms. For this, a three-step statistical approach has been chosen consisting of: (i) a multi-correspondence analysis (MCA); followed by (ii) an ascendant hierarchical classification (AHC); finally (iii) a correlation analysis is used to explain the types obtained. These multi-dimensional exploratory techniques are well adapted for limited sets of cases informed by qualitative data.

(i) First of all, the MCA is designed to analyse the relations between more than two categorical variables that can be presented in multi-way contingency tables. This first step allows us to identify the more discriminating variables and to reduce the dimensionality of the dataset by constructing synthetic variables which express the relationships between these variables. More precisely, the total variation of the data matrix is computed by the usual χ^2-statistics which measures the distance separating the original distribution from the one assuring the independence of the variables. Thus, the sum on all cells of the square of the difference between the theoretical and actual value can be computed, and when divided by the theoretical value, the so-called χ^2-value is obtained. The statistics called inertia (which means variance in this context) is finally formally obtained dividing the latter by the total number of observations (Greenacre, 1993). Total inertia may be interpreted as the percent of inertia in the original correspondence table explained by all the computed dimensions in the correspondence analysis. The percentage of inertia explained is then used to retain the more discriminating axes of the analysis. Usually, the researchers keep only the first two or three axes. We will follow Benzécri (1992) who argues that one should rely on the percentage of inertia explained but also on the general meaning of the axis which will constitute the new synthetic variables.[17]

(ii) The AHC, in turn, is used to partition the population into homogeneous groups. Its inputs are the co-ordinates of the individuals on the axes selected (obtained by projection) which are the main outcomes of the MCA. The AHC

[15] "Increase research volume" implies that the academic partner mainly wishes to obtain research funding from the collaboration, while wishing to "increase his scientific excellence", he is much more cautious with the research contents of the collaborative research which is then directly in line with his own research purposes. When aiming to "valorise expertise", that means the knowledge is already existing and thus is not produced within the collaboration. The collaboration has then a priori no incidence on the academics' research.

[16] As estimated from the beginning of the collaboration and through interviews realised on the firm side.

[17] For more on the interpretation of the outputs MCA, one may refer to Greenacre (1993).

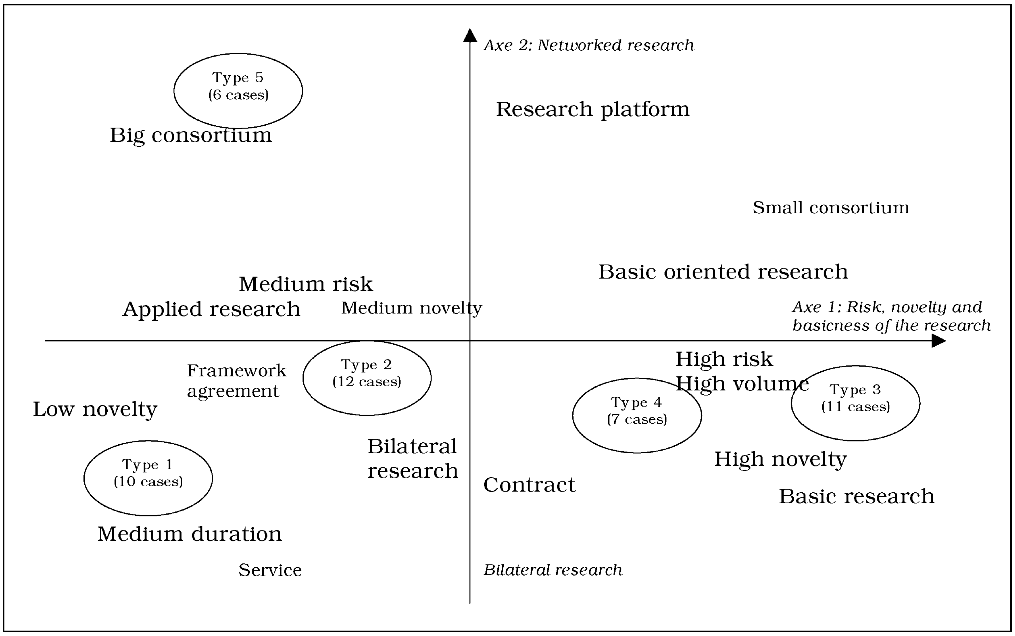

Fig. 1. Representation of the types' centres on and the variables contributing to the two first axes of the MCA.

algorithm proceeds as follows: at each step pairs are formed by merging the closest clusters in order to minimise the within-types variance and to maximise the between-types one. The comparison of these two values is the criterion used for choosing how many types will be retained. There is a benchmark to be made between selecting a relatively small number of types and having a high within-types variance compared to the between-types one. Once the types are retained, the co-ordinates of the type centres can be represented on the axes determined in the MCA. That allows to explain the types.

(iii) Finally, a correlational analysis can be run in order to specify the links between the types and, for instance, some more structural variables that have not been included in the preceding analyses.

4.2. The typology

In our study, what we are looking forward is a typology of collaborations. Thus, the variables concerning the relations are the only ones retained for the MCA. More precisely, the variables used for building the typology are the following: organisational solutions, consortium, volume, duration, novelty, nature and risk of the research.[18] The characteristics of the partners do intervene in the third step of the analysis. What one may expect is the types of relations to be correlated with the characteristics and strategies of both partners. We decided not to include these variables in the typology itself in order to build such information on reliable grounds (the correlation would be then obvious).

Following the MCA, four axes were selected which collectively represented 60.3% of the inertia (end of first step). Then, the AHC was realised based on the co-ordinates of the individuals (relations) on these four axes. It gave us five coherent types of science–industry relations because, in retaining these five types, the within-types variance of the total variance was nearly 70% which is usually admitted to be a very good ratio. Next, the co-ordinates of these type centres were represented on the four axes (Figs. 1 and 2). This is closing the second step.

As Fig. 1 shows, the first axis (contributing for 23.2% of the inertia) states the intensity of the basicity, the risk and the novelty of the collaborative research.

[18] We did not include the variable related to the IPR solutions adopted as it appears to be very linked to national specificities.

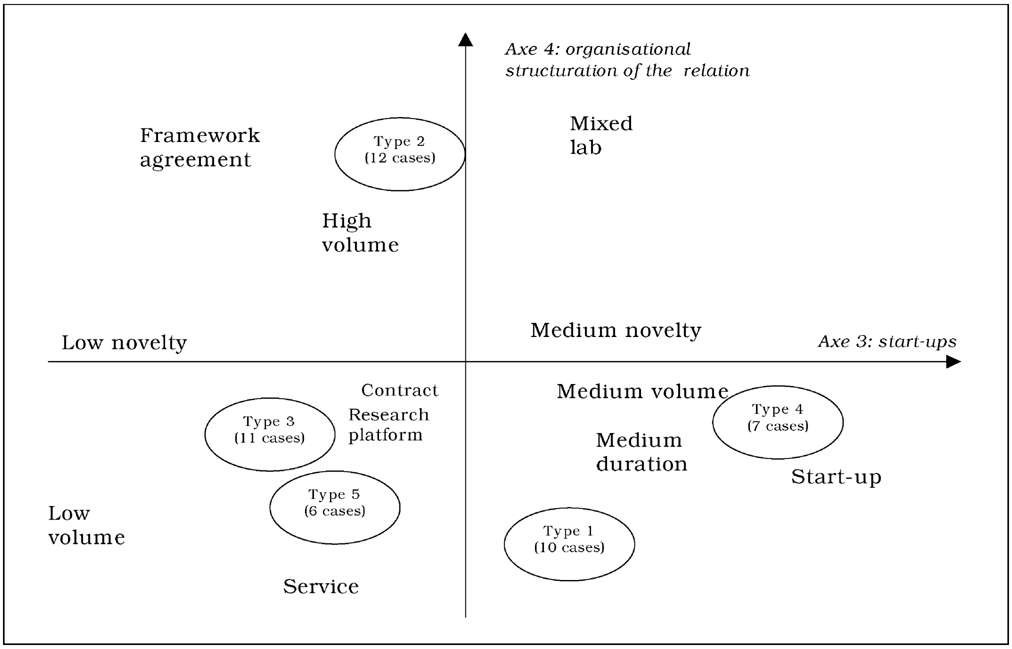

Fig. 2. Representation of the types' centres on and the variables contributing to the third and fourth axes of the MCA.

On this axis, the third and fourth types are opposed to the first, second and fifth ones. The second axis (13.9% of the inertia) opposes the networked research to the bilateral one, clearly distinguishing the type 5 from all the others. In Fig. 2, one can observe that the first and fourth types are opposed to the other ones on the third axis (12.2% of the inertia). This obviously comes from the very originality of start-up creation compared to standard science–industry collaboration (start-up cases being all included in the types 1 and 4). The last axis retained (11% of the inertia) illustrates the distinction between collaborations that are very organisationally structured (mainly belonging to the second type) to the others.

We shall discuss the characteristics of the five types below. We first describe each type basing our arguments on the analysis of the Figs. 1 and 2, and the correlation analysis presented in Table 2 (third step) and secondly interpret these findings, complementing our analyses on the qualitative data collected through the interviews.

Type 1: Involves 10 cases of science–industry collaborations, offers the most simple version of the collaborations. It is constituted on the one hand of low volume, risk and novelty, and service like contractual research and, on the other hand, of applied research valorisation through start-up creation and assistance. When the collaboration implies a start-up creation, the IPRs are usually owned by the academic partner, the common history of the partners is naturally strong, and a transfer institution is involved. Otherwise, the firm usually owns the IPRs, the partners have no common history and no transfer institution is needed. The applications of the research are expected to intervene within 3 years and within the IT sector. The academic partners usually do not exhibit a high specialisation and a high academic excellence.

It illustrates situations in which an academic player already has application potential, expertise or technology. The marginal investment needed to develop it is thus relatively slight and may be accomplished through the creation of a start-up, a doctoral dissertation or even a master's thesis. The academic partner perceives the collaboration simultaneously in terms of a complementary development of his knowledge, an opportunity for student placement and the establishment of an industrial tie which can subsequently be strengthened. The industrial partner sees this

Table 2
Description of the types' characteristics (based on χ^2-tests)

Variables	Significance	Type 1 10 (22%)	Type 2 12 (26%)	Type 3 11 (24%)	Type 4 7 (15%)	Type 5 6 (13%)
Characteristics and environment of the relation						
Organisational solutions						
Simple contract	(***)		−	+	+	−
Mixed laboratory		−	++	−		
Research platform		−	−		−	++
Framework agreement		−	++	−	−	−
Start−up creation and assistance		+	−	−	+	−
Consortium						
Big	(***)	−	−	−	−	++
Small (less than four partners)		−	−	++		
Bilateral relation		+	+		+	−
Volume						
High (more than US$ 1 million)	(***)	−−	++	++	−	−
Medium (more than US$ 100,000)			−	−	++	+
Low		++	−		−	+
Duration						
Long (more than 2 years)	(***)	−−	+	+	+	+
Short		++	−	−	−	−
Novelty						
High	(***)	−	−	++	+	−
Medium		+	+	−−		+
Low		+	+	−	−	
Nature of research performed						
Basic	(***)	−	−	++	−	−
Basic oriented		−	+	+	++	
Applied		+	+	−	−	+
Service		++	−			
Research risk						
High	(***)	−−	−	++	++	−
Low		++	+	−−	−−	+
IPR						
No IPR issue concerned	***		−	+	+	−
Owned by the firm		+	+		−	−
Shared ownership		−	+		−	++
Owned by the academic		++	−	−	++	−
Common history						
Strong	**	+	+		−	−
Weak		−		−	+	++
None		+	−−	++	−	−
Distance						
Same area	ns					
Same country						
Other country						
Significant public funding						
Yes	***	−−	++		−	++
None		++	−		+	−−

Table 2 (*Continued*)

Variables	Significance	Type 1 10 (22%)	Type 2 12 (26%)	Type 3 11 (24%)	Type 4 7 (15%)	Type 5 6 (13%)
Technology transfer institution						
Yes	*	++	+	−−	+	−−
None		−−	−	+		++
Strategy of the academics						
Valorise expertise	***	++	−	−	+	−
Increase volume of research			+	−	−	+
Increase scientific excellence		−	−	++	+	−
Time to development						
More than 3 years	***	−−	−	++	+	−
More than 1 year		+	+	−		−
Less than 1 year		+	−	−	−	++
Firm characteristics						
Type of the firm						
Big multinational	*	−	+	+		
Start up		++	−−	−	+	−
National champion			+	−	−	+
Sector						
Ph/Bio	**	−−	−	++		−
IT		+	+	−−		+
Country of the plant						
France	***	+	++	+	−	−
UK		−	−	+	+	+
Austria					−	++
US		++	−	−	+	−
Germany			+			
Academic partner characteristics						
Scientific domain						
Biology/biochemistry	**	−		++		−
Chemistry/pharmacology		−	−	+		+
Physics			−	−	++	
Maths		−	−	++		
Eng. Sciences			+	−		
Computer sciences		+		−	−	+
Social Sciences		+				
Administrative affiliation						
University	***		−−		+	+
National research institute		++			−	−
Both		−−	++			−
Main type of research						
Basic	***	−	−	++	+	−
Basic oriented			+	−	+	−
Applied		+		−	−	+
Thematic specialisation						
High	***	−	−−	++	++	−
Low		+	+	−−	−−	+
Academic excellence (of the institution)						
Notably high	**	−−	−−	++	++	−
Not high		+	+	−	−	

NB: The superscripts *** and ** denote significance level exceeding 99 and 95%, respectively; ns stands for lower than 90%. ( ) means that the variable has been selected for realising the MCA. ++ (−−) indicates a high positive (negative) contribution of the variables' modalities to the χ^2, while + (−) indicates a less important positive (negative) one.

collaboration as an opportunity to benefit from knowledge at a relatively low cost, which he can absorb totally by purchasing the technology and/or hiring the Ph.D. who has carried out the research. Sometimes the industrial partner considers also the collaboration as a means to create ties with a potentially new academic partner and thus testing his capacities.

Type 2: Counts 12 cases of science–industry collaborations. It consists of strategic bilateral collaborations most often based on framework agreements and mixed laboratory creation extending over 2 years and covering a large volume of research. The research performed is the more usually applied or basic oriented, of a quite low risk and non high novelty. The IPRs are either owned by the firm or jointly owned (the latter situation occurring most of the time when the partners are setting up a mixed laboratory). The partners usually work together and most of the time benefit from public funding. Five cases are mediated through a transfer institution. This way of collaborating is especially used in France and concerns essentially firms of the IT sector (10 cases). The firm is either a multinational or a national champion. The time to development is usually more than 3 years.

The main strategy of the academic partners is to increase their research volume through collaborating. Industrial funding occupies an important share of their budget, which often compensates for difficulties in obtaining a sufficient level of supplementary public funding. Their scientific domains are usually engineering sciences, performing applied or basic oriented research. The industrial partners offer a natural opening for their Ph.D., who cannot all be absorbed by the academic labour market (which reinforces the ties even further over the long run because the Ph.D. become potential clients). Hiring the Ph.D. involved enables him to absorb the knowledge produced (in particular tacit knowledge) if this turns out to be useful. This allows the industrial partner to compensate for the risks of losing competences through the outsourcing of the research. The industrial partner outsources his research in this context mainly on the basis of a low-cost research offer. In seven cases, the industrial partner does insist on maintaining the industrial property rights because such research is rather close to development.

Type 3: Consists of 11 cases of science–industry collaborations which are distinguishable by two main features. For one thing, the research content is of a basic and risky character, concerns domains of a high degree of novelty; for another, it implies significant funding from the firm. Since the research is mainly basic, the ownership of the IPRs is often not an issue. The collaboration is usually of a long duration, without being mediated by a technology transfer institution, even if it is settled between partners that have not significantly interacted so far. The organisational solution adopted is usually only contractual, but becomes a research platform when it concerns several partners through a small consortia (three cases). The industrial partners are firms belonging to the Ph/Bio sector (seven cases) and big multinationals of the IT sector located in the UK (four cases). The period before the knowledge produced is exploited in the development process is expected to be long. The academics, performing basic research, belong to quite fundamental research fields (in biology, biochemistry, maths, chemistry, pharmacology). They exhibit usually high degrees of specialisation and academic excellence, and their main objective for collaborating is to increase their scientific excellence.

These collaborations thus give academic researchers (and often corporate researchers as well) opportunities for important discoveries and major recompenses as pioneers in emerging lines or fields of research. They do not consider themselves constrained in their choice of agendas; on the contrary, the relationship offers important leverage for the advancement of their lines of research. It should also be noted that all the cases of small consortia belong to this type. It then appears that a high budget path-breaking research seems to be well addressed in a restrained research platform.[19]

[19] Type 3 also involves two original cases of science–industry collaborations. These occur within academic research funding programmes developed by European pharmaceutical companies, which use science–industry collaborations as leverage in the reorientation of pharmaceuticals towards biotechnologies. These programmes have allowed them to create numerous ties with academic laboratories which previously had little contact with the firms. In this situation, since the company's main objectives were to establish networks of collaboration and develop multiple learning situations, it did not seem relevant to orientate the academic partners' research topics but rather to benefit directly from the most advance research in the scientific field. Thus, the academic partner profits from industrial funding in order to explore lines of research which he had defined in accordance with his objectives for academic rewards.

Type 4: Covers seven cases of science–industry collaborations: IT bears on collaborations which are also highly risky, of a long duration but which involve a lower budget (all are of a medium volume), research of a less basic character (basic oriented for all the seven cases) and of a lower novelty (high and medium for, respectively, four and three cases) than the ones of the preceding type. These collaborations are mainly organised through bilateral contracts, including also two cases of start-up creation within the biochemistry sector. The partners have usually a weak common history when they do not concern a start-up creation. In three cases, the IPRs ownership is not an issue. They are owned by the academics when the collaboration is settled in the US and when it concerns start-up creation. The industrial partners belong to the IT sector when the plants are located in the UK or the US, the start-ups being created in the UK. The academic partners are performing basic oriented (four cases) and basic (three cases) research, in physics for three of the cases, and they are usually highly specialised and of a notable level of academic excellence. Their strategy towards collaborating with firms aims to increase their scientific excellence whereas it consists in valorising public research when a start-up is created.

The institution to which the academic partner is affiliated is generally at a high level of excellence, specialised in a narrow field of competence and less inclined to let itself be swayed from its research agendas. The industrial funding thus almost exclusively supports lines of research deemed likely to earn recompenses within the scientific community itself. The company takes a great risk in funding this research but it nonetheless commits itself to these collaborations because they should allow it to maintain its capacity for innovation in the middle and long term and/or get beyond a recurring technological obstacle. In this context, the industrial partner is less inclined to influence the academic partners' research agendas, precisely because, in his eyes, their interest lies mainly in their originality. This kind of relationship is most often spontaneously organised and flexible. Type 4 also includes the endowment of university chairs (two cases), the content of which is increasingly directed towards the development of original research projects on behalf of the industrial partner.

Type 5: Concerns six cases of science–industry collaborations, distinguishes itself mainly because it gathers big research consortia associating several research laboratories and firms at a national level. Such network research and research platform naturally lead to sharing the IPRs ownership, to benefiting from significant public funding and to lowering the research volume supported by each firm. The research concerns quite new areas (medium novelty for five cases) but is not necessarily exploratory (applied and basic oriented), pooling together on the one hand resources of multinationals located in the country, of national champions (three cases) and on the other knowledge of academics. The firms mainly belong to the IT sector (five cases). The academics aim to increase their research volume, their research is weakly specialised and not of a significantly high excellence while their interest is dedicated to applied and basic oriented research.

The broad objective, common to academic and industrial partners, is the building of bridges between their two worlds, thus allowing both the development of the interpersonal collaborations which will provide the basis for subsequent bilateral agreements and the joint creation of the cognitive bases for a shared research field. The firms are most often required to make considerable concessions on research content and there may also be significant problems with IPRs and the sharing of technical knowledge because of the large number of partners, who may be direct competitors (while the research projects may be exploited rather quickly).

5. The matching of academics and firms

The typology introduced in the preceding section has shown that the nature of collaborative research may considerably vary according to the characteristics and strategies of the partners. In this section, we are now trying to focus on one dimension which could account for at least some part of the diversity observed, namely the *matching process* leading agents to collaborate. What is usually meant by matching process is the set of various strategic considerations that agents may take into account for preferably interacting with one another. For our purpose we consider here the matching of academic labs and firms R&D funds. More precisely, we examine the reasons which lead a firm to select, for a certain type of research projects, a given academic partner, and what simultaneously would lead him accept or refuse such a collaboration.

In the first subsection, we suggest that the notion of research agenda is crucial for academic agents' strategies as well as for firms', and that it is consequently an important factor explaining the matching. Even if other aspects may intervene, this is in line with the results presented in the second section of the paper. Indeed, Meyer-Krahmer and Schmoch (1998) and Lee (2000) for the academic side and Lee (2000) and Caloghirou et al. (2001) for the firm side, showed that actors' objectives for collaborating clearly take into account the nature of the collaborative research. Thus, in the second subsection, we turn to a systematic exploration of this issue, that is how heterogeneous actors (on each side) consider the collaborations from the point of view of the strategic definition of their own research agendas. This enables us to propose a simple rationale, expressed in terms of research agendas, for the actors' mutual willingness to collaborate and then match. We finally test this "assortative matching" hypothesis on our data in the last subsection.

5.1. Research agendas

The research agendas are the research aims that the agents set for themselves. Since collective knowledge production within the Open Science institution essentially requires disclosure behaviours (Dasgupta and David, 1994), the essential variable in the competition among researchers naturally becomes their ability to choose relevant research purposes. Thus, scientists are confronted to what Ziman (1987) calls "the problem of problem choice" in order to determine their research agendas.[20] The reward system in science, based on reputation among peers often formalised through citations, tends to valorise scientific contributions that are widely used by the scientific community, this way recompensing knowledge spillovers. Then scientists are looking forward to dedicating their efforts toward creating "foundational knowledge" (Cohen et al., 1998) because it may improve their reputation and thus also increase both their satisfactions and their chances to collect further funding for performing research and so on . . . .[21]

Given that any research collaboration requires the definition of a common research topic, science–industry collaborations may imply significant joint costs and benefits that the academic partners integrate into their calculations. The costs may be labelled as the 'opportunity costs of collaborating', that is the expected reward of renouncing to collaborate.[22] The benefits come from the *synergies* generated between their own research and the collaborative one. Taking these into account, the academic partner may compare the two options: to collaborate or to renounce. This leads us to consider the notion of *research agenda* as being a central concept in the apprehension of the matching process between academics and firms. What we argue in the next subsection is that these costs and benefits do differ because of the characteristics of laboratories research agendas.

Furthermore, the calculations of the industrial partners also take similar issues into consideration in relation to their own reward structures which lead them to choose research projects and their academic partners depending on the risk borne (including risk of research, and risk in the effective use of knowledge). While deciding to fund a research project, firms evaluate the chances of research and development success, the costs induced and the expected returns. Usually firms handle different research projects simultaneously, like a portfolio of risky assets (Dasgupta and Maskin, 1987; Bhattacharya and Mookherjee, 1986). They are managing in parallel research projects with different levels of risk, which are likely to give rise to product or process innovations in a more or less long term. In the next subsection, we will show how firms choose their academic partners in order to conduct research projects depending on the level of risk faced.

[20] Noticing the crucial character of research agendas determination within science ("the success of a laboratory depends on the choice of domains and subjects for research"), Ziman states that these choices rely on incentives ("a personal 'stake' of time and effort is to be risked in the hope of a personal 'payoffs' in material reward, social esteem or intellectual satisfaction"), and that these payoffs not only depend on publications but primarily on the impact of new research on subsequent knowledge production: "we spontaneously judge a discovery as important as soon as we see it has implications for an extensive set of existing problems over a wide range of specialties (. . .) measured by citations, for example" (Ziman, 1987).

[21] For a formal investigation of the dynamics of research agendas generation see Carayol and Dalle (2000).

[22] Opportunity costs are usually defined in microeconomics as the expected reward associated with the (next best) alternative choice.

5.2. A simple rationale for the matching

5.2.1. The academics

By accepting to devote time and resources to different research objectives, academic researchers thus renounce using them in a different manner, which means that for them, science–industry collaborations imply an *opportunity cost* reflecting the cost of postponing the pursuit of their own research objectives. Naturally, the following question arises. What are these opportunity costs function of? Because opportunity costs are equal to the expected reward from not accepting the collaboration, they should, in principle, increase with the researchers' ability to set research agendas likely to generate significant recompenses in the Open Science reward structure (i.e. the returns associated with the alternative use of their time and efforts).

A collaboration with an industrial partner should not only be considered as a cost for the academic researchers, however. Indeed, they may exploit *synergies* between collaborative research and research carried out in parallel in the strict respect of their own agendas. Synergies are fed with cross-fertilisation of research activities the topics of which are close. Thus, we suggest that the greater the distance between the academic researchers' subjects of interest and those of the industrial partner, the lower the exploitable synergies. Thus, other things being equal, one may also expect that the more basic the academics' research, the weaker the synergies.

Academics who have high opportunity costs and low exploitable synergies would see their willingness to co-operate with firms to depend much more on the contents of the collaborative research. Thus, they may accept or refuse to collaborate with firms under the main criterion that this research does or does not fit with their own research agendas.

5.2.2. The firms

As the interviews with R&D officers showed, the way firms envisage research agendas selection and collaborations with a potential academic partner is usually two-fold. First of all, as a standard rule, they try to minimise risks while selecting which research projects to support. Thus, they usually prefer to fund collaborative research that presents a lower research risk and has the higher chance to be effectively developed within a reasonable time lag. The firms are then following a research outsourcing strategy towards academics whose arbitrage criterion is mainly that the buying price is lower than the making one.

However, in order to preserve their ability to innovate in the future, and thus to sustain their flow of innovations, firms also have to develop collaborative research projects which are more risky both in terms of probability of research success and its effective use in product or processes. Then firms have to rely much more on the abilities of the academic partner in suggesting path-breaking opportunities, facing a critical informational problem, namely whether the partner chosen will be able to handle such a challenge. This situation is usually referred to as an *adverse selection* (Salanié, 1997), in which a playing agent (the principal) is uncertain of another one's characteristics. A common solution is then to rely on some information that may reduce uncertainty (a signal) so as to maximise the chances of success. Here, we argue that the reputation of the academic's affiliated institution, and the degree of basicity of their research may be used as a signal on his sustainable research capacities relative to such projects.

5.2.3. An "assortative" matching

The bargained 'price' of the research is the adjustment variable between these two relative willingness to collaborate. It is expressed in terms of cash flows and IPRs. Without going into the details of the way these two variables are handled (for a rationale see Aghion and Tirole (1994)) or those of the complex social process of establishing the initial connection, the price requested by the academic partner will increase as his willingness to collaborate decreases, and conversely, the reservation price of the industrial partner increases with his willingness to collaborate. According to very simple microeconomic considerations, while the latter is higher than the former, an agreement should be settled, otherwise it should not.

For the ease of presentation, it is useful to represent the spaces of a priori compatibilities/non-compatibilities by means of two opposite cases both for academic partners, thus giving rise to four configurations (Table 3).[23] An industrial partner who wants to carry

[23] This presentation may be somehow misleading. We do not argue that in reality one can distinguish two extreme forms of collaborations but that collaborations can be ranked along such a continuum.

Table 3
The theoretical zones of preferential compatibility between academics and industrial funds in LL and HH: the "assortative" matching

Industrial funds	Lower opportunity costs higher synergies	Higher opportunity costs lower synergies
Lower risk	LL	LH
Higher risk	HL	HH

out a risky research project will prefer to collaborate with an academic partner of a high excellence (which implies high opportunity costs) in the narrow domain concerned (HH) and thus renounce any involvement with an academic partner below a certain level (HL). An academic partner at a high level opportunity cost will prefer to collaborate with an industrial partner who is ready to accept a higher level of risk (HH) in accordance to his own research objectives and will renounce collaborating with an industrial partner below a certain level of commitment (LH). Last of all, an academic partner with a low opportunity cost will be ready to accept doing research for an industrial partner who wants to get involved with a relatively low-risk research project (LL) in order to improve his research volume and benefit from research synergies.

The two a priori compatible situations in HH and 'LL are very typical "assortative" matching configurations in which the best ranked agents preferably match with the best ranked ones'. We are testing this hypothesis below.

5.3. Testing the "assortative" match

Our testing will be operated in two steps. First, we will check that the characteristics of the academics' research agendas and their "main objective for collaborating" are correlated. This is to check whether the nature of their research is critical for explaining their collaborating strategies. Second, we will directly test the "assortative" matching hypothesis, which requires that the variables characterising the academics' research agendas are positively correlated with the variables characterising firms' research projects. This very simple procedure is standard in the matching literature (e.g. similar to Keller et al. (1996)).

Before doing so, we present the variable that will be used.

(i) The variables used for characterising the academics' research agendas are the "nature" of their research (the more basic, the lower the synergies), and the "level of excellence" of the institution to which the academic partner is affiliated, which we suppose is accounting for the labs' abilities to set research agendas (this way increasing their opportunity costs).
(ii) The variable used for characterising the research strategies of the academic partners is the one indicating their "main objective for collaborating", which can be "increase scientific excellence", "increase research volume" and "valorise expertise". The first modality conveys the idea that, in the choice of the research topics, greater attention is devoted to feeding their own research.
(iii) Finally, we used two variables for characterising the risk undertaken by firms in the collaborative research projects. The first is the "degree of the collaborative research risk" itself (ex ante probability of success as evaluated by firms R&D officers). The second type of risk borne by the firm is the risk of "uselessness" of the results obtained, which we are approximating by the variable "time to development" giving the expected time before the research results enter the development process.

For the sake of simplicity, all the variables retained were dichotomised. Our results show that academics' strategies are correlated to the variables characterising their research agendas. As one may observe in Table 4, the "increase scientific excellence" modality

Table 4
Correlation tests between the variables describing the characteristics of academics' research agendas and their strategies for collaborating

	Academics' research agendas	
	High excellence	Basic research
Academics' research agendas		
Basic research	0.247 ns	–
Academics' main aim for collaborating		
Increase scientific excellence	0.371**	0.326**

NB: The superscripts ∗∗∗ and ∗∗ denote significance level exceeding 99 and 95%, respectively; ns stands for lower than 90%. The variables have been dichotomised.

Table 5
Correlation tests between the variables describing the characteristics of academics' research agendas and the variables characterising firms' ones

Firms' research agendas	Academics' research agendas	
	High excellence	Basic research
High risk of research	0.586***	0.621***
High time to development	0.405**	0.360**

NB: The superscripts *** and ** denote significance level exceeding 99 and 95%, respectively. The variables have been dichotomised.

of the academics' strategy through collaborating variable is strongly positively correlated to a "high level of excellence" of the affiliated institution and to the "performing of basic research". It should also be noted that the variables accounting for the state of the academic's agendas are not correlated since excellence and basicity are independent. These observations tend to support the idea that the nature of the academic labs' 'research agendas are of a crucial importance in the definition of their collaboration strategies'.

Moreover, the most probable occurrence of the two 'compatible' configurations (LL, HH) seem to be confirmed by our data. Indeed, we obtained reliable χ^2-statistics exposed in Table 5, which show that the matching process preferably associates academics whose research excellence tend to be signalled as high (respectively, low), and whose research tend to be basic (respectively, more applied), with firms which are supporting a high (respectively, low) degree of risk (of research itself and its use in products and processes). This 'confirms the "assortative" matching hypothesis'.

Finally, one may also wonder about the connections between the match and the effective collaborations as described in the typology. As a matter of fact, the two are not disconnected. Indeed, we checked that the collaborations of types 1, 2 and 5 are much more likely to belong to the configuration LL and that the ones of types 3 and 4 are included within the configuration HH. That confirms a direct relation between how actors select each others and how they collaborate.

6. Conclusion

In this paper, we have studied the various forms of science–industry collaborations, by reassembling, from various sources, information on a set of heterogeneous collaborations. Using them, we built a typology and obtained five types of collaborations, each of them we described. We then focused our attention on the notion of research agendas in order to more clearly understand the matching mechanism of academics and firms. We suggested, tested and confirmed what we labelled the "assortative" matching hypothesis.

These results could be useful for the management of public and private laboratories in order to link their objectives to potential partners and best practices for co-operation. It might also be suggested to the directors of corporate R&D departments that they should not limit themselves to a single model but rather use both forms of collaboration, insofar as each offers distinct and complementary advantages for the firm.

Moreover, our findings call for some remarks concerning public policy. First of all, one may wonder about the consequences of the science–industry collaborations on the well known cumulative advantages in scientific productivity (David, 1994) which one usually names the "Matthew effect" since Merton (1968). Arora and Gambardella (1997) suggested that the probability that academics receive industrial funding increases with their reputation thus reinforcing cumulative advantages. According to this hypothesis, the less reputed academic laboratories would collaborate less with firms. However, this proposition seems to be contradicted by at least numerous anecdotal evidence: many laboratories, receiving much funding from firms, lag behind the knowledge frontier.[24] Our matching analysis allows us to suggest the following slightly different explanation. Because of their scientific advance, some academics select their research collaborations on the basis of their research contents, i.e. their main criterion for accepting is that it feeds of their own research aims. Then their reputation enables them to benefit much more from the collaborations than the ones who are accepting industrial support in order to maintain or increase their funding. Even if they may collaborate much more frequently, they benefit relatively less from each collaboration. This leads us to the next two conclusions.

On the one hand, there is no "functional barrier" between science and industry that should be introduced

[24] The results of Blumenthal et al. (1996), exposed in the second section, support this empirical evidence at the researchers' level.

as Lundvall and Borrás (1998) suggested, essentially protecting “basic research” from industry needs. Such “barriers” may impeach creative and risky research projects belonging to the HH configuration to be undertaken. Nevertheless, this statement is conditioned upon a sustained public funding of science. Indeed, important cut-offs in public funding may offer incentives to academics to undertake dysfunctional collaborative research projects. “Dysfunctional” means here that academics would be accepting to postpone promising research agendas, essentially aiming to preserve funding.

On the other hand, lock-in effects may arise as suggested by Meyer-Krahmer and Schmoch (1998). For our concern, the lock-in risk is observable at the laboratory level: some laboratories may be locked in service-like forms of collaboration, which could be decreasing the scientific relevance of their research. This risk is then important if they do not stress any coherent strategies for generating research synergies. Nevertheless, facing such situations, academic labs have high incentives for reorienting their research contents toward industry needs, therefore increasing their research volume by fostering collaborations. Then, they are following a “size” strategy, trying to reach a critical level, that could allow them to save enough funds for supporting some fundamental lines of research. As we observed in our interviews, such strategies can be very successful: some “peripheral” laboratories became important actors on large scientific domains, both conducting reputed fundamental research and meeting industry needs.

Finally, we should insist on the empirical limitations of our results being tested on a still relatively small number of cases concerning firms of only two (science based) sectors. We thus call for putting on the research agenda a much larger confirmation of the theoretical insights and the first results presented here, by launching a large international two sided survey of science–industry collaborations.

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