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University Demand and Firm Innovation: A Quantitative and Qualitative Evidence

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University Demand and Firm Innovation: A Quantitative and Qualitative Evidence

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Questa tesi studia il contributo delle università all'innovazione industriale concentrandosi sull'impatto che la domanda universitaria per gli strumenti scientifici ha sull'innovazione delle imprese fornitrici.

Nel *primo capitolo*, conduciamo una rassegna approfondita della letteratura scientifica che ha studiato l'influenza delle università sulle imprese industriali attraverso l'approvvigionamento di materiali e strumenti. Iniziamo discutendo i contributi di storici, sociologi e studiosi di scienza e tecnologia sul ruolo delle università nell'innovazione tecnologica. Quindi passiamo agli studi sul che si sono concentrati sul ruolo della domanda di beni e servizi nell'innovazione, e consideriamo in particolare le ricerche che sull'impatto della domanda delle amministrazioni pubbliche. Infine discutiamo brevemente gli studi sulle innovazioni promosse dagli utenti nel campo della strumentazione scientifica e quelli che hanno evidenziato le viscosità nella trasmissione delle conoscenze scientifiche. Nel capitolo discutiamo anche come, globalmente, i vari filoni di ricerca suddetti abbiano messo in luce la presenza di complesse sinergie tra scienziati e imprese nello sviluppo di nuove apparecchiature scientifiche. Allo stesso tempo, evidenziamo come gli studi esistenti presentino alcune importanti lacune. Una di queste è la mancanza di solide prove quantitative sull'effetto degli appalti universitari sull'innovazione dei fornitori. Collegato a questo, non vi è ancora un'analisi completa delle complesse interazioni tra ricercatori e fornitori che sono alla base dell'emergere di innovazioni nel campo della strumentazione scientifica.

Nel *secondo capitolo*, ci concentriamo sulle imprese fornitrici di strumenti scientifici della seconda più grande università pubblica francese - l'Università di Strasburgo - e studiamo l'impatto quantitativo della domanda universitaria sulla loro performance innovativa. La principale domanda di ricerca affrontata in questo capitolo è: "Qual è l'impatto della domanda universitaria sulla performance innovativa dei suoi fornitori?". Più precisamente, esploriamo se la domanda di strumenti da parte di scienziati accademici può fornire uno stimolo alle imprese per introdurre nuovi prodotti e concetti organizzativi, contribuendo così dare forma alle traiettorie tecnologiche e favorire l'innovazione. Per rispondere a questa domanda, effettuiamo un'analisi microeconometrica in un contesto quasi-sperimentale, e dimostriamo che i fornitori universitari hanno una propensione più elevata a introdurre innovazioni di prodotto nuove sul mercato rispetto ad altre aziende appartenenti agli stessi settori e con caratteristiche simili. I nostri risultati empirici supportano la congettura che le innovazioni e cambiamenti tecnologici emergono non solo come conseguenza delle scoperte scientifiche e tecniche. Esse sono anche il risultato di una complessa reazione a catena innescata dall'interazione tra esigenze specifiche e soluzioni progettate per superare gli ostacoli posti dalle tecnologie esistenti.

Nel *terzo capitolo*, eseguiamo varie analisi di robustezza dei risultati empirici ottenuti nel secondo capitolo. La prima batteria di controlli di robustezza esamina la sensitività delle principali stime econometriche attraverso 1) l'inclusione di nuove variabili; 2) la limitazione della dimensione del campione e 3) adoperando algoritmi di corrispondenza alternativi per l'individuazione dei gruppi di trattamento e di controllo nell'analisi econometrica. Queste analisi costituiscono una preziosa estensione del nostro studio econometrico iniziale, attraverso l'utilizzo degli stessi dati e della stessa metodologia empirica, per mostrare che i principali risultati di significatività ottenuti nel primo capitolo rimangono invariati nelle varie stime alternative effettuate. La seconda batteria di analisi di sensitività che eseguiamo mira invece a verificare l'impatto della domanda universitaria di strumentazione sull'innovazione dei fornitori attraverso l'uso di basi di dati e metodologie empiriche diverse. Più precisamente, stimiamo modelli OLS e Zero-Inflated Negative Binomial (ZINB) per testare l'ipotesi che lo status di fornitore dell'università di un'impresa abbia, a parità di condizioni, un effetto positivo e significativo sul numero di brevetti dell'impresa. I risultati di questa analisi alternativa forniscono un supporto ulteriore ai risultati chiave del secondo capitolo, perché indicano la presenza di un impatto statisticamente significativo e positivo dei laboratori universitari sulle capacità innovative dei fornitori industriali.

Nel *quarto capitolo*, andiamo oltre l'analisi delle relazioni quantitative, che non consentono di esplorare a fondo la complessità delle relazioni inter-personali e inter-organizzative alla base dei processi che spiegano i risultati empirici osservati nei capitoli precedenti. In questo capitolo siamo interessati a saperne di più sulle relazioni suddette e su come esse cambiano nel tempo sotto la pressione di vari fattori e in che modo influenzano l'innovazione a livello di impresa. A tale proposito, il nostro studio mira a esplorare in particolare l'emergere di complementarità dinamiche tra la domanda dei ricercatori per strumenti e le competenze tecnologiche dei fornitori. Per raggiungere questi obbiettivi abbiamo condotto un'indagine sul campo (*field study*) basato su tre dispositivi strumentali sviluppati in stretta collaborazione tra i laboratori dell'Università di Strasburgo da un lato e le aziende appartenenti al nostro set di dati utilizzato nei precedenti capitoli dall'altro. Per comprendere meglio i complessi fenomeni sociali in gioco dal punto di vista dei partecipanti (Partington, 2001), abbiamo realizzato interviste semi-strutturate con ricercatori, ingegneri e direttori delle unità di ricerca coinvolte nello sviluppo di un dato strumento, nonché alcune interviste informali con i fornitori. Il nostro studio sul campo illustra molteplici processi diretti e indiretti attraverso i quali i laboratori universitari fungono da ambiente di apprendimento per i loro fornitori e come fonte di feedback diretti, dettagliati e pratici sui prodotti esistenti; aggiornamenti continui sull'evoluzione delle esigenze degli utenti; lo sviluppo di prototipi di nuovi dispositivi; l'incorporazione di dispositivi esistenti per costruire nuovi sistemi; test alfa, beta e sul campo dei prodotti dei fornitori; produzione di una produzione pre-serie per i fornitori. Il nostro studio illustra inoltre come i dispositivi sviluppati per soddisfare le esigenze specifiche dei ricercatori consentano poi alle imprese di realizzare anche economie di scala, vendendo gli stessi prodotti a una gamma più ampia di clienti. La nostra indagine sul campo mostra anche come i ricercatori siano attratti dai fornitori che possono fornire loro un dispositivo esattamente su misura. Una volta che le aziende hanno la reputazione di personalizzare i propri prodotti, attirano clienti con applicazioni di nicchia e profili di fascia alta che offrono un vantaggio di marketing alle aziende che si concentrano su un mercato più ampio. In termini pratici, i ricercatori aggiungono ulteriori estensioni ai prodotti dei fornitori che ne rendono possibile l'utilizzo in altre discipline, aprendo così nuovi mercati ai loro fornitori. Infine, nella nostra indagine evidenziamo anche il ruolo delle relazioni tra ricercatori e fornitori come un caso speciale di appalti pubblici come fonte di innovazione (Chicot e Matt, 2018; Castelnovo et al.2018; Florio et al.2018; Edquist e Hommen, 2000).

Résumé étendu en français

Cette thèse étudie la contribution des universités à l'innovation industrielle en insistant sur l'impact de la demande des universités sur les performances d'innovation des entreprises.

Dans le *premier chapitre*, nous proposons une revue de la littérature approfondie des principaux axes de recherche étudiant l'influence des universités sur les entreprises industrielles par le biais de l'achat d'instruments. Dans la première partie du chapitre, nous nous concentrons sur les contributions d'historiens, de sociologues et de spécialistes en sciences et technologies, puis nous développons les études axées sur la demande et aux marchés publics innovants. Enfin, nous discutons brièvement des études sur les innovations réalisées par les utilisateurs en insistant sur l'idée d'instrumentation ainsi que sur le caractère « collante » des connaissances scientifiques. L'intérêt et l'apport de ces études résident notamment dans la pertinence de leur mise en évidence de synergies complexes entre scientifiques et entreprises dans les cas des équipements uniques dans diverses circonstances, ainsi que la preuve de l'implication significative des utilisateurs dans l'émergence de nouveaux équipements commercialisés. Néanmoins, nous montrons que les études existantes présentent d'importantes limites, telles que le manque de preuves quantitatives solides concernant l'effet de l'approvisionnement des universités sur les fournisseurs et le récit correspondant des interactions sous-jacentes entre les chercheurs et les fournisseurs.

Dans le *deuxième chapitre*, nous examinons le comportement des fournisseurs d'instruments scientifiques de la deuxième plus grande université publique française - l'Université de Strasbourg - et nous étudions l'impact de la demande des universités sur la performance d'innovation de ces entreprises. La question de recherche abordée dans ce chapitre est la suivante : « *Quel est l'impact de la demande des universités sur les performances des fournisseurs en matière d'innovation ?* ». Nous cherchons ici à savoir si la demande de tels produits de la part des scientifiques universitaires peut inciter les entreprises à introduire de nouveaux produits et concepts organisationnels, contribuant ainsi à façonner des trajectoires technologiques et à favoriser l'innovation. Nous réalisons une analyse micro-économétrique dans un cadre quasi expérimental, montrant que les fournisseurs universitaires ont une plus grande inclination à introduire de nouvelles innovations de produit sur le marché que d'autres entreprises appartenant aux mêmes secteurs d'activité et présentant des caractéristiques similaires. Nos résultats corroborent l'hypothèse selon laquelle les innovations et les changements technologiques découlent non seulement de découvertes scientifiques et techniques, mais également d'une réaction en chaîne complexe déclenchée par l'interaction de demandes spécifiques et de solutions conçues pour surmonter les effets d'entonnoir technologiques.

Dans le *troisième chapitre*, nous procédons à des analyses de robustesse approfondies des résultats empiriques émanant des études menées dans le chapitre précédent via deux méthodologies. Le premier ensemble de contrôles de robustesse examine la sensibilité des estimations principales en ajoutant de nouvelles variables ; en limitant la taille de l'échantillon et en exploitant d'autres algorithmes d'appariement. L'analyse de sensibilité représente un prolongement précieux de notre étude initiale, qui utilise les mêmes données et la même méthodologie pour montrer que les principaux résultats empiriques obtenus dans le second chapitre suivent des trajectoires de signification stable tout au long des diverses estimations. La deuxième analyse de sensibilité que nous effectuons vise à montrer l'effet de la demande des universités sur les fournisseurs au moyen de différentes bases de données sur l'innovation et au niveau de l'entreprise, et à l'aide d'une approche méthodologique différente. La question de recherche abordée dans ce chapitre est la suivante : « *Quel est l'impact de la demande des universités sur l'activité des fournisseurs en matière de brevets ?* ». Pour répondre à cette question, un modèle MCO ainsi qu'un modèle binomial négatif avec excès de zéros (ZINB) sont estimés, et suivant l'hypothèse selon laquelle toutes choses sont égales par ailleurs, nous concluons que l'université a un impact empirique positif sur l'activité de brevetage des entreprises. Cette analyse alternative apporte un soutien très fort aux résultats fondamentaux du deuxième chapitre, en montrant l'impact positif et significatif des laboratoires universitaires sur les capacités d'innovation des fournisseurs industriels.

Dans le *quatrième chapitre*, nous allons au-delà du point de vue focalisé sur les relations quantitatives, qui ne permet pas d'explorer en profondeur la complexité des relations interpersonnelles et inter organisationnelles qui sous-tendent les processus expliquant les résultats empiriques observés dans les chapitres précédents. Nous nous sommes ainsi intéressés à la complexité des liens qui définit les relations chercheurs-fournisseurs, leur évolution au fil du temps sous la pression de divers facteurs et leur incidence ultime sur l'innovation au niveau de l'entreprise. À cet égard, notre étude vise à explorer *l'émergence de complémentarités dynamiques entre la demande des chercheurs et les compétences des fournisseurs.* Pour identifier les processus dynamiques menant aux nouvelles technologies parmi les chercheurs universitaires et leurs fournisseurs, nous avons mené une étude sur le terrain basée sur trois instruments développés en étroite collaboration entre les laboratoires de l'Université de Strasbourg d'une part, et les entreprises appartenant à notre base de données sur les dépenses initiales d'autre part. Pour mieux comprendre les phénomènes sociaux complexes en jeu du point de vue des participants (Partington, 2001), nous avons réalisé des entretiens semi-structurés avec des chercheurs, des ingénieurs et des directeurs d'unité de recherche, ainsi que quelques entretiens informels avec des fournisseurs. Notre étude de terrain illustre de nombreux processus directs et indirects par lesquels les laboratoires universitaires agissent comme un environnement d'apprentissage pour leurs fournisseurs et comme une source de feedback directe, détaillé et pratique sur les produits existants, les mises à jour continues sur l'évolution des besoins des utilisateurs, le développement de prototypes de nouveaux dispositifs, l'incorporation de dispositifs existants pour construire de nouveaux systèmes, les essais alpha, beta et sur le terrain, les produits des fournisseurs, et la production des unités de pré série pour les fournisseurs. Notre étude montre comment des dispositifs sur mesure développés pour répondre aux besoins spécifiques des chercheurs permettent aux entreprises de réaliser des économies d'échelle en vendant les mêmes produits à un plus grand nombre de clients. Nos résultats empiriques montrent également que les chercheurs sont attirés par les fournisseurs qui peuvent leur fournir un appareil parfaitement adapté. Une fois que les entreprises ont la réputation de personnaliser leurs produits, elles attirent les clients avec des applications de niche et des profils haut de gamme qui offrent un avantage marketing aux entreprises qui se concentrent alors sur un marché plus vaste. Concrètement, les chercheurs ajoutent de nouvelles extensions aux produits des fournisseurs, ce qui permet ensuite leur utilisation dans d'autres disciplines, ouvrant ainsi de nouveaux marchés à leurs fournisseurs. Enfin, nous soulignons également le rôle des relations entre chercheurs et fournisseurs en tant que cas particulier des marchés publics qui représentent une source d'innovation (Chicot et Matt, 2018; Castelnovo et al. 2018; Florio et al. 2018; Edquist et Hommen, 2000).

Introduction

Cette thèse met en avant l'idée selon laquelle les universités ont une influence significative sur le comportement d'innovation de leurs fournisseurs industriels par le biais de la demande d'instruments scientifiques des chercheurs. Elle également explore en profondeur les processus sous-jacents d'apprentissage technologique mutuel qui émergent entre chercheurs et fournisseurs.

Les universités jouent un rôle fondamental pour la recherche et l'éducation dans les sociétés modernes. Cependant, les universités européennes ont subi une transformation majeure depuis le 19ème siècle. À l'époque, les universités se concevaient comme des structures sociales et se situaient d'une manière ou d'une autre en dehors de la sphère économique. Par exemple, l'université « Humboldtian » était perçue comme une institution unificatrice de valeurs sociales et culturelles, destinée à inspirer un sentiment d'appartenance et une vision commune (Cowan, 2005). Sa mission principale était la formation de la prochaine génération de citoyens. La fin du 20ème siècle a marqué un tournant dans la perception des universités par les décideurs politiques, avec la reconnaissance de leur position centrale dans l'économie, dite "fondée sur le savoir". Ce phénomène a été déclenché par un changement radical dans la conception de la manière dont la connaissance est générée et dont elle s'articule dans le processus d'innovation. Ce changement de perception des universités s'inscrit également dans un processus historique plus long, caractérisé par le déclin de la R&D interne et par une plus grande dépendance des grandes entreprises vis-à-vis des sources de connaissances externes, telles que les universités, pour soutenir leur effort d'innovation et leur croissance (Mowery, 2009; Higgins et Rodriguez, 2006; Arora et Gambardella, 1990). La baisse de l'investissement des entreprises en R&D était liée aux pressions concurrentielles résultant de la mondialisation, ainsi qu'à la rapidité et à la complexité croissantes des processus de gestion du savoir par rapport au champ d'action plus étroit des entreprises et à la diminution des incitations à développer des produits radicalement nouveaux et des processus propres à leur marché. En outre, le retrait des grandes entreprises du secteur de la recherche a conduit à une sorte de division du travail en innovation, entre entreprises et universités, poussant les grandes entreprises à faire du développement et de la commercialisation de nouveaux produits leur cœur d'activité, au détriment de la lignée initiale centrée sur les idées novatrices et les solutions, qui est alors laissée aux universités (Arora et Gambardella, 1994).

Par conséquent, la recherche universitaire s'est révélée de plus en plus pertinente et attrayante pour les industriels (Freitas *et al.*, 2011). De même, la réduction de l'intervention gouvernementale dans l'économie ainsi que la rareté des fonds publics alloués à la recherche ont poussé les universités à collaborer de plus en plus avec les entreprises (Geuna et Muscio, 2009). Dans ce contexte, les gouvernements anglo-saxons dans un premier temps, puis les gouvernements européens, ont introduit des mesures visant à inciter les universités à se lancer dans des activités de recherche et de transfert de technologie en collaboration avec l'industrie. La justification de ces mesures reposait sur l'idée que les interactions entre les universités et l'industrie pourraient accroître le taux d'innovation dans l'ensemble de l'économie (Spencer, 2001). Dans le contexte européen et français, ces mesures ont également été mises en place pour résoudre le prétendu « Paradoxe européen », qui dévoile une contradiction entre l'excellence des universités européennes en matière de recherche et leur apparente incapacité à diffuser les résultats de leurs recherches au-delà du monde universitaire (Commission européenne, 1995). Les liens entre les deux sphères ont été établis à travers la promotion de la commercialisation du savoir universitaire par le biais de la délivrance de brevets et de licences d'inventions universitaires, ainsi que de l'entreprenariat universitaire.

Ces mesures politiques, ainsi que les discours et les théories déployés pour les justifier, ont fait l'objet de nombreuses études sur les interactions université-industrie (U-I). Ces contributions explorent les différents aspects de la commercialisation des inventions académiques, qu'elles soient individuelles (Bercovitz et Feldman, 2008; Stuart et Ding, 2006) ou institutionnelles (Di Gregorio et Shane, 2003; Mansfield, 1995; O'Shea *et al.*, 2005; Owen-Smith et Powell, 2001; Sine *et al.*, 2003) et les déterminants organisationnels (Lockett et Wright, 2005; Siegel *et al.*, 2003).

Cependant, l'existence même du « Paradoxe européen » et la pertinence des politiques correspondantes ont été réfutées par plusieurs ouvrages sur l'économie de l'innovation (cf. Dosi *et al.*, 2006; Goldfarb et Henrekson, 2003; Mowery *et al.*, 2001; Henrekson et Rosenberg, 2001). Ces travaux critiquaient l'étude de la commercialisation de produits académiques comme représentation simpliste des interactions université-industrie, dans la mesure où celles-ci ne s'intéresseraient qu'aux flux unidirectionnels de connaissances fondamentales des universités vers des applications industrielles et ne tiendraient ainsi pas compte de la véritable nature interactive des relations université-industrie (Colyvas *et al.*, 2002).

Cette insatisfaction a déclenché une nouvelle vague d'études visant à identifier un ensemble plus vaste d'interactions entre les universités et d'autres entités. Ces interactions sont communément appelées « engagement universitaire » et sont définies par Perkmann *et al.* (2013) comme des «*knowledge-related collaborations by academic researchers with non-academic organisations*» (p. 424). L'engagement académique implique des liens formels et informels tels que la recherche collaborative, la recherche sous contrat, le conseil, le conseil *ad hoc* et la mise en réseau entre autres (Perkmann et Walsh, 2007; D'Este et Patel, 2007; Meyer-Krahmer et Schmoch, 1998; Bonaccorsi et Piccaluga, 1994). Ces études montrent que les pratiques d'engagement universitaire sont beaucoup plus répandues que celles de commercialisation et mettent l'accent sur leur alignement avec les missions universitaires traditionnelles. Elles mettent par ailleurs en avant l'engagement des individus et des départements et permettent de questionner les antécédents et les conséquences de ces interactions (Perkmann *et al.*, 2013).

Bien que les contributions concernant l'engagement universitaire apparaissent comme une alternative à l'approche étroite des études de commercialisation, elles ne sont pas non plus exemptes de critiques. Une remarque commune consiste à dire que les deux types d'étude limitent le lien université-industrie aux seules activités technologiques, réduisant ainsi le rôle des universités à celui de « fournisseur » de connaissances et de technologies pour des applications industrielles (Kenney et Patton, 2009).

Cette thèse tend à contribuer à ce dernier courant d'études en proposant et en évaluant un mécanisme d'interaction université-industrie jusqu'ici négligé, à savoir celui qui concerne la demande des universités en équipements, matériels et outils scientifiques. La vision schumpétérienne traditionnelle de l'innovation technologique met généralement l'accent sur les aspects scientifiques et technologiques du processus d'innovation, négligeant ainsi l'aspect demande. L'opinion selon laquelle la technologie peut être façonnée par les moteurs de la demande, mais qu'elle découle toujours d'une dynamique évolutive plutôt indépendante de l'influence des forces du marché, a été développée à travers une série de contributions et de concepts. Par exemple, Rosenberg (1969) définit les mécanismes d'incitation comme étant inhérents aux impératifs technologiques résultant des déséquilibres techniques entre processus interdépendants, qui conduisent finalement à l'amélioration de certaines technologies. Nelson et Winter (1977) décrivent ces trajectoires d'évolution technologique comme des trajectoires naturelles et soulignent leur contexte cognitif enraciné dans la conviction des ingénieurs quant aux solutions réalisables, ou du moins valant la peine d'être envisagées. Dosi (1982) combine les notions mentionnées ci-dessus pour introduire les concepts de paradigme et de trajectoire technologique, où l'offre est initialement responsable de la création d'un paradigme, qui définit le champ des modalités possibles en fonction du développement de la technologie. Les moteurs de la demande sélectionnent ensuite les trajectoires de développement au sein d'un paradigme donné en fonction de leur importance économique.

Dosi (1982, p. 156) identifie également les marchés publics en tant que moyen par lequel la demande influe de manière significative sur le développement de tels paradigmes. Dans cette perspective, les innovations sont façonnées par les utilisations existantes ou émergentes (Lundvall, 1988, 1992a, 1992b) et répondent à une demande croissante pour assurer des performances économiques (Mokyr, 1990). À la suite de ces réflexions, un grand nombre de contributions connexes ont souligné l'importance des marchés publics liés à la défense en tant que facteur déterminant de la structure des mutations technologiques au 20ème siècle. Par exemple, Mowery et Rosenberg (1982) soulignent que l'achat de composants et de systèmes à des fins de défense nationale et d'exploration spatiale a conduit à des développements technologiques radicaux dans les industries des semi-conducteurs, de l'informatique et de l'aviation. Levin et Nelson (1982) considèrent la demande gouvernementale comme un grand preneur de risques en matière d'investissement dans les technologies des semi-conducteurs, telles que le transistor au silicium et le circuit intégré, au cours des premières années de leur développement. En outre, dans l'industrie des semi-conducteurs, les gros contrats d'achat ont stimulé la R&D industrielle et le développement de certaines des technologies essentielles dans le domaine a finalement été motivé par les besoins et les exigences militaires. En effet, les entreprises ont investi pour développer de nouvelles technologies dans le but final de répondre à une demande publique mais dans l'idée de remporter des grands projets d'achat (Mowery, 2011).

Parallèlement, Freeman (1995) souligne l'importance des flux de connaissances à la fois vers et depuis les sources de connaissances scientifiques et techniques, ainsi que depuis les utilisateurs de produits et de processus. Par exemple, Freeman (1995, p. 479) identifie la « circonscription » scientifique comme un facteur déterminant dans l'introduction et la mise au point d'innovations radicales dans le secteur de l'informatique électronique. De même, Pavitt (1984) élabore une taxonomie des entreprises industrielles sur la base de l'analyse d'une longue liste d'innovations spécifiques au Royaume-Uni en fonction de la source des connaissances en innovation; comment on y accède, par qui et quelles sont les caractéristiques de la technologie de production. Selon la taxonomie de Pavitt, les entreprises d'instruments scientifiques et de mesure appartiennent au secteur des sciences et s'appuient beaucoup sur la recherche publique comme source de leurs connaissances. Rosenberg (1992) a très bien documenté cette dépendance vis-à-vis de la recherche publique. Il fournit un compte-rendu historique du développement de certains instruments commercialisés et identifie les laboratoires de recherche publics comme le berceau de ces technologies. Rosenberg (1992) souligne également le fait que de nombreux produits industriels constituent en fait un sous-produit involontaire de la science publique dans les universités. Dans un style similaire, Mazzucato (2015) explore le contexte des innovations industrielles modernes (par exemple, l'histoire du développement d'Internet et de l'écran tactile qui ont finalement été intégrés à l'iPhone et à l'iPad, voir Mazzucato, 2015), ainsi que des instruments (pensons notamment au rôle fondamental du microscope électronique en microbiologie). Elle souligne que, bien que ces éléments semblent entièrement résulter d'une activité industrielle, leur existence est en fait due aux investissements publics continus (et aux achats) dans la recherche. En outre, Mazzucato (2016) souligne que les achats publics de technologies jouent un rôle essentiel dans les initiatives politiques axées sur la mission visant à relever un plus large éventail de défis qui nécessitent des engagements à long terme en matière de développement technologique, ainsi qu'un taux de changement technologique et institutionnel élevé et continu. De même, Matt et Chicot (2018) examinent dans quelles conditions les marchés publics contribuent à la mise au point de solutions à de grands défis, et avancent trois types de défaillances pouvant être traitées par les marchés publics, à savoir les défaillances liées à la demande, à l'offre et aux interactions fournisseur-utilisateur.

Dans cette thèse, nous étudions l'impact des achats des universités publiques sur l'émergence de l'innovation dans l'instrumentation. Nous soulignons le fait que cette émergence a de fortes caractéristiques évolutives et qu'elle est très « axée sur les achats publics », c'est-à-dire que le rôle des chercheurs dans la promotion de l'innovation ne se limite pas à celui de simples clients ayant des besoins spécifiques. Ils contribuent fondamentalement au développement de nouveaux instruments grâce à leurs connaissances scientifiques. De cette manière, la thèse fournit également un compte-rendu différent des canaux indirects par lesquels les connaissances des universités publiques parviennent aux destinataires au-delà du milieu universitaire et peuvent être bénéfiques pour les entreprises.

Malgré leur pertinence, l'étude des canaux indirects de transfert de technologie universitaire mentionnés ci-dessus a été jusqu'à présent largement sous-explorée, en raison notamment du manque de micro données appropriées permettant de capturer « des instances de collaboration qui pourraient ne pas être documentées par des archives généralement accessibles » (Perkmann *et al.* 2013 p. 430) et de la complexité de ces relations induites par des « interdépendances échangées » qui pourraient dominer les interactions chercheurs-fournisseurs (Perkmann et Walsh, 2007 p.30).

Dans le but de combler ces lacunes, le premier chapitre de la thèse propose une analyse bibliographique approfondie de la littérature interdisciplinaire, qui aborde sous différents angles les liens existants entre les instruments scientifiques en tant que ressource et résultat des activités des universités et l'innovation industrielle des fournisseurs. Les études existantes sur les interactions université-industrie se concentrent principalement sur les canaux immédiats de transfert de technologie et d'acceptation des résultats de la recherche par le marché, tels que le brevetage et la licence d'invention, ainsi que sur l'esprit d'entreprise universitaire (Markman *et al.*, 2008). Néanmoins, il existe de nombreux autres moyens par lesquels la recherche universitaire est transférée aux entreprises (Salter et Martin, 2001). Un canal qui a jusqu'ici attiré peu d'attention consiste en une nouvelle instrumentation et méthodologie introduite par les universitaires au cours de leurs recherches. Bien que les économistes s'accordent largement sur l'importance de l'instrumentation dans le monde universitaire et sur ses avantages potentiels pour l'économie, l'étude de la manière dont l'instrumentation est développée est encore un sujet peu documenté et étudié dans la littérature économique. Cela reflète en partie le manque de micro données appropriées sur les équipements au niveau universitaire, qui permettraient de retracer l'apparition des technologies liées aux équipements et d'identifier les voies par lesquelles elles se diffusent au sein de la communauté universitaire et vers les entreprises industrielles.

En revanche, l'étude du développement de l'instrumentation scientifique a suscité l'intérêt d'un large éventail de spécialistes extérieurs à l'économie, notamment d'historiens et de sociologues, ainsi que celui des spécialistes de la science et de la technologie dans les études de gestion.

Par exemple, des historiens des sciences ont exploré l'importance de l'équipement pour le travail quotidien des chercheurs. Dans son analyse des différences sous-jacentes entre le développement technologique scientifique des siècles précédents et de nos jours, Mokyr (1997) souligne le caractère scientifique dominant des technologies modernes, à savoir qu'elles reposent sur une compréhension globale des forces, des phénomènes et des principes qui les régissent. Derek de Solla Price (1965, 1968) est l'un des premiers à reconnaître l'importance de l'équipement pour le développement des connaissances scientifiques et son influence sur le changement de la manière dont la science est menée à partir de la révolution scientifique. Il explique que "*predominantly it was the instruments, not any special logic of Francis Bacon, that gave rise to the philosophy…If you did not know about the technological opportunities that created the new science, you would understandably think that it all happened by people putting on some sort of new thinking cap. The changes of paradigm that accompany great and revolutionary changes may sometimes be caused by inspired thought, but much more commonly they seem due to the application of technology to science*" (1965, p. 247). De manière semblable, Rosenberg (1992) affirme que le développement de nouveaux instruments et méthodologies représente un produit clé de la recherche fondamentale financée par des fonds publics qui a ensuite été adopté par les industriels. Rosenberg conclut que les outils scientifiques peuvent être assimilés aux biens d'équipement industriel de la recherche et décrit leur chemin de diffusion comme suit : *"Instrumentation originating in the world of academic research has, in the post-World War II years, also moved in massive amounts into the realm of certain industrial technologies"* (Rosenberg 1992, p. 384). Dans la première partie du chapitre, nous examinerons le courant d'études des sociologues et des historiens de la science et de la technologie susmentionné, et nous verrons comment ces études ont mis en lumière l'existence de nombreux canaux d'échange et d'influence entre scientifiques et entreprises concernant l'instrumentation scientifique.

De plus, l'acquisition d'instruments par des universités auprès d'entreprises industrielles s'inscrit dans le cadre juridique des procédures de passation des marchés publics. Les interactions entre chercheurs et fournisseurs constituent un cas particulier de *marché public innovant* (Rolfstam, 2009). Les premières études sur les marchés publics (Lichtenberg, 1988; Geroski, 1990) ont montré l'impact considérable des marchés publics sur l'innovation par le biais du canal de stimulation de la demande pour les nouvelles technologies. En effet, les marchés publics peuvent également être considérés comme un moteur d'innovation généré par la demande. L'hypothèse d'innovation par la demande a considérablement évolué depuis les premières contributions empiriques examinant la demande du marché en tant qu'influence dominante sur le processus d'innovation dans les années 50, 60 et 70 (Myers et Marquis, 1969; Langrish *et al.*, 1972; Sherwin et Isenson, 1997, 1967; Bureau du Directeur de la recherche et du génie de la défense, 1969;

Fellner, 1962; Gibbons et Gummett, 1977; Gibbons et Johnston, 1974; Carter et Williams, 1957; 1959).

Cette première vague d'études a fait l'objet de vives critiques de la part de spécialistes de l'innovation tels que Mowery et Rosenberg (1979) et Dosi (1984). Ces critiques ont suscité le débat entre deux visions opposées concernant la source de l'innovation. Le cœur de la question résidait alors dans le rôle de l'offre et de la demande vis-à-vis de la détermination du rythme et de la direction du processus d'innovation. Le débat a mis en suspens les études axées sur la demande jusqu'à leur retour progressif par le biais d'études qualitatives concernant les innovations des utilisateurs réalisées par Von Hippel (1976), puis par des études sur la manière dont la demande pourrait stimuler la R&D privée en tant que source d'informations précieuses (Malerba et al., 2007; Fontana et Guerzoni, 2008; Guerzoni, 2010). Par la suite, les spécialistes se sont concentrés sur un type spécifique de demande, celui des marchés publics, et l'ont considéré comme un outil de politique industrielle (Georghiou, 2006; Edler et Georghiou, 2007; Edquist et Hommen, 2000; Uyarra et Flanagan, 2010; Slavtchev et Wiederhold. , 2011; Rolfstam, 2009, 2012), pour ensuite évaluer son efficacité par rapport aux outils de politique d'offre (Aschhoff et Sofka 2009; Guerzoni et Raiteri, 2015). En outre, des chercheurs ont tenté d'évaluer l'impact économique de l'apprentissage technologique pour les fournisseurs issus de relations d'approvisionnement avec des infrastructures de recherche financées par des fonds publics au moyen de quatre types de méthodologies, tels que des études de cas (Nordberg, 1997; Autio *et al.*, 2003, 2004; Vuola et Hameri. , 2006; Autio, 2014), des enquêtes (Florio *et al.*, 2018); des études d'entrées-sorties (Schmied, 1982, 1987; Streit-Bianchi *et al.*, 1984) et, plus récemment, via des évaluations quantitatives à grande échelle de fournisseurs du CERN (Castelnovo *et al.*, 2018).

Le débat sur l'innovation susmentionné a également déclenché un courant de recherche axé sur les interactions de la science et de la technologie au-delà de l'opposition entre l'offre et la demande et davantage tourné vers le rôle de la connaissance et de l'apprentissage en relation avec le processus et les systèmes d'innovation (Freeman, 1987). Ces contributions ont mis l'accent sur le caractère crucial des contacts entre l'industrie et la science et sur l'interdépendance croissante des sciences et de la technologie (Nelson, 1962; Freeman, 1974; Mansfield, 1980; Rosenberg, 1982, 1990, 1992 et 1993). En outre, Pavitt (1993) a déclaré que les contributions de la science à l'innovation industrielle reposaient principalement sur des schémas indirects, consistant à recruter des personnes possédant des compétences et des connaissances précieuses, plutôt que des transferts directs tels que des publications. De même, Levin *et al.* (1987) ont montré que les industriels appréciaient davantage les compétences et les techniques scientifiques de base que les résultats de la recherche universitaire, tels que les articles. Dans leur étude sur les innovations radicales, il a été démontré qu'une partie des innovations révolutionnaires du 20ème siècle auraient été inconcevables sans l'accumulation préalable de connaissances scientifiques. En effet, les progrès scientifiques et les techniques ont joué un rôle crucial au cours de la phase de développement de ces innovations (Mansfield, 1991). Des études ultérieures sur l'innovation ont pleinement confirmé ces résultats en montrant que la capacité des entreprises des secteurs de la chimie et des industries à tirer parti de sources externes d'expertise scientifique, constituait un déterminant essentiel de leur succès (Freeman, 1974; Rothwell *et al.*, 1974). Pour que cela se produise, il a été démontré que les contacts informels avec des scientifiques universitaires revêtaient une grande importance dans plusieurs industries (Gibbons et Johnston, 1974).

En résumé, dans cette revue de littérature, nous soulignons les principales contributions de la littérature telles que la discussion sur les marchés publics liée au débat sur le rôle de la demande en tant que source d'innovation qui permet de repenser le processus d'innovation en replaçant l'apprentissage interactif entre les utilisateurs et les producteurs à son fondement. Dans le même temps, nous mettons en avant certaines limites de cette littérature, telles que l'absence d'évaluation quantitative de l'instrumentation en tant que résultat précieux et percutant des universités de recherche publique, et nous soulignons la nécessité d'explorer davantage les interactions entre chercheurs et fournisseurs au niveau microéconomique.

Le *deuxième chapitre examine* le rôle des fournisseurs d'instruments scientifiques de la deuxième plus grande université publique française - l'Université de Strasbourg – ainsi que l'impact de la demande des universités sur la performance d'innovation des entreprises.

Les critiques visaient depuis longtemps le manque d'implication des chercheurs universitaires dans les activités de transfert de connaissances et de technologie. Cependant, au cours des trente dernières années, les décideurs politiques ont profondément modifié leur perception de la situation, au moment où ils commencent à reconnaître leur rôle d'acteur central dans une économie fondée sur la connaissance. Les attentes croissantes du rôle que les universités peuvent jouer à travers leur "troisième mission" ont conduit à une série de transformations politiques visant à renforcer les liens entre les universités et l'industrie. La commercialisation des connaissances universitaires par le biais du dépôt de brevets, de licences et de spin-off constitue la pierre angulaire des politiques en matière de science et d'innovation (S & I) depuis le début des années 80 (Mowery *et al.*, 2001). Par exemple, la loi Bayh-Dole (1980) autorisait les universités américaines à obtenir des droits de propriété intellectuelle sur les inventions financées par le gouvernement fédéral américain et leur permettait de concéder des licences pour ces inventions. Un certain nombre de gouvernements de l'OCDE ont adopté des mesures similaires (Mowery et Sampat, 2004). La raison d'être de ces initiatives reposait sur la conviction que les universités produisaient de nombreuses inventions d'une grande valeur économique mais ne parvenaient pas à les transférer au-delà des frontières du monde universitaire et donc à en tirer les bénéfices correspondants (Kenney et Patton, 2009).

Le modèle université-invention-propriété a généré un vaste corpus de recherches orienté presque exclusivement sur les mesures axées sur l'offre, telles que les activités commerciales universitaires, afin de forger des liens université-industrie, ou telles que la performance des acteurs impliqués dans le processus (voir Bonaccorsi et Piccaluga, 1994; Jensen et Thursby, 2001; Schartinger *et al.*, 2002; Thursby et Kemp, 2002; Cohen *et al.*, 2002; Mowery et Ziedonis, 2002; Shane, 2004). Toutefois, ces études risquent de donner une image trop simpliste des interactions entre les universités et les entreprises et de ne pas prendre en compte la diversité et l'effet correspondant des mécanismes par lesquels les connaissances académiques sont transférées à l'industrie (Dosi *et al.*, 2006; Nelson, 2012; Autio *et al.*, 2014; Kenney et Mowery, 2014). Des contributions plus récentes examinent un éventail plus large de mesures alternatives pour les liens formels et informels université-industrie, y compris la mobilité du personnel (Dietz et Bozeman, 2005; Zolas *et al.*, 2015); l'embauche d'étudiants diplômés (Stephan, 2009); la recherche et développement en collaboration (Monjon et Waelbroeck 2003; Fritsch et Franke 2004; Lööf et Broström 2006), la recherche contractuelle, le conseil (Jensen et al., 2007; Murray, 2002) et les activités de de conseil ponctuel. L'implication de scientifiques universitaires dans de telles activités est désormais appelée *engagement universitaire* (voir, par exemple, D'Este et Patel, 2007; Perkmann et Walsh, 2007; Perkmann *et al.*, 2013). Bien que la commercialisation implique qu'une invention académique soit exploitée de manière à en retirer des avantages financiers, l'engagement académique englobe un ensemble plus large d'activités et est poursuivi pour plusieurs objectifs, tels que l'accès aux ressources pertinentes pour les activités de recherche via des fonds supplémentaires et des équipements spécialisés, pour accéder aux opportunités d'apprentissage via des essais sur le terrain ou pour obtenir de nouvelles perspectives sur des questions pratiques (Lee, 2000; D'Este et Perkmann, 2011). Néanmoins, ces études récentes ne sont pas exemptes de critiques, car elles reposent exclusivement sur des mesures axées sur l'offre (Nelson, 2012). En particulier, elles ont souvent tendance à réduire le rôle des universités à celui de fournisseur de connaissances et de technologies pour des applications industrielles.

Ce deuxième chapitre vise ainsi à développer le cadre susmentionné en évaluant de manière empirique un mécanisme d'échange de connaissances université-industrie, jusqu'ici négligé. Nous présentons une perspective différente selon laquelle ces échanges et les avantages correspondants se matérialisent en raison de la demande de biens et de services personnalisés. Conformément à la vision schumpétérienne traditionnelle de l'innovation technologique, nous avons souvent tendance à nous concentrer sur les aspects scientifiques / technologiques du processus d'innovation et à négliger le côté de la demande. Cependant, historiens de l'économie et économistes de l'innovation ont depuis longtemps adopté l'idée que les paradigmes technologiques émergents peuvent être façonnés par la dynamique de la demande du marché (Dosi, 1982, 1988; Mokyr, 1990; Bairoch, 1993).

De fait, ce chapitre tend à enrichir les études existantes à travers une quantification de l'impact de la demande des universités sur les performances novatrices des entreprises qui font partie de la chaîne de valeur scientifique - c'est-à-dire les entreprises qui fournissent des biens et des services aux universités de recherche. Nous supposons que les exigences des universités vis-à-vis des entreprises sont assez uniques, car les scientifiques universitaires rencontrent souvent un besoin spécifique bien avant que la majorité des entreprises présentes sur le marché ne le rencontrent et, de plus, les universités sont mieux placées pour en tirer un bénéfice significatif. Par conséquent, les scientifiques peuvent tenir le rôle de *lead users* de technologies et supporter indirectement les coûts d'apprentissage et de perfectionnement associés au développement de nouveaux produits (von Hippel, 2005; Stephan, 2012). Pour résumer, la demande émanant de scientifiques et de spécialistes pour des produits et services personnalisés peut inciter les entreprises à introduire de nouveaux produits et concepts organisationnels, contribuant ainsi à façonner les trajectoires technologiques et à favoriser les innovations en matière de produits et de processus.

Ce chapitre est ainsi l'occasion de mener une analyses micro-économétrique dans un cadre quasi expérimental pour évaluer l'impact d'une grande université publique française sur les performances innovantes de ses fournisseurs d'équipements et de matériaux de recherche. L'approche quantitative est possible grâce à un ensemble original et unique de données contenant des informations détaillées sur les achats des universités ainsi que sur les fournisseurs associés. Ces données sont complétées par des informations précises sur divers aspects du processus d'innovation, par les états financiers des fournisseurs de l'université et un échantillon représentatif des entreprises françaises. L'infrastructure de données nous permet d'exploiter un large éventail de variables liées à l'innovation pour évaluer les performances des fournisseurs et d'autres entreprises, tout en contrôlant un grand nombre d'attributs au niveau de l'entreprise et de facteurs contextuels. Nous montrons que les entreprises fournissant des laboratoires universitaires ont une propension nettement plus élevée à introduire des innovations de produits sur le marché et à bénéficier de ventes plus importantes pour ces produits, toutes choses étant égales par ailleurs. En revanche, nous n'observons aucun effet significatif sur l'innovation de procédé.

Dans le *troisième chapitre*, nous procédons à des analyses de robustesse approfondies des résultats empiriques détaillés ci-dessus via deux méthodologies. D'abord, nous étendons et enrichissons l'analyse précédente en se posant la question de savoir si l'effet de l'université sur la performance des fournisseurs que nous avons déduit dans le deuxième chapitre est toujours présent lorsque nous affinons nos données et nos paramètres empiriques. Dans la première partie du chapitre, nous réalisons une batterie d'analyses de sensibilité, en ajoutant de nouvelles variables aux données au niveau de l'entreprise utilisées dans le deuxième chapitre. Plus précisément, nous prenons d'abord en compte d'autres interactions possibles entre une université et ses fournisseurs (collaborations R&D). Dans un second temps, nous répétons notre analyse en nous concentrant uniquement sur un sous-échantillon spécifique, celui des instruments scientifiques de haute technologie. Puis, nous considérons uniquement les entreprises situées en Alsace. Enfin, nous examinons l'impact des différents modèles de régression et des algorithmes d'appariement sur les résultats des effets de traitement (ATT).

Les analyses présentées ci-dessus s'appuient sur des données issues d'enquêtes d'innovation pour identifier des informations au niveau de l'entreprise liées à l'innovation. Bien qu'elles soient largement utilisées, les données des enquêtes sur l'innovation souffrent de plusieurs limites. La critique majoritairement adressée concerne la nature transversale des données, la représentativité de l'échantillon, le manque de variables financières et comptables et la subjectivité des informations rapportées (Archibugi et Pianta 1996; Mairesse et Mohnen 2010). Ainsi, dans la deuxième partie du chapitre, nous reprenons le débat en cours sur les principaux écueils des données d'enquête sur l'innovation, et nous menons une analyse empirique supplémentaire en appariant nos données de dépenses à une base de données alternative au niveau de l'entreprise. Nous utilisons les brevets des entreprises comme proxy pour l'activité d'innovation des entreprises. Nous procédons à une régression MCO et une régression binomiale négative avec excès de zéros (ZINB). Les résultats des analyses de sensibilité et de brevets corroborent de manière convaincante nos premiers résultats, par une démonstration de l'impact positif et significatif de la demande des universités sur la propension des fournisseurs à introduire des produits nouveaux sur le marché et à en tirer des ventes plus importantes. Ces résultats révèlent une continuité cohérente dans la tendance de significativité à travers les différentes vérificatios. Par ailleurs, l'ensemble des résultats de ce troisième chapitre corrobore et enrichit la preuve empirique principale du deuxième chapitre.

Dans le *quatrième* chapitre, nous explorons les mécanismes concrets par lesquels les universités favorisent l'apprentissage et l'innovation chez leurs fournisseurs industriels. Dans ce dernier chapitre, nous étudions donc de manière approfondie ces mécanismes et nous tentons de démontrer *comment se développent les complémentarités dynamiques entre la demande des chercheurs et les compétences des fournisseurs.*

Étant donnée la nature exploratoire de notre enquête, notre choix méthodologique est de mener une étude qualitative approfondie sur le terrain, basée sur une étude de cas multiples (Yin, 2014). Nous étudions trois cas de technologies développées par des chercheurs de trois unités de recherche différentes de l'Université de Strasbourg (UNISTRA) et leurs fournisseurs industriels. Les cas portent sur trois instituts majeurs biomédicaux et de chimie (de premier plan) de l'Université. De septembre à décembre 2018, nous avons mené 10 entretiens formels et 5 entretiens informels avec des chercheurs afin de recueillir des données factuelles sur leurs fournisseurs. Les principales questions posées dans les entretiens portent sur le contexte et le début des relations des chercheurs avec leurs fournisseurs, ainsi que sur leur évolution dans le temps, à la fois au sein et en dehors du cadre des marchés publics.

Ce chapitre s'appuie sur et affine les études précédentes dans le domaine selon au moins deux manières. Premièrement, alors que de nombreux efforts de recherche ont été consacrés à l'étude de la contribution économique des universités de recherche publiques, la plupart de ces études ont été axées sur des activités décrivant le transfert de technologie de manière directe, linéaire et unidirectionnelle (voir par exemple Dosi *et al.*, 2006; Perkmann *et al.*, 2013). Ces activités ont en commun de faire l'objet de procédures formelles mises en place par les bureaux de transfert de technologie ou d'autres institutions connexes. En outre, le transfert de technologie entre les universités et l'industrie est décrit comme une boîte noire, ce qui crée beaucoup d'ambiguïté quant au fonctionnement des universités en tant qu'espace d'apprentissage pour les entreprises. Néanmoins, un examen plus approfondi du fonctionnement pratique des universités révèle que de nombreux transferts de technologie ne se font pas par des voies « *officielles* » (Rosenberg, 1992). Les connaissances essentielles générées par la recherche universitaire sont souvent transférées à l'industrie sans avoir recours à l'aide des bureaux de transfert de technologie (TTO) ou de mécanismes de transfert de technologie similaires. Le plus souvent, les technologies vont et viennent entre chercheurs et entreprises industrielles en tant que sous-produit d'autres relations réciproques, par exemple, la demande d'instruments. Un cas typique est représenté par les interactions à forte intensité technologique entre les universitaires et leurs fournisseurs (Perkmann et Walsh, 2007). En conséquence, les chercheurs ont souligné la nécessité d'intensifier les efforts de recherche sur l'étude de modes de transfert de technologie plus interactifs (Lundvall, 1988; Salter et Martin, 2001; Pavitt, 2005). Une telle approche fournirait également une preuve plus rigoureuse des processus de transmission du savoir entre les universités et les entreprises.

Deuxièmement, le rôle joué par les universités en tant qu'acteurs fondamentaux de l'innovation par la demande représente un cas particulier du rôle des marchés publics en tant que source d'innovation. Ce sujet a beaucoup retenu l'attention au sein des débats récents sur les politiques publiques en matière de science et technologie (Edquist et Hommen, 2000; Edler et Georghiou, 2007; Castelnovo *et al.*, 2018; Florio *et al.*, 2018). Le succès de la procédure de passation des marchés publics dépend en grande partie des interactions utilisateur-fournisseur, qui peuvent être entravées par des asymétries d'information et par de faibles complémentarités dynamiques (Malerba, 1996, 2006; Chicot et Matt, 2018). Dans le cadre des marchés publics, les interactions entre chercheurs et fournisseurs sont cruciales pour le développement d'interfaces menant à l'innovation (Rolfstam, 2009). Ce chapitre améliore les études susmentionnées en explorant de manière approfondie les mécanismes de communication et les interactions entre chercheurs et fournisseurs. En mettant l'accent sur ces interactions, nous avons également mis en lumière les facteurs qui entravent la collaboration entre les acheteurs et les fournisseurs orientés vers le développement de nouvelles technologies (Chicot, 2017).

Troisièmement, en discutant des opportunités d'apprentissage stratégiques et technologiques offertes par les universités à leurs fournisseurs, nous cherchons à contribuer à des études antérieures axées sur l'activité des fournisseurs des grands centres scientifiques qui ont abordé à la fois les aspects directs (Autio *et al.*, 2004; Nilsen et Anelli, 2016), mais aussi l'impact financier secondaire de l'achat public par les grands centres scientifique sur leurs fournisseurs industriels (Schmied, 1982, 1987; Streit-Bianchi *et al.*, 1984). Ces études fournissent des informations précieuses sur les mécanismes d'apprentissage et d'innovation des fournisseurs de telles infrastructures de recherche (par exemple, le CERN). Dans le même temps, ils appellent à une exploration plus approfondie de ces mécanismes dans le contexte de l'université.

Nos études de cas illustrent une multitude de schémas permettant aux chercheurs de partager leurs connaissances technologiques avec des fournisseurs industriels. Nous avons montré comment, en partageant avec les fournisseurs des connaissances ou des technologies spécifiques, les chercheurs aidaient les entreprises à développer de nouvelles capacités pour la production d'un appareil donné. Ces compétences ont ensuite été appliquées à la fabrication d'autres types de dispositifs, ce qui a entraîné une expansion et une diversification des activités des fournisseurs. Ainsi, les compétences techniques acquises au cours de la recherche à l'université ont des applications directes dans les processus de production des fournisseurs. En résumé, l'effet des universités sur les fournisseurs génère des nouvelle capacités et technologies développées ou améliorées pour répondre aux besoins spécifiques et sans précédent des chercheurs. En outre, une fois que les connaissances acquises par les universités ont été maîtrisées, les fournisseurs les utilisent à d'autres fins et applications.

En outre, notre étude de terrain montre que, même si le processus régissant les interactions entre chercheurs et producteurs est principalement déterminé par l'état de la technologie fournie par les entreprises au début, il est aussi fortement influencé par la demande des chercheurs par la suite. En effet, les chercheurs sont en mesure de communiquer aux entreprises de fournisseurs des exigences que d'autres types d'organisations ne seraient pas en mesure d'imposer et, de cette manière, de les influencer de manière significative dans leur évolution au sein d'un certain paradigme technologique (Dosi, 1982). En ce sens, nos éléments de preuve montrent que les exigences des universités publiques sont de grande valeur car elles sont associées aux compétences scientifiques et technologiques des chercheurs. Cependant, les résultats de notre étude de terrain vont au-delà de l'idée que les chercheurs ne sont que de simples clients et que les fabricants s'engagent ensuite dans les processus de production vers le produit final. En effet, nos éléments de preuve montrent qu'il n'y a pas de distinction nette entre les contributions des chercheurs et celles des fabricants. En outre, le rôle des chercheurs ne se limite pas à leur demande et à leurs exigences particulières. Ils apportent également une variété de services à leurs fournisseurs. Ces services peuvent varier, allant du test des équipements à différentes étapes de son développement, en produisant des unités de présérie pour la société, en passant par la production du prototype d'équipement dans un laboratoire universitaire. Par conséquent, l'impact des chercheurs sur les performances innovantes des fournisseurs par le biais de l'achat d'instruments semble relever d'un effet combiné d'une demande très sophistiquée tournée vers l'avenir, de connaissances technologiques scientifiques et de capacités pratiques. Enfin, notre étude de terrain montre que le transfert de connaissances entre chercheurs et entreprises peut avoir lieu à différentes étapes du processus de passation de marché, mais principalement via des canaux informels déclenchés par les procédures de passation de marché formelles. Finalement, notre étude de terrain sur les interactions chercheurs-fournisseurs met en lumière les mécanismes actuels par lesquels les achats universitaires exercent un effet significatif et positif sur l'innovation des entreprises. Plus précisément, nos éléments de preuve montrent la présence d'un phénomène d'innovation « *axé sur les achats publiques* », dans lequel les chercheurs universitaires fournissent aux entreprises des informations uniques en agissant à la fois comme demandeurs d'équipements et comme fournisseurs de connaissances scientifiques sur les instruments, permettant aux entreprises d'explorer de nouvelles trajectoires innovantes.

Abstract

This dissertation studies the contribution of universities to industrial innovation by focusing on the impact that university demand has on the innovative performance of firms.

In the *first* chapter, we conduct an in-depth literature review of the main research streams studying universities' influence on industrial firms through the procurement of instrumentation. In the first part of the review, we focus on contributions of historians, sociologist and science and technology scholars, then we turn to demand-side studies and innovative public procurement and finally we briefly discuss the user-innovations studies on instrumentation as well as the sticky nature of scientific knowledge. Among the main merits of these studies is the germane account of the complex synergies between scientists and companies in cases of single equipment across various circumstances, as well as the evidence of significant user implication into the emergence of new commercialized equipment. At the same time, we highlight that existing studies present some important limitations such as the lack of robust quantitative evidence about the effect of university procurement on suppliers and correspondent account of the underlying interactions between the researchers and suppliers.

In the *second* chapter,we consider the scientific instruments suppliers' of the second largest French public university – the University of Strasbourg - and we investigate the impact of university demand on firms' innovative performance. The research question addressed in this chapter is "*What is the impact of university demand on suppliers' innovative performance?*" We explore whether the demand for such goods by academic scientists can provide a stimulus to firms to introduce novel products and organisational concepts, thereby contributing to shaping technological trajectories and fostering innovation. We carry out a micro-econometric analysis in a quasi-experimental setting, showing that university suppliers have a higher propensity to introduce new-to-the-market product innovations than do other firms belonging to the same sectors and with similar characteristics. Our results bring support to the conjecture that innovations and technological changes emerge not only from scientific and technical discoveries but also of a complex chain reaction triggered by the interplay between specific demands and solutions designed to overcome technology bottlenecks.

In the *third* chapter, we perform extensive robustness analyses of the above empirical results via two methodologies. The first battery of robustness checks examines the sensitivity of the main estimates by adding new variables; by restricting the sample size and by exploiting alternative matching algorithms. The sensitivity analysis represents a valuable extension of our initial study, that makes use of the same data and methodology to show that the main empirical results obtained in the first chapter follow stable paths of significance throughout various estimations. The second sensitivity analysis we perform aims to show the effect of university demand on suppliers by means of different innovation and firm-level datasets as well as of a different methodological approach. The research question addressed in this chapter is "*What is the impact of university demand on suppliers' patent activity?*" To answer this question, an OLS and Zero-Inflated Negative Binomial (ZINB) models are estimated and the hypothesis that the status of university suppliers has, all other things being equal, a positive and significant effect on companies' patent activity is empirically tested. This alternative analysis provides very strong support for the core results of the second chapter, by showing evidence of a significant and positive impact of university labs on the innovative capabilities of industrial suppliers.

In the *fourth* chapter, we go beyond the excessive focus on quantitative relations which does not allow one to fully explore the complexity of inter-personal and inter-organisational relations underlying the processes explaining the observed empirical results in the above chapters. We are interested in learning more about the complex nexus of links that define researchers - suppliers relationships how they change over time under the pressure of various factors and how they ultimately affect innovation at the firm level. In that respect, our study aims to explore *the emergence of dynamic complementarities among researchers' demand and suppliers' competencies.* To identify the dynamic processes leading to new technologies among academic researchers and their suppliers, we conducted field-study based on three instrumental devices developed in close collaboration between University of Strasbourg laboratories on the one hand, and firms belonging to our initial expenditures dataset on the other hand. To gain a better comprehension of the complex social phenomena at play from the perspective of participants (Partington, 2001), we realized semi-structured interviews with researchers, engineers and research unity directors as well as few informal interviews with suppliers. Our field-study illustrates manifold direct and indirect processes through which university laboratories act as a learning environment for their suppliers and as a source of direct, detailed and practical feedbacks on existing products; continuous updates about the evolvement of user requirements; the development of prototypes of new devices; the incorporation of existing devices to build new systems; alpha, beta and field-testing of suppliers products; producing a pre-series production for the suppliers. Our study depicts how tailor-made devices developed to fulfil researchers' specific need allow then companies to realize economies of scale by selling the same products to a wider range of clients. Our empirical evidence also shows that researchers are attracted by suppliers that can provide them with an exactly tailored device. Once firms get a reputation for customizing their products, they draw customers with niche applications and high-end profiles that offer a marketing advantage to companies that focus on a wider market. In practical terms, researchers add further extensions to the suppliers' products which then make their use possible in other disciplines, thus opening new markets to their suppliers. Lastly, we also highlight the role of researcher-suppliers relations as a special case of public procurement as a source of innovation (Chicot and Matt, 2018; Castelnovo et al. 2018; Florio et al. 2018; Edquist and Hommen, 2000).

Introduction

This dissertation puts forward the perspective that universities have a significant influence on the innovation behaviour of their industrial suppliers by way of researchers' demand for scientific instrumentation and it explores in-depth the underlying processes of mutual technological learning that unfold among researchers and suppliers.

Universities play a fundamental role for research and education in modern societies. However, European Universities have undergone a major transformation since the 19th century. Back then universities were social structures and stood somehow outside of the economic sphere. For instance, the "Humboldtian" university was perceived as a unifying institution of social and cultural values, intended to inspire a feeling of belonging and a common view (Cowan, 2005). Its primary mission was the formation of the next generation of citizens. The end of the 20th century marked a turning point in the perception of universities by policymakers, with the acknowledgement of their central position in the so-called "knowledge-based" economy. This was triggered by a radical shift in the conception of how knowledge is generated and of how it is articulated within the innovation process. The shift in perception of universities is also part of a longer historical process, characterised by the decline of firm's internal R&D and by the stronger reliance of large firms on external sources of knowledge, like universities, to sustain their innovation and growth (Mowery, 2009; Higgins and Rodriguez, 2006; Arora and Gambardella, 1990). The decline of companies' investment in R&D has been related to competitive pressures arising from globalisation as well as to the increasing speed and complexity of knowledge processes vis-à-vis firms' narrower scope and decreased incentives to develop significant new products and processes on their own. In addition, the retreat of large firms from research has led to a kind of division of labour in innovation between firms and universities, in which large companies' focal point is the development and commercialisation of new products, instead of the initial generation of innovative ideas and solutions, which is then left to universities (Arora & Gambardella, 1994).

Accordingly, university research became increasingly relevant and attractive for industrials (Freitas et al., 2011). Similarly, the reduction of government intervention in the economy and the scarcity of public funding for research drove universities to collaborate increasingly with companies (Geuna and Muscio, 2009). In this context, Anglo-Saxon governments first, and then also European ones introduced policy measures to incentivize universities to engage in research and technology transfer activities with industry. The rationale for these measures rested on the idea that interactions between universities and industry could increase the rate of innovation in the economy as a whole (Spencer, 2001). In the European and French context, these measures were also put in place to solve the so-called European Paradox: the excellence of European universities in research but their apparent incapacity to diffuse the results of their research beyond the academic world (European Commission, 1995). The links between the two spheres were established via the promotion of university knowledge commercialisation by engaging in patenting and licensing of university inventions along with academic entrepreneurship.

These policy measures and the narratives and theories used to justify them, became the subject of a large body of studies on university-industry (U-I) interactions. These contributions explore the various aspects of the commercialisation of academic inventions, ranging from its individual (Bercovitz and Feldman, 2008; Stuart and Ding, 2006), institutional (Di Gregorio and Shane, 2003; Mansfield, 1995; O'Shea et al., 2005; Owen-Smith and Powell, 2001; Sine et al., 2003), and organisational determinants (Lockett and Wright, 2005; Siegel et al., 2003).

However, the very existence of the 'European paradox' and the relevance of the related policies were debunked by several works in the economics of innovation literature (see Dosi et al. 2006; Goldfarb and Henrekson, 2003; Mowery et al. 2001; Henrekson and Rosenberg, 2001). These works criticized the commercialization of academic products as a simplistic depiction of university-industry interactions putting emphasis only on unidirectional flows of fundamental knowledge from universities into industrial applications, and thus failing to account for the true interactive nature of university-industry relations (Colyvas et al., 2002).

This dissatisfaction triggered a new wave of studies aimed at identifying a broader set of interactions between universities and other entities. These interactions are commonly known as "academic engagement" and are defined by Perkmann et al., (2013) as "*knowledge-related collaborations by academic researchers with non-academic organisations*" (p. 424). Academic engagement involves both formal and informal links such as collaborative research, contract research, consulting, ad hoc advice and networking among others (Perkmann and Walsh, 2007; D'Este and Patel, 2007; Meyer-Krahmer and Schmoch, 1998; Bonaccorsi and Piccaluga, 1994). These studies find academic engagement practices to be a lot more pervasive than commercialisation and emphasize their alignment with traditional academic missions. They tend to emphasize individual and department level engagement and address the antecedents and consequences of these accounts (Perkmann et al., 2013).

Although academic engagement contributions show up as an alternative to the narrow approach of commercialisation studies, they are not exempt from criticism either. A common remark is that both streams of studies limit the university-industry nexus solely to technological activities, restricting the role of the universities to that of a "provider" of knowledge and technology for industrial applications (Kenney and Patton, 2009).

This dissertation tries to contribute to the latter stream of studies by proposing and assessing a so far neglected mechanism of university-industry interactions, namely the one relating to universities' demand for scientific equipment, materials, and tools. The traditional Schumpeterian view on technological innovation usually focuses on science and technological aspects of the innovation process, neglecting the demand-side of the story. The view that technology can be shaped by demand-pull drivers, but still ensues evolutionary dynamics rather independent from the influence of the market forces, has been elaborated throughout a series of contributions and concepts. For instance, Rosenberg (1969) define *internal inducement mechanisms* the technological imperatives brought by technical imbalances between interdependent processes that ultimately lead to the improvement of certain technologies. Nelson and Winter (1977) describe these paths of technology evolvement as *natural trajectories* and emphasize their cognitive background rooted in engineers' beliefs about which solutions are feasible or at least worth attempting. Dosi (1982) combines the above notions to introduce the concept of technological paradigms and trajectories, where the supply-side is initially responsible for creating a paradigm, which defines the universe of possible modalities according to which technology will develop. Demand drivers subsequently select developmental trajectories within a given paradigm according to their economic significance.

Dosi (1982, p. 156) also identifies public procurement as a mean through which demand-side effects significantly the development of such paradigms. In this perspective, innovations are shaped by existing or emerging use (Lundvall, 1988, 1992a, 1992b), and they meet an expanding demand to ensure economic performances (Mokyr, 1990). Following the above insights, a large body of related contributions stressed the importance of defence-related public procurement as leading factor in shaping the patterns of technological change in the 20th century. For instance, Mowery and Rosenberg (1982) highlight that procurement for components and systems for purposes of national defence and spatial exploration led to radical technological developments in the semiconductor, computer, and aviation industries. Levin and Nelson (1982) point to government demand as a great risk-taker of investment in semiconductor technologies, such as the silicon transistor and the integrated circuit, in the early years of their development. Furthermore, in semiconductor industry, big procurement contracts provided stimulus for industrial R&D and some of the essential technologies in the domain were actually prompted by military needs and requirements. Indeed, the opportunity to gain a large procurement project served as a prize for companies that invested to develop new technologies with the final aim to meet public demand (Mowery, 2011).

Along similar lines, Freeman (1995) emphasizes the importance of knowledge flows both towards and from sources of scientific and technical knowledge as well as from users of products and processes. For instance, Freeman (1995, p. 479) identifies science "constituency" as a leading factor in originating and shaping subsequent radical innovations in the field of the electronic computer industry. Likewise, Pavitt (1984) develops a taxonomy of industrial firms on the ground of the analysis of a long list of discrete innovations undertaken in the UK according to the source of innovation knowledge; how it is accessed, by whom and what are the characteristics of production technology. According to Pavitt's taxonomy, scientific and measurement instruments firms belong to the science-based sector and draw significantly on public research as sources of their knowledge. This dependence on public research is very well documented by Rosenberg (1992), which provides a historical account of the development of certain commercialized instruments and identifies public research laboratories as the birthplace of such technologies. Rosenberg (1992) also emphasizes how a lot of the industrial products come as an unintended by-product of public science at universities. In a similar style, Mazzucato (2015) explores the background of modern industrial innovations (e.g. the history of the development of internet and of the touch screen which were eventually embedded in the iPhone and the iPad, see Mazzucato, 2015) as well as instruments (e.g. think to the fundamental role of electron microscope in microbiology) and highlights that although these items seem to me entirely industry-made they were instead brought by continuous public investments (and procurement) in research. Moreover, Mazzucato (2016) points out that public technology procurement plays an essential role in mission-oriented policy initiatives that aim to address a broader range of challenges that require long-term commitments to technological development and a continuing high rate of technical change and set of institutional change. Along similar lines, Matt and Chicot (2018) examine under what conditions procurement contributes to the achievement of solutions to grand challenges and put forward three types of failures that can be tackled by public procurement, namely demand-side, supply-side and user-supplier interaction failures.

In this thesis, we study the impact of public university procurement on the emergence of innovation in instrumentation. We highlight how this emergence has strong evolutionary traits and it is very "procurement-led" i.e. researchers' role in nurturing innovation is not just limited to the one of mere customers with a specific need. They fundamentally contribute to the development of new instruments with their scientific knowledge. In such a way, the thesis also provides a different account of the indirect conduits through which knowledge from public universities gets to recipients beyond the academia and can be beneficial to companies.

Despite their relevance, the study of the above-mentioned indirect conduits of university technology transfer has so far been largely unexplored, due to the lack of appropriate micro-data that allows to capture "collaboration instances that may not be documented by generally accessible records" (Perkmann et al. 2013 p. 430) and these relations' complexity induced by "traded inter-dependencies" that might dominate researchers-suppliers interactions (Perkmann and Walsh, 2007 p.30).

With the aim to fill the above gaps, in this thesis, we *first* conduct an in-depth literature review of the main research streams studying universities' influence on industrial firms through the procurement of instrumentation. In the first part of the review, we focus on contributions of historians, sociologist and science and technology scholars, then we turn to demand-side studies and innovative public procurement and finally we briefly discuss the user-innovations studies on instrumentation as well as the sticky nature of scientific knowledge. Among the main merits of these studies is the germane account of the complex synergies between scientists and companies in cases of single equipment across various circumstances, as well as the evidence of significant user implication into the emergence of new commercialized equipment. At the same time, we highlight that existing studies present some important limitations such as the lack of robust quantitative evidence about the effect of university procurement on suppliers and correspondent account of the underlying interactions between the researchers and suppliers.

Second, we consider the suppliers' scientific instruments of the second largest French public university – the University of Strasbourg - and we investigate the impact of university demand on firms' innovative performance. The research question addressed in this chapter is "*What is the impact of university demand on suppliers' innovative performance?*" We explore whether the demand for such goods by academic scientists can provide a stimulus to firms to introduce novel products and organisational concepts, thereby contributing to shaping technological trajectories and fostering innovation. We carry out a micro-econometric analysis in a quasi-experimental setting, showing that university suppliers have a higher propensity to introduce new-to-the-market product innovations than do other firms belonging to the same sectors and with similar characteristics. Our results bring support to the conjecture that innovations and technological changes emerge not only from scientific and technical discoveries but also of a complex chain reaction triggered by the interplay between specific demands and solutions designed to overcome technology bottlenecks.

Third, we perform extensive robustness analyses of the above empirical results via two methodologies. The first battery of robustness checks examines the sensitivity of the main estimates by adding new variables; by restricting the sample size and by exploiting alternative matching algorithms. The sensitivity analysis represents a valuable extension of our initial study, that makes use of the same data and methodology to show that the main empirical results obtained in the first chapter follow stable paths of significance throughout various estimations. The second sensitivity analysis we perform aims to show the effect of university demand on suppliers by means of different innovation and firm-level datasets as well as of a different methodological approach. The research question addressed in this chapter is "*What is the impact of university demand on suppliers' patent activity?*" To answer this question, an OLS and Zero-Inflated Negative Binomial (ZINB) models are estimated and the hypothesis that the status of university suppliers has, all other things being equal, a positive and significant effect on companies' patent activity is empirically tested. This alternative analysis provides very strong support for the core results of the second chapter, by showing evidence of a significant and positive impact of university labs on the innovative capabilities of industrial suppliers.

Fourth, we go beyond the excessive focus on quantitative relations which does not allow one to fully explore the complexity of inter-personal and inter-organisational relations underlying the processes explaining the observed empirical results in the above chapters. We are interested in learning more about the complex nexus of links that define researchers - suppliers relationships how they change over time under the pressure of various factors and how they ultimately affect innovation at the firm level. In that respect, our study aims to explore *the emergence of dynamic complementarities among researchers' demand and suppliers' competencies.* To identify the dynamic processes leading to new technologies among academic researchers and their suppliers, we conducted field-study based on three instrumental devices developed in close collaboration between University of Strasbourg laboratories on the one hand, and firms belonging to our initial expenditures dataset on the other hand. To gain a better comprehension of the complex social phenomena at play from the perspective of participants (Partington, 2001), we realized semi-structured interviews with researchers, engineers and research unity directors as well as few informal interviews with suppliers. Our field-study illustrates manifold direct and indirect processes through which university laboratories act as a learning environment for their suppliers and as a source of direct, detailed and practical feedbacks on existing products; continuous updates about the evolvement of user requirements; the development of prototypes of new devices; the incorporation of existing devices to build new systems; alpha, beta and field-testing of suppliers products; producing a pre-series production for the suppliers. Our study depicts how tailor-made devices developed to fulfil researchers' specific need allow then companies to realize economies of scale by selling the same products to a wider range of clients. Our empirical evidence also shows that researchers are attracted by suppliers that can provide them with an exactly tailored device. Once firms get a reputation for customizing their products, they draw customers with niche applications and high-end profiles that offer a marketing advantage to companies that focus on a wider market. In practical terms, researchers add further extensions to the suppliers' products which then make their use possible in other disciplines, thus opening new markets to their suppliers. Lastly, we also highlight the role of researcher-suppliers relations as a special case of public procurement as a source of innovation (Chicot and Matt, 2018; Castelnovo et al. 2018; Florio et al. 2018; Edquist and Hommen, 2000).

The dissertation is organized as follows. In chapter 1, we discuss the main theoretical and empirical achievements – as well as the limitations - of the literature on public procurement for innovation. In addition, we discuss the relevant contributions related to research instrumentation within the more general science and technology studies as well as in the vein of user-innovation literature. In chapter 2, we study the effect of the University of Strasbourg on the innovative behaviour of its suppliers in terms of new-to-the-market products and their turnover. In Chapter 3, we discuss the major flows of both the CIS data the propensity score matching we employ in the first chapter and reappraise the initial empirical evidence by employing an alternative firm-level data and different empirical approach. Thereby, once we have established that the significant effect of university demand on suppliers innovation performance is clear and persistent in different datasets and empirical frameworks, in the fourth chapter we turn to explore their inner relations and processes conducive to the emergence of the phenomenon. In chapter 4, we give flesh and body to our empirical account through field-study evidence about the development of new scientific equipment among university researchers and suppliers. We dedicate special attention to the processes of formation of trusts, loyalty and informal conducts as features of organized markets where these relations unfold. Finally, we conclude and discuss the agenda of future work.

Chapter 1

University procurement of scientific equipment and corporate innovation: a literature review

1.1 Introduction

This chapter sets the theoretical background we shall use throughout the rest of the thesis. It represents an in-depth review of the interdisciplinary literature that addresses from various standpoints the links between scientific instruments as a particular resource and outcome of universities' activities and industrial innovation introduced by companies. Existing studies on university-industry interactions mainly focus on immediate channels of technology transfer and market acceptance of research outcomes, such as patenting and licensing of inventions as well as academic entrepreneurship (Markman et al., 2008). Nevertheless, there are many other channels through which university research is transferred to companies (Salter and Martin, 2001). One channel that has received few attention so far consists of new instrumentation and methodologies introduced by academics in the course of their research. While economists widely agree about the importance of the instrumentation within the academic world and about its potential benefits to the economy, the study of how instrumentation is developed is a still a scarcely documented and investigated subject in economic literature. This partially reflects the lack of appropriate microdata on equipment at the university level that would allow one to trace how equipment-related technologies emerge and to identify the paths through which they diffuse within the academic community and towards industrial companies.

In contrast, the study of how scientific instrumentation is developed has attracted the interest of a wide range of scholars outside economics, including historians, sociologists, as well as the interest of scholars in science and technology in management studies.

For instance, historians of science have explored the importance of equipment for researcher's day-to-day work. In his discussion of the underlying differences among technology development in science in the previous centuries and nowadays, Mokyr (1997) emphasizes the prevailing scientific nature of modern technologies i.e. they are built upon a comprehensive understanding of the forces, phenomena and principles that govern them. Derek de Solla Price (1965, 1968) is among the first to acknowledge the importance of equipment for the development of scientific knowledge and its influence in switching how science is conducted from the Scientific Revolution and on. The work explains that "*predominantly it was the instruments, not any special logic of Francis Bacon, that gave rise to the philosophy…If you did not know about the technological opportunities that created the new science, you would understandably think that it all happened by people putting on some sort of new thinking cap. The changes of paradigm that accompany great and revolutionary changes may sometimes be caused by inspired thought, but much more commonly they seem due to the application of technology to science.*" (1965, p. 247). Along the same lines, Rosenberg (1992) argues that the development of new instruments and methodologies represents a key output of publicly funded basic research that was subsequently adopted by industrials. Rosenberg concludes that scientific tools can be assimilated to the industrial capital goods of the research endeavour and described their diffusion path as following : *"Instrumentation originating in the world of academic research has, in the post-World War II years, also moved in massive amounts into the realm of certain industrial technologies."* (Rosenberg 1992, p. 384). In the first section of this chapter, we shall survey the above-mentioned stream of studies by sociologists and historians of science and technology, and we shall discuss how the studies have shed light on the existence of many channels of exchanges and influences that take place between scientists and firms concerning scientific instrumentation.

The acquisition of instrumentation by universities from industrial companies takes place within the legal frame of public procurement procedures. Interactions among researchers and suppliers represent a special case of "innovative public procurement" (Rolfstam, 2009). The first procurement studies (Lichtenberg, 1988; Geroski, 1990) have illustrated the significant impact of procurement on innovation through the channel of demand inducement for new technologies. Indeed, public procurement can also be seen as a demand-pull driver of innovation. The demand-pull hypothesis has evolved considerably since the first empirical contributions that examined market demand as a dominant influence upon the innovation process in the 50s, 60s and 70s (Myers and Marquis, 1969; Langrish et al., 1972; Sherwin and Isenson, 1967; Office of the

Director of Defence Research and Engineering, 1969; Fellner, 1962; Gibbons and Gummett, 1977; Gibbons and Johnston, 1974; Carter and Williams, 1957; 1959).

This first wave of studies became subject of intense critics by innovation scholars as Mowery and Rosenberg (1979) and Dosi (1984). These critiques sparked the so-called "technology-push" versus "demand-pull" debate. The heart of it was the question about the role of demand and supply in determining the rate and direction of the process of innovation. The debate put the demand-side approach studies on hold until their graduate rebound through qualitative studies on user innovations by Von Hippel (1976) and later with studies of how demand may provide a stimulus for private R&D as a source of valuable information (Malerba et al., 2007; Fontana and Guerzoni, 2008; Guerzoni, 2010). Subsequently scholars focused on a specific type of demand - that of public procurement - and they considered it as an industrial policy tool (Georghiou, 2006; Edler and Georghiou, 2007; Edquist and Hommen, 2000; Uyarra and Flanagan, 2010; Slavtchev and Wiederhold, 2011; Rolfstam, 2009, 2012) and then evaluated it's efficiency compared to supply-side policy tools (Aschhoff and Sofka 2009; Guerzoni and Raiteri, 2015). In addition, scholars have tried to assess the economic impact of technological learning for suppliers from procurement relationship with publicly funded research infrastructures by four types of methodologies such as case studies (Nordberg, 1997; Autio et al., 2003, 2004; Vuola and Hameri, 2006; Autio, 2014), surveys (Florio et al., 2018); input-output studies (Schmied, 1982, 1987; Streit-Bianchi et al., 1984) and, more recently, via large-scale quantitative assessments of CERN suppliers (Castelnovo et al., 2018).

The above innovation debate further triggered a research stream focusing on the interactions of science and technology beyond the opposition of demand and supply, and which paid more attention on the role of knowledge and learning in relation to the innovation process and systems (Freeman, 1987). These contributions emphasized the crucialness of contacts between industry and science and the increasing interdependence of science and technology (Nelson, 1962; Freeman 1974; Mansfield, 1980; Rosenberg, 1982; 1990; 1992; 1993). Furthermore, Pavitt (1993) stated that the contributions of science towards industrial innovation mostly take indirect patterns, through the recruitment of people with valuable skills and knowledge, rather than direct transfers such as publications. Similarly, Levin et al., (1987) showed that industrials appreciated basic scientific skills and techniques more highly and relevant compared to academic research results such as articles. In a study of radical innovations, it has been shown that some of the ground-breaking innovation of the 20th century would have been inconceivable without the prior accumulation of scientific knowledge. Indeed, scientific advances and techniques played a critical role during the development stage of those innovations (Mansfield, 1991). Subsequent studies on innovation have fully confirmed these results by showing that the ability of companies in the chemical and instrumental industries to benefit from external sources of scientific expertise, that were a crucial determinant of successful outcome (Freeman, 1974; Rothwell et al., 1974). For this to happen, informal contacts with university scientists have been shown to be of great importance across several industries (Gibbons and Johnston, 1974). Finally, we consider the characteristics of knowledge exchange and interactions (formal vs informal) between researchers and suppliers, and we conclude our literature review with a brief discussion about the nature of instrumentation-related scientific knowledge (Collins, 1985; Barnes et al., 1996, Latour and Woolgar, 2013). In that we also recall the basic distinction between tacit and codified knowledge (Nelson and Winter, 1982).

The rest of the chapter is organized as follows. In section 2, we review some descriptive studies of sociologists and historians of technology on various scientific equipment-related phenomenon. Such studies constitute a rich background for our subsequent field-study (Chapter 4) as they provide several historical insights from the 19th century which are still valid even in the more technologically advanced economies of the 21th century. In section 3, we recall relevant contributions belonging to two intrinsically related streams of study: demand-side and public procurement studies. We also highlight some research gaps concerning university procurement that we try then to fill in in Chapters 2 and 3. In section 4 we discuss the sticky nature of scientific knowledge embodied in instrumentation for the purpose of establishing the possible knowledge transmission mechanisms among researchers and manufacturers, which is the main focus of the study carried out in Chapter 4. Section 5 concludes.

1.2 Some historical roots

Historians of science and technology have extensively proven the existence and perhaps non-uniqueness of instrument-related phenomena. The historic approach to the emergence of scientific instruments diverges from other social studies of science in that it has a hard time to assume the opposition among science and technology, according to which technology represents the practical uses of science and remains somehow separate from the autonomous sphere of science (Layton 1971a). Such an opposition is deemed inappropriate for any inquiry into the role of instruments by historians and sociologists. Instead, technology, comprehended as a technical instrument and its underlying knowledge systems is quite pervasive to all societal systems. Therefore, main struggle of historic analysis remains how to characterize and conceive the dynamic relationship between scientific spheres and other societal spheres, and how to conceive the role that technological matters play in this relationship (Latour, 1992).

Shinn and Joerges (2011) collect a body of contributions around the notion of research-technology, a concept that finds its origins in the early 30s in an exchange between Pieter Zeeman, a Dutch Nobel Laureate physicist and Aimé Cotton, a famous French physicist. Originally, the concept of research-technology applied to general, flexible, multipurpose devices for detection, measurement and control with a large range of potential applications, that were introduced by a community connected to both science and industry. Shinn and Joerges' work evolve around the conjecture that research-technologies create a momentum that drive scientific research, industrial production and technological-related state activities to move forward along their corresponding trajectories.

These technologies were developed by individuals connected to both academia and industry, and they often emerged as an outcome of research activities oriented towards technologies that facilitated both the production of scientific knowledge and the manufacturing of other industrial products (Joerges and Shinn, 2001). As an example of successful research-technology interactions Joerges and Shinn (2001) mention the development of Jesse Beams' ultra-centrifuge as a by-product of his PhD thesis at the University of Virginia. The story of the centrifuge indicates how instrumentation was introduced before WWII i.e. by academic scientists for their investigation of new scientific problems.

After the second world war, the increase in the scale of the biomedical enterprise and its public funding had an important impact on instrumentation. A good example in this respect is the impact of the evolution of the electron microscope on biological instrumentation (Gaudillière, 2001). Nicolas Rasmussen (1997b) reconstructs the early development of biological electron on the grounds of the relationship between the Radio Corporation of America (RCA) that introduced the prototypes and a group of biologists who were their first users. RCA's strategy was to build a group of users of their microscopes that had pre-existent local goals and expertise in the domain where the new instrument could be useful. The relationship was mutually beneficial. The researchers enjoyed the admiration and prestige from the life science scientific community, while the RCA gained sales, increased its market share and obtained government support. Beyond profits, there was another goal underlying RCA's efforts: the desire to show know-how and the ability to master certain techniques with respect to its main competitor at the time (General Electric, see Rasmussen, 1997b).

The work by Lenoir et Lécuyer (1995) uncovers similar patterns regarding the role played by Varian Associates in the manufacturing of several models of Nuclear Magnetic Resonance (NMR) for academics in the 50s and documents the company's attempt to guide the adoption of NMR as a unified tool for chemical analysis. In addition, this work highlights the key role played by the manufacturer in the development of the new scientific instrument. In 1948, a group of researchers, among which the chief of the Stanford Physics Department, joined together to create a physics and engineering research company (Varian Associates) in the surroundings of Stanford. They aimed to develop technologies relevant for military use (ex: klystrons and travelling wave tubes) but also technologies with an important industrial application out of the scope of Stanford laboratories devoted to nuclear physics. Lenoir et Lécuyer (1995) also stress the role played by the shared culture between Varian and Stanford. They emphasize how Varian combined both the strive to introduce a profitable research invention of an industrialist and the academic research community values of Stanford, defined by common goals and values represented in the management and the conduct of the company. Around the 50s a group of former Felix Bloch's students joined Varian after they designed and improved existing NMR instruments. This transfer accounted just for a small part of the back and forth exchanges between a university (Stanford) and an industrial firm (Varian) during the development of the NMR. The sequences of NMR models introduced from the beginning of the 1950s until 1965 were the outcome of continuous improvements of various elements and technologies of NMR. Indeed, these improvements were made possible through close interactions with Stanford researchers, like Arnold and Packard, through careful monitoring of information in other domains and by attending academic meetings. These modifications led to a major progression in the art of NMR resolution. Communication and interdependencies between Varian and Stanford researchers and engineers took place during Bloch's weekly seminars, to which Varian's staff was invited. The seminars were a place for open discussion and stimulated reciprocal give and take between academia and industry. For instance, an early central enhancement of the new instrument was the technique for spinning the sample in the magnet, that led to the dramatic improvement of NMR resolution. This contribution was incorporated into the Varian's NMR design by the two Stanford physicists. Another important upgrading of Varian's machines, again by Stanford researchers, was the inclusion of an automatic feedback loop linking magnetic field and frequency, originally developed at CERN in Geneva and brought to Stanford in 1955. Varian's inspiration and source of innovation go beyond its nearby Stanford community to the company-wide range of scientific customers. Varian's customers addressed their demand and suggestions for instrumentation possible adjustments to the company engineers. An example of such a modification was the super stabilizer in the 60s, the idea introduced to Varian by Shell Oil's Houston Laboratory, although it originally stemmed from a discussion with Princeton physicist.

Another interesting historical example of the importance of university-industry interactions in the development of scientific instrumentation is the evolution of the use of laboratory mice in medical research documented in Gaudillière and Lowy (1998). They analyse the increasing production of laboratory mice in a period of transformation in the features of biomedical instrumentation and the development of large biomedical systems. Part of their study is about the creation and development of a private research centre, the Jackson Memorial Laboratory, which quickly turned into a large mouse supplier. Even if Jackson Laboratory's original mission was research and development, its workers were perceived by academic researchers as suppliers of their instruments. The growth of the Jackson Laboratory arose as a consequence of the rapidly expanding research market, that opened venues for the serial construction and sale of apparatus and tools. This expansion let to the emergence of conferences and journals dedicated to the scientists involved in the breeding and standardization of laboratory mice. Lowy and Gaudellière's historical account reveals that the field of mouse genetics displays several treats in common to instrument-centred disciplines.

Various phenomena in biology were brought to light thanks to the development of new instrumental settings. These developments had an important impact on biologists because they enabled them to pursue a scientific career dedicated to the use of these instruments. Finally, contrary to instrument makers, scientists accountable for instrument innovation introduced highly specific packages of tools and methods rather than generic devices.

Science and technology scholars have approached the role of instrumentation produced by industrial firms through an in-depth inquiry into the communities of users behind these devices and the resulting networks connecting academics users and industry. Thus, firms can also exert a considerable influence over scientists' practice through the formalization or regulation of certain procedures. For instance, Keating and Cambrosio (1998) consider the standardization of measurement of lymphocyte counts in the blood with a cell-sorting machine (Gaudelliere et Lowy, 1998). They focus on the relationships between academic and industry through the establishment of standards for instrument performance, showing that standards were not imposed on already existing procedures but represent an integral part of the establishment of facts about blood components (e.g. in the case of the flow cytometry). Thus, standards emerged as the outcome in a network populated by academic and industrial research unities, wherein interactions take place through workshops, exchange of materials, quality control trials, etc. In that, standardization can be viewed as another emergent property of the symbiosis between industrial and public laboratories.

Finally, the study of Akera (2007) examines synergies between IBM commercial representatives of the Applied Science Department on the one hand and IBM scientific customers on the other hand. It documents how IBM representatives acted as information pipelines for scientific customers' specific requirements needs, which IBM gradually integrated into its corporate policy and product-development strategies. It describes the successful example of one of the first IBM salesmen in California (Donald Pendery), who was able to gather new ideas from users while travelling from site to site. In this way, he developed an ability to collect strategic information that was relevant and most certainly beneficial to IBM's product development.

Overall, IBM's Applied Science Department achievements consisted in the establishment of a "social mechanisms" to channel profitable information and allowed the matching between IBM scientific customers' demands and its manufacturing capabilities, which eventually led to the design of an appropriate product line. This relationship of mutual dependency entailed an extensive exchange of knowledge, based on academic norms of open exchange. The early exchange network initiated by the Applied Science Department team grew into the more formalized transfers that would take place between IBM and its users' group SHARE (see Akera, 2007).

The above historical discussion provides a rich account of the possible interactions between academics and industry and of their impact on firm innovation. A common aspect of the above narratives is the active role of scientists both as stand-alone researchers and as part of a community of users. However, instrumentation acquisition at modern universities takes place in a particular legal framework – researchers cannot purchase a piece of equipment from any given supplier but only the one who has won a public procurement bid. This is because, interactions among academic researchers and manufacturers of instruments have also attracted the attention of public procurement studies that we survey in the next section.

1.3 Demand-side studies and innovative public procurement

Being a particular instance of demand, public procurement is intrinsically linked to the debate about the role and magnitude of demand as a source of innovation. The emergence of scholars' interest and contributions for the demand-pull hypotheses can be traced back to the seminal work of Gilfillan (1935) that points to market demand as a leading factor determining the rate and direction of innovation via monetary incentives. The literature on the demand-pull hypothesis mostly developed in the 60s and the 70s. For instance, Myers and Marquis (1969) explored the initial sources of information used for the further development of innovation at the firm level in a sample of 567 innovations across 5 industries. Their main finding was that the identification of market demand is a more frequent factor in innovation than the existence of a technical potential. Next, Langrish et al., (1972) performed case studies on 84 commercially successful innovations which received the Queen's Award for innovation in the period 1966-1976. While just 11 innovations (or 13% from the whole sample) were categorized as "major", the identification of needs was found to be driving force in 16.7% of the total observations. Therefore, Langrish et al.

inconclusively acknowledge their difficulty to disentangle among different types of innovation within large samples.

Furthermore, with the HINDSIGHT project, the U.S. Department of Defence carried out a cost-benefit analysis of the importance of needs for the emergence of 710 technological events such as satellites, aircraft, and missile systems (Sherwin and Isenson, 1966; Greenberg, 1966). The results revealed that only 9% of inventions were “science events” due to both basic and applied research, while 91% were “technology events”, triggered by earlier technological inventions. Sherwin and Isenson (1967) establish that 97% of science events were induced by a certain need while only the remaining 3% appeared as a result of directionless research.

As a response to these results, the U.S. National Science Foundation launched a subsequent project (TRACES) aimed to analyse the relative importance of science and technology for innovation by adopting a lengthier period of observation and focusing on the earlier phases of the process. The foregoing project’s main finding was that basic research had a major role in 341 research events: in 70% of them were a mix of mission-oriented (prompted by research without specific regard for application) and non-mission-oriented (to develop knowledge relevant for a specific application in view of the development of prototype, product or engineering design) projects, 20% were clearly mission-oriented and 10% were involving prototype development and engineering directed toward the demonstration of a specific product or process.

In another study, Gibbons and Johnston (1974) explored the sources and nature of the information involved in the problem-solving process related to 30 innovations. They found that while upstream research can generate new research avenues, downstream technical progress can also influence upstream research. According to Gibbons and Johnston, perceptions of needs and demand, shaped by more fundamental understandings influence the outcome of the dynamics among upstream and downstream research. Personal contacts with scientists are pointed out as a direct source of applied and diversified knowledge for particular equipment or alternative designs.

Moreover, following a linear representation of innovation endeavour, Carter and Williams (1957, 1959) explored technology as a component in the circuit linking basic research scientists at laboratories to final consumers of products. Concerning demand, they concluded that explicit consideration of market demand was rare in firms’ decisions about their investment in R&D.

However, considering the inception of R&D projects, they find that 25% of innovations were initiated in companies' internal R&D departments, while 18% were spurred off by the forecasting that future market existed for that particular product. Likewise, Baker et al. (1967) explored the nature of the stimuli to the research of corporate R&D laboratories focusing on the emergence of new idea and concepts within firms' R&D teams. Their main finding is that the sources of the most valuable ideas are often to be found outside the company i.e. 85% of the best ideas were found to arise from need-means sequences.

Finally, the SAPPHO (Scientific Activity Predictor from Patterns with Heuristic Origins) project conducted at the Science Policy Research Unit (SPRU) at the University of Sussex provided evidence about the importance of users in the development of new products and processes. To this end, the study compared two groups of similar, twins' innovations whereas one of them represented success and the other one a failure. A comparison between the two groups revealed that smooth interactions among companies' departments and with external organisations such as customers and suppliers emerged as the most significant difference among failure and success (Rothwell 1972, 1977). Along similar lines, Schmookler (1996) empirical study made use of invention and secondary innovation data to show that innovation is higher in fields where market demand is strong. Schmookler (1996) also finds a stronger statistical correlation between the volume of innovative activity in capital goods, measured by patents and the volume of investment activity in user industries, compared to the relation between the volume of innovative activity and output in the supplier industries.

The above studies consisted in a much-needed effort to inform policymakers through empirical analysis of the influences which drive innovation and channel its direction. At the same time, they became subject to extensive scrutiny by innovation scholars who emphasized both their theoretical and empirical flaws. First Mowery and Rosenberg (1979) and then Dosi (1984) argued that most studies on demand-pull approach fail to deliver a sound theoretical and empirical support of the idea that needs expressed through market signalling are the main driving force of innovative activity. These critiques focused on three main points.

Firstly, the definition of demand and needs across studies was judged as inconsistent, too broad and overall ambiguous to be considered as an economically relevant concept (Mowery and Rosenberg, 1979; Scherer, 1982; Kleinknecht and Verspagen, 1990; Chidamber and Kon, 1994).

Dosi (1984) pointed out that the demand-pull approach fails to district demand from the "limitless set of human needs". For this reason, the main flow of all those studies consists of the "incapability of defining the why and when of certain technological developments instead of others and of a certain timing instead of other" (Mowery and Rosenberg 1979, p.229). The second line of criticism was that demand theory is overall not fit to account for both major and minor technological advances. Instead, it explains incremental technological progress on existing products and processes better than it does disruptive changes, thereby failing to explain for the most significant innovations (Mowery and Rosenberg, 1979; Walsh, 1984). A third critique focused on some implicit assumptions concerning firm capabilities, expressing scepticism about the mechanisms through which firms can effectively identify latent needs from an almost infinite set of possible human needs. Besides, scholars have questioned the extent to which firms, in general, have access to a large enough stock of techniques to address the variety of needs that could be expected to emerge and how far firms might venture from existing routines to satisfy unmet demands (Simon, 1959). Finally, scholars expressed doubts as to what extent the demand approach took into consideration important microeconomic aspects of technological efforts that also account for the interplay among science, technology and manufacture, thereby undermining the ability of the approach to apprehend the whole complexity of scientific and technological processes (Dosi, 1984).

An important outcome of the above debate was the emergence of a new perspective on innovation reflecting the interactions between technology and demand (Lundvall, 1985, Rosenberg, 1976). The resulting framework integrated more balanced versions of each approach and claimed that both supply and demand-side factors were important in order to explain the emergence of innovation. Mowery and Rosenberg (1979 p. 143) explained that neither technology nor demand could be by itself an enough to spur innovation but "*One should consider them each as necessary, but not sufficient, for innovation to result; both must exist simultaneously.*". Likewise, after empirically revisiting and re-examining Schmookler's work, Kleinknecht and Verspagen (1990) found a considerably lower effect of demand, therefore they stressed the importance of combination between both influences. In a similar vein, Freeman (1974) showed a high correlation among the probability that an innovation reaps commercial success and developers' comprehension about user and customer needs. Furthermore, Pavitt (1984) showed that industry-specific characteristics influence the relative importance of supply and demand and defined four categories of firms and sectors: supply-dominated; scale-intensive; specialized suppliers and science-based producers. Mowery and Rosenberg (1989) suggest that the final acceptance of technology could be dependent on its complementary status to other innovations. Eventually, Freeman (1994) declared the confrontation between demand and technology as irrelevant and asserted that it is the coevolution and evolvement of technology and demand that should be taken into consideration by scholars.

As a result of these developments, demand-oriented studies evolved a lot. Scholars made methodological efforts to refine the demand-pull approach and the notion of demand itself. The vague idea of demand present in seminal studies was replaced by a more precise set of consumer needs with a high need determinateness (Teubal 1979, Clark 1985) and sophistication (Guerzoni, 2010). The individuals with such specific forward-looking technical competences were labelled "lead users" (von Hippel, 1986); "pioneers" (Rogers, 1995) or "experimental users" (Malerba, Nelson, Orsenigo and Winter, 2007). The seminal work of von Hippel (1976) focused on the sectors of scientific instruments and semiconductors. The work found that 77% of commercialized new products were originally designed by instruments users of academic or industrial labs, who transferred their prototypes to companies that took care of testing, further development and marketing. Furthermore, Von Hippel observed that in the domain of scientific instrumentation users are largely responsible for disseminating their innovations as they made an effort to publish or disclose information about the usefulness of their inventions as well as instructions of use in the form of scientific papers, communications and brochures. In later works, von Hippel explored the emergence of innovation in the semiconductor sector and established that 67% of the most valuable innovations originated from users and 46% of them were transferred to producers through multiple interactions. These results refine the former ones and give a shred of further evidence about the active involvement of users into the process of transformation of their inventions into commercialized products as they do so in close collaboration with manufacturers (von Hippel, 1977). In addition, Riggs and von Hippel (1994) examined the characteristics of innovations made by users and manufacturers that upgraded two major types of scientific instruments. They show producers' innovations mostly aim at improving the efficiency of already existing features wheras users' modifications to the instruments add new functionalities allowing the implementation of new uses of the same device. For instance, in the case of electron microscopy researchers' innovation allowed observation at sub microscopic dimensions, while the manufacturers introduced automatic adjustment to facilitate the function (Riggs and von Hippel, 1994).

In this perspective, Guerzoni (2010) identifies two distinct mechanisms for the influence of demand on innovation. Firstly, the effect takes place through the size of the marker i.e. the volume of the demand and larger market induces higher expected profits for companies, increasing firms' incentives to invest in R&D. This first effect is called the "incentives effect" (Schmookler, 1962). Second, demand can influence innovation through its specific quality i.e. as a source of valuable information from users to producers it reduces the uncertainty inherent to the development of new products. This second effect is called the "uncertainty effect" (Myers and Marquis, 1969). Fontana and Guerzoni (2008) explore empirically the joint effect of the above mechanisms on firms' product and process innovations using cross-section data on innovative companies in Europe. They found statistical evidence that the incentive effect leads mostly to process innovation, while the uncertainty effect to product innovation.

Besides the aforementioned works on lead-users, the demand-pull vs. technology-push debate had a significant impact on the field of public technology procurement or public innovative procurement. Among the first significant contributions in the domain is the study of Lichtenberg (1988) that explored the effect of competitive and non-competitive procurement contracts on firms R&D. Employing Compustat and the Federal Procurement Data panel of 169 firms, Lichtenberg found that the effect of public (competitive) procurement on firms‘ propensity to engage in R&D is significantly higher than the effect of private (non-competitive) procurement contracts. In a subsequent study on defence procurement, Geroski (1990) assesses public procurement as a greater stimulus for industrial innovativeness than R&D subsidies. Geroski's results suggest that public procurement can act as a relevant policy tool for the generation and diffusion of new technologies by creating demand for new products or processes and ensuring a minimal market size in the initial phase of innovation. Dalpé et al. (1992) investigated the role of the public domain as the first user of technological innovations and found out that 25% of Canadian innovations were for the first time applied by the public sector. On these grounds, Dalpé et al. (1992) conclude that public procurement can support the risk that novel technologies present and, in such a way, support the emergence of markets for such technologies. In a subsequent work, Dalpé (1994) specified the improvement of public services and the achievement of certain public goal as the two major arguments for the use of procurement as a policy tool.

Furthermore, Edquist and Hommen (1998) provided a theoretical framework of public procurement and distinguished between three types of procurement: public, catalyst and cooperative. In addition, Edquist et al. (2000) gathered a compelling set of cases illustrating the potential for innovation involved in procurement as a policy instrument.

The study of Edler and Georghiou (2007) is represented as a turning point in the demand-side literature as the authors proclaim government procurement as an essential tool of a demand-oriented public policy and explain its rationales and justification by the existence of market failures. Edler and Georghiou's contribution revived scholars' and policymakers' interest into public procurement as an innovation-related policy tool and triggered a new wave of studies on the subject. These contributions aimed to establish taxonomies among various types of the broad range of different interactive environments in which public organizations may act as lead users of innovations (Hommen and Rolfstam, 2009; Rolfstam, 2015). Similarly, Uyarra and Flanagan (2010) discuss a framework to analyse the ways through which procurement can impact upon innovation and put forward a typology of procurement based on the type of goods and services procured.

Despite the above-described bulk of studies, the empirical evidence of the actual impact of various procurement categories on innovation remains rather rare since the first studies in the 80s and 90s. Among the handful of recent empirical studies Aschhoff and Sofka (2009) evaluates the effect of public procurement at the firm level using cross-sectional survey data on 1 100 German firms. The Mannheim Innovation Panel data allows them to connect firm-level innovative performance with various policy instruments instead of only one policy at a time. The four sources of innovation influences are public customers; law and regulations; universities (R&D collaborations) and R&D public funding. Information on public procurement comes from a question addressed to firms with respect to the industry origin of their customers. If the latter belonged to the domain of public administration; defence or social security the respondent was considered as public procurement related. Among the four policies, non-defence related public procurement and universities collaborations are found to have the highest and equal impact on companies' market novelties sales. Furthermore, Slavtchev and Wiederhold (2011) develop a Schumpeterian growth model with heterogeneous industries and simulate the dynamic effect of a variation in public demand spending on the economic growth path. An analysis of the empirical plausibility of their model with US industry-level procurement data for the period 1999-2007 showed that government procurement leads to higher return and technology diffusion in technologically intensive industries. The study of Guerzoni and Raiteri (2015) provides fresh empirical evidence on the impact of public procurement on firms' innovation taking into consideration both demand and supply-side policies in a multi-treatment quasi-experimental framework. Their study uses cross-section survey data from the Innobarometer on "Strategic Trends in Innovation covering 5238 companies in the period 2006-2008. Such data allowed to the authors to include a very accurate indicator of whether the firms have received the procurement treatment by including a question indicating if at least one procurement contract that the company has won gave it the possibility to sell innovation. Guerzoni et Raiteri's investigation also challenges previous supply-study studies by showing that when controlling for other policies, subsidies' efficiency decreases significantly while public procurement becomes more effective in comparison to other tools. Therefore, their results show that public procurement is effective in raising private investment in R&D in particular when it is combined with other technology policies. Ghisetti (2017) explored the effect of innovative green public procurement on 3001 manufacturing firms in the EU, Switzerland and the USA by means of propensity score matching and found out that the treated firms sample counted 11% more environmentally innovative companies than the counterfactual group. The effect of green public procurement on non-green innovations were found to be positive and significant while weaker in magnitude – the number of innovating treated firms being 6.6% higher than the control units. Along the same lines, Czarnitzki et al., (2018) study the impact of innovation-directed procurement contracts on the innovative behaviour of 2844 firms in the 2013 German Community Innovation Survey (CIS) by estimating the Average Treatment Effect on the Treated. Contrary to the previous studies, Czarnitzki et al., (2018) find that treated firms enjoyed higher sales from products new to the firms, but not to the market. Therefore, they concluded that instead of opening new markets, procurement contracts stimulated the diffusion of new (yet already existing) technologies and firms' imitation.

Finally, in a very recent study, Raiteri (2018) explores the impact of public procurement in terms of adoption and pervasiveness of given technologies using patent data and patent citations in a quasi-experimental setting. Raiteri detects that patents receiving a citation from patents related to public procurement have a higher generality level index compared to the counterfactual group without such citations. In a subsequent contribution, de Rassenfosse, Jaffe and Raiteri (2019) put together a 3PFL data on Patents and Publications with a Public Funding Linkage that holds information on public procurement and research grants and performed an empirical analysis of procurement contracts.

The above quantitative studies reveal the efforts of scholars to explore in depth the effect of innovative public procurement on suppliers' innovation performance utilizing quantitative methodology. Nevertheless, the empirical evidence remains somehow sparse and scattered. Besides, scholars have argued that it is important to assess the impact of public procurement regardless of it is explicitly geared towards innovation, since often new technologies emerge as an unintended by-product of "regular" procurement. For instance, Dalpé (1994, p.66) describes such effects as following: "decisions concerning prices, quantities, and standards affect innovation, positively or negatively, in a group of industries involved in government procurement." In the same spirit, Uyarra and Flagan (2010) recall that what is often been presented in the literature as procurement-induced innovation, is a side-effect of normal procurement instead of an outcome of an intentional drive to foster innovation. Hence, innovation as a side-effect of public procurement has been related to the ability of the public domain to act as "early-state or lead-user" of technologies and in such way to support the costs and risks of learning and refining novel products (Aschhoff and Sofka 2009 p.2).

One central issue in the processes of knowledge dissemination and co-invention among users and manufacturers, which were the main focus of all the above described studies, concerns the nature of the knowledge transmitted. Scientific knowledge related to techniques has a very important tacit dimension that makes it costly to communicate (Stephan, 2012). Therefore, scientific knowledge is tacit and sticky (Von Hippel, 1994). The stickiness of scientific knowledge is a central notion for our subsequent analysis (Chapter 4) because it has a straightforward consequence of the analysis of the interactions' mechanisms among researchers and suppliers. For instance, the communication of sticky knowledge calls for close interactions with researchers through face-to-face and informal contacts and has a lot to do with the placement of people and their physical contacts. In the following section, we shall discuss at length the tacit nature of scientific knowledge and the role it has on knowledge transmission mechanisms between universities and industry.

1.4 Nature and varieties of scientific knowledge

The distinction between "tacit" and "codified" knowledge finds its origins in a debate within the community of sociologists of scientific knowledge that emerged in opposition to the established approach of Robert Merton (Barnes et al. 1996, Collins 1985). Merton's main point was the study of "the normative *structure of science with its institutionally distinctive reward system*". In contrast to Merton, other studies focused on the cognitive features of researchers' work and the influence of sociological notions on scientific ideas themselves (Collins 2001, Latour and Woolgar 2013). These works revealed that some varieties of knowledge in day-to-day scientific activity, for instance how to handle a new and experimental scientific instrument, are not communicated in an explicit way between researchers. For instance, in a study of a set of scientists working on the building-up and use of the Transversely Excited Atmospheric (TEA) laser, Collins (1974) observes that learning, skill and knowledge sharing among them did not occur through any kind of written or formalized means. Other sociologists provided further evidence that knowledge diffusion comprehends something that cannot be transmitted in a written way and therefore should not be assimilated to information (Callon, 1995). The main result of these studies was that scientific knowledge contains important tacit and sticky aspects (context matters, and knowledge is very localized). Consequently, to get benefits from scientific knowledge, firms should maintain close interactions with universities. Rather than distant communication e.g. via skype or videoconferences, such interactions should occur in the most natural face-to-face way. The stickiness of scientific knowledge also imposes to firms to be in physical contact with university researchers. In other words, the cost of knowledge transmission increases with the distance from its source. Applying this argument to the domain of scientific instrumentation, knowledge about the functioning of a given technology that arises as a by-product of researchers' scientific activity has been pointed out to be intrinsically more tacit per se. The high tacit component of such knowledge is pointed out as one of the reasons manufacturers would be attracted by the proximity to the place of emergence of this valuable knowledge (Pavitt 1987, Nelson 1992, Patel and Pavitt 1995).

The distinction between codified and tacit can be very superficial or even misleading for the economic discussion of the transmission mechanisms of technological knowledge. Indeed, once some of the more elaborate aspects of the concept of tacit knowledge are put forward, it becomes clear that more nuanced view of the various mechanisms and their peculiarities should be considered. Nelson and Winter's Evolutionary Theory of Economic Change (1982) emphasizes these aspects and it explores in depth the tacit aspect as a reflexion of various features related to the holder of a certain piece of knowledge, his awareness about it, his incentives to put it in words and his environment. By drawing on the Michael Polanyi (1962) concept of "personal knowledge", Nelson and Winter (1982) develop and discuss the importance of tacit knowledge, providing useful insights into an alternative sphere of knowledge – that of organizational capabilities and routines approached by the analogy of individual behaviour and skills. According to Nelson and Winter (1982) individual skills are often highly tacit such that *"a skilful performance is achieved by the observance of a set of rules which are not known as such to the person following them."* (Polanyi, 1962 p. 49). The rules "not known as such" even to the person who complies with them refers to the difficulty to express or to articulate them in words. This implies that the person could not provide an exact explanation of the rule itself and therefore he might not be even aware that he has been following a sequence of rules. The lack of awareness suggests that one might only be partially conscious of the rules that are followed. Moreover, tacitness is not an intrinsic knowledge feature since "*The same knowledge, apparently, is more tacit for some people than for others*" Nelson and Winter (1982, p. 78). The degree of tacitness of a certain piece of knowledge will depend on the knowledge base of each of the parties and on their incentives to communicate and articulate given know-how.

Cowan *et al.* (2001) build upon Nelson and Winter's notion of "articulability" and focus on the knowledge that can be articulated and encoded with the final aim of establishing the circumstances under which such knowledge will be codified (Cohendet and Steinmueller, 2001). Cowan *et al.* (2001) discuss the importance of codes, standards, models and rules under the notion of "*codebook*". The codebook can act as a reference or a repertory when all the parties can interpret the codes and have similar interpretations of them. Since not everybody has the same specialized knowledge, a piece of codified knowledge "*for one person or group may be tacit for another, and an utterly impenetrable mystery for a third.*" (p. 10). Thus, Cowan *et al.*, (2001) join Nelson and Winter (1982) in emphasizing the importance of knowledge activities' context for the development of a solid codebook.

In our study, we aim to explore knowledge activities and interactions between researchers and suppliers and we are thus interested in how the above-mentioned codebooks are developed initially – i.e. at the beginning of interactions between two parties; in a new discipline; for new technology. In the beginning, there will be no codebook. So, to create it, all the participants will start to codify relevant pieces of knowledge to express models and create elements for the codebook. However, the starting codification requires the establishment of a specialized dictionary and language between participants. The dictionary consists of a specific vocabulary by the means of which participants will describe the models. At the beginning of the emergence of new technology, the establishment of a standard language is an essential part of the collective activity of codification (Cowan et al., 2001). In such a framework, knowledge can be taxonomized according to the existence or not of the codebook. When knowledge is articulated and codified, it is recorded in a standard codebook and serves as a reference. When knowledge is unarticulated, instead, it is not explicitly referred to during knowledge activities. In this case, two possible instances should be considered.

In the beginning, the knowledge is unarticulated and truly tacit, because it is not embodied in devices or has not been described and therefore it cannot be recorded in any type of codebook. In the second phase, although knowledge is unarticulated, it is embodied in instrumentation, artefacts and thus a codebook exists. However, in the course of knowledge activities and interactions, the codebook has not been mentioned as a reference by the parties. Since from an outside perspective the codebook is not obvious, it looks like the people involved in the interactions are relying on truly tacit knowledge even if no codebook is available at all. This situation is called a "*displaced codebook*" (Cowan et al., 2001) and it involves a codified background knowledge, even if this knowledge is not evident, manifest. A reference codebook does exist, but it is imperceptible because it is rarely indicated. Therefore, participants in activities building on this type of knowledge use advanced terminology, technical language and disciplinary jargon and still understand each other without any reference to manuals or codebooks. In this setting, the participants often have taken the codes and models of the underlying codebook as given. Accordingly, to penetrate their group and have a worthwhile interaction with them, one should be able to overcome the need to rely on the codebook and show that he has the same internalized perspective of it.

The displaced codebook represents an instance in which background knowledge is codified although its codification is not evident because of the existence of other norms between individuals operating within the same domain of knowledge. According to Cowan and al. (2001) this type of codified (in general) but not articulated (in the specific context) knowledge corresponds to the scientific endeavour as described by Kuhn's concept of normal science (Kuhn, 1962). In this framework, researchers explore various theoretical and experimental trajectories within a given *scientific paradigm* or *explanatory framework*. They draw upon and contribute to a codified body of knowledge. However, the underlying content of that knowledge remains tacit among community members. It can be questioned and challenged in the event of a debate on its substance, storage and recollection. Similarly, a technology that emerges in such a framework is codified although the content of its codebook is not evident.

The finer distinction between different types of knowledge beyond the dichotomy of simple codified and tacit knowledge allows one to refine the analysis of the communication mechanisms that are engaged in the processes of learning and transfer of such knowledge. Furthermore, such a distinction allows one to get a more complete and nuanced vision of the various channels and ways through which knowledge is created and diffused among researchers and their suppliers and, ultimately, on how the latter can significantly benefit from it.

1.5 Conclusion

In this chapter, we provided a brief survey of the literature that has explored the relationship between the demand for instrumentation and innovation performance. We started with an overview of the various conduits of influence of scientific equipment development on innovation by examining the works of sociologists of scientific knowledge and historians. These studies provide a general guideline for our further analysis and shed light on the various paths of mutual knowledge exchanges occurring between researchers and industrials in the development of research technologies. Next, we reviewed the earliest studies on demand as a source of innovation and we surveyed the subsequent debate that confronted technology and demand as two conceptually and empirically different perspectives on the emergence of innovation. This debate gave rise to a more balanced view of innovation as a complex process of learning among users and producers of technologies. We also discuss how the above debate led to a new wave of studies on a specific type of demand – the one coming from public institutions such as the military equipment and large science infrastructures. Our review of this recent and growing field of procurement studies showed a great variety in the methodology applied by researchers consisting of case studies; surveys and large-scale empirical works. However, it also reveals a few important gaps concerning the study of instrumentation procurement at universities. Although scholars have emphasized the importance to study the impact of public universities procurement as extension to the existing evidence on big science infrastructures (Autio et al., 2003, 2004; Florio et al., 2018; Castelnovo et al., 2018), to the best of our knowledge none of the existing contributions tackles the procurement spending by public universities. Furthermore, the handful of existing empirical works on the impact of procurement on innovation do not employ a specific micro-data on procurement spending. Finally, even if scholars in the domain have discussed the importance of procurers' knowledge in the vein of competence demand-pull innovation (Antonelli et Gehringer, 2019) there is still lack of studies on how or if university procurement differs from the tendering of other public institutions. In addition, it is not clear via what kind of mechanisms procurement affects suppliers' innovation behaviour and the broader economy. Lastly, in the fourth section, we made a quick review of the types of scientific knowledge involved into the development and management of university scientific equipment concluding that equipment embodies a lot of tacit or unarticulated knowledge. One main point emerging from this review is that to get access to such scientific knowledge companies need to establish and maintain specific kind of rich informal interactions with academic researchers. Instrumentation related formal and informal interactions have been pointed out as a special channel of university-industry interactions which contrary to the bulk of existing evidence arises from the university procurement of equipment instead of its traditional role of mere suppliers of knowledge.

In the following chapter of this dissertation, we shall try to tackle the above gaps through mixed-method methodology. First, we shall employ original first-hand micro-level dataset on university expenditures to study empirically the effect of university procurement on suppliers' (Chapter 2 and Chapter 3). Next, we shall turn to study the context and underlying mechanism of this influence and discuss in detail how university procurement is special (Chapter 4).

Chapter 2

Demand-pull innovation in science: Empirical evidence from a research university's suppliers[1]

2.1 Introduction

In the 1920s, Philipp Ellinger, a professor of pharmacology at Heidelberg University, was performing cutting-edge research on the functions of human organs and the detection of bacteria in living tissues. At that time, existing fluorescence microscopes were of little use for observing and studying samples from opaque living organs, so Ellinger decided to develop his own intravital fluorochroming prototype. A few years later, inspired by Ellinger's work, the German manufacturer Carl Zeiss was able to produce a new fluorescence microscope, a sophisticated instrument incorporating vertical illumination with a water immersion objective and filters. Between 1929 and 1931, Ellinger used the Zeiss microscope to make significant advances in our understanding of the physiology of urine formation. But the story does not end there. The use of this new instrument, intimately bound to Ellinger's methodological insights, aroused great interest among instrument manufacturers and academic researchers alike. Indeed, it was not long before other firms – most notably Bausch & Lomb, Leitz, and Reichert – were developing similar devices in close cooperation with other biomedical researchers eager to apply Ellinger's technique (Masters, 2006; Kohen, 2014). Ellinger's story is by no means an isolated case of a joint development project involving science and technology, but it is one of the first successful cases illustrating the effect of academic demand on corporate innovation.

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[1] This chapter is based on a paper with the same title co-authored with Stefano Bianchini (BETA Strasbourg) and Patrick Llerena (BETA Strasbourg) and published in Research Policy

Criticism has long been levelled at the lack of involvement of academic researchers in the activities of knowledge and technology transfer. However, the last thirty years have seen a significant shift in the perception policymakers have of universities, as they begin to acknowledge their role as central actors in the knowledge-based economy. Increasing expectations of the part universities can play in this so-called "third mission" have led to a series of policy transformations aimed at fostering links between academia and industry. The commercialisation of academic knowledge via patenting, licensing and spin-off companies has been the cornerstone of science and innovation (S&I) policies since the early '80s (Mowery et al., 2001). For instance, the Bayh-Dole Act (1980) authorised US universities to obtain intellectual property rights on inventions funded by the US federal government and enabled them to license these inventions. Similar policy actions were taken by a number of OECD governments (Mowery and Sampat, 2004). The rationale behind these initiatives was the belief that universities were producing numerous inventions of high economic value but were failing to transfer them beyond the boundaries of the academic world and so obtain the corresponding economic benefits (Kenney and Patton, 2009).

The university-invention-ownership model generated a large body of research that focused almost exclusively on supply-side measures, such as academic commercial activities, as a way of forging university-industry links and the performance of actors involved in the process (see, among many, Bonaccorsi and Piccaluga, 1994; Jensen and Thursby, 2001; Schartinger et al., 2002; Thursby and Kemp, 2002; Cohen et al., 2002; Mowery and Ziedonis, 2002; Shane, 2004). However, these studies run the risk of providing an overly simplistic image of the interactions between universities and firms, and of failing to account for the diversity, and corresponding impact, of the mechanisms via which academic knowledge is transferred to industry (Dosi et al., 2006; Nelson, 2012; Autio et al., 2014; Kenney and Mowery, 2014). More recent contributions consider a wider range of alternatives measures for both formal and informal university-industry linkages, including personnel mobility (Dietz and Bozeman, 2005; Zolas et al., 2015); hiring of graduate students (Stephan, 2009); collaborative R&D (Monjon and Waelbroeck 2003; Fritsch and Franke 2004; Lööf and Broström 2006), contract research, consulting (Jensen et al., 2007; Murray, 2002) and providing ad hoc advice. This involvement of academic scientists in such activities has become known as "academic engagement" (see, for example, D'Este and Patel, 2007;

Perkmann and Walsh, 2007; Perkmann et al., 2013).[2] While commercialisation implies that an academic invention is exploited so as to reap financial rewards, academic engagement encompasses a broader set of activities and is pursued for manifold objectives, such as to access resources relevant for research activities via additional funds and specialised equipment, to access learning opportunities via field testing, or to obtain new insights into practical questions (Lee, 2000; D'Este and Perkmann, 2011).

Nevertheless, these recent studies are not exempt from criticism either, as they exclusively rely on supply-side measures (Nelson, 2012). In particular, they often restrict the role of the universities to that of a provider of knowledge and technology for industrial applications.

This chapter aims to improve the above framework by empirically assessing a so far neglected mechanism of university-industry knowledge exchanges. We present a different perspective according to which these exchanges, and their corresponding benefits, materialise as a result of demand for customized goods and services. In line with the traditional Schumpeterian view on technological innovation, there is often a tendency to focus on scientific/technological aspects of the innovation process and to neglect the demand-side of the story. However, economic historians and economists of innovation have embraced for long time the view that emerging technological paradigms can be shaped by market demand dynamics (Dosi, 1982, 1988; Mokyr, 1990; Bairoch, 1993).

Our work is also related to historical and sociological studies of science that explored research laboratories as a place of production of science (Lowy et Gaudillière, 1998). Within this literature, sociologists and historians of science have focused on the research endeavour as an organized activity which relies on instrumentation, methodologies and work configurations. Studies in this research strand also explore the circumstances under which some scientific instruments have emerged and evolved in light of changing demands inside and outside the academic community (Shinn, 1998).

Overall, these contributions provide a detailed and compelling account of the myriad of circumstances and technological fields where scientific instrumentation played role in scientific advances and innovation. They reveal multiple forms of associations, institutions, journals,

[2] Although of recent development, the concept has a long tradition, particularly at universities that seek to provide practical and technical education whilst assisting local firms and the local economy. Interested readers should consult the historical anecdotes recounted in this regard by Mowery et al. (2015).

meetings and the multi-professional and -personal identities that endorse these technologies (Joerges and Shinn, 2001). These studies tremendously enrich our understanding of university-industry interactions. At the same time, they do not address at all the issue of the quantitative measurement of the direct effects of these technologies on firm performance.

This study aims to improve the above literature by quantifying the impact of university demand on the innovative performance of firms that constitute part of the scientific value chain – i.e., firms that supply goods and services to research universities. It is our conjecture that the demands universities make to firms are quite unique, since academic scientists often encounter a specific need long before the majority of firms in the marketplace encounter it, and, moreover, universities are better positioned to benefit significantly by obtaining a solution to that need. As a result, scientists may act as "lead-users" of technologies and indirectly support the costs of learning and refining associated with the development of new products (von Hippel, 2005; Stephan, 2012). In short, the demand of academic scientists for custom goods and services may provide a stimulus for firms to introduce novel products and organisational concepts, thus contributing to the shaping of technological trajectories and fostering product and process innovations.

Here, we perform micro-econometric analyses in a quasi-experimental setting to assess the impact of a large French public university on the innovative performance of its suppliers of research equipment and materials. The quantitative approach is possible because of an original and unique dataset containing fine-grained information on university purchases and associated suppliers. These data are complemented by accurate details on various aspects of the innovation process and by the financial statements of the university's suppliers and a representative sample of French businesses. The data infrastructure allows us to exploit a wide set of innovation-related variables to benchmark suppliers and other businesses in terms of their innovative performance, while controlling for a large number of firm-level attributes and contextual factors. We show that firms supplying university laboratories have a significantly higher propensity to introduce new-to-the-market product innovations and to enjoy higher sales from these products, all other things being equal. In contrast, we do not observe any significant effect on process innovation. All these findings are very robust to different econometric methods and alternative proxies of technological innovations.

The contributions made by this chapter build on and extend the previous literature in several ways. From a theoretical perspective, our results indicate that public universities may also have a considerable economic impact on innovation via the demand side. As such, the study makes a unique contribution to the existing literature on university-industry interactions which to date has focused mainly on supply-side factors. Furthermore, our results contribute to the rich literature analysing the scale and breadth of the economic contribution made by universities (see, for example, Drucker and Goldstein, 2007; Lane and Bertuzzi, 2011; Valero and van Reenen, 2016). Recent studies have focused on alternative measures of large research infrastructures' impact on their suppliers of high-technology orders. Exploring the collaborations between CERN and its suppliers, Florio et al. (2018a) find that being a CERN supplier has a positive effect on firms' performance and on spill overs along the supply chain. Along the same line, in a quantitative assessment using balance-sheet data for 350 CERN suppliers for the period 1991-2004, Florio et al. (2018b) show a statistically significant correlation between procurement events and suppliers' R&D efforts, knowledge creation, productivity and profitability (and economic performance).

Indeed, universities have far-reaching impacts on the economy, effects that are often interrelated. The purchase of goods and services is just one of these impacts, as it increases turnover, and supports employment, in the companies that supply them (Lane et al., 2018).[3] Our findings suggest that the actual contribution made by research universities could be much larger than what is typically estimated, since it also includes dynamic effects in the economy associated with demand-pull innovations. Finally, this study complements a large body of fine-grained studies that delved into similar dynamics emphasized by scientific practitioners, sociologists, historians as well as science and technology studies scholars (Lenoir and Lécuyer 1995; Rasmussen, 1996; Gaudilliere, 1998; Keating and Cambrosio, 1998; Joerges and Shinn, 2001; Akera, 2008), by providing a quantitative evaluation of this phenomenon.

The rest of the chapter proceeds as follows. In Section 2, we identify some of the theoretical roots of our study. We describe the data infrastructure in Section 3 and the methodology we

[3] For instance, a recent policy report (LERU 2015) quantifies the economic contribution of a combined group of 21 universities located in ten countries throughout Europe and shows that the direct "suppliers effect" represents more than 6% of the total contribution in terms of gross value added and more than 10% in terms of jobs supported. By way of example, common supply-side mechanisms such as technology licensing, consultancy, start-up and spin-off companies account, respectively, for 1.1, 4.4, and 3.8% in terms of gross value added, and for 1.3, 5.3, and 4.3% in terms of jobs supported.

employ in our analysis in Section 4. Empirical results are presented in Section 5. Finally, Section 6 discusses the implications of our results in light of the existing literature and concludes.

2.2 Conceptual framework

Understanding the impact of university demand on corporate innovation first requires a clear understanding of how this demand is created. This in turn calls for a careful consideration of the complex patterns of co-development formed by science and technology throughout history. Take for instance what is considered the first scientific instrument – Galileo's telescope. In the 16th century, the telescope could be designed thanks to the development of thick concave lenses, which made it possible to see distant objects. Once the Galilean telescope has been introduced, it had a tremendous impact on how scientists undertook their research, but it also became an object of constant development and refinement, motivated precisely by inquiries into the daily research activities of academics. Later, in the 17th century, scientists were interested in determining just how the instrument worked, which in turn stimulated further developments in the field of optics, leading, eventually, to the development of modern microscopes (de Solla Price, 1968).

This desire to broaden the domain of observation has been pointed out as one of the main driving forces behind the development of new scientific instrumentation and methodologies in academia (Masters, 2006; Franzoni, 2009; Stephan, 2012). New tools are adopted to observe natural phenomena, study them in detail, measure them and collect novel data. The simple act of reporting fresh evidence about previously unknown (invisible) facts is sufficient justification to pursue further research in a specific direction. But academic scientists require highly efficient scientific equipment, the performance of which is critical inasmuch as it determines how far they can advance with respect to existing knowledge. The research process is a highly uncertain undertaking, its results are highly unpredictable; hence, it is always better to be able to conduct observations that offer finer granularity and a broader scope. Researchers using high-performance instruments are more likely to provide unexpected findings and new data that can lead them down novel scientific avenues (Stephan and Levin, 1992). The reward system governing academia is a peculiar one, since what is prioritised is reputation, and reputation provides a mechanism for capturing the externalities associated with a given discovery (Merton, 1957; Dasgupta and David, 1994).[4]

An additional scientific endeavour that obliges academics to develop new tools is the testing of existing theories. Franzoni (2009), for instance, reports an insightful example from the field of high energy physics. Here, elementary particles are studied at very high temperatures, which requires large, costly instruments, such as spectrometers. Scientific instruments are central to the field of particle physics, making the development, supply and support of new tools an essential part of a researcher's work in that discipline. Once more, the success of the research, indeed of the scientists themselves, is critically dependent on the performance of their lab equipment.

New scientific instruments and methodologies are not always inspired by the desire to do something completely novel, but also by the need to apply standard procedures at a larger scale. Many scientific tools were originally developed in seeking to execute a common task faster and more efficiently. Equipment that can save time, manpower and energy facilitates the performance of familiar tasks at a new scale and so changes the focus of analysis to a broader dimension. Automating a time-consuming procedure provides not only efficiency gains but also the possibility of tackling entirely new types of research question. A good example of this is provided by DNA sequencing methods in the biological sciences. Here, the transformation of the whole field of biotechnology went hand in hand with the constant progress made in the efficiency of equipment for undertaking DNA analysis and manipulation (Stephan, 2012). The significant improvements achieved in the performance of new instruments allowed scientists to engage in ambitious, large-scale studies that otherwise would have been unimaginable in a researcher's lifetime.

In short, a vital part of an academic's work is to develop new instruments, methodologies and processes for conducting their research (Rosenberg, 1992; Rosenberg and Nelson, 1994). The locus of innovation theory (von Hippel, 2005) claims that the persistent use of a given item

[4] The importance of developing scientific instruments to a researcher's curriculum is perfectly illustrated by the advice Leroy Hood, biologist at Washington University and inventor of ground-breaking scientific instruments in biotechnology, received as a PhD student from his mentor William Dreyer: "*If you want to practice biology, do it on the leading edge and if you want to be on the leading edge, invent new tools for deciphering biological information*" (Stephan, 2012, p. 268).

(instrument, tool or equipment) in a specific context results in users developing a certain amount of tacit knowledge. The acquisition of this knowledge and related capabilities is attributable to the learning effect in challenging environments of use, as typified by scientific research. What is important for our study here is that this tacit innovation-related knowledge enables scientists to visualise and develop future extensions of existing products. However, researchers may lack the resources or in-house expertise to change the functionalities of existing tools and design "exactly the right product", while firms may be equipped to build custom products faster, better and cheaper than the researchers are able to do themselves. Although many mass manufacturers may well be unwilling to accommodate "out of the ordinary" requests, there are firms that specialise in developing products for a limited number of users. The rationale for this specialisation is that such businesses can gain a competitive advantage from their innovative capabilities in one or a few specific solution types, in the expectation that these solutions will be transformed into higher profits either when used in the development of other products (i.e., through economies of scope) or when they become common in the marketplace (von Hippel, 2005; Bogers et al., 2010; Di Stefano et al., 2012).

According to theories advanced in the existing literature, we can expect university demand to affect firms' innovation performance via two channels[5]. On the one hand, in an intrinsically uncertain environment (as is that of scientific research), the needs driving demand provide a guideline for change. As Witt (2009) pointed out, these needs and wants are themselves adaptive to novelty; indeed, the extent to which they can be adapted to novelty is necessary for markets to emerge and develop. By providing producers with knowledge and detailed information about their needs, academic scientists can contribute to the emergence of new concepts and/or ideas, reducing in turn the uncertainty and risk of failure that inherently characterise the innovation process (Malerba et al., 2007, Fontana and Guerzoni, 2008; Guerzoni, 2010; Di Stefano et al., 2012). Scientists can also act as users of technologies that are not yet demanded by industry (e.g. prototypes, proofs of concept), and by so doing can indirectly support the costs of learning

[5] In this work, we approach university and industry, as two separated spheres. This choice is mainly motivated by the characteristic of our data, although the historical studies we discussed in Section 2.1 indicates how such a separation can often be more nuanced. Within our transaction data we distinguish between "the consumer"- the university that purchase a certain item and "the supplier" – the firm that delivers the item. It is possible that in progress of their relationships, they exchange roles for example when the company signs a service agreement with the university, in this case the university turns out to be the one that provides for the company. However, one should keep in mind that often these subsequent accounts follow up the initial customer-supplier contact between university and companies.

and refining associated with the development of these technologies (von Hippel, 1977; Clark, 1985; Bogers et al. 2010). Stimulating firms' innovative performance by reducing the uncertainty associated with product innovation has been labelled the "uncertainty effect". On the other hand, public spending on equipment and research materials (which are typically the outcome of public procurement bids) ensures a minimal market size in the early stages of innovation, as the university and its associated supplier frequently enter into a binding contract for a certain period of time. This minimum market size provides firms with an incentive to improve their production practices given that lower production costs would imply higher profits, all other things being equal (Malerba et al., 2007). In this way, demand acts as a multiplier of a firm's mark up and should trigger process innovation in what is known as the "incentive effect" (see, for example, the seminal discussion in Schmookler, 1962; or more recent debates in Fontana and Guerzoni, 2008).

In the light of the above discussion, we expect university demand to have a positive and significant effect on the innovation performance of its suppliers, all other factors being equal. This conceptual framework is tested in our empirical analysis.

2.3 Data and measurement

2.3.1 The context

We focus our study on one of the largest research-oriented universities in France: the University of Strasbourg (henceforth, UNISTRA). This public university has a long-standing tradition of excellence in both basic and applied research conducted in three major fields: the life sciences, engineering, and the social sciences and humanities.

UNISTRA constitutes a vibrant ecosystem formed by a network of researchers, high-tech industrial firms, and technology transfer activities. Since 2009, UNISTRA has implemented a research policy based on openness and the pursuit of research excellence. To this end, it boasts the second largest, and most diverse, student community among French universities (around 20% of its student body are foreigners). Rated among the top 100 universities in the Shanghai ranking, UNISTRA stands 19th in the 2015 ARWU global rankings in chemistry and 16th worldwide according to Nature's 2017 Lens score. UNISTRA's scientific excellence is further attested to by the fact that its research staff have received various prizes, including the Kavli prize in nanosciences (2014) and three Nobel prizes for medicine (2011) and chemistry (2013 and 2016), the recipients of which are still active researchers.[6]

The university's unique know-how is built around its massive scientific facilities at the cutting-edge of research, permitting, for instance, physico-chemical and chemical analyses of known molecules and new molecules synthesised in its laboratories. Given its profile, UNISTRA represents an ideal environment for our study.

2.3.2 Data sources

This section describes in detail the process by which the data used in the econometric analysis were assembled. Our study draws on three data sources: (i) fine-grained data on university expenditure and its associated suppliers, (ii) innovation-related data from the non-anonymised French Community Innovation Survey (CIS), and (iii) firm-level accounting, financial and employment data from the FARE (*Fichier Approché des Résultats d'Esane*) dataset.

University expenditures data

Under strict confidentiality protocols, we manually downloaded from UNISTRA's Information System granular information about all input purchases made by all the university's research laboratories for the period 2011–2014.[7]

The format of the expenditures data exploited for the analyses is the result of a merging between

[6] Given the characteristics and sources of our data, we focus our empirical study on the scientific domains for which the University of Strasbourg is well known. Nevertheless, demand-side dynamics can affect other domains, as social sciences, art, museums (Nelson, 2005). Thus, it is possible that demand-driven effects on innovation can be much more pervasive than what is captured by our analysis.
[7] Before 2011 the university employed a different Information System. Despite attempts to migrate the old accounting records into the new Information System, the type of information stored before 2011 is substantially different and not suitable for our study.

a few individual data sets, collected at different phases of our project. The parent data on transactions contained information coming from the Information System of the University of Strasbourg (SAP); more precisely we downloaded information on the identification number of the projects active in each research unit, vendors' name, the rubric number (to classify the type of purchase), amount and date of the transaction. To this basic structure, we added the code of research unit to each transaction and its domain (ex. Vie et Santé) and discipline (ex. Biologie). Finally, we joined various variables about suppliers: SIRET code, country, city, address, and postcode. Thus, the format of the data would allow us to investigate the nature and the geographic distribution of research expenditures. Initially, we mapped 57,124 economic transactions, corresponding to a total volume of about €50 million, involving 2,961 suppliers.

The peculiarity of our data is that each transaction is classified by UNISTRA's Information System using different object codes that reflect the nature of the purchase, and which we aggregate into five macro-categories: namely, mobility & meetings (Networking expenses), operating costs (Operating expenses), research materials (Scientific expenses), personnel and other expenses. Table 1 below shows the details on the classification and grouping of the initial data according to the UNISTRA's Information System across 71 distinct object codes which are univocally assigned to each purchase.

Expenditure category	*Supplies subcategories*	
Networking expenses	6185	Costs of seminars, symposia, conferences
	623	Advertising, publications, public relations
	624	Public transport
	6251	Travel and transportation
	6254	Registration fees for conferences
	6256	Missions
	6257	Receptions
Operating expenses	60612	Fuels and lubricants
	60617	Water
	6062	Purchase of paper
	6064	Administrative supplies
	6132	Real estate rentals
	6135	Rents
	6152	Maintenance and repairs on immovable property
	6155	Maintenance and repairs on movable property
	6156	Maintenance
	6184	Reprography
	622	Intermediary remuneration and fees
	6264	Phone
	6265	Postage
	6281	Various competitions
	6282	Laundry

	6286	Cleaning
	6288	Various other external services
	63F	Taxes and similar payments
	658811	Central management fees
	65888	Various other current operating expenses
	671	Extraordinary expenses on management operations
Scientific expenses	2151	Complex technical systems
	2153	Scientific equipment
	2187	Hardware
	2188	Various materials
	6063	Janitorial supplies and small equipment
	6065	Linen, work wear
	6067	Supplies and materials of teaching and research
	617	Studies and research
	6183	Technical documentation and library
Personnel expenses	621	External staff
	6283	Training of facility staff
	65711	Scholarships
	65712	Gratuities Internship
	63P	Staff - Taxes and similar payments
	64111	Main remuneration of officials and contractual
	64112	Accessories compensation
	6412	Paid holidays
	6413	Bonuses and gratuities
	6414	Allowances and other benefits
	6415	Family allowance
	645	Charges of Social Security and pension
	647	Other social security charges
	648	Other personnel expenses
Other expenses	205	Concessions and property rights (e.g. patents, license)
	213	Construction
	214	Constructions on the ground of others
	2184	Furniture
	231	Tangible assets
	60618	Other non-storable supplies
	6068	Other materials and non-stocked supplies
	608	Additional purchase costs
	616	Insurance premiums
	6181	General documentation
	6255	Transport costs
	627	Banking and related services
	651	Fees for concessions, patents, licenses ...
	6575	Grants received and distributed by the EPSCP
	6576	Various subsidies
	6578	Other specific charges
	6583	Cancellation of revenues in previous years
	658812	Federations and management fees UB
	658813	Internal financial flows

Table 1. Classification of expenses according to UNISTRA meso-categories

Our data include spending originating from all the funding sources available to UNISTRA's researchers during the period considered, that is, public competitive grants (regional, national, EU), private grants, and university block funding.

Figure 1 shows the distributions of expenses for each funding source across the five categories defined above. We can see that expenses for Research material represent the largest share for each funding source. However, it is possible to notice that, depending on the source, the composition of expenditures displays some peculiarities: for example, expenses on personnel is underrepresented for DOTAT (only 5%) and overrepresented for PUBL (about 50%). In the case of research material, we see that these expenses are underrepresented for VALO, but in all the other cases the percentage is close to 30%. The picture changes if we exclude laboratories belonging to specific disciplines, for instance, social science and humanities, in which research material plays typically an irrelevant role. On the other extreme, some applied research laboratories (e.g. genetic engineering) require very expensive equipment, thus the share of research material on the total purchases can easily reach values above 90%. We can finally observe that a significant share of DOTAT are used to finance mobility & meeting of researchers (more than 20%).

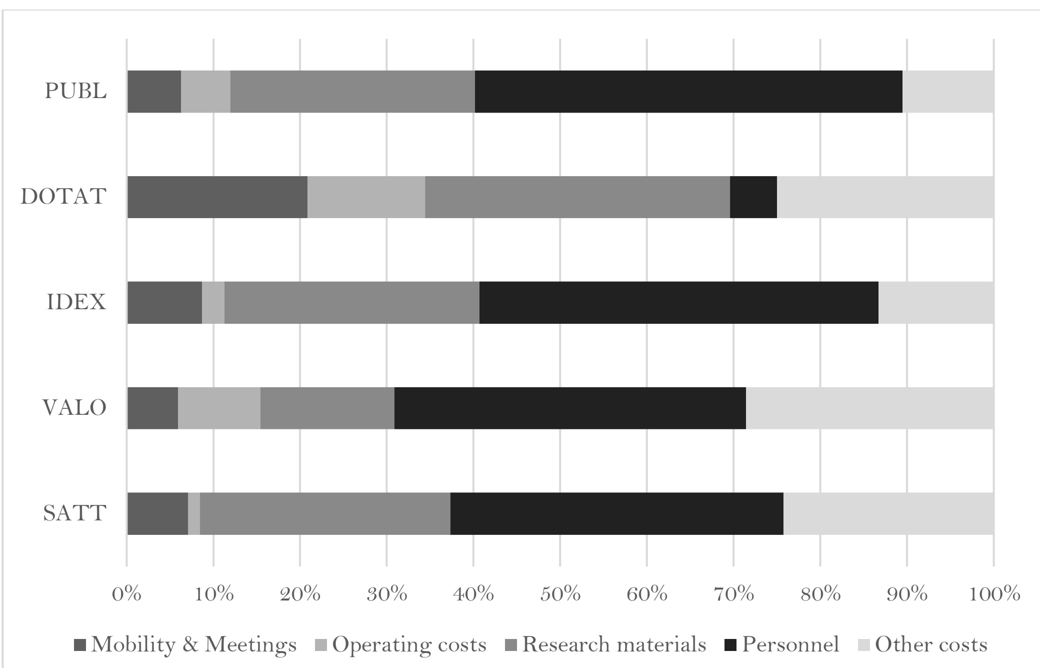


Figure 1. Distribution of expenses by funding source

Figure 2 shows the distributions of expenses by the source of funding according to the five categories excluding direct expenditures for hiring personnel. In this case, research materials emerge as the most important category in the total expenditures. Purchases of research materials represent around 60-70% of the expenditures in Public and Idex and 40% in Valo and Dotations.

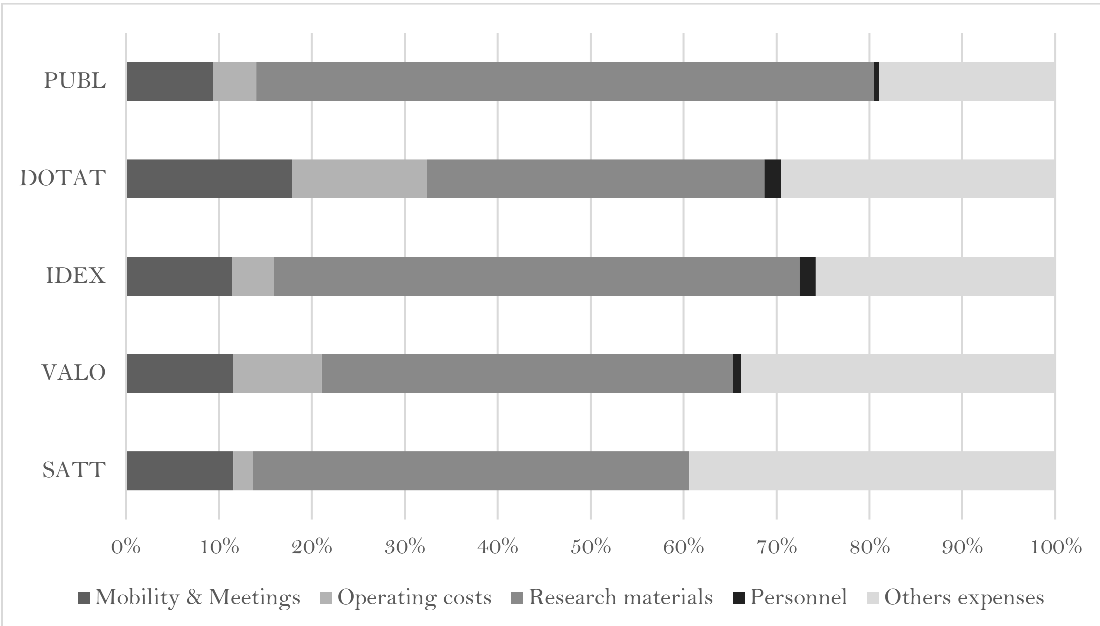


Figure 2. Distribution of expenses by funding source without personnel

Irrespective of the funding source, most of the vendors identified in the data are located in France and the remaining are mostly located in Europe (see Table 2).

Country	Number of transactions	Share of total transactions
FR	53615	93,25%
DE	1002	1,74%
NL	893	1,55%
GB	657	1,14%
BE	387	0,67%
US	358	0,62%
CH	128	0,22%
IT	57	0,10%
SE	47	0,08%
ES	45	0,08%
Others	305	0,53%

Table 2. Vendors by country of origin in total expenditures

However, we should approach the results reported about the country of origin of firms in our data set with caution. As we saw the majority of the companies is located in France, but this does not necessarily mean that these companies are French by origin. Detailed research about each of the companies confirms that a big share of them are not French by origin but are just French-based entities of foreign companies. For example, one of the biggest suppliers in scientific equipment CARL ZEISS is located near Paris so our initial analysis considers ZEISS as a french supplier. However, the company is german, established in Jena and its headquarters are located in Oberkochen (Baden-Wuttermberg). After a detailed manual checking, we confirm that in our database there is an important number of French-based entities of German, American and other foreign companies. Table 3 shows the leading suppliers by the source of funding. In the column Postcode Plant, we report the address of the company in our database and in the last column the Country of origin of the company. Most of the times the postcode is French, but the country of origin is Germany, USA or UK.

IDvend	Vendor	Postcode Plant	Total amount	Transactions	Country of Origin
PUBL					
11849	CARL ZEISS SAS	78161	1 312 011,63	6	DE
54	FISHER SCIENTIFIC S.A.	67403	527 242,25	1096	USA
117	CARLSON WAGONLIT TRAVEL	67000	460 073,47	1486	USA
209	DOMINIQUE DUTSCHER	67172	449 203,97	1050	FR
72	SIGMA ALDRICH CHIMIE SARL	38297	410 758,03	1528	USA
11582	HAVAS VOYAGES	75904	348 669,50	1282	FR
120	VWR INTERNATIONAL SAS	67100	300 355,38	737	USA
3523	BIO RAD	92430	292 272,13	309	USA
4119	AGILENT TECHNOLOGIES FRANCE	91978	288 315,22	60	USA
95	LIFE TECHNOLOGIES SAS	91190	275 624,84	212	USA
DOTAT					
117	CARLSON WAGONLIT TRAVEL	67000	1 129 411,75	3774	USA
11582	HAVAS VOYAGES	75904	716 308,81	2985	FR
3666	INSERM ALSACE DR GRAND-EST	67037	570 045,38	33	FR
3541	LEICA MICROSYSTEMES SAS	92000	508 321,03	31	DE
134	EBSCO INFORMATION SERVICES SAS	92183	392 776,44	123	USA
1235	CAMPUS FRANCE	75010	337 432,06	254	FR
4597	FONDATION FRC	67000	268 985,31	73	FR
11100	CEGELEC LORRAINE ALSACE	54520	253 491,03	54	FR
209	DOMINIQUE DUTSCHER	67172	237 404,94	549	FR
120	VWR INTERNATIONAL SAS	67100	233 545,86	341	USA

IDEX					
12298	SANCHEZ TECHNOLOGIES	95270	298 458,91	4	USA
11582	HAVAS VOYAGES	75904	267 825,13	964	FR
3788	UNIVERSITE LUMIERE LYON 2	69365	186 762,00	2	FR
14337	ISTO	28700	179 670,00	3	FR
3523	BIO RAD	92430	174 072,73	39	USA
95	LIFE TECHNOLOGIES SAS	91190	168 678,88	85	USA
1621	THERMO ELECTRON SAS	91140	110 935,24	3	USA
960	BECKMAN COULTER FRANCE	93420	104 254,18	8	USA
54	FISHER SCIENTIFIC S.A.	67403	104 070,60	158	USA
13763	CHARITE UNIVERSITATSMEDIZIN BERLIN	10117	99 459,21	3	DE
VALO					
5279	THERMO ELECTRON GMBH	76227	321 789,00	4	USA
117	CARLSON WAGONLIT TRAVEL	67000	278 514,47	784	USA
4597	FONDATION FRC	67000	117 073,81	11	FR
72	SIGMA ALDRICH CHIMIE SARL	38297	106 922,98	432	USA
6240	ADVION BIOSCIENCES LTD	NR9 3DB	105 000,00	3	GB
9146	CYRIUS CONSULTING	67520	93 113,98	3	FR
3260	OST OBSERVATOIRE SCIENCES TECH	75015	90 000,00	3	FR
11582	HAVAS VOYAGES	75904	83 039,77	305	FR
12901	SOCIETE DES AMIS DE L'ESPCI	75005	82 064,28	4	FR
10730	DECATHLON SA	59650	79 588,37	1	FR
SATT					
1595	CERBM GIE	67404	154,219	24	FR
11582	HAVAS VOYAGES	75904	130,570	738	FR
3479	CHARLES RIVER LABORATORIES FR	69210	66,559	115	USA
4119	AGILENT TECHNOLOGIES	91978	58,832	13	USA
95	LIFE TECHNOLOGIES	91190	50,527	67	USA
1868	BRUKER AXS SAS	77447	48,100	1	DE
209	DOMINIQUE DUTSCHER	67172	47,431	99	FR
72	SIGMA ALDRICH	38297	45,550	228	USA
3523	BIO RAD	92430	43,503	50	USA
4019	OPTON LASER INTERNATIONAL	91893	42,324	3	FR

Table 3. Top 10 vendors by cumulative amount and funding source
(for scientific material highlighted in grey)

Following, we performed a manual cleaning of the data to remove duplicates and other inconsistencies.[8] The resulting dataset consists of 47,373 transactions and 1,908 suppliers, for a value of about €40 million. The distribution of the value of these transactions is skewed, since most are small and correspond to scale purchases, such as office supplies and trips of short

[8] For example, the initial dataset contained many entities that are not relevant to our study, including liberal professionals (translators, doctors, web designers, etc.), non-profit organizations and foundations.

duration. However, the dataset also includes several large-scale transactions (> €1 million) for major scientific supplies and research infrastructure. The mean value per transaction is about 900€. Although a few suppliers are associated with thousands of transactions, the average number of transactions per supplier is about 20, with many suppliers of dedicated scientific equipment responsible for just one.

This grouping allows us to isolate all the supplies related to research materials, which represent the highest share in terms of their economic value (Figure 3, panel a). The category "scientific expenses" can be disaggregated to a finer level of granularity, giving three additional subcategories of supplies, namely: lab equipment and consumables, scientific instruments, and various lab materials (Figure 3, panel b).

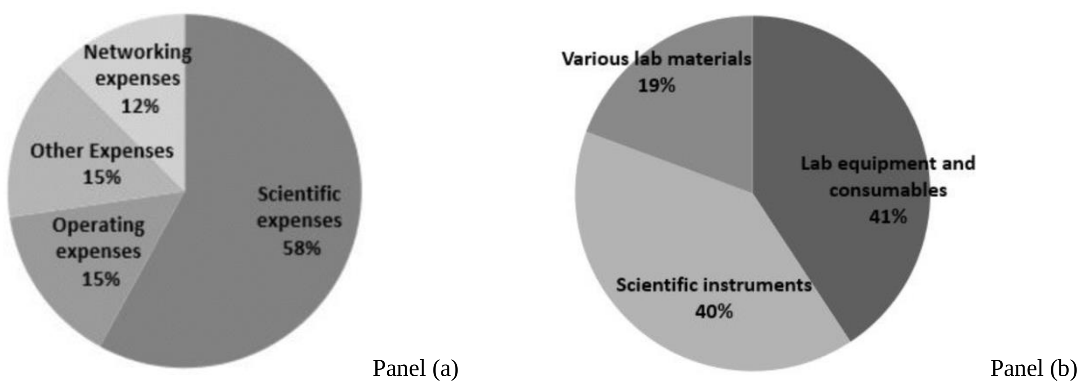


Figure 3. Distribution of expenses broken down by category (Panel a) and by subcategory within "scientific expenses" (Panel b)

For illustrative purposes, Table 4 presents examples of the scientific supplies included in our dataset. They include small and medium-sized lab equipment and products, such as filters, thermometers, synthetic antibodies, and chemical reagents. The supplies also include scientific instruments, such as a dual-beam microscope, mass spectrometer, DNA sequencer, odontological pre-clinical simulator, magnetic resonance imaging scanner for small animals, to name just a few. Finally, although, we refer to scientific instrumentation as high-tech equipment, in our database we have plenty of other low-tech materials, related to daily research activity, including small low-tech instruments and consumables as accessors for distribution of liquids; biopsy punches; powder spatulas; cryotubes; microscope slides as well as janitorial supplies as portable recorders; specific workwear as nitrile gloves; protective face masks and technical documentation and library along with scientific journal subscriptions and books.

Table 4: Examples of supplies broken down by subcategories

Category	*Subcategory*	*Example of supplies*
Scientific expenses	Lab equipment and consumables	Mini-protean short plates Membranes for filtration Reagent for detection of biomolecules DNA sequencing reagent Synthetic antibodies
	Scientific instruments	Double-beam microscope Next-generation DNA sequencer Femtosecond laser Confocal microscope Multi-station magnetic stirrer
	Various lab materials	Anti-static lab coats Technical documentation

Each transaction is associated with a given supplier, and each French supplier is identified in our data by means of a univocal firm-level code provided by the French national statistics office (INSEE). This code allows us to match university expenditure data to the non-anonymized Community Innovation Survey (CIS) and FARE datasets, both made available to us under confidentiality protocols by INSEE. In conclusion, here, we focus on 682 French suppliers, accounting for around 5,000 supplies of research materials for a total volume of about €18 million.[9]

[9] To be more accurate, our focus is, in fact, on businesses located in France. A manual check confirmed that a high share of the suppliers are French-based entities of foreign companies. Unfortunately, our dataset does not contain any meaningful firm-level identifier for companies located outside France; hence, we have been obliged to discard these firms from the analysis.

CIS and FARE datasets

We exploit the latest two waves of the French Community Innovation Survey (CIS 2012 and 2014) to provide accurate information on various aspects of firms' innovation activities, including the introduction of new product and process innovations, investment in R&D activities, forms of cooperation to develop innovations, among others. Albeit with certain limitations, the CIS has served as the empirical foundation for many innovation-related studies and proved to be a reliable source of data (Mairesse and Monhen, 2010).[10] Innovation surveys, however, contain only a limited set of firm-level attributes related to a firm's operating capabilities. Thus, we also exploit the structural business registers contained in the FARE (*Fichier Approché des Résultats d'Esane*) dataset. FARE assembles accounting and performance data (i.e., year of foundation, sectoral affiliation, turnover, value added, profitability measures, etc.) for the totality of French businesses, except firms with no employees, or those belonging to the agricultural or banking and financing sectors.

The final dataset

We merge the three data sources described above by means of the univocal firm-level code, common to all sources. Figure 4 shows the details of this procedure. The resulting dataset consists of an augmented CIS. In short, in the two original innovation surveys we identify those firms that supplied UNISTRA's research laboratories and we include other operating performance variables. Finally, we pool the two augmented datasets.

[10] In conducting the robustness checks, we also consider patent data drawn from PATSAT, an alternative proxy of firms' innovation capabilities, and replicate the main analysis. For more details, see Chapter 2.

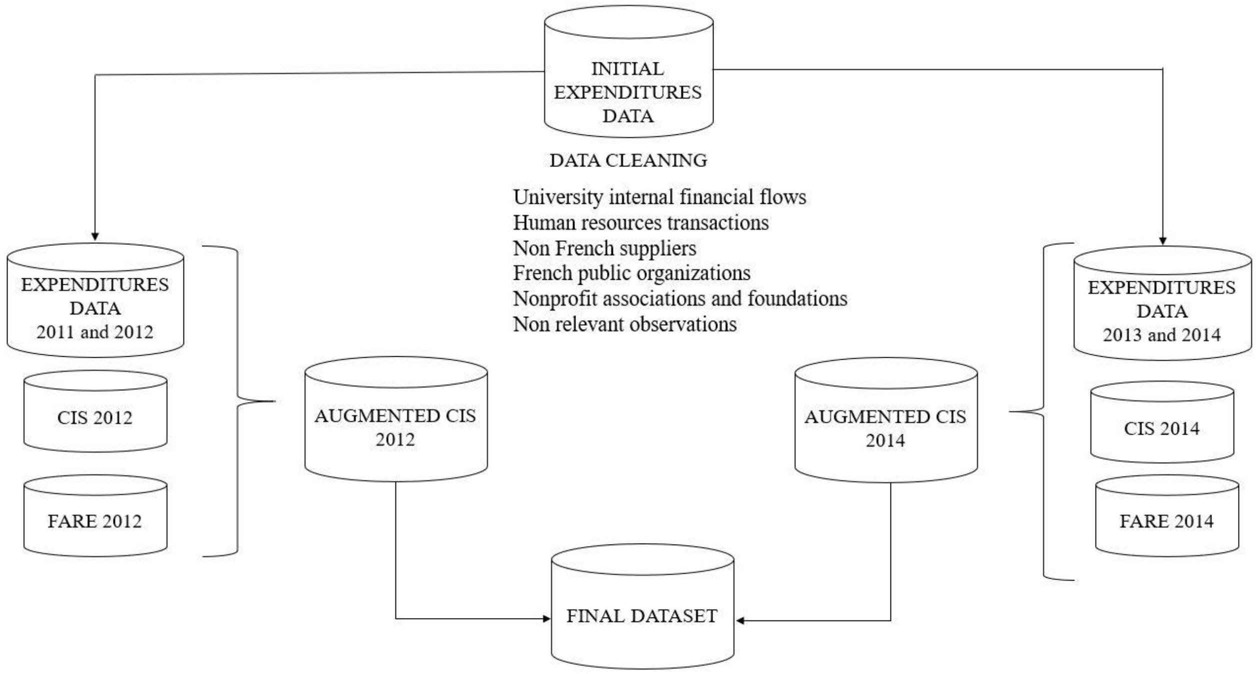
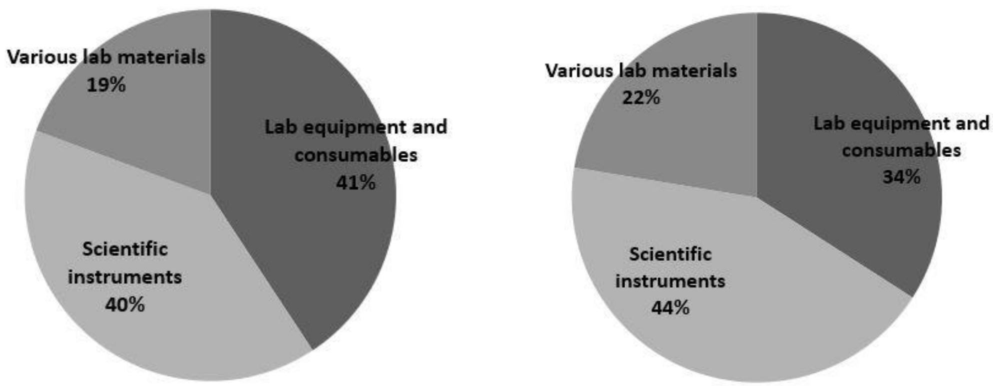


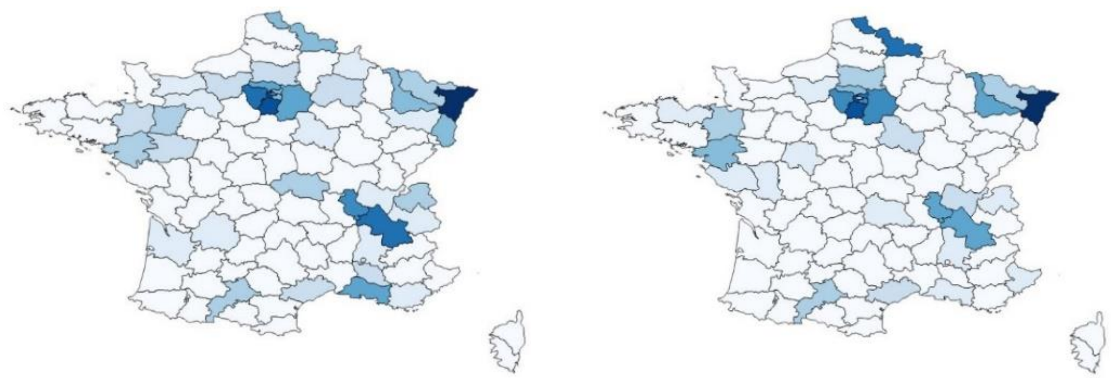
Figure 4. The merging procedure

We match 199 firms supplying lab equipment and scientific instruments out of the 682 in the initial dataset. These firms, representing 30% of the total, account for more than 40% of the total economic value. Although the final sample is relatively small in terms of size, we are confident it is representative. As shown in Figure 5, the distribution of spending across the subcategories associated with the matched firms closely mimics that associated with all the firms in the parent data (panel a). A further concern is that we are only matching suppliers located in certain geographical areas. However, as shown in Figure 5 (panel b), the geographical spread of input purchases pre- and post-merging remains essentially the same.

With various caveats (for a discussion see the following sections), we are now in a position to exploit a rich set of innovation-related variables linked to benchmark suppliers and other businesses included in the survey in terms of their innovative performance, while controlling for a large number of firm-level attributes.



Panel (a)



Panel (b)

Figure 5. Distribution of expenses broken down by category (panel a) and geographical spread of input purchases (panel b) [left: Expenditure data; right: Final dataset]

2.3.3 Measures

Dependent variable

We use different variables to reflect various aspects of a firm's innovative performance. First, we consider two proxies that capture a firm's ability to achieve product innovations: (i) a dummy indicating if the firm has introduced "new-to-the-market" products (*New Mkt*), and (ii) a continuous variable measuring the volume of sales (in logs) stemming from those products (*New Mkt Volume*). Second, we consider a standard dummy of process innovation (*Iproc*), measuring whether the firm has re-organized its production practices or whether it has implemented new or significantly improved production processes.

The three variables considered here seek to capture the mechanisms via which university demand might effect the firms' innovation outcomes, as described in Section 2. Thus, while *New Mkt* and *New Mkt Volume* capture the "uncertainty effect", *Iproc* captures the "incentive effect".

Other variables

We need to rely on a set of observable characteristics so as to create viable control groups and to isolate the net impact of university demand on corporate innovation. Hence, we first build an exhaustive vector of firm-level attributes that include the following: a proxy for firm size based on the number of employees (*Empl_log*); firm age computed by year of foundation (*Age*); a proxy for a firm's financial status in terms of return on sales (*ROS*); a labor productivity index (*LabProd_log*) calculated as the ratio between total value added and number of employees; R&D intensity (*R&D*) as a traditional proxy of innovation inputs, obtained by dividing total R&D expenditure by firm turnover; and, finally, three dummy variables, respectively, taking a value of 1 if the firm belongs to an industrial group (*Group*), receives public financial support for innovation (*PubFund*), or has an internal R&D department (*R&DDep*), and zero otherwise.

Second, we introduce additional variables reflecting a firm's external collaboration strategies. We consider a proxy for the breadth (*Breadth*) of the firm's cooperation with other enterprises or organisations on innovation activities (Salter and Laursen, 2006). The CIS asks firms to indicate whether or not firms have formal innovation collaboration links with eight different external sources (e.g., suppliers, clients or customers, competitors, etc.). Each of these eight sources is, therefore, encoded as a binary variable, 0 indicating that they do not use them and 1 indicating that they use the given source. Subsequently, the eight sources are combined so that a firm obtains a 0 when it does not cooperate with any external partners, while it obtains the maximum value of 8 when it has links with all eight partners. Finally, to capture the existence of university-industry links more effectively, we build a binary indicator taking a value of 1 if the firm has formal R&D collaboration agreements with French universities or other higher education institutions in France (*UniColl*).[11] Concise definitions and the labels of the variables used in this chapter are reported in Table 5.

[11] Note that this additional variable is especially relevant to our study as it allows us to detect the "net" effect of the university as a customer (and, therefore, user), isolating the effect of the university in its role as a collaboration partner. Yet, it should be stressed that the R&D collaboration variable considered here is quite uninformative about the specific university the firm collaborates with, be it UNISTRA or not. In Chapter 3 we exploit other UNISTRA administrative data on university-firm collaborations to tackle this issue more thoroughly.

Table 5. The variables for this study

Variable	*Description*	*Source*
New Mkt	Product innovations (goods or services) new-to-the-market (dummy)	CIS
New Mkt Volume	Sales stemming from new-to-the-market products (in log)	CIS
Iproc	Process innovations (dummy)	CIS
Empl_log	Number of employees (in log)	FARE
Age_log	Date of incorporation (in log)	FARE
Group	Part of an enterprise group (dummy)	CIS
R&D	R&D expenditures over sales	CIS
R&DDep	Presence of R&D laboratory within the firm (dummy)	CIS
PubFund	Public financial support for innovation activities (dummy)	CIS
Breadth	Number of cooperation partners on innovation activities	CIS
ROS	Net revenue over sales	FARE
LabProd_log	Labor productivity (in log) computed as value added over number of employees	FARE
UniColl	Cooperation with French universities or other HEI (dummy)	CIS
Sector	Industry dummies (2-digit NACE classification)	CIS
Region	Regional dummies at the department level	CIS

Descriptive statistics

Table 6 reports the basic descriptive statistics for the set of variables considered. Substantial differences between university suppliers and other companies are found in relation to almost all characteristics. For instance, the former are found to be significantly larger and older. Furthermore, 67% of university suppliers belong to an enterprise group compared to 60% of other firms, and the former also benefit more from public financial support. University suppliers present a higher degree of openness, using on average more than one collaboration partner and collaborating more frequently with universities or other higher education institutions (30% maintain collaborations with French universities compared to 14% in the population of other firms). Finally, suppliers tend to invest more in internal R&D activities and to produce “radical” product innovations (90% of them introduce new-to-the-market products, compared to 69% in the overall sample of French businesses) whilst, in contrast, they seem less likely to introduce process innovations.

Taken together, these descriptive statistics show that university suppliers and the population of other companies present very heterogeneous profiles; hence, the need to use appropriate statistical techniques to build a reliable counterfactual. This is the argument developed in the next Section.

Table 6. Descriptive statistics of the variables

	All Firms		Suppliers (1)		Other firms (2)		(1) – (2)
Variable	Mean	SD	Mean	SD	Mean	SD	*t*-test
New Mkt	0.6945	0.4607	0.9036	0.2969	0.6927	0.4614	4.1574***
New Mkt Volume	4.9788	4.0053	7.7455	3.7522	4.9552	3.9994	6.3326***
Iproc	0.6394	0.4802	0.6145	0.4896	0.6397	0.4801	-0.4761
Empl_log	4.5051	1.6038	6.0676	1.9158	4.4917	1.5944	8.9495***
Age_log	3.0893	0.7333	3.3772	0.6060	3.0868	0.7339	3.5942***
Group	0.6120	0.4873	0.7711	0.4227	0.6106	0.4876	2.9882***
R&D	5.0267	11.6206	5.2153	11.3547	5.0251	11.6234	0.1485
R&DDep	0.7869	0.4096	0.8675	0.3411	0.7862	0.4100	1.8012*
PubFund	0.3023	0.4593	0.4578	0.5012	0.3009	0.4587	3.1005***
Breadth	1.4711	2.0347	2.2892	2.4070	1.4641	2.0210	3.6807***
ROS	0.0308	0.1804	0.1075	0.5473	0.0302	0.1739	3.8898***
LabProd_log	10.9993	0.5756	11.2554	0.4804	10.9972	0.5758	4.0728***
UniColl	0.1431	0.3502	0.3012	0.4616	0.1418	0.3488	4.1334***
Obs	9 796		199		9 597		

Note: Significance level: *** p<0.01, ** p<0.05, * p<0.1

2.4 Econometric approach

Our empirical strategy is to consider university supplier status as the "*treatment*".[12] According to the conceptual framework outlined in Section 2, this treatment should affect different aspects of the firms' innovative behaviour, namely their product and process innovations. We proceed in two complementary steps: first, we estimate the effect of "being a university supplier" on the set of innovation variables using standard regression techniques; and, second, we adopt a quasi-experimental framework and employ propensity score matching (PSM) to obtain the impact of the treatment.

[12] Note that some firms included in the overall sample might also be considered "treated" if, for example, they supply other universities. Unfortunately, we are not able to test this hypothesis but, as discussed in Section 5, our estimates would nevertheless reflect the lower bound of the treatment effect. In other words, we are confident that if a bias exists, it would not run counter to our conjectures.

Regression analysis

We start by applying a standard regression model:

$$Inno_i = \alpha \, Supplier_i + \mathbf{X}_i \beta + \varepsilon_i \qquad (1)$$

where the dependent variable *Inno* represents the three innovation proxies considered (*New Mkt; New Mkt Volume; Iproc*), the main regressor *Supplier* is a binary variable taking a value of 1 if firm *i* is a university supplier, **X** is a vector of firm-level controls (as described in Section 3.3), and ε_i is an idiosyncratic error term. The model is estimated using Ordinary Least Squares (OLS) and the coefficient of interest in Equation (1) is α, representing the effect of the treatment on the innovative performance of firms.

Sources of selection bias

Although easily interpretable, the above econometric approach embeds an important assumption: namely, that the data come from randomised trials – i.e., the assignment of the treatment to firms (that is, being a supplier of the university or not) is completely random. However, here, we are dealing with non-randomized observational data as the university chooses its own suppliers and the latter are likely to differ substantially from other firms in many respects (see Table 6). This absence of randomly assigned treatment to firms introduces a bias in the regression estimates.

Indeed, there are two primary sources of bias. First, a university typically plays a "picking the best" strategy. As the university organises public procurement bids to choose its suppliers, it is reasonable to assume that it will pick "good companies", essentially those characterized by the soundness of their financial conditions and a high degree of innovativeness. Second, it is also possible that firms self-select themselves to become suppliers. For instance, some companies may have better search capabilities, or other types of competitive advantage, that allow them to detect, and thus strategically apply for, a public procurement competition. In short, university suppliers are likely to be intrinsically different from non-suppliers even in the absence of the treatment, and we need to account for this possibility.

Propensity score matching

The goal is to estimate the expected value of the average treatment effect on the treated (ATT), defined as the difference between the expected outcome values with and without treatment for those who actually participated in the treatment. Formally:

$$\tau_{ATT} = E(\tau | T = 1) = E[Y(1)|T = 1] - E[Y(0)|T = 1] \quad (2)$$

where $E[Y(1)|T = 1]$ is the expected value of the outcome variable of the treated units and $E[Y(0)|T = 1]$ is the expected value of this variable when the units are not treated. As the counterfactual mean for the units treated is not observed, we have to choose a substitute for this value in order to estimate the ATT. We apply propensity score matching (PSM) to construct the pseudo-counterfactual or the control. Matching estimators are based on a comparison of the outcomes obtained by the treated units (i.e., university suppliers) and those obtained by a "comparable" control group (i.e., a subsample of other companies), conditional on a set of defined characteristics. Under certain assumptions, the difference in mean outcomes between the two groups can be attributed exclusively to the treatment.[13]

The matching procedure requires the definition of a set of characteristics X, which leaves the estimate prone to the well-known "curse of dimensionality". In short, this problem requires the estimation of a high-dimensional vector of exogenous covariates to find an exact twin for each treated unit. Rosenbaum and Rubin (1983) suggest it is possible to compress this vector into a single scalar index – that is, the propensity score – and to use this index to search for similar (in statistical terms) units. In our framework, the propensity score measures the probability of a firm becoming a supplier of scientific materials and equipment to UNISTRA based on a set of observable characteristics.

PSM requires three important methodological choices: i) the model to be estimated; ii) the variables to be included in the model; and iii) the matching algorithm to be applied. In the case of the first choice, because our treatment is a binary variable, we estimate a probit regression.

[13] Two identifying conditions must be fulfilled: namely, unconfoundedness and common support. Unconfoundedness, or the conditional independence assumption, states that the outcome should be statistically independent of the treatment. For this condition to hold, all the variables likely to affect simultaneously the probability of receiving the treatment and the potential outcomes should be known and taken into consideration. The common support condition states that the control group should contain at least one sufficiently similar observation for each treated unit.

Caliendo and Kopeinig (2008) show that, in the case of binary treatments, probit and logit regressions generate very similar results. As regards the choice of variables, we exploit the entire set described in Section 3.3 to determine the probability of firms receiving the treatment. This choice was dictated by existing empirical evidence but, above all, by the idea of mimicking the practices adopted by UNISTRA's public procurement office when selecting suppliers. As pointed out above, the university's suppliers are selected via public procurement bids, a procedure that has a dual objective – to uphold competition and transparency during the selection process and to guarantee the effective spending of public money. Hence, we conducted three semi-structured interviews with the university's public procurement managers to understand the implementation of the selection procedure, its various stages, selection criteria, and the role played by researchers in the process. The managers confirmed the appropriateness of our set of variables.[14] Finally, regarding the choice of the matching algorithm, we opt for the bias-corrected nearest-neighbour (NN) matching estimator proposed by Abadie and Imbens (2006). Given the large sample and the similar distribution of propensity scores between treated and control units, we apply a NN search without replacement and with oversampling – i.e., we match each treated unit with three untreated observations. As the results may be sensitive to these implementation choices (Caliendo and Kopeinig, 2008), in Chapter 2 we perform a series of robustness analyses implementing alternative specifications.

Thus, we proceed as follows. First, we obtain the propensity scores associated with the binary treatment via the estimation of the probit model (or selection equation) containing the original set of variables. Next, we apply the NN algorithm and use the estimated propensity scores to match the subsample of suppliers with the most similar group of firms in the sample. Finally, we compute the ATT to draw conclusions about the effect of university demand on the innovativeness of its suppliers.

[14] The interviews took place in September 2017 at UNISTRA's public procurement office, and lasted about one hour each. Specifically, the managers ranked the firms' financial status and their receiving public support for innovation (acting as "reputation effect") as being among the most important criteria for assessing candidates. Other important criteria were identified as the firms' fiscal status and whether they respect the codes of ethics governing labour law. As it is the applicants themselves that provide the information related to these last two criteria, it proves quite challenging to include a reliable proxy for them in our estimation.

2.5 Results

2.5.1 Regression analysis

Table 7 presents the results of the regression analysis. Two major findings merit discussion. First, the coefficients of the regressor *Supplier* associated with the two product innovation proxies (*New Mkt* and *New Mkt Volume*) are positive and statistically significant at the 1% level. These estimates imply that university suppliers exhibit a higher propensity to introduce new-to-the-market products and to enjoy higher sales from these products. Taken together, these results support our conjecture that university demand for goods and services affects the innovative performance of suppliers, and that this effect is positive in the case of product innovations. Indeed, as discussed in Section 2, university demand seems to act in two complementary ways: on the one hand, because of their quite specific needs, scientists can contribute to the emergence of new concepts and ideas, reducing the uncertainty and risk of failure that is inherent to the innovation process; while, on the other, scientists can act as lead-users of technologies, thus indirectly bearing the costs of learning and refining associated with their development.

Second, we observe that the regressor *Supplier* does not have any relevant effect on process innovations. In our conceptual framework, we argued that university demand might provide firms with a minimal market size, hence, providing incentives to improve production practices and achieve scale economies. A tentative explanation for the lack of effect found might be that scientists' needs are highly specific and, as such, represent needs that are not yet common in the marketplace[15]. This is especially true of high-tech instrumentation that only serves very specific research aims. While idiosyncratic demand grants firms competitive advantages in specific solution types and fosters the development of new products, it may prevent the exploitation of economies of scale, at least in the short-term.

[15] We would like to thank a lot to anonymous referee for his stimulating and intriguing remark on the subject. The hypothesis underlying our research is that tailor-made instruments can also be useful for other users beyond the scientific community. Although these items might not trigger particular volume effect for the firms involved, they might still have learning by doing effect on firms' manufacturing capabilities, which is related to economies of scale

The coefficients of the control variables conform, by and large, with those reported in previous studies (i.e., Laursen and Salter, 2006; Cohen, 2010; Beck et al., 2016; Scandura, 2016). The intensity of R&D investments (*R&D*) and public support for innovation (*PubFund*) positively affect the propensity to achieve product innovations. The breadth of openness of firms' innovative cooperation (*Breadth*) also appears to be an important factor in explaining innovative performance. More efficient companies (*LabProd_log*) tend to innovate more in terms of new products, though not in terms of new processes. The lack of significance of the role of universities and PROs as collaboration partners in innovation (*UniColl*) is surprising yet consistent with the fact that the breadth measure could absorb this effect. Finally, it seems that large (*Empl_log*) but young (*Age_log*) companies belonging to industrial groups (*Group*) enjoy higher sales from their product innovations, whilst these demographic features do not present robust patterns across the other specifications.

Table 7. Regression analysis, OLS estimates

	New Mkt			New Mkt Volume			Iproc		
Variable	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Supplier	0.1695***	0.1633***	0.1498***	1.4907***	1.4188***	1.3121***	-0.0770	-0.0765	-0.0797
	(0.0341)	(0.0340)	(0.0329)	(0.3960)	(0.3789)	(0.3710)	(0.0540)	(0.0542)	(0.0520)
Empl_log	0.0245***	0.0239***	0.0044	0.7711***	0.7612***	0.5872***	0.0373***	0.0377***	0.0164***
	(0.0034)	(0.0034)	(0.0036)	(0.0318)	(0.0316)	(0.0328)	(0.0035)	(0.0035)	(0.0037)
Age_log	-0.0139	-0.0191***	-0.0089	-0.1802***	-0.2548	-0.1744***	-0.0095	-0.0072	-0.0020
	(0.0067)	(0.0067)	(0.0065)	(0.0553)	(0.0555)	(0.0540)	(0.0070)	(0.0070)	(0.0070)
Group	0.0266**	0.0186*	0.0101	0.4139***	0.2941***	0.2204***	-0.0018	0.0025	-0.0098*
	(0.0112)	(0.0113)	(0.0110)	(0.0856)	(0.0862)	(0.0842)	(0.0115)	(0.0116)	(0.0116)
ROS		-0.0178	-0.0216		-0.5458	-0.5839**		0.0470*	0.0431
		(0.0235)	(0.0201)		(0.2466)	(0.2505)		(0.0250)	(0.0259)
LabProd_log		0.0528***	0.0389***		0.7937***	0.6740***		-0.0283***	-0.0412***
		(0.0089)	(0.0085)		(0.0818)	(0.0793)		(0.0092)	(0.0091)
R&D			0.0026***			0.0189***			-0.0010**
			(0.0004)			(0.0033)			(0.0005)
R&DDep			0.2197***			1.4543***			-0.0639***
			(0.0128)			(0.0986)			(0.0129)
PubFund			0.0378***			0.2754***			0.0342***
			(0.0104)			(0.0874)			(0.0113)
Breadth			0.0278***			0.2487***			0.0443***
			(0.0028)			(0.0256)			(0.0031)
UniColl			-0.0208			0.1188			-0.0273*
			(0.0152)			(0.1438)			(0.0172)
Sectors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	9 796	9 796	9 796	9 796	9 796	9 796	9 796	9 796	9 796
R^2	0.0278	0.0314	0.1022	0.1327	0.1432	0.1989	0.0162	0.0171	0.0518

Note: Robust standard errors in parenthesis. Significance level: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

2.5.2. Propensity score matching

We now turn to examine the results of the matching estimates. We first discuss the process of selection and the reliability of the control group. Next, we present the chapter's main findings.

The results of the estimation are reported in Table 8 (left panel). The estimated coefficients represent the influence that each variable has on the probability of a firm becoming a university supplier. Note that the percentage of correctly predicted zeroes and ones implies a satisfactory goodness of fit. It emerges that larger firms have a higher probability of becoming suppliers of scientific material and equipment to UNISTRA. Moreover, we find that firms benefiting from public support for innovation and with a higher labour productivity index are also more likely to be selected as university suppliers. Firm profitability affects positively and significantly the probability of receiving the treatment, although at a low significance level. The other variables do not play any relevant role. Overall, these estimates suggest that a selection process is actually in place and that financial conditions and reputation are the most relevant factors.

Before discussing the final results, in Table 8 (right panel), we report a *t*-test for equality of means between treated and untreated units before and after the matching. Pre-matching comparisons (unmatched) show that the two groups present statistically significant differences in almost all the variables considered. If the matching procedure is effective, the sample of untreated firms should not differ in statistical terms from the sample of treated firms in any dimension. We find equality of means in the treated and control groups post-matching (matched), indicating that the matching procedure has generated a reliable counterfactual.

Finally, Table 9 shows the results of the propensity score matching. The first column reports the mean value of the outcome variables for the suppliers, the second column the mean values for the control group, while the third column represents the main parameter of interest, namely the ATT.

In line with the results presented in Table 7 above, we confirm the positive and statistically significant effect of the treatment in the case of product innovation. University suppliers are more innovative compared to other firms insofar as they show a higher propensity to introduce "radical" product innovations and to reap greater revenues from the sales of these products. It is worth stressing the actual magnitude of these effects. First, 90% of suppliers achieve product innovations compared to about 75% of firms operating in the same industries and with similar characteristics.

Second, the sales of suppliers' market novelties are about 1.5 times higher than those of other firms. Again, we do not find any significant effect on process innovations.

Table 8. Selection equation estimates (left panel) and balance checking (right panel)

Selection equation		*Balance checking*			
Variable	Supplier	Status	Treated	Control	*t*-test
Empl_log	0.2054***	Unmatched	6.0676	4.4917	8.95***
	(0.0335)	Matched	6.0676	5.8787	0.65
Age_log	0.0587	Unmatched	3.3772	3.0868	3.59***
	(0.0545)	Matched	3.3689	3.3535	0.15
Group	-0.1761*	Unmatched	0.7711	0.6106	2.99***
	(0.1069)	Matched	0.7683	0.7520	0.24
R&D	0.0033	Unmatched	5.2153	5.0251	0.15
	(0.0038)	Matched	4.7128	4.2838	0.27
R&DDep	0.0952	Unmatched	0.8675	0.7862	1.80*
	(0.1276)	Matched	0.8659	0.8943	-0.56
PubFund	0.2008**	Unmatched	0.45783	0.30094	3.10***
	(0.0908)	Matched	0.45122	0.4187	0.42
Breadth	-0.0499*	Unmatched	2.2892	1.4641	3.68***
	(0.0266)	Matched	2.2317	2.0569	0.48
ROS	0.2919*	Unmatched	0.1075	0.0302	3.89***
	(0.1497)	Matched	0.0482	0.0430	-1.11
LabProd_log	0.2245***	Unmatched	11.255	10.997	4.07***
	(0.0759)	Matched	11.24	11.284	-0.57
UniColl	0.1326	Unmatched	0.3012	0.1418	4.13***
	(0.1343)	Matched	0.2927	0.2642	0.40
Sectors	yes				
Regions	yes				
Obs	9 796				
Correctly Classified	99,15%				
Pseudo R^2	0.1307				

Note: Robust standard errors in parenthesis. Significance level *** p<0.01, ** p<0.05, * p<0.1

Table 9. Average Treatment Effect on the Treated (ATT), main results

Variable	Treated	Controls	ATT	*t*-test
New Mkt	0.9024	0.7561	0.1463***	3.22
New Mkt Volume	7.8399	6.3702	1.4698***	2.80
Iproc	0.6098	0.6707	-0.0610	-0.92
Obs	199	9 597		
Off support	1	0		

Note: Significance level *** p<0.01, ** p<0.05, * p<0.1

All in all, the above findings confirm that university demand exerts a very strong effect on the innovative performance of its suppliers. It was our conjecture that the persistent use of a given item (tool, equipment, or more generally, a given technology) in the challenging environment of scientific research induces scientists to develop some tacit knowledge. This knowledge enables scientists to visualise future extensions of existing technologies or completely new solutions. According to our results, it seems that university-firm interactions via such demand allow suppliers to increase their innovation potential.

2.6 Conclusions

Innovation theories generally consider the innovation process as being generated by advances in scientific and technical knowledge that lead to discoveries and their technological and economic applications. And in the generation of these discoveries universities are accredited with playing a central role. Yet, there is much less consensus regarding the mechanisms by which university-generated knowledge reaches final users and creates value. Innovation theories in economics often assume the existence of pure externalities, supposing that academic knowledge spills over the economy and reaches all private agents (especially business companies) at no, or at quite a low, cost. These externalities benefit both the economic sectors and the regional activities centred upon the sources of technological change. More recent theories, however, have stressed the presence of transaction costs (i.e., the costs incurred in order to acquire knowledge and benefit from it) and the importance of market-mediated mechanisms. This new emphasis has led to a series of policy transformations aimed at encouraging and fostering knowledge and technology transfer from research universities and PROs to private businesses.

While research on university-industry interactions has focused almost exclusively on supply-side factors, and, in so doing, emphasized the role of academic commercialization and technology transfer activities, here we have proposed a complementary approach by focusing on the impacts emanating from the demand created by the university itself. In this study, we have empirically examined the impact of a large French public university on the innovative performance of its suppliers of research equipment and materials, and to do so we have employed a unique university expenditure dataset. Our results clearly point to the fact that university suppliers have a higher propensity to introduce more "radical" product innovations, which we attribute to the special role played by academic scientists as knowledge brokers, bringing to firms insights about the evolution of technologies and needs that are not yet common in the marketplace. In this sense, we embrace the conjecture forward by economic historians that innovations and technological changes are the result not only of scientific and technical discoveries, but also of a complex chain reaction triggered by the interplay of quite specific demands and solutions designed to overcome technology bottlenecks.

The results presented in this chapter serve to enrich the literature on the scale and breadth of the economic contribution made by universities. Indeed, since most of the purchases in our data are funded by public money, this study delivers new empirical evidence about the positive return of public investment in science. This question is particularly important in the context of the increasing pressure being exerted by the institutions to evaluate the economic benefit of academia. As Salter and Martin acknowledge (2001, p. 528) *"[t]hese benefits are often subtle, heterogeneous, difficult to track or measure, and mostly indirect"*. In this respect, our results bolster traditional justifications for the continuing public support of the research universities. We show that governments and funding agencies need to devote sufficient funding for the purchase the tools and equipment requested by researchers for their research projects. They also need to support the financing of such equipment maintenance. Indeed, maintenance of laboratory equipment is essential for the productivity, the continuity of performance and equipment's cost of operation. Maintenance represents an additional cost for researchers and laboratories. Since universities and CNRS policy in France is to extend the duration of the instrumentation use as long as possible, researchers often put in place maintenance contracts with their suppliers. These contracts are calculated by the companies on the nominal value of the systems and represent an enormous financial burden for universities and a crucial source of revenues for the firms involved, which is often comparable to commercial benefits from the equipment itself (Personal communication, 2018).[16]

The results proposed in this chapter could be extended in various ways. First, it would be interesting to complement the quantitative evidence about the statistical significance of researcher-suppliers interactions with a field study that allows us to inquire into how the above result take place at the aggregate level. Among the aspects that deserve closer attention would be the descriptive account of technologies that suppliers have been developing with researchers, the types of knowledge that academics provide and the respective mechanisms of transmission through which it is combined with suppliers manufacturing capabilities. Compared to our quantitative assessment, the strength of qualitative research methods resides in their ability to provide a fuller description of the mechanisms involved and so to understand better the complex reality of the phenomenon under investigation from the perspective of participants. Second, we have focused on one of the largest French research-oriented universities. This university stands out in terms of the impressive research achievements of its members, which owe much to the use of sophisticated research equipment. However, it would be interesting to broaden the analysis to other contexts. In this way, it would be possible to perform comparative studies across universities and countries, and so gain a greater understanding of the characteristics of the eco-systems that are conducive for demand-pull innovation. Third, more sophisticated work could usefully be conducted on patent data and over longer time horizons, for instance, considering the impact of university demand on patent quality (e.g. number of citations received or the generality index), patent characteristics (e.g. patent scope), and network of inventors.

[16] Furthermore, laboratories do not dispose of a specific budget for such purpose. Researchers know that they can ask money for new equipment, but not for a maintenance contract (Personal communication, 2018). Recently, the situation has changed and now when researchers purchase an equipment, they also buy a maintenance contract guarantee for five to eight years at the time of purchase (Personal communication, 2018). Thus, previous interactions with the suppliers can impact significantly the cost of the total "package".

Chapter 3

Alternatives approaches for the analysis of universities' impact on suppliers' performance

3.1 Introduction

In the previous chapter, we investigated whether university suppliers innovate more than other companies with similar characteristics by employing micro-level data on university expenditures combined with CIS and FARE data. We provided evidence about the existence of a significant positive effect of university demand on firms' innovation performance.

In the present chapter, we extend and enrich the previous analysis by exploring whether the university effect on suppliers' performance we inferred in the first chapter is still present when we refine our data and empirical settings. In the first part of this chapter, we perform a battery of sensitivity analyses by adding new variables to the firm-level data employed in the first chapter. More precisely, we firstly account for other possible interactions that take place between a university and its suppliers (R&D collaborations). Secondly, we repeat our analysis by focusing only on a specific sub-sample, the one of high-tech scientific instruments. Thirdly, we consider only companies located in the region of Alsace. Fourthly, we examine the impact of alternative regression designs and matching algorithms on the average treatment effects (ATT) results.

The above analyses rely on CIS data to identify innovation-related firm-level information. Although widely used, innovation survey data suffer from several limitations. The most critical ones concern the cross-sectional nature of the data, the representativeness of the sample, the lack of financial and accounting variables, and the subjectivity of the information reported (Archibugi and Pianta 1996; Mairesse and Mohnen 2010). In the second part of this chapter, we discuss the ongoing debate on the pitfalls of innovation survey data, and we carry out an additional empirical analysis by matching our expenditures data with an alternative firm-level database and we use firms' patents as a proxy for innovation. We perform an OLS and zero-inflated negative binomial (ZINB) regressions. Both the sensitivity and patent analyses convincingly corroborate our initial results in the first chapter, by showing that the positive and significant impact of university demand on suppliers' propensity to introduce new-to-the-market products and obtain higher sales from them persists following a consistent path of significance across the various checks.

The rest of the chapter proceeds as follows. In Section 2, we discuss the theoretical and methodological underpinnings of each sensitivity analysis we carry out. In section 3, we present the results of the sensitivity checks and discuss their implications regarding the robustness of the study presented in the previous chapter. Section 4 discusses the drawbacks of CIS dataset. Section 5 introduces the alternative firm-level database (Amadeus BvD) and the patent data (PATSTAT) that we use in the additional empirical study on university suppliers' innovativeness, a study that we perform in Section 6. Finally, Section 7 summarizes the results of the chapter and discuss their implications for the robustness of the analysis performed in the first chapter.

3.2 Sensitivity analysis

We begin our robustness analysis by performing a set of estimations targeting various aspects that might influence significantly the results presented in the first chapter. The sensitivity analysis aims to remove doubts as to other influences that might be responsible for the significant effect inferred by our initial analysis. Therefore, we control for R&D collaborations among suppliers and the University of Strasbourg (a); whether the results are affected by changing the number variables in the selection equation (b); or the type of supply (c); suppliers belonging to the university's geographical region (d) and finally to test for variations of the nearest neighbour matching algorithms as well as three other matching techniques (e).

3.2.1 Controlling for University-Industry R&D collaborations

Research and development collaborations are part of the broad scope of possible interactions between universities and firms geared towards the transfer of science and technology-related knowledge. These agreements are formal and include various forms of relationships, as research partnerships; contract research; consulting agreements; joint research centres as well as materials and personnel transfer agreements. Moreover, since University-Industry interactions gained an essential place in policy-makers agenda as policy tools to promote firms' innovation activities and performance (Scandura, 2016; D'Este and Iammarino, 2010; Fisher et al., 2009; OECD, 1998, 2002a), they also became a subject of academic and policy consideration since the 80's. The impact of University-Industry collaborations on firms' performance has been examined by various studies belonging to different streams of the innovation literature. Employing different measures of firms' innovation performance, these studies find a positive impact of R&D collaborations on firms' sales of innovative products (Klomp and van Leeuwen, 2001; van Leeuwen, 2002; Lööf and Heshmati, 2002; Criscuolo and Haskell, 2003) and on firms' patent activity (Vanhaverbeke et al., 2004; Szücs, 2018).

Among these works, only a few focus on the impact of different kinds of research collaborations strategies (the effects of different types of partners), although they end up with somehow inconclusive outcomes. For example, Faems et al. (2005) find a positive linkage between university cooperation and the share in firms' total turnover of new to the market innovative products in the automotive industry. On the contrary, other collaborations strategies that do not involve universities can be related to increased firms' share of innovative products which are new solely to the firm and not to the market. Belderbos et al. (2004) explore the impact of four types of R&D partners on firm performance, distinguishing between competitors, suppliers, customers and universities, pointing collaborations with universities as the ones with most significant and positive effect on innovations intended to open new markets and segments, as measured by firms' innovative sales growth. Exploring the effects of collaborations and spillovers on innovation success, Monjon and Waelbroeck (2003) show that collaborating with universities boosts firms' probability (likelihood) to introduce new to the market products. Lööf and Heshmati (2002) analyse empirically a selected group of cooperation types within an innovation output equation for Swedish manufacturing firms and find that cooperation with domestic universities and competitors impact firms' knowledge capital positively, as measured by the ratio of innovation sales to total sales, while cooperation with customers has been found to have a negative effect on it.

Overall, the above studies provide mixed evidence concerning the various outcome measures of the performance effect on firms. Nevertheless, they find a positive impact of engaging in R&D collaborations with universities on firms' performance. Some results are more recurrent, as the one that shows that R&D with universities are globally associated with higher shares of innovative sales (or sales from new products), higher probability to introduce new to the market products and to patent. These results are in line with the main results of our study, thus motivating us to control whether or not the effect that we find in the first chapter is robust when we control for the suppliers of the University of Strasbourg being also R&D partners of the university.

The first sensitivity check we carry out introduces a more accurate control variable in the selection equation that accounts explicitly for R&D collaboration agreements with the Universtiy of Strasbourg (UNISTRA), as opposed to universities in general, as in the main analysis. To this end, the university's technology transfer office (TTO) gave us access to the complete list of joint research contracts among researchers and industrial partners in the period 2011–2014. This list enables us to define a finer grained dummy variable to control for more traditional university-industry linkages, and so to isolate the net effect of university demand on firm performance. Accordingly, we put forward the hypothesis that the positive and significant effect of university demand on suppliers' innovation persists when we introduce control for firms' R&D collaborations with the university.

3.2.2 Applying a parsimonious selection equation

The second sensitivity analysis we perform aims to test one of the most important methodological choices in the application of the propensity score matching – the choice of variables to include in the selection equation.

According to the conditional independence assumption, the assignment to the treatment is independent of the outcomes, given a set of observable covariates. Hence, for the correct implementation of the matching, the selection equation should include observables that account for all the differences related to the outcome between treated and control firms. The variables in the selection equation should simultaneously influence the probability to receive the treatment, i.e. the chances that firms could win a public procurement bid and the outcome variables. However, according to the common support condition, the variables included in the selection equation should not either provide a perfect estimation of the probability to receive the treatment. In this case, the firms in our data would be either always receiving the treatment or never and the matching would be unfeasible. In order to capture firms with similar characteristics from both groups (treated and non-treated), we need to keep some randomness in the equation (Heckman et al., 1998b).

The "trimming" of the selection equation – the process of modelling the probability of becoming a university supplier - raises the question as to whether it is better to include too many variables as opposed to too few.

In the process of deciding which variables to include in the equation, the issue of the number of variables to be considered might be relevant (Caliendo et Kopeinig, 2008). Existing studies have advanced at least two rationales against over specifying the probit model (Bryson et al. 2002). Including unrelated or irrelevant variables might lead to a common support issue. Moreover, over-parameterization necessarily implies the inclusion of variables with no significant effect on the probability to be treated; it has been shown that over specifying the probit model can result in inconsistent estimates of the propensity scores and, in turn, to misleading conclusions (Caliendo and Kopeinig, 2008).

To demonstrate the effect on estimates' variance, Augurzky and Schmidt (2001) perform propensity score matching with three different sets of variables, showing that including the three groups of variables leads to higher variance in samples with a limited number of observations, because of the need of replacement of untreated observations.

As an alternative, scholars suggest a more careful approach in favour of parsimonious models including only (a scarce number of relevant) the relevant variables in the propensity score estimation (Rubin and Thomas, 1996).

Heckman and Smith (1999) and Black and Smith (2004) examine three methods for the selection of variables to be used in estimating the propensity score. Caliendo and Kopeinig, (2008) summarise the three approaches known as hit or miss method; statistical significance and Leave-One-Out Cross-Validation. Following the statistical significance approach, we re-estimate the selection equation retaining only those covariates that were significant at the 1% and 5% levels in the original specification, and so obtain what is known as a parsimonious equation. These variables were *Empl_log*, *PubFund* and *LabProd_log*.

Accordingly, we assume that estimating the propensity score associated with the treatment by a parsimonious model produces similar results as the selection equation presented in the main analysis.

3.2.3 Restricting the treatment to scientific instruments

In the main analysis presented in chapter 1, we considered supplies of research materials ranging from small purchases to high-cost research infrastructure. To verify whether the results are sensitive to the type of good supplied, we replicate the analysis with a sub-sample of companies that supplied goods with high technological content (or, more precisely, we consider only those purchases in the subcategory "scientific instruments", as reported in Table 1). Thus, we do not consider here supplies related to general lab equipment and consumables that might only represent off-the-shelf products. The number of treated units falls (143 firms), but the sample is large enough to obtain meaningful statistical inference. Finding that when we restrict the treatment to suppliers of high-tech instruments the results do not differ significantly, is evidence that our results are not driven by a small group of very innovative firms. Thus, we expect that the magnitude and significance path of the outcome variables will not change when we restrict the analysis to suppliers of high-technological instrumentation.

3.2.4 Restricting the treatment to regional suppliers

A further sensitivity analysis focuses exclusively on companies located near the University of Strasbourg, that is in the region of Alsace. This exercise allows us (at least partially) to addresses the concern that some firms in the control group may be suppliers of other universities beyond Strasbourg.

3.2.5 Applying different numbers of neighbours (NN) and matching algorithms

Finally, as far as the matching algorithm is concerned, it is well established that there is no best option. Different algorithms diverge with respect to underlying rules for the definition of the neighbourhood for each treated observation and the common support, along with the weights (importance) that they attribute to these neighbours. In doing so, different algorithms involve different trade-offs between estimate variance and bias (Caliendo and Kopeinig, 2008). Therefore, we first replicate the analysis by employing the same matching algorithm but changing the number of matching partners (neighbours) for each treated individual. While in the initial analysis we matched every treated firm with three nearest neighbours, here we match each supplier with one nearest neighbour (NN1) and then with five neighbours (NN5). According to the propensity score matching methodology, it is recommended to oversample, i.e. to use more than one nearest neighbour. Using more observations to build the counterfactual for each treated firm leads to decreased variance but it could increase bias if the included observations do not represent good quality matches (Smith, 1997).

Next, we test whether the results are significantly influenced by a change in the matching algorithm. When applying propensity score matching, the choice of matching estimator is made among three techniques: nearest neighbour; caliper and radius or kernel matching estimator. The nearest neighbour (NN) matching estimator is the most commonly applied matching estimator so that we decided to use it as the matching estimator in our main analysis. The essential principle is that the nearest firms from the counterfactual groups in terms of propensity score are chosen as a matching partner for each treated firm. However, in case that the nearest control observation is far away from the treated one, applying the NN estimator could lead to including bad matches into the estimation. To decrease the risk of including unreliable control units in the estimation, one could constrain the maximum deviation of propensity score between the control and treated unit. This can be done by imposing the maximum distance between the two observations by an alternative matching technique: the caliper (Cochran and Rubin, 1973). The underlying rule that the caliper matching follows is that untreated firm from the comparison group that lies within a certain propensity score range with respect to the treated firm and is the closest neighbour is chosen as a matching partner. In case that no untreated observation matches the treated firms within the width of the defined caliper, the latest are excluded from the analysis, which is also a way to enforce a common support condition. By applying caliper matching, the risk of bad matches is minimal, thus the overall quality of the matching increases.

Nevertheless, by not including some observation into the analysis, fewer matches could be carried out, which would lead to an increase in the variance of the estimates. A practical drawback of the caliper matching consists in the choice of the maximum tolerance level (Todd, 2006). Discussing the choice of the caliper size, Rosenbaum and Rubin (1985) note that when the variance of linear propensity score is twice the variance of the control group, a caliper of 0,2 standard deviation clears away 98% of the bias in a normally distributed covariate. Rosenbaum and Rubin generally suggest a caliper of 0.25 standard deviation of the linear propensity score. Wang et al. (2013) find that a caliper of 0.2 of the pooled standard deviation of the logit of the propensity score provides better performance in the estimation of treatment effects. As a second approach to perform the matching, we use radius matching estimator introduced by Dehejia and Wahba (2002) as a modification of the caliper matching.

In contrast with the caliper, radius matching picks not only the nearest untreated counterpart observation within each caliper but all the counterfactual observations within the caliper. The main advantage of this matching technique is that it includes in the estimation as many untreated observations as they are accessible within the calipers' boundaries. In this way, the radius matching favours the handling of more control observations when suitable matches are available while limiting the inclusion of bad matches. Therefore, the radius matching technique combines the desired methodological aspects of oversampling on the one hand while avoiding the risk of bad matches on the other hand.

A common feature of the NN, caliper and radius matching algorithms is that they all use only a limited number of untreated observations to build the counterfactual group. Compared to the above approaches, the Kernel matching technique takes into consideration weighted averages of almost all untreated observations to build the counterfactual. The modalities depend on the choice of the kernel function to be applied. Accordingly, the principal advantage of the Kernel estimator is that it takes into consideration a great range of information, which decreases the variance of the estimations. At the same time, it involves a risk of including unsatisfactory matches into the estimation.

In its application, the kernel represents a kind of weighted regression of the control group on an intercept with weights given by the kernel weights (Smith and Todd, 2005). Their loads depend upon the distance between each untreated and treated observation. According to Caliendo et Kopeinig's methodological note (2008), the kernel places higher loads on observation near to the treated individuals in terms of propensity score and lower loads on distant observations. The practical application choice to make with respect to the kernel estimators are the kernel function and the width parameter. While the choice of kernel function is considered by scholars as a minor issue (DiNardo and Tobias, 2001), the definition of the width parameter can have some important consequences in terms of variance and bias[17].

Our short remind of the basic underlying rules and methodological choices associated with each algorithm confirms that there is not one of them that represents the best choice according to all the criteria. However, showing that our analysis produces similar outcomes using different estimators is a sign of methodological robustness. Consequently, we expect that the results of our initial analysis will not change in a significant way according to the matching estimator we employ.

3.3 Sensitivity analysis results

We now turn to present and discuss the results of the various sensitivity analyses introduced in the previous sections. The estimations are summarized in Table 10.

Firstly, The ATT estimates reported in column 1 indicate that the results are unaffected when we account for suppliers' R&D collaborations as we observe similar patterns in terms of magnitudes and levels of significance. As expected, once we control for collaborations, the magnitude of the coefficient that represents the new to the market products slightly decreases - instead of 14% now 12% of the suppliers introduce such products. Similarly, the significance of new products' sales decreases to 5%. Overall, the results of including R&D collaborations in the selection equation modifies the results slightly, without impacting considerably their magnitude

[17]A higher number of width produces a smoother estimated density function, resulting in a better fit and a decreased variance between the estimated and the real underlying density function. However, a large width of the kernel can also give rise to biased estimations, because it sleeks quite certain basic features. Thus, the methodological decision of the bandwidth value presents an arrangement between a small variance and an unbiased estimate of the true density function.

and significance level. These outcomes lead us to accept our first hypothesis that the effect of university demand on suppliers remains once we control for one of the most widespread instances of interactions between universities and firms: R&D collaborations.

Secondly, we re-estimated the selection equation retaining only those covariates that were significant at the 1% and 5% level in the original specification. The ATT estimates reported in column 2 show that our main findings hold with respect to both the magnitude and the significance of the outcome variables.

Thirdly, we focus our analysis on a specific sub-sample of suppliers of high-technology instruments. Interestingly, what we would expect here might be to observe an important variation in the estimates based on the idea that the providers of the most high-tech tools are also the most innovative companies in our sample. Thus, the results of the analysis for such suppliers would be a lot more amplified than for "regular" suppliers. The estimates reported in column 3 show that the results are not sensitive to the type of suppliers. The new-to-the-market variable has the same value as in the main analysis 13% and exhibits the same significance level of 1%. However, the new-to-the-market volume variable drops both in magnitude – from 1,46 to 1,03 and in significance from 1% to 10%. Thus, we observe that overall the estimates follow a consistent path with our initial results. In contrast with our main analysis, the variable process innovation becomes significant at the 5% level. The negative effect on firms' process innovation could be explained by the diversity of possible interactions that unfold between researchers and suppliers parallel to the purchase of instruments. Our field study presented in the next chapter of the thesis reveals how these interactions evolve. A common practice for suppliers is to settle services contracts with the university laboratories. Within the framework of these agreements, the university builds items and prototypes for the companies. In this way, university and suppliers switch places and the researchers can play the role of providers for the companies. Such practices explain the possible negative effect on suppliers' process innovation: firms prefer to use the university laboratories as workshops instead of establishing new processes of production.

Fourthly, we tested whether restricting the treatment to regional suppliers changes substantially the ATT estimates. As shown in column 4, the ATT estimates are significant at the 5% level for new-to-the-market products as well as sales and the magnitude of the impact is now more than twice as large. Also, in this case, the sample size falls, but we still detect a positive effect of the treatment. These results point out that companies located within the regional boundaries benefit to a higher extent from the University of Strasbourg than overall French companies.

Finally, changing the number of nearest neighbours for the building of the counterfactual group also shows that whether we include 1 or 5 non-treated firms to build the control group of non-treated firms, does not alter the results of the analysis significantly (columns 5-7). Furthermore, when switching between three other matching algorithms, we observe that the results are highly persistent across the different alternatives (columns 7-9). As our research hypothesis states, the ATT results do not change significantly according to the matching algorithm.

Table 10: Average Treatment Effect on the Treated (ATT), robustness check analysis

Variable	UNISTRA (1)	Parsimon. (2)	Scient. Inst. (3)	Regional (4)
New Mkt	0.1260^{***}	0.1825^{***}	0.1389^{***}	0.2178^{**}
New Mkt Volume	1.0255^{**}	1.4165^{***}	1.0372^{*}	2.4974^{**}
Iproc	-0.0691	-0.0635	-0.1556^{**}	-0.0055
Treated	199	199	143	33
Off support	1	0	1	0
Controls	9 597	9 597	9 597	455
Off support	0	570	0	0

Variable	NN1 (5)	NN5 (6)	Kernel (7)	Caliper (8)	Radius (9)
New Mkt	0.1341^{***}	0.1390^{***}	0.1479^{***}	0.1463^{***}	0.1514^{***}
New Mkt Volume	1.0499^{*}	1.3862^{***}	1.3896^{***}	1.4698^{***}	1.4254^{***}
Iproc	-0.0976	-0.0610	-0.0866	-0.0610	-0.0867
Treated	199	199	199	199	199
Off support	1	1	1	1	1
Controls	9 597	9 597	9 597	9 597	9 597
Off support	0	0	0	0	0

Note: Significance level *** p<0.01, ** p<0.05, * p<0.1

To sum up, the main results of the first chapter established that university suppliers introduce more new products and increase their sales out of them. The sensitivity analysis provides a refinement to the foregoing analysis with respect to five data and methodological dimensions. By introducing a more sophisticated measure of R&D agreements with Strasbourg academia, we showed that the positive effect of university demand on suppliers revealed in the first chapter is indeed not due to other well-known formal channels of university impact on firms such as R&D contract collaborations. In addition, the sensitivity analysis showed that our core results are not driven by a small group of very innovative firms in the CIS that deliver high-tech equipment demonstrating the broader relevance of the phenomenon under study. Furthermore, restricting the sample to regional suppliers, allowed us to deal with possible overlapping of influence for firms that are suppliers to other universities besides Strasbourg showing that the treatment effect on companies located in proximity of the university is higher.

Finally, we could test the stability of the central estimates through variations of the matching algorithm and demonstrate that all the matching techniques deliver estimates consistent with our core results. We conducted four exercises to empirically examine the sensitivity of our core propensity score matching estimates by modifying various parameters of our main analysis shown in the first chapter. By showing that the coefficients of our initial analysis are stable across each sensitivity check, we provide additional support for the plausibility and validity of the evidence presented in the previous chapter. Despite the fact that we put the significant effect of universities on companies to extensive tests, the first part of our robustness analysis did not leave any doubt about the empirical resilience of the effect.

The sensitivity analysis presented in the first part of this chapter supports the central results of the thesis through a series of exercises that take place within the same database. In what follows we adopt a different approach to show the robustness of our core results drawing on different datasets.

3.4 CIS data limitations and suppliers' patent analysis

The sensitivity analyses discussed in the previous sections illustrated the soundness of our main empirical finding by showing a significant positive effect of universities on suppliers under nine distinct auxiliary ATT estimations. In this second part of the chapter, we conduct an additional robustness check, this time adopting an alternative firm-level and patent datasets. This further analysis is motivated by the ongoing debate in the research community on the utility and relevance of the CIS data for innovation studies. In the following sub-section, we briefly discuss the origins of the CIS data and main drawbacks put forward by scholars in the domain.

3.4.1 The two methods of collecting data on industrial innovation before innovation surveys

The two standard proxies of innovation and technological change are R&D expenditures and patents. R&D expenditures have regularly been recorded since the 50's according to the Frascati Manual. The existence of patents data can be traced to the 19th century, the first establishment of intellectual property rights and national patent offices. However, the use of both data has been subject to various criticism: R&D expenditures are just one input among others that might be difficult to approach and measure (Freeman, 1987; van Raan, 1988; van Raan et al., 1989; Barr et al., 1994), and patents do not account for all innovations, but only for the ones that are sufficiently new and considered worthy to be patented. Furthermore, firms sometimes apply alternative methods to protect innovation that do not include patenting, as industrial secrecy (Fontana et al., 2013; Hall et al., 2013). These and other critical remarks led to the introduction of the third source of innovation measures from innovation surveys.

3.4.2 A brief note on the history and origins of the CIS

Although the first official versions of the Community Innovation Survey (CIS) appeared in their formal status in the Oslo Manual in the early 90's, the original variants of the survey have been put in place in several countries across Europe and in the United States since the middle of the last century (Mairesse and Mohnen, 2008).

In the 50's there had been occasional initiatives on data collection conducted by government departments, academic units and statistical agencies, that were built upon available data as patents or R&D expenditures (Godin, 2002). Among these examples are Carter and Williams's (1958) surveys in the 50's for the Science and Industry Committee of the British Association for the Advancement of Science. Mansfield, Myers and Little conducted a similar project for the National Science Foundation during the 60's. Innovation survey was established at the Science and Policy Research Unit (SPRU) in Brighton and led by Keith Pavitt (Pavitt, 1984; Robson et al., 1988). Pilot tests were then carried out in many countries such as France, Germany, Italy, Luxembourg, and the Netherlands among others.

The first official surveys were an outcome of the joint work of OECD and Eurostat, and appeared in the Organisation for Economic Co-operation and Development's report, "The Measurement of Scientific and Technological Activities, Proposed Guidelines for Collecting and Interpreting Technological Innovation Data", also known as the Oslo Manual (1992, 1996, 2005). The Oslo Manual presented guidelines for the collection and treatment of industrial innovation data. The CIS provided qualitative and quantitative data on industrial innovation activities and the introduction of various types of innovation on the market. The surveys emerged as a common goal of researchers and policymakers towards a better understanding of the extent and distribution of innovation activities by way of direct and economy-wide indicators of innovation inputs and outputs at the firm level. The survey data includes measures on tangible and intangible inputs in innovation; data on outputs in the form of sales of innovative products and data on external sources of information as collaborations partners and others.

Since its launch, the survey has expanded to be the largest innovation survey in the world according to the number of participating countries and responding companies and, as a consequence, it turned to be among the most exploited statistical surveys by economists. The CIS has also been used for the elaboration innovation indicators related policies that are applied in Europe's Innovation Union Scoreboards and by the OECD. By way of example, Arundel and Smith (2013) count six among the 25 indicators in 2011 scoreboards that are derived from the CIS data, incorporating indicators for innovation expenditures as a share of turnover; the percentage of SME that develops in-house innovation; and the share of turnover of new-to-the-market or new-to-the-firm innovations.

Furthermore, the survey became a reliable source of data for researchers in several disciplines, especially in economics. A careful examination of the evolution of innovation surveys through the years shows that the active part in their modification and development can easily be traced back to academic researchers' interest, as significant drivers of innovation research and to a lesser extent to government agencies like the European Commission and NSF. The active participation of academics influenced the collection of valuable micro-data for research in four respective fields of economics (Arundel and Smith, 2013): interactive models of innovation; evolutionary economics; the role of learning; and national systems of innovation (Smith, 1997). Academic studies using CIS since the 90's have increased exponentially. These works explore various innovation-related subjects and could be divided in two broad research streams: 1) contributions that explore the determinants of innovation; 2) contributions that study the effects of innovation.

By and large, while the CIS data has been seen as an important tool in the hands of researchers that enable them to tackle questions that have not been possible to address with other data sources, recently their utility has been brought into question. In what follows we are going to recall the main drawbacks of the CIS data that has been raised by scholars as part of the motivation for the analysis that we perform next.

The first point that scholars rise when considering CIS data is directly related to our brief introduction of its origins. It is namely that the CIS initial aim was not to provide data for econometric analysis of innovation that focuses on the better understanding of innovation processes but to supply aggregate indicators and scoreboards for the ranking of EU countries overall innovation performance. In a recent debate on the subject (Druid conference, 2018) scholars have pointed to the conflict of interests between scholars and statistical institutes in charge of the data collection as the main reason for the lack of improvement of the CIS as a tool for academic analysis. In order to remain a valuable research tool in innovation studies, the CIS data should be subject to change. In the next sections we briefly review the drawbacks of the CIS that are commonly highlighted by scholars.

3.4.3 CIS data harmonisation across countries and waves

Although one of the CIS data advantages is that it covers several countries in different periods, scholars have pointed out that this does not allow real comparability across countries. The main obstacle consists in the existence of significant differences between waves over time and between countries regarding sampling; response rate and most importantly the content of the questionnaire. The sampling methods of the companies in the survey should be the same across countries, and if it is not possible, scholars point out that the survey should include detailed information about the sampling approach in order to allow for the correction of possible biases (Mairesse and Mohnen, 2002).

A further problem is that many questions have been modified in the various waves of the CIS. Some questions that were considered as less relevant were discarded, for example, the questions on the relative importance and effectiveness of different appropriation mechanisms were left out of the survey after the first CIS. Thus, researchers emphasise the idea that the criteria of which questions should be included in the survey or not remain somewhat ambiguous. The same is in force when considering the inclusion of new questions: the rationale for introducing new questions is exclusively dependent on statistical offices agenda and not the research community using the surveys. Thus, the structures in each subsequent survey are defined by the current needs of the statistical offices rather than academic scholars' interests. While variations of the questions according to different countries are to some extent coherent, because of specific country issues, scholars urge to establish a group of central questions asked in every country. Such questions should be following uniform definitions and identical wording. Furthermore, in order to enable comparison analysis across time, the core identical questions between countries should be the same for each wave.

3.4.4 CIS data access

Access to Eurostat data can be also quite difficult for scholars who do not work for a ministry or official statistical office. As to the access for a specific country data, the procedure consists of a demand addressed to a specific statistical office of the country (INSEE in France) through research institutions. In France, under a rigorous confidentiality engagement, it is possible to obtain access to a non-anonymized firm-level data in the framework of specific research projects at universities.

Once the access is obtained, the issue of confidentiality of the firm-level individual information disclosed in the survey is to be considered. Such a confidentiality issue can be a real obstacle to an econometric analysis by economists since they make it impossible to match the surveys to other data, which is where most of the value added for academic research stands. Merging of CIS with other data as accounting; administrative or other survey data is crucial for the addressing of potential selection bias and provides researchers with more instruments to correct for endogeneity and various measurements errors. Therefore, merging CIS with supplementary firm-level information is a source of more explanatory variables to be included in models, increasing their relevance and explanatory power (Mairesse et Mohen, 2010).

3.4.5 Cross-section data

The biggest drawback of the CIS data researchers continuously complain about is the cross-sectional nature of the data. Essentially the CIS gathers data for a group of firms in different periods. The sample of firms that overlaps across periods is a little share of the total number of participants. The outcome is that the same firms are not surveyed wave after wave. The lack of panel observation makes it complicated to explore the dynamics of innovation over time and to control for firm invariant with time characteristics and individual unobserved heterogeneity (Mairesse et Mohnen, 2002). Thus, it makes it very difficult to address econometric endogeneity issues and to study the direction of causality in innovation studies. Moreover, these constitute an important practical issue in innovation studies.

Strategic decisions of firms as whether or not to engage resources in R&D and innovate or what kind of appropriation strategy to put in place are often intertwined among them and are closely associated to third factors, which are difficult to observe in practice and for which to find an appropriate exogenous or instrumental variable is complicated (Veugelers, Druid conference, 2018).

3.5 Using alternative datasets

In the previous section we reviewed the main pros and cons of CIS data for empirical studies on innovation. In light of this debate, we perform an alternative analysis; we propose an additional analysis that relies on two alternative sources: BvD AMADEUS and PATSTAT. The study aims to address some of the criticisms concerning CIS data. We first present the data and empirical approach of the robustness analysis. In the next section we turn to explain the empirical methodology we use for the analysis and illustrate its results.

The main firm-level data we rely on in this alternative analysis is the Amadeus database of comparable financial and business information of private companies' activity across Europe. Amadeus is a panel dataset and covers 19 million companies in 33 European countries and incorporate a variety of financial and ownership information. The data is provided by a European electronic publishing firm - the Bureau van Dijk (BvD). The BvD collects data via a network of information providers of Amadeus in each country; for France, the official public body in charge of collecting the annual accounts is the INPI (National Institute of Intellectual Property). We retrieve financial and accounting information for all French businesses from the Amadeus database, for the period 2011–2014. This database does not include, however, complete and precise information on the innovation activities of firms; thus, we retrieve additional patent data from the European Patent Office (EPO) – Worldwide Patent Statistical Database (PATSTAT). The PATSTAT dataset offers bibliographic and legal status patent data for more than 100 patent offices around the world (Thomas et al., 2010). It contains data on over 67 million patent applications and 35 million granted patents. Academic researchers and policymakers consider PATSTAT as the reference database for patent analysis as the calculation of patent indicators and the production of technology indicators (OECD).

Nevertheless, the matching of financial and patent firm-level data is not a trivial task. We implement the matching of firm-level and patent data via a semantic matching procedure based on the firms' names. We use a general-purpose methodology algorithm developed by Tarasconi (2014). The method is carried out in three steps: harmonisation, matching and filtering. Firstly, firms' and applicants' name could be spelt out differently between the two datasets, which would complicate the automatic association between patents application by the same entity under a single label. Thus, the data is harmonised by the Patstat Person Augmented Table (Magerman et al., 2009) that identifies the patent sector allocation and allows to remove individuals from the data. Then the remaining firms' names are further adjusted by eliminating legal designations and other non-standard characters as points, double spaces, and other common misspellings. The quality of the matching is assessed according to three criteria: perfect matches; alphanumeric matches and Token similarity. The last step of the algorithm is the filtering of the matches and aims at minimising the introduction of false positives as true matches. Several approaches are used by Tarasconi (2014) to detect possible false positives. Among them is the possibility to control for the same technology fields of patents and companies (cross-check via IPC-NACE consistency); control for inter-temporal consistency between the date of the patent application and firms' beginning of existence, and other relevant firm-level characteristics, as positive R&D expenses. By adding the "also known as" firms' names to the name pool and by checking for patents application date and firms' foundation year, Tarasconi's methodology of matching financial and patent data presents significant variation with respect to previous techniques in terms of precision.

Once we performed the matching between financial and patent firm-level data, we succeeded in identifying 682 UNISTRA's suppliers in the AMADEUS-PATSTAT dataset. However, given the extent of the missing information, the sample of suppliers that can be exploited for the empirical analysis falls substantially, and we end up with 121 firms.

The variable of interest in our analysis is the number of patent applications by a firm (*Patents*). To be consistent with our 1st chapter analysis, we select (wherever possible) the same group of control variables. Thus, we include the size of the company (*Empl_log*), the age (*Age_log*), an index of profitability (*ROS*) and labour productivity (*LabProd_log*), a dummy to account for R&D collaboration agreements with UNISTRA (*UniColl_Unistra*), and a full set of industry (NACE 2 digits) and regional dummies. We also control for the firms' previous innovation efforts and propensity to patent by including the stock of patents (*PatStock*). Finally, we proxy the firms' innovation capabilities by considering their intangible assets (*IntAss_log*).[18]

[18] In this context, too, we find substantial differences between university suppliers and other companies with respect to the characteristics considered. Descriptive statistics for the sample are not reported in the text but are available upon request.

3.6 Empirical methodology and results from using patent data

To carry out our econometric analysis, we first estimate an OLS regression, where the dependent variable is *Patents*, the main regressor *Supplier* is the binary variable taking a value of 1 if the firm is a UNISTRA supplier, while we also include a vector of firm-level controls, as discussed above. However, the patent applications variable presents a skewed distribution with the presence of many zeroes. Furthermore, in our data, we observe that the conditional variance of *Patents* exceeds its conditional mean. Thus, it seems appropriate to complement the OLS estimation with a zero-inflated negative binomial model (ZINB). Such models estimate two equations simultaneously, one to describe the relationship between the response variable and the set of covariates and one to model the excess of zeroes. We use intangible assets as a zero-inflator since we expect firms with lower intangible assets (i.e. lower R&D investment) to exhibit a lower propensity to patent.

Table 11 reports the results of the patent analysis. The coefficients of *Supplier* are positive and statistically significant (at the 5% level) in both regressions, implying that university suppliers exhibit a higher propensity to patent, all other things being equal. These results are consistent with our core estimates. They indicate that university suppliers are more prone to file in for patent compared to the large population of untreated firms in the Amadeus dataset. The effect of university demand on firms leads them to introduce more new-to-the-market innovations that have a high market value and need to be protected by patent applications. In this analysis, we showed the positive effect of university demand on suppliers by employing an alternative measure of innovation coming from a different dataset. These estimates further corroborate the main findings discussed in the first chapter of the thesis and show that the results of our main analysis were not CIS data driven.

Table 11: OLS and ZINB estimates

Variable	OLS (1)	ZINB (2)
Supplier	0.3539**	1.9739***
	(0.1511)	(0.4367)
PatStock	0.0017***	0.0023**
	(0.0002)	(0.0009)
Empl_log	0.0141***	0.9504***
	(0.0016)	(0.0842)
Age_log	-0.0094***	-0.1368
	(0.0023)	(0.1233)
ROS	0.0074***	0.2472
	(0.0016)	(0.3989)
LabProd_log	0.0081***	0.5671***
	(0.0013)	(0.1299)
UniColl_Unistra	0.8074*	-0.3401
	(0.4131)	(0.4214)
IntAss_log	0.0036***	
	(0.0008)	
Inflation:		
IntAss_log		-0.6282***
		(0.0988)
Sectors	Yes	Yes
Regions	Yes	Yes
Obs	155 963	155 963
R^2	0.6250	

Note: Robust standard errors in parenthesis. Significance level *** p<0.01, ** p<0.05, * p<0.1

3.7 Conclusions

In this chapter, we performed a battery of sensitivity analyses with the aim to refine the empirical evidence presented in the first chapter of the thesis. For this purpose, we applied two distinct approaches to test the robustness of our central empirical results according to the dataset and methodological framework we employed.

We started the second chapter of the thesis by investigating the robustness of the results with regards to four theoretical, practical and methodological aspects. We formulated a set of brief research hypothesis and test them making use of our initial data on university expenditures and community innovation survey, including new key variables from Strasbourg SATT office.

Next, we switched the firm-level survey data with Amadeus BvD and patent data drawn from PATSTAT. Exploring the effect of supplier status on companies patenting activity, we have shown that university suppliers patent significantly more than other firms with similar characteristics.

The results of the above robustness checks demonstrate that our main empirical results hold to a series of sensitivity checks and are not dependent on certain methodological choices as the matching algorithm or number of variables included in the selection equation. Furthermore, by using an alternative measure of innovation – patents instead of community survey data – we found that suppliers exhibit a significantly higher propensity to patent. These results support and validate further our empirical study presented in the second chapter.

In spite of the fact that our analysis so far has provided comprehensive empirical evidence about the existence and persistence of the impact of universities on suppliers' innovation, our empirical approach puts too much emphasis on relations among quantitative variables. Such a quantitative approach does not allow to "open the black box" of researchers-suppliers interactions and break-down the processes through which their interactions occur and unfold to give rise to specific innovation performance benefits for the suppliers. The study of these dynamics goes beyond the scope of the methodological tools applied in chapter 2 and 3 of the dissertation, although we deem it essential for a profound understanding of the complex researcher-supplier interactions. Therefore, in the next chapter of the thesis, we complement the quantitative evidence about the statistical significance and robustness of the outcomes associated to researcher-suppliers interactions with a field study that allows us to inquire into how universities serve as a learning environment for their suppliers.

Chapter 4

Opening the black box of university-suppliers' co-invention: some field study evidence

4.1 Introduction

The aim of this thesis is to investigate in-depth the emergence of technologies and their impact in the context of academics' interactions with their suppliers of scientific instrumentation. In the second chapter, we employed an econometric strategy to test whether university demand exerts a significant and positive effect on the innovative performance of their industrial suppliers of equipment. The main results of this quantitative study indicate that university suppliers introduce more new-to-the-market innovative products and they enjoy higher sales from those products. Furthermore, in the third chapter, we ran extensive robustness analyses of the results presented in the second chapter, by employing two different methodologies. The first of them examines the sensitivity of the main estimates by adding new variables; restricting the sample size and varying the matching algorithms. The sensitivity analysis represents a valuable extension of our initial study, that makes use of the same data infrastructure and methodologies to show that the main empirical results obtained in the second chapter follow stable paths of significance throughout the various estimations. The second robustness analysis we performed aimed at testing the effect of university demand on suppliers by means of different innovation and firm-level datasets as well as with a different methodological approach. These robustness analyses provide very strong support for the core results of our study by showing the presence of a significant and positive impact on the innovative capabilities of industrial suppliers even within an alternative empirical framework.

Altogether, while the second chapter of this thesis brings to light the existence of an unexplored channel of influence between universities and their industrial suppliers, the third one reinforces the initial results and provides further empirical evidence about the existence and the robustness of the phenomenon. At the same time, these quantitative studies do not shed light on the actual mechanisms through which universities favour learning and innovation in their industrial suppliers. In the present chapter, we thus move to explore in-depth such mechanisms and we try to provide evidence about *how do dynamic complementarities among researchers' demand and suppliers' competencies emerge.*

Given the exploratory nature of our inquiry, our methodological choice is to conduct an in-depth qualitative field-study based on multiple-case study design (Yin, 2014). We study three cases of technologies developed by researchers from three different research unities of the University of Strasbourg (UNISTRA) and their industrial suppliers. The cases focus on three leading biomedical and chemistry institutes of the University: the Institute in Molecular and Cellular Biology (case 2, Institute 2); the Institute in Supramolecular Science (case 3, Institute 3) and the Institute in Chemistry (case1, Institute 1). In the period September – December 2018, we have conducted 10 formal and 5 informal interviews with researchers to gather factual data about their suppliers. The main questions in the interviews relate to the background and outset of researchers' relationships with their suppliers, and to their evolution over time both inside and outside the framework of public procurement bids.

This chapter builds on and refines previous studies in at least two ways. First, while a lot of research efforts have been directed to study the economic contribution of public research universities, most of these studies have been focusing on activities that depict technology transfer in a direct, linear-wise and unidirectional way (see e.g. Dosi et al., 2006; Perkmann et al., 2013). A common feature of these activities is that they all are mediated by formal procedures put in place by the technology transfer offices or other related institutions. In addition, the technology transfer that takes place between universities and industry is depicted as a black box which creates a lot of ambiguity about how universities operate as a learning space for firms. Nevertheless, a closer look at how universities work in practice reveals that many technology transfers do not take place via "official" channels (Rosenberg, 1992). Essential pieces of knowledge generated by university research are often transferred to industry without having recourse to the support of technology transfer offices (TTO) or similar established technology transfer mechanisms. More often, technologies flow back and forth between researchers and industrial firms as a by-product of other reciprocal relationships, for example, the demand for instrumentation. A case in point is represented by technology-intensive interactions between academics and their suppliers (Perkmann and Walsh, 2007). Accordingly, scholars have emphasized the need of greater research efforts into the study of more interactive modes of technology transfer (Lundvall, 1988; Salter and Martin, 2001; Pavitt, 2005). Such an approach would also provide a more rigorous evidence about the knowledge transmission processes among academia and companies.

Second, the role played by universities as fundamental actors in demand-driven innovation is a special case of the role of public procurement as a source of innovation, a topic which gained a lot of attention in recent technology policy debates (Edquist and Hommen, 2000; Edler and Georghiou, 2007; Castelnovo et al. 2018; Florio et al. 2018). The success of the public procurement procedure depends largely on user–supplier interactions which can be hampered by information asymmetries and by weak dynamic complementarities (Malerba, 1996, 2006; Chicot and Matt, 2018). In the framework of public procurement, interactions between researchers and suppliers are crucial for the development of interfaces leading to innovation (Rolfstam, 2009). This chapter improves the above studies by exploring in depth the communication mechanisms and interactions between researchers and suppliers. By focusing on these interactions, we also shed light on the factors that hamper collaboration between procurers and suppliers oriented towards the development of new technologies (Chicot, 2017).

Third, by discussing the strategic and technological learning opportunities offered by universities to their suppliers, we seek to contribute to previous studies focusing on big-science centres' suppliers' activity that have tackled both the direct (Autio et al., 2004; Nilsen and Anelli, 2016) but also the secondary financial impact of big-science procurement on their industrial suppliers (Schmied, 1982, 1987; Streit-Bianchi et al., 1984). These studies provide valuable insights about the mechanisms generating learning and innovation of big centres' (e.g. CERN) suppliers. At the same time, they call for further exploration of these mechanisms in universities-suppliers procurement interactions as well.

The rest of the chapter proceeds as follows. In Section 2, we discuss some theoretical landmarks and state the research propositions that guide our analysis. We describe our research methodology in Section 3 and we discuss the selection criteria of the three case studies, the questionnaire used for the interviews as well as the advantages and the limitation induced by the qualitative approach with respect to the quantitative chapter 2 and 3. We present each case in Section 5. Section 6 discusses the results in light of the existing science and technology literature.

Finally, Section 7 concludes with some implications for policy and with a discussion of the limitations and possible extensions of this work.

4.2 Some theoretical landmarks

Technology transfer has been defined as a "intentional, goal-oriented interaction" (Autio and Laamanen, 1995) "between two or more persons, groups or organizations in order to exchange technological knowledge and/or artefacts and rights" (Amesse and Cohendet, 2001) and "during which the total sum of technological knowledge possessed by the parties stays stable or increases" (Autio et al., 2004).

The aim of this chapter is to challenge some aspects of the above definition of technological transfer, namely its intentional and goal-oriented features and the idea that learning among organizations can be reduced to the sum of knowledge acquisition processes of their members (Marengo, 1992). The underlying principle of our approach is that relations among different organisations, as defined by their history and socialization practices, play a fundamental role in driving and shaping collective learning processes.

Such a conception of technological innovation has interactive learning at its core and hence calls for further exploration of the interactions that unfold between firms and universities; the mechanisms through which these interactions and their respective outcomes evolve; the characteristics of inter-organizational relations and the degree of formalization and legal framework within which these relations are built.

More precisely, our study aims to explore *the emergence of dynamic complementarities among researchers' demand and suppliers' competencies and identify the (dynamic) processes leading to new technologies.* Formally, interactions between academics and suppliers take place within the framework of public procurement procedures. Since there is spending of public funds the procurement procedures represent a formalized process driven by the principles of transparency, efficiency and equal treatment. In this context communication between researchers and companies during the procedure is restricted and considered illegal since it can imply favouritism in benefit of certain candidates. Although university procurement is not specifically geared towards the generation of innovations, it has a significant impact on firms' innovative performance (as shown in chapter 1) and represents a special case of the role of public procurement as a source of innovation wherein innovation appears as a positive by-product of the procurement process.

To analyse public procurement processes that are exclusively designed with the aim to stimulate new technologies, the literature uses the concept of Public Procurement for Innovation (PPI). Public Procurement for Innovation can be defined as the purchase "of a not-yet-existing product or system whose design and production will require further, if not completely novel, technological development work" (Edquist and Hommen, 2000 p. 5). While universities represent a common type of public procurement, public procurement for innovation "occurs when a public agency places an order for a product or system which does not exist at the time, but which could (probably) be developed within a reasonable period" (Edquist and Hommen 2000, p. 5). In this setting, governments define the functional requirements of the expected new item leaving its practical achievement to the creativity of the suppliers (Rothwell and Zegveld, 1981; Geroski, 1990; Edler and Georghiou, 2007).

4.2.1 Formal and informal mechanisms of communication

To understand the characteristics of communication processes involved in knowledge development, we turn to organizational behaviour research and to the concept of "socialization" that has firmly been established over the years. The seminal works of Van Maanen (1977) and Van Maanen and Schein (1979) paved the way to other studies who applied the above concepts to fields such as consumer behaviour (Moschis and Churchill, 1978), goal and value orientation (Kraimer, 1997), and strategic multinational and joint venture agreements (Chung *et al.*, 2000). As defined by Gupta and Govindarajan (2000), socialization is the level of interaction, and communication of multiple actors within and between different organizations' facilities, leading to the strengthening of personal familiarity, collective problem solving and enhanced communication.

Socialization processes can be broken down into formal and informal processes (Cousins *et al.*, 2006; Lawson *et al.*, 2008; van de Vijver *et al.*, 2011; Hietajärvi and Aaltonen, 2018). Formal processes typically consist of physical forms of indirect communication, wherein pieces of knowledge are transferred through a systematic language or formal representations (Lei et al, 2001). This shared formal language or common rules are based on cognitive artefacts such as confidential reports, emails, and letters (Agarwal, 2014). Agarwal (2014) also described formal communication as a style that maintains authority, is clear and effective, contains an orderly flow, but can also be rigid and slow, lacking a personal touch. When using the formal mechanism, supplier and customer create impersonal, low-rich communication channels, which are more suitable for the transfer of explicit, articulated unequivocal pieces of knowledge, clear messages, and standard data (Daft & Lengel, 1986). According to the formal socialization approach, these designated structures of communication share knowledge between buyers and suppliers through mechanisms such as cross-functional teams, joint workshops, and matrix style reporting (Cousins et al., 2006).

Informal socialisation mechanisms are instead based on human interactions beyond a defined formal framework or workplace and are often embedded in social relations (Hietajärvi and Aaltonen, 2018). They can be described as non-physical forms of direct communication such as face-to-face meetings, telephone conversations and personal mobility. As described by Krause *et al.*, (1998), informal processes consist of workshops, social events, off-site meetings, and communication guidelines (e.g. "we have an open-door policy"). Agarwal (2014) discusses this communication style as one that flows in every direction, as it does not need to follow specific rules or a chain of command, where information flows through the "grapevine" during social occasions, such as community interactions or business dinners. Using the informal style of communication to transfer knowledge gives rise to a structure shaped by interpersonal, high-richness communication channels (Balboni et al., 2017). Balboni et al. (2017) also describes the informal mechanism as being preferred for managing highly ambiguous, not manifest and implicit knowledge, since the recipient is in direct contact with the provider, which reduces potential conflicting interpretations of the information, thereby reducing information flow errors. Due to the high richness of this type of channels, informal interactions create communication pathways that must be maintained through a continuous commitment and resource investments by both parties (Daft & Lengel, 1986; Lo & Lie, 2008).

Formal and informal mechanisms for communication have been described in several different ways. Some have described them according to the socialization processes they entail while others have labelled them as the vehicle of knowledge transfer between the buyer and supplier relationship. According to Amesse and Cohendet (2001) socialization is important in knowledge-based environments, where the effectiveness of the knowledge-transfer process is dependent on the way firms manage and transmit knowledge. The overall descriptions mutually depict the formal and informal mechanisms as channels of communication, which has been found to be important in the transference of knowledge but also in transferring and developing technological capabilities (Lynskey, 1999).

Studies that explore socialization in supply-chains have developed an understanding of socialization in bilateral customer-supplier relationships in the manufacturing context (Cousins *et al.*, 2006; Cousins and Menguc, 2006). To explain how socialization impacts organizations performance, scholars use the notion of relational capital that refers to the establishment of solid interpersonal relationships through a history of interactions, which facilitates trust and reciprocity between individuals belonging to different organizations (Lawson *et al.*, 2008) and eventually enhances their respective performance (Cousins *et al.*, 2008; Cousins and Menguc, 2006). The concepts of "relational" or "social capital" are used interchangeably (Ancona, 1993; Burt, 1992, 2000). Cousin *et al.*, (2006) explore the relative importance of formal and informal socialization processes on customer-suppliers' relationship performance with a survey addressed to 111 manufacturers in the United Kingdom. They define relational capital as "*the configuration and social structure of the group through which resources are accessed.*" (p. 853) and they proxy it by the degree of close interactions, trust and mutual respect that exist among customers and suppliers. Cousin *et al.*, (2006) show that informal socialization processes have a significant impact in the creation of relational capital, which in turn can lead to improved supplier relationship outcomes whilst formal socialization channels appear to play a minor part in deriving these benefits. Yli-Renko and Janakiraman (2008) study the impact of suppliers' new product development using the concept of *relational embeddedness.* It refers to embedded links between customers and suppliers that rely on long-term, reciprocal informal exchanges, mutual trust and collective problem solving. In contrast short-length links refer punctuated transactions, opportunistic profit-seeking behaviour and are framed by formal contractual governance. Renko and Janakiraman (2008) show a positive significant relationship between the degree of customers' relational embeddedness and suppliers' capabilities to introduce new products.

Furthermore, Balboni *et al.*, (2017) analyse the moderating effect of trustworthiness, as relational dimension, to understand knowledge exchanges between customers and suppliers. Both formal and informal transfer mechanisms positively impact knowledge acquisition. However, trustworthiness is found to exert a positive moderating effect of informal conduits and negative moderating effect of formal conduits of knowledge exchanges. This is due, in fact, to how formal mechanisms are recognized as the main conduit for explicit, encoded and manifest knowledge, while informal mechanisms are more conducive to the communication of tacit, not articulated or not manifest knowledge (Becerra et al., 2008). Since there is more value placed in tacit than explicit knowledge, in regard to having a competitive advantage (Geneste and Galvin, 2015), an expansion of supplier trustworthiness would strengthen the informal mechanism in order to capture to greater extent the more valuable tacit knowledge.

Autio et al. (2004) borrow the social (relational) capital theory and apply it in their case study of CERN suppliers to explore the impact of the Big Scientific Infrastructure on its suppliers' capabilities. In this framework, the extent to which suppliers learn and benefit depends on the partner-specific absorptive capacity developed between the two organisations (Lane and Lubatkin, 1998). Such partner-specific absorptive capacity is defined as the aggregate partner-specific resources that support knowledge dissemination and communication among them. That kind of resources represents the relation-specific social capital, and their accumulation depends on both partners assets' complementarity (Nahapiet and Ghoshal, 1998) and partners' goals compatibility (Dyer and Singh, 1998; Inkpen, 2001).

Social capital has been shown to improve customer-supplier inter-organizational learning and knowledge exchanges in three ways (Yli-Renko et al., 2001). First, through the openness of parties to provide each other with access to their respective networks, social capital increases the quantity and the quality of knowledge possible to tap in for both parties. This "structural component" is operationalized as "structural social capital" by Autio *et al.* (2004) and as customer network ties by Yli-Renko *et al.* (2001). Second, as a higher level of mutual trust develops from a culture of reciprocity, a relation capital related to trustworthiness acts as a reinforcing mechanism and increases the share of extra potential knowledge that is disclosed between participants. This "relational component" is labelled "relational social capital" by Autio *et al.* (2004) and as social interaction by Yli-Renko *et al.* (2001). Third, relational capital enhances the efficiency of knowledge exchange by expanding collective knowledge and shared understanding between participants. This "cognitive component" is labelled as "cognitive social capital" by Autio *et al.* (2004) and as relationship quality by Yli-Renko *et al.* (2001).

In light of the above conceptual reflections, we expect that researchers' and suppliers' relationships are a complex locus of formal and informal interactions. We believe that besides the formal procurement process and market transactions between both there is a lot more that could hardly be observed and accounted for by the quantitative methodologies applied in the first and second chapters of this thesis. University technological knowledge has an important latent component that could be classified as pure tacit knowledge and that obliges industrial suppliers to develop close, long-term and informal relations with researchers in order to be accepted as participants in an intensive and potentially beneficial dialogue with them. In this respect, we are going to explore how these first contacts between researchers and suppliers take place. Furthermore, we put forward the hypothesis that the dynamics complementarities between researchers and suppliers occur following threefold patterns: structural, relational and cognitive. The structural construct suggests that universities are special because of the network they propose to their suppliers. The relational construct operates through by inspiring trustworthiness, reciprocity and good-will. The cognitive construct refers to the increase of knowledge sharing thanks to the shared vision and aims of researchers and suppliers.

One first conjecture of our study is that the dynamic processes driving technological learning among researchers and suppliers lie at the intersection of these three conceptual constructs and the nature of these processes is determined by how the three patterns relate to each other. Besides the indirect effect of relational (social) capital, we expect that university laboratories affect suppliers also directly through their specific demands of instrumentation and serving as test-beds for suppliers' products.

4.2.2 The centrality of researcher-supplier interactions for public procurement procedures

Researcher-supplier interactions are also central for the successful outcome of public procurement of innovation (see Rolfstam, 2009). Scolars have studied the role of procurement procedures in the intermediation between demand and supply (Edler and Yeow, 2016) as well as the failures that can inhibit collaborations between public users and suppliers such as the lack of sufficient interactive space (Chicot, 2017). On the one hand, these failures might take place because an essential factor necessary to trigger off dynamic complementarities is deficient or too weak. This deficiency might be related to a lack of competencies and to low absorptive capacities. On the other hand, too loose or inexistent connections among heterogeneous agents and/or the lack of complementary activities among them might be at the origin of user-supplier failures. In this sence, public procurement can be seen as a policy tool able to tackle user-supplier interaction failures.

The Public Procurement for Innovation literature has identified some guidelines for the interactions that are essential for the effective learning between users and suppliers in the generation of innovation within the public procurement framework. For instance, Chicot and Matt (2018) analyse user-supplier interaction failures in two cases. First, the "simple" case in which the researcher-supplier interaction does not aim to establish a durable collaboration (co-development) but it ensures the communication of public needs to producers. In this context, public procurement procedures frame the identification of the need and the precise communication to the possible suppliers by means of formal call of tenders. Formal procurement procedures are assumed to be enough in reducing informational asymmetries, related to firms' lack of knowledge about public needs and in triggering a demand-pull effect (Edler and Georghiou, 2007). Next, Chicot and Matt (2018) address user-supplier interactions when they must refer to each other as co-developers of a technology. In this case their smooth and rich communications are central to the process in which users provide companies with valuable knowledge about their experience with products and opinion about future possible developments, this, in turn, allows suppliers to adjust their products. In this case, procurement serves as a frame where both actors can communicate, enabling users to exert an important effect on suppliers innovation behaviour and performance (Chicot and Matt, 2018). This process of learning and reinforcing each-other technological knowledge base is referred to as *dynamic complementarities* (Malerba 2006, 1996). It follows that public procurement for innovation (PPI) can provide the space and time for the emergence of dynamic complementarities between users and suppliers. To ensure such an environment of awareness and frequent interactions within the formal procurement process, there are practices such as competitive dialogue (Uyarra 2016), which "allows the contracting authority to have discussions with the candidates during the procedure so to better define its needs and the appropriate means to achieve its objectives" (Telles, 2010, p. 1)[19].

The establishment of formal contractual agreements among procurers and suppliers for the definition of contractual terms as milestones; deliverables and intellectual property is shown

[19] also cited by Chicot (2017)

to have a negative influence on their collaborations (Matt et al., 2012). Therefore, another body of possible malfunctions stems from users' and suppliers' collaborative norms i.e. the respective willing of users and suppliers to commit in reciprocal collaboration (Chicot, 2017; Schiele, 2006; Walter *et al.*, 2003). Considering the degree of information exchange and level of cooperative norms between users and suppliers in a 2x2 matrix, Wang and Bunn (2004) discuss four groups of user-supplier interactions. Intensive information change and norms correspond to a "frequent, intensive and open" way of communication (Wang and Bunn 2004 p. 95). On the contrary, when norms and information sharing is not valued and practised, the procurement parties' relation is qualified as "arms-length" type whereas no particular cooperation and communication take place. Besides these two extreme cases, Wang and Bunn (2004) introduce "supervisory relationships" and "recurrent relationships". These four categories completely echo to the notions of relational embeddedness as highly intensive and rich relations versus arms-length transaction type contacts that we discussed earlier (cf. Section 3.2.2). A further group of collaboration failures refers to the daily communication between users and suppliers within the frame of the competitive dialogue and it can manifest as lack of knowledge exchange (Wang and Bunn, 2004) and coordination among parties (Rolfstam, 2009).

Besides analysing failures occurring in various stages of the procurement process, the PPI literature stresses the role of trust (and the lack of it) in the success (and otherwise in the failure) of user-supplier interactions. Trust is a transversal concept that affects all the aspects of user-supplier collaboration. Since confidence, trust and trustworthiness form progressively with experience and involve "socio-psychology bonds of mutual norms, sentiments, and friendships" (Ring and Ven, 1994, p. 93), it is unlikely that it will develop in standard procurement procedures (Chicot, 2017). Within the formal framework, trust is only based on contractual arrangements and the confidence in institutions. Since at the university, procurement procedure does not include competitive dialogue and is delicate to combine with collaborative R&D projects, early interactions, that would allow for trust-building between researchers and companies, are rather difficult to sustain. Emphasizing the essential role of trust in inter-organisational collaboration, procurement scholars (Rolfstam, 2009, Chicot, 2017) call for the in-depth exploration of the trust-building processes in the context of limited interactions by formal rules.

Our second and final research conjecture is that in university procurement, researchers and suppliers engage in informal interactions that take place outside of the procurement process. Therefore, in our field-

study investigation, we expect to find more about the links between these informal accounts and trust-building processes leading to the creation of dynamic complementarities.

4.3 The field-study methodology

To explore direct and indirect learning processes that unfold among researchers and companies in our original dataset, we interacted with university staff at various administrative levels in order to be able to identify the most appropriate contacts to interview among researchers' that have purchased equipment in the period 2011-2017.

The analysis of researchers-suppliers' interactions is done in the course of a fieldwork conducted in three research unities at the University of Strasbourg in the period May-December 2018. In the following sections we spell out our research protocol – we explain our baseline methodological choices in conducting the field-study such as sampling techniques; data collection and analysis approaches.

4.3.1 Case study as a tool of social sciences

To explore how dynamic complementarities, emerge between researchers and their suppliers we employ a multiple case study approach. To identify practices, their corresponding underlying mechanisms and how they are conducive to knowledge-intensive interactions between researchers and suppliers from the researchers' perspective, we conducted qualitative interviews with researchers as a primer data collection method. Our methodological choice is motivated both by the characteristics of the interactions under study and by the precise research question we strive to tackle. Technological learning between researchers and suppliers is a complex phenomenon, as it involves many processes and patterns of relations between the processes and the individuals evolved. A multiple case study looks as an appropriate empirical tool to analyse in depth such a phenomenon because it allows focusing only on certain cases and examine them through a comprehensive and realistic perspective (Yin, 2014).

4.3.2 Definition of the cases and sampling selection strategy

When a phenomenon has no solid theoretical background, the case study methodology suggests selecting a "case in point" or unique case of the phenomenon as being most revelatory (Miles et al., 1994). In addition, the study of multiple cases is pointed out as a preferable approach that provides a deeper understanding of the processes and outcomes that the cases illustrate. Examining more than one case offers the possibility to test research hypotheses and yields a fair representation of field-based (grounded) causation. Conducting two- or more cases is encouraged as the findings are likely to be more robust than having one single case. Yet the cases should not necessarily be homogeneous among them (Yin, 2014) and they might include sub-cases embedded within them. Following the methodological guidelines in the domain, we purposefully converged towards three cases that are fairly heterogeneous among them and include a multiple case study i.e. a case with sub-cases. In concordance with a recent study on the interaction of formal and informal technology transfer channels at the University of Strasbourg (Schaeffer, Ocalan-Ozel and Penin, 2018) we focused on three specific cases of interest rather than aiming at maximizing the number of observations. However, the restricted number of cases should not be perceived as limitation of this study, as highlighted by Cunningham et al. (2017) (p. 937–938 and p. 941): *"The question of how many cases are sufficient for a qualitative case methods study is one that is of concern for qualitative case methods researchers. Our findings show that the majority of researchers used less than four cases or more than twenty-five cases [...] This suggests that there are two case extremes emerging, those studies that rely on a small number of cases and authors that used a significant number of cases for their studies. We suggest that this heterogeneity in the number of cases is beneficial for the field of technology transfer research as it gives case methods researchers continued flexibility as to the number of cases [...] Small numbers of cases allow for in-depth analyses. Larger numbers of cases might support the generalizability of the findings."*

Selecting the cases to be studied is an essential step in the implementation of the case study methodology. Our starting ground was the expenditures dataset of the University of Strasbourg for the period 2011-2014 employed in the first quantitative analysis of the thesis. The final data include 47.373 transactions between 91 research unities[20] and 1.908 suppliers. We needed to

[20] The total number of research units equals 91 unities. In 2012 many transformations took place in the structure of the University of Strasbourg, i.e. fusions of laboratories. Some of them existed under a different label or as part of a larger lab. See the Appendix for extensive list of all the research unities.

restrict our scope to a handful of representative cases among the whole data. For this reason, we followed two approaches. First, we established a shortlist of research unities, by retaining only those which had purchased equipment and rank them from the highest to the lowest amount in order to obtain some idea about how each laboratory accounts in the total data in terms of value. However, this ranking of research unities was not so operational because we did not dispose of any contact at the laboratory level. Thus, we contacted the director or the responsible person of the equipment platform within each research unity in order to present them our study and ask them to relate us to the most appropriate researcher(s) that had purchased a piece of equipment.

Meanwhile, in order to restrict the scope of the data and to obtain reliable contacts on the research side, we contacted the personnel of the public procurement office of the University of Strasbourg. Besides interviewing them for the purpose of this study, they also provided us with a detailed list of purchases made by research unities during the period 2011-2017. The sample consisted of 40 scientific instruments, and for each transaction it enclosed information about the purchased item, name of the researcher who commissioned the technical specification, and supplier who delivered the equipment. We contacted randomly researchers from this sample belonging to research unities within our initially established ranking. Following this procedure, we could obtain the first two contacts that agreed to participate in the study. We then applied reputational case selection also called “snowball sampling” (LeCompte and Goetz, 1982; Patton 2002, 2008) to add a third participant to the study. We asked our two participants for a recommendation of further contacts that could possibly accept to be involved to the study. From a methodological perspective, combining these two sampling strategies - random and reputational - is considered as a good practice as it increases confidence in the analytic finding of the study as a consequence of cases representativeness.

4.3.3 Data collection

The main goal of our field study is to collect a rich dataset of information for each research-supplier case. To achieve this goal, we relied on multiple sources of evidence. For each case, we collected extensive documentation information: personal documents provided by researchers and engineers (e.g., slides describing instrumentation, presented by researchers in an event with suppliers); written reports of events; reports of laboratories assessment; newspapers articles;

administrative documents that describe the general procedures of public procurement; reports of laboratory activity among others. Besides documentation, the real-life setting of cases that characterizes our field study allowed us to get direct observations as part of our data collection methods. These observations concern the immediate environment of the research unity where we were meeting our contacts; their (spontaneous) reaction towards our questions and other subjects; their relations to other people in the cases in which we could interview two people at the time; their access to certain data as for example when we were asking about suppliers' contacts - some researchers had the suppliers' personal phone number directly accessible on their cell phones. In addition, we could visit at least part of the equipment platform of each research unity and could see various pieces of equipment while researchers were working on them. This allowed us to obtain an authentic impression about the laboratory environment and have an informal exchange with researchers about their equipment. Direct observations thus consist of noticing all types of details that could allow us to confirm or question evidence received by other more formal ways.

Finally, we conducted face-to-face interviews based on a semi-structured questionnaire. The main goal of the questionnaire was to collect information about the general background of researchers and suppliers' relations; how they start and what are the initial conditions with the ultimate aim to trace their evolution. Second, we were interested in the different modes of communication between researchers and suppliers and on their specific outcomes. We wanted to know what the benefits for both sides were. Finally, we wanted to understand how these processes are related to formal public procurement procedures. The answers to these questions helped us to characterise to what extent researcher-supplier interactions are affected indirectly by the creation of relational embeddedness with each other (Macneil, 1982; Uzzi, 1997). The latter can further be decomposed into cognitive embeddedness (i.e. common vision and language); structural embeddedness (i.e. network reach) and social embeddedness (i.e. trustworthiness) (Autio *et al.*, 2004). In addition, we were able to identify more direct ways by which university laboratories serve as a learning ground for their suppliers. These key direct and indirect dimensions are discussed at length in section 3.6 of the chapter. The information gathered during the interviews may be summed up in the following points:

1. *The genesis of the relation*: we were interested in the way the researchers and suppliers enter for the first time in contact and chose each other, as well as in the general features of the process:

criteria of selection; what the research unity searched as equipment; initial characteristics of each party.

2. *The emergence of new technology/new equipment*: we collected evidence about a particular equipment and technology that emerged in each case. We intended to grasp the contributions of each party (in terms of knowledge, people, financial means, equipment etc.).

3. *Legal framework:* we studied the legal dimension of their accounts/co-development. What kind of exchanges does it include for both parties?

4. *Communication style*: We were interested in the modes of communication and exchange between partners (formal and/or informal), in their frequency and duration, but also in the division of tasks.

5. *Outcomes*: We wanted to identify the main benefits for the suppliers and the impact for their subsequent relations with the university.

We conducted 10 (prolonged) recorded and 5 (shorter) informal interviews between May and December 2018 (one exploratory interview took place in November 2017) and collected the perspectives of 11 individuals: researchers, engineers, heads of equipment platforms, directors of research unities, managers of public procurement procedures and one of the supplier companies' ex-director. All of our interviewees were directly involved in the process of equipment purchase or development.

The 10 recorded meetings lasted 90 minutes on average for a total duration of 15 hours. They were transcribed, which gave place to 140 pages of verbatim data. Following our case study protocol, we stored formally the entire range of data collected and made it available for potential inspection by an outside observer. The insights and observation obtained in the interviews were matched, for validation purposes, with documentation and direct observation data (Yin, 2014). Table 12 below summarizes some key information about each meeting, its duration and the profile of the person interviewed.

Case	Date	Duration	Interviewees profile	Subject of the interview
1	November 2017	2 hours	Former director of Company 1	How are industrial suppliers interested by UNISTRA as a customer and co-inventor of equipment? Discuss the case of Company 1.
2	May 2018	1h30min	Engineer at Institute 2	General description of Institute 2 and its suppliers.
1	June 2018	1 hour	Director of the liquid NMR service at the Institute 1	The development of a measurement accessory with large NMR supplier.
1/2/3	July 2017	2 hours	Managers at the Public procurement office of the University of Strasbourg	How is the Purchasing and Public Procurement Department organized?
2	July 2018	2h15min	Engineer at Institute 2	Visit of the Imagery Centre and presentation of the various equipment and their backgrounds.
3	July 2018	1 hour	Director of equipment platform	General description of Institute 3 and its suppliers.
2	October 2018	40min	Purchasing Manager at the Institute 2	The process of public procurement at IGBM, comparison with UDS.
2	October 2018	2h30	Researcher at the Institute 2	The development of CLEM 2.0.
2	October 2018	1 hour	Director of the Imaging Centre at Institute 2	The beginning of Imagery Centre, how did they choose their first suppliers and how did these links evolve over time.
3	October 2018	1 hour	Director of equipment platform at Institute 3	The case of Exactive plus EMR and interactions with its supplier.

Table 12. Overview of the 10 recorded interviews basic information

We performed a pattern matching analysis of the verbatim. The analysis consists into confronting two patterns of research-suppliers' relations: theoretically based predicted pattern, developed before the actual data collection with an empirically based one emerging from the evidence of our cases (Trochim, 1989; Sinkovics, 2018). Showing that the theoretical and empirical pattern exhibit similar characteristics is strong evidence for case study internal validity. Patterns can be related to both dependent variables, when a given process can have a variety of relevant outcomes to consider, and independent variables, when several cases have the same outcome and the study focuses on the reasons why this outcome emerges in each case. When in each case, a set of possible outcomes emerges, the matching pattern is performed by considering the initially predicted values for each outcome; if those haven't been challenged by alternative patterns revealed by empirical observations, this could allow for a causal inference to be made. In essence, we will compare the suppliers' performance outcomes across the three cases and the patterns of their realisation with the theoretical propositions, exposed throughout and at the end of the theoretical background.

4.3.4 Rival theories

The above logic of analysis might be exposed to some threat of internal validity (Cook and Campbell, 1979). It may occur that another event or process, as for example a long-term R&D collaboration between the laboratory and the supplier, is a source of influence besides the demand-supply relations we explore as a focus of our study. In this case there is a rival explanation to be considered, namely that the technologies developed among researchers and suppliers result from the R&D formal agreements and not from their relations as customer and supplier. This plausible alternative explanation can be considered according to two possible perspectives. Being aware of the possible alternative influences, we actively collected data concerning them, as if we were trying to show the explanatory power of these other processes up, until we demonstrate there is no strong enough evidence to continue (Patton, 2002; Rosenbaum, 2002). Another way to include rival theories in the study is to identify a subset of initial dependent variables and illustrate that they would follow a different pattern if the technology we observe were developed within traditional R&D agreements i.e. if the R&D collaboration were the actual reason of the observed outcomes. In considering such rival theories, our aim was to identify those that could jeopardize the internal validity of our study and to show that we have not omitted any evidence that could support an opposing argument.

In the following Section 4, we provide brief summaries of our cases and then in Section 5 we provide a full description of each case content. Next, in Section 6 we discuss the main evidence arising from our case studies and whether it validates or not the main theoretical conjectures formulated above in Section 2 of this chapter.

4.4 Brief overview of the three cases

Case 1. The first case study revealed how in 2015 a University of Strasbourg laboratory in chemistry has collaborated with one of its essential long-term suppliers to develop a new Nuclear magnetic resonance (NMR) equipment. The case describes the processes associated with the development of the new equipment. It all started with the supplier that had developed an in-house prototype of the device. The university laboratory then was contacted and asked to be the first user and beta-tester of the prototype. The supplier put the device at the laboratory disposal for a year. During this period the researchers ran daily experiments, which were documented and addressed to the supplier. Two years later, the supplier was able to introduce a commercial product resulting from the tested prototype. The supplier-company was the first on the market to introduce this kind of device and at the moment of the interview (2018) is still the sole manufacturer in the world.

Case 2. The second case illustrates the emergence of three different devices developed in collaboration among researchers and engineers at Strasbourg research unity in Molecular and Cellular Biology on the one hand and two of the institute's suppliers of optical systems. At the beginning of the 90's, the Institute had a unique need to perform observation on a broad scale of micro and macro samples, which drove researchers to come up with the idea of the macroscope fluorescence. They produced the first prototype and shared it with their supplier of microscopes who then introduced the macroscope as a commercial product. The introduction of the macroscope opened a new market for the supplier and the collaboration led to a whole series of new developments and to microscopy instruments such as the confocal scanner that we describe as well as other specialized accessories. Furthermore, researchers also use various part of existing products as building blocks for new systems. Adapting them to a new environment of functioning results often into an introduction of new valuable extensions of the initial device. We examine this case in point in-depth by considering the microtome integrated microscope put together by the researchers.

Case 3. The third case describes the emergence of a hybrid equipment among researchers of an Institute in Supramolecular Science and one of their laboratory equipment suppliers together with a spin-off company. The new device allowed combination of two already existing techniques performed by two different instruments. Since the manufacturer of these devices was reluctant to the new development because it could deteriorate its existing market, the university approached a spin-off company of the supplier in order to develop the first prototype of the hybrid device. Progressively the supplier became aware of the potential of the new equipment and purchased the prototype from the spin-off company to pursue the development until the final product was developed. The third case thus reveals a complex pattern of interactions among the research unity and the two companies involved through the whole process of development of the new device.

The table 13 below summarizes the essential information about each case, the supplier evolved and the technology.

Cases	(1) Nuclear Magnetic Resonance Spectroscopy	(2) Microscopy /Optics		(3) High-resolution sample analysis
Company	Company 1	Company 2.1	Company 2.2	Company 3
Type of firm(s)	Established manufacturer of scientific instruments in NMR	Manufacturer of microscopes	Manufacturer of optical devices	Genetic testing and precision laboratory equipment manufacturer
Nationality	USA	Germany	Japan	USA
Size[1]	6 000/200-299	4 000/100-199	4 420/20-49	70 000/250-499
Year of foundation[2]	1960/1968	1869/1975	1953/1985	1956/1994
Technology	Prototype technology was developed by the company, then beta-tested and further adapted by the university	Prototype technology was developed by the researchers, then transferred for large-scale production to the supplier	Underlying scientific principals were known, combining instrumental modules from various suppliers, researchers built a new ultra-sensitive microscope system	Researchers suggested the combination of two existing techniques of analytical chemistry in one new equipment.
Presence of formal agreement	Secret collaboration agreement	None	None	None
Outcomes	New to the world product for the company	New market product for the company	New functionalities of existing products of the company	New to the world product for the company
Number of people interviewed by case	3	4	4	3

[1] Number of employees at the company level and at the French plant

[2] Year of foundation of the company and the French plant

Table 13. Overview of the three cases essential data

4.5 Presentation of the cases

We now turn to a detailed presentation of the three cases. For each case we start with a brief presentation of each research unity and supplier and then move to a thorough account of how new instrumental devices emerged as the result of mutual learning between university researchers and supplying firms.

4.5.1 Case 1. The development of an NMR measurement accessory

The chemistry institute founded in 1871 at the Faculty of Sciences of the University of Strasbourg, is a joint research unity, associated with both the French National Centre for Scientific Research (CNRS) and the University. The Institute's scientific agenda has a multidisciplinary approach with chemistry at its core. The research carried out within the 20 teams is the outcome of the joint forces of theoretical chemists, synthetic chemists as well as of physicists and biologists. It strives to push the frontiers of knowledge in the field of chemistry and to meet current significant challenges such as the discovery of new therapies, the preservation of the environment, the discovery of new sources of energy among others.

To carry out their studies, researchers at the Institute of Chemistry of Strasbourg count on a large equipment allowing physicochemical and chemical analysis of known molecules as well as of samples synthesized in the laboratory. The equipment is shared by five scientific departments, and it constitutes a platform that is almost unique in scope and importance in France[21].

In 2014 the chemistry institute and two other research unities – the Institute of Supramolecular Science and the Institute of Engineering and Chemistry of Complex Systems - constituted a scientific consortium led by CNRS and acknowledged by the University of Strasbourg, that allows to unify scientific equipment. The decision to mutualize the equipment

[21] The platform puts together equipment in nuclear magnetic resonance (NMR): liquid and solid NMR; X-ray diffraction; mass spectrometry; the electronic paramagnetic resonance. A fifth research axis focuses on elemental analysis, fluorescence spectroscopy and circular dichroism and rotatory power.

and scientific material was done with the intention to optimize the efficiency of the use and purchase of equipment and eventually reduce their costs. Before 2014 the equipment was already shared among the three laboratories, and it was called “common platform”. However, the services associated to the platform were managed by only one research unity while they were functioning for the whole community. Eventually, the financial load for one research unity was excessive, and this led to the establishment of the reunification of services for 4 years (2014-2018). The person we interviewed was the director of the service during this period. He was working halftime as a director and halftime as an engineer in spectroscopy at the Institute of chemistry. As the director of the common platform, he was responsible for the purchase and scientific policy of the platform in accordance with the directors of each research unity.

When the mandate of the reunification service came to an end, the 1st of January 2018 it progressed towards a new structure called Federation of Chemistry “Le Bel”, a completely independent organisation with independent leadership and affiliated personnel. In addition to its missions of coordination and animation, the Federation provides the scientific community with a high-level analytical platform for chemistry. At the moment of the interview, our interviewee was the vice-director of the Federation “Le Bel” and manager of the purchases and the maintenance of instrumentation.

Background and history of the relationship with the supplier

The company 1 is a manufacturer of analytical and medical instruments including Nuclear magnetic resonance (NMR); Mass spectrometry; Preclinical Imaging; Infrared Spectroscopy and X-ray Diffraction and Elemental Analysis. The relationship between the firm and the University of Strasbourg is a long-term, historically grounded one. It has been facilitated and reinforced by the physical proximity: the site of the supplier French establishment, is localized only 70km far from Strasbourg. The relationship between the company and the University of Strasbourg has been developing via all possible channels, one of which is the exchange of students and personnel, as many of the university students have been recruited by the company. Historically, most of the company French plant presidents are University of Strasbourg’s graduates, like for instance one of our interviewee was president of the company for 37 years (1973-2010) a former PhD student of Jean-Marie Lehn, the 1987 Nobel laureate in chemistry. During his time at the company he has kept close and active contacts with the University, by way of research collaborations; exchanges of students and researchers from the Strasbourg academic milieu that were later recruited as commercial directors and engineers by the company.

Besides relationships between the two organizations, it is also interesting to consider how interpersonal relations among the company's sales representatives and technicians and university researchers and engineers were established. Our interviewed person started to work in the field of NMR in 1993 while he was a PhD student. Already as a PhD student, he entered in communication with the supplier's technicians and engineers at the hotline. While he was working on the machines, it was somewhat common to encounter problems, which needed direct contact with the company staff in order to be fixed.

The development of new device

In 2015 the Institute of Chemistry developed with their supplier an NMR accessory. It is called "DiffBB NMR Probe" – a measurement sensing head, whose use is to emit and receive NMR signal which then researchers' study in order to describe the structure of molecules. The team of the interviewee worked with the supplier to establish the technical description and the user's manual of the future equipment (*cahier des charges*), i.e. an exact description, using technical vocabulary, of the functionalities that the future device should include. Moreover, the research unity did a series of beta-tests in real conditions in order to validate the company's prototype that then became a commercial product. To perform these developments, followed by several visits and face-to-face meetings in situ in 2015 the company underwrote a secret collaboration agreement with the research unity. The prototype was then installed in the university laboratory for almost a year. During this period, the researchers ran on it their experiments and performed daily routine manipulations. They then addressed regular reports to the supplier describing exactly which trials went well and which instead were difficult to accomplish with the prototype item.

The beta tests performed by the university for an entire year could not have been run by the company alone: the supplier was missing the central element that is the scientific production, which enables testing their equipment on interesting, rare and real cases. The company alone would have been obliged to work on well-known and studied samples of molecules which do not have the same nature and significance as to work on latest samples synthesized in the laboratory that tend to answer new research questions. Besides, by finalizing the secret agreement, the manufacturer had the opportunity to benefit from the researchers' scientific parameters. Working with few researchers in the NMR team, the company obtained access to the whole University of Strasbourg laboratories' molecules.

Furthermore, the company was able to receive detailed customer feedbacks as a result of close relationships with researchers at the Institute of Chemistry. While the standard satisfaction surveys leave several options to express their opinions, they are not precise enough for companies, and the surveyed subjects often do not understand all the questions and possible replies. In this setting, researchers and the supplier had instead direct, almost daily interactions for almost a year. The framework in which these exchanges took place, their intensity and precision made a difference and added value for the supplier.

Furthermore, these interactions allowed the supplier company to adapt their production processes. Working with the researchers and acquiring a first client experience helped the company to correct for eventual defects before setting the mass production of the future product. In addition, in practice, the supplier reduced the costs of development associated with the personnel by having two university engineers working full time on their project for a year.

This exchange between research unity and suppliers was also beneficial for the university researchers. First, they got to use a piece of brand-new high-end equipment, essential for their scientific activity, during a year for free. In this way, at the end of the period, the researchers could enjoy something rare in the domain – they had a tool specifically tailored for their needs and work environment. Finally, at the end of the agreement, the supplier proposed to the researchers to purchase the material for less than 50% of its market price. The research unity considered the acquisition very advantageous for them since they could use the device in their everyday work.

Researcher-Supplier interaction within the framework of public procurement bids

Initially researchers compare what the various suppliers' catalogues propose. From the options of the selected catalogue, researchers interact with the supplier to customize the equipment they would like to obtain. These interactions occur before the launching of the public procurement procedure. Therefore, at the formulation of the technical requirement of the future purchase, both sides have already had the chance to interact to and decide all the options, technicalities and accessories. These exchanges occur in an informal way (phone call or lunch) when researchers meet with sales representatives' ex-ante and explain them their future acquisition plans. In such a way, exchanges on equipment-related technical issues and negotiation among researchers and suppliers start well before the actual call for tender procedure. This practice has been described as "a usual way of doing". The process of negotiation is very important to researchers, and it looks like they use their image as influencers in negotiating with their suppliers. The process of negotiation is only possible if researchers have done extensive communication with all the possible suppliers in a given market. Hence when they deal with a supplier who is the unique and exclusive manufacturer of a given equipment, the university's bargaining power is weaker. However, even in this case, researchers emphasize that their most persuasive argument remains the worldwide fame of the university in chemistry. Our interviewed subject stressed that, besides the commercial success, supplier 1 also placed great importance on communication done in the best possible way. Being a supplier of a university performing Nobel-prize-level chemistry research and everything that goes with it was valued as part of the company communication strategy.

4.5.2 Case 2. The development of the Fluorescence macroscope, the Confocal scanner and the Correlative Light and Electron Microscope

The Institute of Genetics and Molecular and Cellular Biology (IGBMC) was created in 1990 following the federation of two Strasbourg laboratories, the Laboratory of Molecular Genetics of Eukaryotes (LGME) and the Structural Biology Laboratory, headed by Pierre Chambon[22] and

[22] Pierre Chambon, considered as the founder of IGBMC, is currently professor at the Advanced Studies Institute of the University of Strasbourg (USIAS). He holds a research Chair of molecular biology and genetics at the University and was ranked fourth among the world's leading life sciences researchers in the period 1983-2002.

Dino Moras. It is France's largest research unity, under the institutional tutelage of the INSERM, the French National Centre for Scientific Research (CNRS) and the University of Strasbourg. Since its official inauguration in 1994, the institute has been building a momentum to become a centre of excellence in biomedical research, fully endorsed by the international scientific community.

Over the years, IGBMC has acquired technical tools to accompany the research carried out in the teams. Today the Institute has no less than 6 platforms in imaging, bioinformatics, structural biology and genomics, proteomics, genomeast, as well as high-throughput screening. These platforms offer a variety of advanced technical services and are open to the wider of the scientific community.

Since its beginning, the institute's main lines of research have evolved over time as follows. Initially, while the director was Pierre Chambon (1994-2002), the research conducted at the institute focused on the regulation of gene expression. Later, from 2002 until 2009, the institute was headed by Jean-Louis Mandel and Dino Moras, whose scientific interests were on human genetics and structural biology axes. Next, under the directorship of Olivier Pourquié in the period 2009-2012, the development of muscles and vertebrae was the main domain of research. From 2012 to 2013 the institute was led by Brigitte Kieffer, whose research on opioid receptors is internationally renowned. Finally, since 2014, Bertrand Séraphin and Yann Hérault have been named Director and Deputy Director of the IGBMC. The research domains of the institute nowadays reflect these different developments and range from developmental biology to integrative structural biology, via functional genomics, cancer, translational medicine and neurogenetics.

In our second case, we focus our study on the imaging and microscopy centre of IGBMC (ICI). The platform's interdisciplinary approach operates at the boundaries of biology, physics, informatics and chemistry and it holds a unique expertise in advanced multiscale bio-imaging. In the beginning of the 90's Pierre Chambon recruited one of his students Jean-Luc Vonesch as the Head of the Imaging facility at IGBMC. Beforehand, Professor Vonesch worked at a couple of other research unities at the University of Strasbourg and made use of photonic microscopes. In one of these labs he used Wild Leitz's microscopes and had a very good experience with the brand. Once Professor Vonesch joined IGBMC and was appointed to set up the imaging facilities for the institute, he had the opportunity to explore the different microscopes through a market analysis based on his experience so far. During this phase, he found that the previous Leitz's had become company 2.1 – manufacturer of microscopes and that they were best suited for the needs of the future facility. Besides, he employed other selection criteria such as the quality of tools, the customer service; maintenance and the suppliers' culture to innovate. Customer service and maintenance were very important because the systems were very elaborate and required significant maintenance. Moreover, the suppliers' capabilities to innovate was one of the most important criteria in the professor's choice, because it represented some kind of guarantee that, since the beginning of his encounter with them, they could share a common vision of the future equipment and make them evolve together. Such a common vision about future developments gave a sense of continuity to the relationship. It is important to stress that the pre-existent personal relations with the company played a minor role in this specific choice of supplier while the platform was set up. It was considered a necessary but not sufficient condition by the interviewee.

In contrast, what was considered important by the interviewee was to have access to people who had important decisional positions and power at the suppliers' companies. In 1991, the president of the supplier 2.1 visited for a first time the platform while the research unity was still under construction. At this early stage, the director had the opportunity to explain the future plans about the creation of the various services. This meeting marked the beginning of a strong relationship between IGBMC and company 2.1 : twice a year, the supplier's production director from Heidelberg would visit the lab and discuss with Professor Vonesch and his team concerning the development of biology, about its the most recent achievements in the fields and what was yet to come (backwards and mostly forward oriented discussion).

In this early stage of the existence of the image platform, Professor Vonesch recruited a microscope specialist, D. H, who had 15 years of experience in the industry as an engineer – and namely at the supplier 2.1. One of his missions at the research unity was to create synergies with industrial companies in order to create new systems that could answer biologists' questions.

The fluorescence macroscope

Upon Mr. H. arrival at IGBMC, one of the very first questions he got asked by Professor Vonesch was: *"Is it possible to create an optical system with an optical path, with a long working distance and with* *a very large field of view?"*. Mr. H. candid reply was that this system already existed. Professor Vonesch disagreed: *"No, otherwise I would have bought it"*. According to the interviewee, this was the beginning of the development of the fluorescence macroscope by the scientific and engineering team of the imaging facility at IGBMC.

To obtain an in-depth understanding of complex correlations in living organisms, a compulsory step of researchers' work is to perform sophisticated genetic studies and cellular examinations on appropriate living organisms. The similarity and comparability in many regards of the cell biology and physiology among the mouse and the human, make the mouse to be the most suitable biological model for in-vivo experiments that study the causes of human diseases and develop new therapeutic approaches.

These in-vivo studies called for a flexible microscope device that could enable researchers to examine the causes of diseases on living animal models with maximum precision and resolution within an intensely fluorescent image field and to be captured in digital images. Therefore, researchers needed a microscope that could integrate the advantages of macroscopy with those of high-resolution fluorescence technology. To answer the research questions related to the in-vivo observation of living samples, researchers needed a certain sensibility at the light that is captured, larger fields and higher resolution – that could ultimately allow them to see fine-grained details. The fluorescence macroscope device allowed to combine the three required features altogether.

Figure 6. Expression of green fluorescence in an EGFP
(Enhanced Green Fluorescent Protein) transgenic mouse, Imaging Centre IGBMC
Source: Brochure Macro Fluorescence

The fluorescence macroscope was the first major development of the interactions between IGBMC and supplier 2.1. The support by the company's president was crucial for this outcome. He put the engineers and researchers from IGBMC in direct contact with the production managers and engineers at the company. The university lab team was able to go and show their first prototype to the supplier. The whole process of development was a person-to-person communication and exchanges that happened in informal way, without the signature of any kind of agreements until the very end. This process was also quite unusual because the inventors of the new equipment were directly involved at every stage: those who created the system contacted the suppliers; they did the technical demonstration to the company and finally discussed a licence agreement.

Through these stages, an equipment inspired by the current struggles of biologists to obtain better optical performance for their in vivo experiments developed by IGBMC engineers and researchers, was shared with the industrial supplier to become a commercial product, manufactured by company 2.1 and sold all over the world. The outcome was the "Fluorescence Macroscope", a macroscope that could combine the long working distances and object fields of a stereomicroscope with the vertical light path typical of a microscope. The macroscope advantage was that it allowed a maximum precision for examining in details entire in vivo organisms and it ensured images non impacted by any parallax errors[23].

Figure 7. The fluorescence macroscope Source: Supplier 2.1 official website

[23]Parallax is a deceptive change in the relative position of an object with a change in the position of the observer. If the measurement is made wrong by viewing from a wrong position instead of the correct position leads to an error in the measurement, this error is called parallax error.

Besides the development of the microscope's prototype, IGBMC did also the alpha and beta testing of the device. The detailed brochure with the technical description of the microscope on the site of the company 2.1 contains almost exclusively images from the Imaging centre of IGBMC. What is even more interesting to observe is that on the first page of the catalogue there is an acknowledgment which states "*Special thanks to J L V and D H of the Institut de Génétique et de Biologie Moléculaire et Cellulaire (IGBMC), Illkirch, France for their close cooperation in developing the MacroFluo*".

The True Confocal Scanner (TCS) Laser Scale Imaging (LSI)

Another innovation introduced as a result of the cooperation between IGBMC and supplier 2.1 was the combination of macroscopy with confocal technologies: this led to the "True Confocal Scanner". IGBMC had an important influence upon both technologies involved in the new microscope – confocal systems and macroscopy.

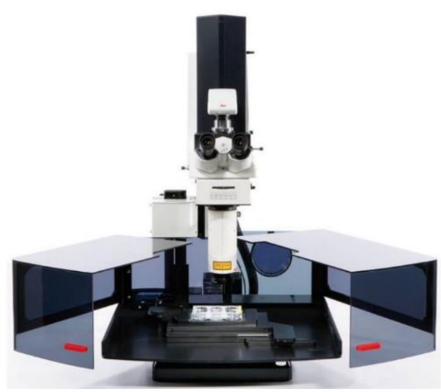


Figure 8. True Confocal Scanner Laser Scale Imaging (TSC LSI)
Source: Company 2.1 official website

The principle of the confocal microscope is that it allows one to make an optical cut inside the sample. Given that the cuts are optical they do not destroy the sample, and this enables one to work on living species. By saving on each cut, it is possible to make a 3D reconstruction of the observed sample and to manipulate it by rotating it. The first purchase of a confocal system by IGBMC occurred in 1994. At that time, the researchers tested and evaluated carefully the offers of four different companies: supplier 2.1, Carl Zeiss, Nikon and Biorad. The confocal produced by company 2.1 was significantly more efficient and researchers could benefit from a system that, for the same price was more efficient, easier to adjust and therefore with simpler processes of maintenance. Furthermore, the director of the supplier's Heidelberg manufactory plant who was producing the confocal microscope would regularly ask for IGBMC researchers' advice. When the company had a new confocal idea that was about to come out, they visited the research unity to ask for researchers' opinion and find out what they would expect from a confocal system in the future. In the context of shrinking credit sources, researchers replied that for them it was important to be able to purchase an evolving (scalable) confocal system. Previously, the confocal microscopes that the facility was purchasing were a closed system that required the purchase of everything at one time. The way companies sold confocal systems shifted and nowadays it is possible to buy 150,000 euros confocal and progressively make it grow until it becomes a very complex and powerful one-million-euro tool.

In the 90s while the majority of public research was trying to go into the infinitely small and was interested into the super resolution of optical systems, IGBMC's scientific agenda focused on the dimension ranging from half a millimetre to 10 centimetres, which falls into the field of macroscopy. Furthermore, researchers at the institute were working on various levels of details among different samples as the zebra fish; the drosophila's or the mice and needed to be able to observe on all of these levels. As the prevailing majority of public research, companies were mainly focused to develop super resolution technologies, as molecular magnifiers and they were convinced that these same technologies were enough to look also at larger objects. However, these magnifiers showed many flaws and defects for measurements and proved to be unsuitable. It is easier to observe and understand smaller micro phenomenon than larger ones, the latter being more complex to approach and understand. For these reasons, industrial companies were not able to see the potential of the macroscopy market. IGBMC engineers were obliged to use a piece of supplier 2.1 equipment to make a new device – the Macrofluo. Once the concept of the macroscopy was available, an increasing number of scientists started to extend their focus of bio-research from the single cell studies to entire organisms, analysing the complex interactions within whole living animals. Such studies required an integrated imaging system which offered high resolution, a large workspace and a large field of view. It was necessary to integrate the features of fluorescence macroscope with the features of confocal optical system. These patterns gave emergence to the next optical system that was developed by the IGBMC imaging platform – the first microscope with super zoom confocal that combines high resolution with broad field of view for in vivo imaging. Thanks to its confocal technology, the confocal system was able to provide a crystal-clear image of the highest resolution to observe the finest details of living organisms. The new microscope reduced dramatically the preparation time, pre-selection and orientation of the samples, that allowed researchers to perform new experiments. It also increased the well-being of the living samples, by avoiding the need to move between various imaging tools, reducing the stress supported by the animals and increasing the survival rate of the samples.

The system was developed in three years and its final achievement passed through three prototype phases. The first prototype was introduced and tested by the imaging platform that shared their ideas with company 2.1. The system became one of the successful commercial products of supplier 2.1 for years. On their site, they show picture of the new equipment with the researchers from IGBMC describing them as "*The fathers of the first super-zoom confocal system*".

Figure 9. The picture of IGBMC microscope engineer D H and the Head of the IGBMC Imaging centre J L V with the first super-zoom confocal system Source: supplier's official site

The fluorescence macroscope and the integrated confocal system are two examples of developments of new equipment resulting from close cooperation between researchers and engineers at the imaging facility and their supplier. In both cases, driven by a particular scientific question, researchers were changing and adapting an existing optical system of the supplier to develop a new one. In addition, researchers were also often in the situation where they were obliged to develop a new system using fragments from various suppliers. In what follows we are going to present an on-going case of an ultra-sensitive microscope system associated with a microtome, developed by IGBMC engineers by combining instrumental modules from various suppliers.

The Correlative Light-Electron Microscope 2.0

Our interviewee is an R&D engineer at the imaging platform. In 2014, the IGBMC research team where the interviewee had realized his Post-Doctoral degree, carried out a research project with the Karlsruhe Institute of Technology (KIT).

The aim of the project was to study the process of repair of muscle cells. All living organisms have some muscle cells that are gradually degrading. However, organisms are not impacted thanks to repair mechanisms. Despite that, sometimes the genes that are in the reparative proteins do not function well and this gives rise to very serious pathologies, which can result in premature death of the organism. The focus of IGBMC's research was the formation of this molecular patch with the final aim of grasping what does not work in pathological cases. The formation of this molecular patches represents a rare event in a large organism, that was at the time unknown to researchers, i.e. they would not be able to detect how this event look with respect to other processes in the living organisms.

The study of these molecular patches required the combination of different imaging modalities. Fluorescence microscopy allows high resolution imaging of the sample and to follow the movement of the proteins within the cells, that move into different parts of the organisms, thanks to the fluorescent mark. However, a drawback of the fluorescence microscopy is that it does not provide any image of the non-fluorescent cellular environment, which is left to electron microscopy and tomography. Otherwise, researchers can combine two light-based imaging modalities such as fluorescence and confocal microscopy. The employment of different imaging modalities requires the treatment (as sectioning, staining or fixation) and the relocation of the living samples. The sample handling poses a technically difficult issue of the tracking of the region of interest among the various imaging modalities. Locating a rare cellular event that might be present in multiple regions or cells within the large tissue volume of an entire living organism is like tracking few red leaves in a forest full of oaks whose leaves are red. The tracking of the region of interest were then impossible with the existing methods. Moreover, researchers could not tell if they failed either because of loss of the area or because of optical malfunctioning or, finally, because of a third unknown reason. Having multiple variables shifting simultaneously without a clear vision about the occurring process was not a convenient context of work for researchers in applied science.

To overcome these complex problems, IGBMC's researchers needed a new instrument that could address the technical obstacles presented by previous methodologies and could therefore make possible to follow and detect the rare events as the repair of injured muscle cells. That instrument is called Correlative Light-Electron Microscopy (CLEM) 2.0 and one of its distinctive tools is the Microtome-Integrated-Microscope (MIM). Researchers developed a compact and highly sensitive fluorescence microscope that was fixed over a microtome with the aim to realize fluorescence localization and imaging using this single instrument.

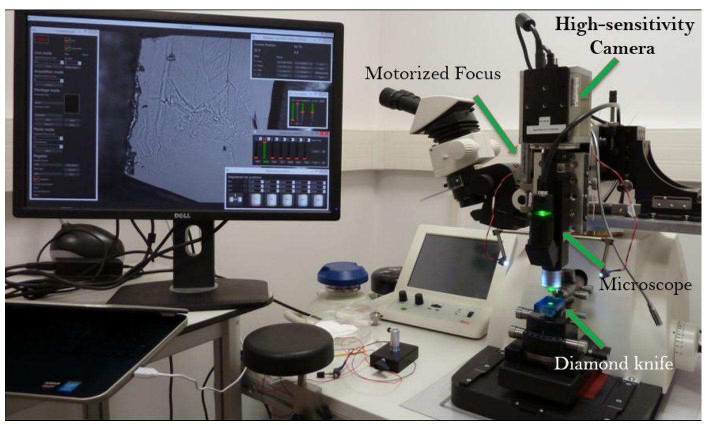


Figure 10. Microtome Integrated Microscope (MIM)
Source: Pictures and technical details provided by the CLEM 2.0 inventors

To construct the MIM and the CLEM, researchers used tools from various suppliers. First as a basis, MIM was installed on the head of an ultra-microtome by Leica UC7. Second, to be able to identify fluorescence signals in the tissue, researchers needed to optimize the MIM for light sensitivity. This was achieved by building a customized optical tube within the minimum of lenses and then by connecting it to an ultra-sensitive Camera produced by supplier 2.2. Third, the whole set up was managed by in-house developed IGBMC software called MIM Manager.

The microtome

At the beginning of the research project on repair of muscle cells, IGBMC did not dispose of the most recent microtome that would allow them to put together the new equipment in the best conditions. This time, instead of asking their supplier, the institute obtained the microtome directly from their colleagues from the Karlsruhe Institute of Technology (KIT). Since KIT's researchers could not use the microtome alone for the project because they needed an integrated system, they made an equipment loan to IGBMC.

The camera

Second, researchers needed to find a very sensible sensor in order to capture the photons that were emitted by the few fluorescence molecules they had to study. For this they needed a high-end sensor. IGBMC's researchers started to have a look on everything that was available on the market and found out that, historically, the Japanese company 2;2 offered the most sensitive sensors and cameras. Driven by the idea to obtain access to the most sensible camera, IGBMC contacted the Japanese manufacturer and discussed with them about their ongoing activity. Up until that moment, our interviewee had already had contacts with the company several times and IGBMC also had purchased equipment from them. However, there were not any specific long-term relationship between the company and the University of Strasbourg. Thus, researchers considered supplier 2.2 just like a supplier among the many. Despite this context, our interviewee got in contact with the manufacturer, and they agreed to lend their ultra-sensitive camera to IGBMC. IGBMC's engineers also did many demonstrations so they could be sure that the new camera allowed IGBMC's researchers to capture the required images. Furthermore, along the camera itself, the supplier granted the lab with access to the application codes and software of the camera that allowed the user to develop the application and go beyond the mere use of the equipment. The material loan was not formalized by any kind of written engagement, so the university lab did not have any commitment towards the supplier as for example to purchase the camera or to compensate the company in any direct or indirect way. However, researchers appreciated a lot the effort made by the supplier's representatives.

Since university engineers followed different procedures of work compared to industrial engineers, they had to exchange their procedures with the supplier in order to be able to modify the camera's software. Afterwards, IGBMC shared the modified software code with the supplier company, so they would be able to use it in computer repair and troubleshooting with future clients. In addition, if the supplier needed software support in the use of this camera on an embedded system, they can use the library provided by the lab and acquire that too. Since then, there has been a more regular and recurrent exchanges between the company and the university lab. These exchanges happened as following: the company was sent the company's latest products that had not even been released for testing or the supplier had several ideas and presented them informally in front of its university contacts. In this framework researchers would say what was not worth or what was promising, and this helped the company a lot in the refinement process of the new products.

The software

The third challenge that researchers at IGBMC had to face was developing the software able to manage the whole Microtome-integrated microscope system.

To manage the movement of the camera with the rest of the system - the microscope (which is set by a motorized and computer-controlled focussing operator) and the microtome, it was necessary to develop a dedicated software - the MIM Manager. The MIM Manager navigates the motor of the focus and also the direction of the fluorescence light. Developing this software was not only technically challenging. Researchers had also to take into consideration many constraints related to their laboratory environment because the microtome itself needed plenty of space around it for the different services as for example to distil water; materials to clean the diamante knife etc. So instead of a workstation one had a large area that was occupied. Because of the lack of space and the willingness to design a flexible system that could be put in various labs and be used by as many users as possible people, researchers using big computers with huge screens. Consequently, they needed to develop a software that could be used on a small system as a laptop for example could be introduced by USB port, instead of additional memory cards. This requirement added additional complexity to engineers' job. The final software that was developed was completely modular. The modularity allowed the software to be used also in other disciplines and to explore more unconventional samples. One example of additional research field where the microtome could be used thanks to the new modular software was the exploration of the formation of bacteria film in physics. To study the formation of the film, physicians needed an optical system and a rotation system to move the samples. Thanks to the camera and the optical system, physicians could use the software and make the needed images. This case shows that the software developed by the university facilitated the use of the CLEM beyond the field of biology.

Researcher-Supplier interaction within the framework of public procurement bids

According to our IGBMC interviewees, the public procurement procedures represented the first occasion of interaction between suppliers' companies and researchers. Regardless if the company wins the procurement bid or not, the procedure often creates several exchanges between them. The formal evaluation procedures include tests that the university should perform to all the candidates. Once each equipment is evaluated, researchers indicate the pros and cons: which are the features that reply to the technical description of the expected (demanded) device and which are the flaws of the proposed item. The full lists for all the candidates then serve for the ranking and the final choice of the best offer.

Even companies that followed the formal procedure and were not selected enter in discussions with researchers and engineers to obtain better and more details understanding of which weak points prevented them from winning the bid and improve their equipment. This discussion and examination of the equipment by the lab reveals technical flaws that should have been taken in account when the device has been designed by the R&D department of the supplier.

As part of the legal framework, researchers always follow the principle that there cannot be any overlapping between the formal procurement procedure and this following informal part. Even in the context of this legal framing, important exchanges between suppliers and researchers occurs also ahead (prior) of the starting of the formal process. In this case, the lab and the company enter in contact way before the procurement process. A typical illustration of such instance is the case of optical company that lent a prototype to the platform. The device was in-between alpha and beta stage. The IGBMC was like alpha prime beta tester of the device. However, as for any prototype, there were a connection (adaptation) piece that was not quite working as the supplier expected. The machine workshop at the imaging platform repaired the piece and helped the suppliers to improve it. The repair took 20 minutes to the micromechanics workshop of the lab, while it would have taken 3 weeks for the supplier representative to return to Germany and ask for it in the supplier production plant. In this case, the lab worked with the supplier prior to the procurement process and conceived something more effective. The resulting system was then purchased by the lab following the procurement procedure. The institute obtained a generous discount, stronger than usual client because the involved researchers were considered as master-developers by the supplier.

4.5.3 Case 3. The development of a hybrid device (LC-GC) for proteins analysis in their native state

The Supramolecular Science and Engineering Institute (ISIS) is a research unity under the double institutional tutelage of University of Strasbourg and of CNRS. The institute was founded in 2002 by the Nobel Prize Laureate Jean-Marie Lehn and it focuses on developing and promoting top-level multidisciplinary research at the interface between Chemistry, Physics and Biology, in particular on supramolecular approaches for the understanding of complex matter. ISIS includes international interdisciplinary research groups featuring senior researchers and eminent scholars such as Jean-Marie Lehn (Nobel Prize in Chemistry 1987), Martin Karplus (Nobel Prize in Chemistry 2013), Jean-Pierre Sauvage (Nobel Prize in Chemistry 2016), Thomas Ebbesen (Kavli Prize 2014), just to name a few. In accordance with the institute's scientific excellence, ISIS is equipped with massive scientific instrumentation platforms at the cutting edge of research, allowing researchers to tackle scientific questions at the highest levels of complexity. Beyond the French context, the role of ISIS is also acknowledged internationally. According to the evaluation report of the French High Council for Evaluation of Research and Higher Education (HCERES) ISIS could only be compared to outstanding research institutes, such as the Medical Research

Council Centre Cambridge (MRC) and The Scripps Research Institute (TSRI) in California (HCERES Evaluation campaign, 2016-2017).

At the beginning of 2016, researchers at ISIS needed to calibrate molecules using mass-spectrometry and to combine these measurements with two other techniques of analytical chemistry. These techniques were the Liquid chromatography–mass spectrometry (LC-MS), which combines the physical separation capabilities of liquid chromatography (HPLC) with the mass analysis capabilities of mass spectrometry (MS) and the Gas chromatography–mass spectrometry (GC-MS), an analytical method exploiting the features of gas-chromatography and mass spectrometry to identify different substances within a test sample. Although the University of Strasbourg Esplanade chemistry technological platform was equipped with around 30 mass spectrometers at the time, none of them was adapted to combine all the above-mentioned techniques altogether. In addition, a piece of equipment that combined both liquid and gas chromatography with mass spectrometry was actually not existing on the market. So, ISIS's aim was to develop such a hybrid equipment for the first time. The institute's platform manager had a very good experience in working with supplier 3, an American laboratory equipment development company, and had shared with people from the company the laboratory's willingness to develop the hybrid equipment.

At that time the company was proposing two techniques – (Liquid chromatography) LC and (Gas chromatography) GC – but they were carried out by two distinct devices. The company had expressed a considerable reluctance to pursue the development of a hybrid device combining both analytical chemistry techniques because it could engender their existing business and make them lose market shares on other existing devices. There was a debate within the supplier' company about whether the introduction of this new tool will have an overall negative impact on their existing company's commercial activity. During a conversation among our interviewee and people from the company, suppliers' representatives had identified a small-scale German company that could participate in the development. The company was a spin-off of supplier 3 and was founded by its former engineers in 1991 in Bremen. Its initial activity was to offer service and support for high-resolution mass spectrometers by supplier 3 while today the spin-off develops interface systems for suppliers' 3 high-resolution and other GC-MS devices. The small spin-off company was identified as the appropriate firm to develop the device that was requested by the ISIS researchers in order to link the two pre-existing techniques – LC and GC. In addition, because of the spin-off small-scale production, researchers could also aim to obtain an exactly customized device. The development of the first prototype happened in close collaboration between ISIS and the spin-off.

ISIS' researchers tested the first prototype at the company's site. In February 2017, the development process started and after only 3 months there was already a functional first device. ISIS' encouraging results obtained in those tests triggered, supplier's 3 interest, which then started to increase its communication with ISIS about the new device.

The Universtiy of Strasbourg could have purchased the equipment directly from the spin-off company however they saw it as a considerable risk to bear. The company was small and this would have created difficulties for the university to get replacement pieces and maintenance services in the case that the company would have disappeared or be purchased by another company, To avoid such risks, our interviewee preferred to associate supplier 3 in the purchase process. Supplier 3 bought the prototype from the spin-off and sold it to the university, at the same time guaranteeing the maintenance and warranty. Our interviewee emphasized the importance of company's 3 reputation and his previous experience with them for the successful outcome of this procurement procedure.

The procedure was beneficial to ISIS in several ways. Firstly, they were able to purchase the equipment at an exceptionally low price. In addition, they obtained a machine with better technological characteristics. The supplier also offered to the lab for free a specific device's option called "extended mass range" (EMR), which allowed researchers to treat a great range of molecules: from the smallest ones to bigger molecules on the same equipment. This particular option made the device unique on the market with this kind of precision and resolution and it allowed to study all kinds of molecules the institute was interested in. In a long-term perspective, the device was also very efficient since its costs of functioning and usage were very low compared to similar devices on the market. Another important characteristic valued by ISIS was that the device was accessible and easy to use. The institute also got an incredibly generous offer on maintenance service whenever it needed any kind of fix. It was not just standard maintenance but a high-end contract which allowed an immediate feedback from the supplier.

Furthermore, the returns for supplier 3 were also significant. Less than a year after the launching of the prototype the supplier had already contracted the sales of 3 devices to other research institutes, which indicates that they got a new market for themselves. Moreover, the new technology became completely adaptable on all their previous systems (on their "simple" mass spectrometers), which then made it highly attractive for their existing customers.

The characteristics of the new device were totally different with respect to what was available on the market before. The way in which structural analysis are derived in the GC component are unique and this has many possible applications. This specificity is due to the combination of both techniques. In this sense, the university laboratory served to company 3 as a testing platform. The tests they performed assured the supplier that the device could be used routinely, on a daily basis and regularly, and that it was robust and completely compatible with their existing systems and products.

What is unconventional about this case is that the supplier that commercialized the equipment never had it to test in-house. The development and the testing of the equipment actually occurred between the laboratory and spin-off. Then once supplier 3 bought the prototype from the spin-off, two engineers from the compay visited ISIS in the testing phase. Since the new device was a hybrid of two techniques (GC and LC) the two engineers were from two different suppliers' departments. They spent a week at the research unity playing with the device. The main goal of their stay was to really learn about the device, see how it worked and to run several days of tests on it. They could also compare the specifications of the system at ISIS with the ones of the system that would be eventually sold by the company. Once the standard tests were completed, supplier's engineers spent 2 additional days to study the system in-depth i.e. how-to assembly, disassembly, cleaning, set up the system and calibrate it.

It is important to stress that the testing and the putting together of the device prototype were not regulated by any formal contractual agreement between the university on the one hand and supplier company 3 and the spin-off on the other hand. Our interviewee deliberately did not conclude any contract with the final supplier because this could have been an obstacle for the public procurement process through which the purchase took place later. In addition, the lack of any formal link with the supplier did not oblige ISIS to purchase the final device. Finally, not entering in a formal exchange was a way to keep the supplier at a distance and unsure whether the university would purchase or not the device which was a source of additional negotiation power for the university.

According to our interviewee the above-described collaboration with supplier 3 was not an isolated one, but it was following another successful partnership on the development of a software system. The past exchange was very profitable for both sides and although it did not involve the same people from the supplier's side the previous partnership gave confidence to our interviewee that the informal exchanges with the supplier company would have been smooth and effective. This confidence was reciprocal since according to his opinion also supplier representatives were at ease with non-official practices of mutual exchanges with the university.

An important indirect benefit for the supplier came from the exceptional reputation of ISIS at international level. Indeed, ISIS is an attractive customer for any supplier in the domain. For most of them it is already a breakthrough if they sell an equipment to ISIS and if they can certify it, e.g. by showing a short note addressed by ISIS's director on their site.

In the following table 14, we summarize the main case study evidence for every construct presented in the theoretical section of the study (indirect technological learning) and describe the mechanisms of direct technological learning that we could identify throughout the three cases.

	Construct	Theoretical proposition	Case 1	Case 2	Case 3
Direct Technological Learning	Source of diverse knowledge and application environment	University labs represent very different knowledge environment (compared to industrial R&D labs) that offers potential for learning by enabling the combination of previously unrelated technologies.	Two NMR experts - an engineer and a researcher from the lab worked for an entire year on developing the suppliers' prototype.	The diverse technological expertise of the various IGBMC services contributed to the emergence of the macroscope and additional accessories. Researchers also combined existing techniques in a novel way to serve their research purposes.	Fundamental and complex characteristics of the institute research query required the combination of two techniques into one new equipment.
	Link to larger scientific community	University researchers provide an access to the broader science community in certain field creating boundary-crossing links for the supplier.	The interviewee served as an entry point and contact of the supplier with the various departments of the whole research institute, providing for the company diverse advantages.	The successful incorporation of the camera into researchers' newly constructed device was noticed by other academics working on similar topics that became also interested in working with the same equipment.	Being supplier of the university institutes significantly speeded up the development of the technology for the supplier.
	Experimental users with high technological requirements and forward-looking needs	(1) Research unities often develop technical solutions that are then transferred to suppliers. Alternatively, university labs refine companies' prototype by (2) testing them for extended period of time and (3) incorporating them into new settings of functioning.	The research unity conducted one year of beta-tests and experiments with the suppliers' prototype. The results were addressed regularly to the supplier.	Researchers developed a prototype of the macroscope and conducted all the alpha beta and field tests of the device before its commercial launch. They extended the field of application of the high-sensitivity camera and further developed its libraries for the supplier.	Researchers developed the prototype of the hybrid equipment with the supplier and its spin-off and later the research unity served as a testing ground for a specification/functionality that would be applied to future customers.

Table 14 continued	Construct	Theoretical proposition	Case 1	Case 2	Case 3
Indirect Technological Learning	Cognitive Embeddedness Common language vision and goals	Researchers and suppliers develop a common language of communication that evolves around instrumentation and induces feeling of common direction, congruence and shared goals among both parties.	The university engineer had evolved through the years being in close contacts with technical support engineers from the company. Such parallel evolvement created strong informal ties among them and allowed for an easy and high in value exchange of knowledge.	The University lab recruited an engineer from the company. Exchange of people fostered their common drive to high performance instruments and practically facilitated the development of risky and pioneering technologies.	The University lab was confident to pursue the development with the supplier because of the past experience among different people at university and company level. During this experience the university lab got to know the values of the company and develop common language.
	Structural Embeddedness Social network access	At the long-term, industrial suppliers obtain access to university's social network and various scientific communities and such social inclusiveness can have significant influence on companies' capabilities to develop new technologies.	The suppliers obtained access to the most novel samples from each research team within the Institute to be used in the testing of the prototype.	The supplier benefited significantly (although indirectly) from the joint work between IGBMC researchers and their colleagues at KIT. The German institute provided equipment and expertise to their French counterparties in order to speed up the development of the CLEM which integrated the high-sensitivity camera of the supplier.	The ISIS Institute provided the suppliers with detailed information about their inhouse developed molecule samples across various research teams and used them to generate the idea of the hybrid device.
	Relational Embeddedness Trustworthiness, norms of reciprocity, formal & informal socialization	While developing a trustful and loyal relation with suppliers, researchers will be more prone to make available complementary resources for companies to tap into through informal connections. Knowledge complementarities among researchers and suppliers enhance knowledge sharing and learning.	The research unity and supplier have a rich history of relations thanx to the exchange of people among them and the scientific background of the company. The suppliers French plant director was University of Strasbourg PhD student. On these common grounds, researchers and supplier staff engaged in informal meetings and exchange of equipment.	The strong relation among the research unity and company was outcome of the previous experience of the institute director with the manufacturer (tradition) and the further transformation of these links to higher level of confidence came with significant exchange of devices and staff among them. Confidence and non-official methods of communication played a great role into the emergence of macroscope.	The research unity and the supplier had developed previously software tools. Both sides benefited significantly from this experience and developed mutual understanding of each other practices. Based on this previous development with the same supplier, researchers point out the company trustworthiness as main reason to pursue further developments with them.

Table 14 continued	Construct	Theoretical proposition	Case 1	Case 2	Case 3
Innovation benefits	Reduce uncertainty	Thanks to their frontier-pushing scientific knowledge and technical expertise, universities can significantly reduce risk and uncertainty associated with the processes of technology development.	The university lab provided regularly evaluations of various products of the supplier. In this case the university researcher and engineer tested the device for one-year period of time and identified a series of modifications in order to transform it into product.	University engineers delivered production pre-series unities of the suppliers' equipment and allowed to the company to identify various production processes flaws. In this way, the university allowed to the company to evaluate whether it worth it continue or not with the full-scale production of the device.	The university institute formulated the first request for the hybrid equipment and suggested the exact way I which the two existing techniques should be combined into the new device. The research unity also served as testing ground for the supplier, where new specifications of the device could be checked before being applied to new customers.
	Open new markets and attract new customers	By sharing their views about future evolvement of instrumentation, researchers can open new markets for their industrial suppliers. In addition, the international prestige of the University turns them into valuable reference for their suppliers allowing them to attract new customers.	The tested device was brand new to the market and opened new market niche for the company. Until today the company is the only one in the world to produce the accessory.	Once the macroscope was introduced by IGBMC researchers, researchers from other domains wanted to get access to the new technology which opened new markets for the supplier. Similarly, other university teams were attracted to purchase the high-sensitivity camera. The research unity produced detailed rapports about the possible results that could be achieved with the devices and these were included into companies' commercial brochures.	The institute served as a show room of the supplier, where the first prototype of the device could be visited by people from the supplier company and its spin-off in the early period of its development. This is a common practice for the institute. The director of the research unity is often approached by manufacturers of equipment with request of recommendation letters that are later published on companies' sites. Such letters certify equipment quality and allow companies to benefit from the university image within the scientific community.

Table 14. Case study evidence

4.6 Putting the threads together: technology co-invention versus technology transfer

In the present section, we put together the conceptual framework laid down in section 2 with the empirical evidence gathered in the three field-case studies presented in section 5. More precisely, we analyse whether the field-study evidence we gathered corroborates or not the main theoretical conjectures that we outlined in Section 2 and whether exchanges occurring between researchers and their suppliers go beyond simple contractual relationships and whether they embed learning and trust, which in turn favour the emergence of new technologies.

We begin by examining the direct mechanisms of knowledge exchange among researchers and suppliers that are illustrated by our field-study. We stress how researchers are a source of specific and advanced feedbacks on existing equipment; they provide alpha, beta and field-testing for the manufacturers and also use existing devices as components in the building of new systems at the university labs.

Second, we highlight how the researchers-suppliers interactions that we observed in our field study produced also indirect effects. More precisely we discuss how these interactions were characterized by the types of embeddedness discussed in Section 2: 1) "cognitive embeddedness", that is the capacity of developing common language, shared vision and goals between the partners involved in the interactions, 2) "relational embeddedness", which captures the quality of the relationships in terms of good-will, trust and reciprocity among partners and, finally, 3) "structural embeddedness" which refers to the generation of new and useful connections in the partners' networks.

Third, we review how the above direct and indirect effects of researchers-suppliers interactions were produced during the formal public procurement procedures for the selection of suppliers.

Finally, we relate the various types of interactions observed in our case studies to the innovation benefits identified in the first and second chapter of the thesis. We also discuss the conduits of knowledge we find in the light of previous research on the economic value-added generated by public science infrastructure.

4.6.1 Universities as catalysts of suppliers' technological capabilities

Overall, our field study indicates that university laboratories represent a unique source of technological knowledge for suppliers because of their specific requirements about instrumentation. In particular, the interviews confirmed our main hypothesis that researchers turn to suppliers to ask them for something specific when they do not find what they need on the market. So, the starting point of the process is that researchers' scientific agenda includes, by its very nature, very specific scientific questions and it often requires new approaches to observation and measurement which then call for different devices from what is available on the shelf, on the market and/or in suppliers' catalogues. This phenomenon emerged at various instances throughout the three cases and its presence is neatly confirmed by one of our interviewees:

"We make developments on the basis of a scientific question and this is a bit different than a company because the company is going to have a set of demand - see a homogeneous market and produce a product that will respond somehow to the requests but which necessarily must be general enough so that it can be useful to a greater number of customers and suddenly will not suit perfectly nobody. And in science, researchers are advancing in a theme - the more specific and specialized applications become. But then we inevitably fall into cases where the systems driven by the companies respond almost but not enough so we have to do from time to time checks and sometimes find a completely new solution with pieces of systems of different suppliers that we are going to put together." (interviewee 1, case 1)

When researchers contact the suppliers in order to discuss a precise need for a device, the communication takes place in a very meticulous way, which already enables suppliers to receive a real and practical feedback about their existing products. The feedbacks received on a precise device by researchers differ substantially from the abstract feedbacks that are often received from customers by sales representatives and which are then transferred to the R&D service of the company. The case of macroscopy (Case 2) illustrates well how significant the consequences of these feedbacks can be for suppliers. In the 90s the majority of public research was striving to observe infinitely small objects and it was oriented towards super-resolution. Meanwhile, researchers at IGBCM (case 2) were interested also on larger objects, i.e. at a dimension from half a millimetre to 10 centimetres such as zebrafish, drosophila and mice. This resulted in a huge demand for devices able to make observations at different levels, i.e. not just limited to infinitely small scales. However, manufacturers of optical systems were not interested in devices that could allow such a variety in observational levels. Moreover, companies did not work in this area, because they couldn't see the interest in macroscopy, they could not understand and master it. The lack of any available solution on the market forced researchers to build their own macroscope by combining existing pieces of supplier's devices. When they showed their first prototype to the suppliers' engineers, their only reaction was: « *We didn't see this coming* » (Interviewee 1, Case 2). As a result, interacting with university laboratories keeps suppliers aware of the real needs of laboratories and helps them to see new technological opportunities. Feedbacks from researchers have let suppliers to redirect and re-orient their activities to an emerging field of interest for the scientific community, which then resulted in the opening of a new promising market for these companies.

Another way through which researchers' feedback serve as a source of learning and valuable information is when suppliers reach out to academics for their opinion on products before launching them on the market. These processes are illustrated by the confocal optical system developed with researchers' help, and also discussed in the second case study. Typically, confocal microscopes were closed systems that required the purchase of everything - an integrated system at one time. Constrained by the shrinking university budget and by the desire of making their equipment evolve, researchers addressed to their suppliers requests to deliver a confocal system that was modular and buildable. Such requests shifted the way companies sold confocal systems. Thus, under the pressure of budget constraints researchers identified the desired devices characteristics and they communicated them to the supplier to influence the evolution of the equipment (to become more modular). Our second case study also confirm that the modifications that suppliers introduced based on researchers' suggestions made the devices more flexible and effective.

Furthermore, we find that researchers contribute to the opening of new markets for suppliers also by enlarging the field of applicability and usage of existing devices. Researchers do not always construct new solutions, but they use existing suppliers' pieces in such a way that that adds value to "old" devices and enlarges their domain of possible application. These dynamics are well illustrated by the case of the hypersensitive Japanese camera (Case 2) that researchers integrated within new version of correlative light-electron microscopy system they put together (CLEM 2.0). The integration of the camera in the CLEM prompted two ways of influence. First, researchers obtained an open access to the camera software in order to adapt it for their specific purposes. As a result, they created and enriched the libraries code of the camera software and shared these new libraries with the supplier that could use them afterwards for problem-solving of other customers. Second, in order to manage the whole new system researchers, put in place a modular software that allowed the camera to be combined with rotation system and made is usable to explore more unconventional samples in research fields other than biology (e.g. physics) where more complicated experiments are requested. Therefore, the camera was later purchased by medical physicists and served in their study of the formation of bacteria film. Bacteria form a film to protect themselves and become resistant, increasing the tendency to clog catteries in hospitals, which leads to nosocomial infections and diseases. To study the formation of the film, physicists needed an optical system and a rotation system to move the samples. Thanks to the camera and the optical system, physicists could use the software and make the images they need. This example shows that the software developed by the university facilitated the use of the camera and the CLEM beyond their initial field of application. In this way, researchers made possible a number of possible uses of the camera, opening new markets for the supplier. The new software added value to the camera and gave an important solution to a common obstacle that researchers would face every time when they had to use the camera in combination with other devices.

Furthermore, university labs also act as a relevant testing-ground for prototypes and products. Researchers testing suppliers' products was a common practice observed in all the three cases. We identify three types of testing according to the degree of technological maturity of the tested item: alpha-testing of suppliers' prototypes; -beta-testing and field-testing of suppliers' products.

Case 1 illustrates well the role of researchers in alpha-testing: it is when a device is barely developed, and it is a prototype. The aim of this testing procedure is to identify certain flaws of the device and provide a detailed account to the supplier whether the product works or not. Therefore, it means that researchers participate to a certain extent at the design, final development and construction of the device. Testing is related to the scientific production (samples) that researchers use to experiment with suppliers' devices. Therefore, along with the testing, relations with researchers provide to the suppliers also access to their broader scientific parameters. Once alpha-tests are completed, it ensures that the device can be beta-tested.

Researchers also provide beta-tests for the suppliers. This is evidenced by all three cases. The aim of beta-testing is to know whether the device works smoothly and how it could possibly be improved. Beta tests take users on a guided tour of the product to answer the question: do customers like the product? The tests also consist of detailed surveys about the device and of an application letter that suppliers publish on their website to explain how exactly the equipment is to be used. Researchers and lab directors also give interviews for the supplier explaining the advantages of a given device and showing the results that could be obtained with them. Another possible outcome related to equipment testing is a working paper – i.e. a paper explaining the techniques and how researchers obtained certain results. Such working papers are published on the website of the company. The diffusion of information about researchers using certain equipment comes in various forms – such as articles, videos (e.g. YouTube) and they provide a significant support for suppliers' products. The potential value of such communication channels for suppliers lays on researchers' expertise in a certain field. In return, the university also benefits significantly from these channels in terms of free worldwide communication.

Testing is thus a significant aspect of researchers-suppliers' interactions in all the three cases. Our empirical evidence also shows that testing can be implemented via different legal frameworks. For example, in Case 1, the testing of the accessory lasted for one year and it was organized via secret collaboration agreements between the researcher unity and the supplier. In contrast, in the second case alpha and beta testing took place in rather informal context although researchers produced a great deal of formal documentation by way of detailed reports, brochures and working papers. Likewise, in the third case, testing occur in absence of any kind of contractual agreement as a consequence of researcher's choice. Interestingly enough, avoiding a formal agreement with suppliers was a strategic choice. It gave researchers freedom in their decision for the selection of supplier and assured them a better negotiation status during the procurement process.

Lastly, university laboratories can serve as a locus for exchanges among companies and a "social shelter" (Autio et al., 2004 p. 124) for developing new solutions. Our evidence shows how university labs may directly foster their suppliers' learning by putting them in contact with other companies competing in the same markets, thus creating a space for knowledge exchanges among industrials. Such exchanges are prompted by researchers who typically combine technologies from different manufacturers in new ways. This process not only has a positive influence on suppliers, as we discussed above. It also triggers an open dialogue among suppliers of the initial devices. In addition, research unities serve as a "brainstorming place" where companies can pursue the development of something different than their core business. In that respect, laboratories act as incubators for technologies that would be too expensive to develop by a company on its own and/or because the laboratory has a specific expertise in a given field that the company does not have yet. Our three cases represent to a different degree the above described processes of influence. In some instances, the research units allocated dedicated space and personnel for their supplier, allowing the latter to better focus on technology development (Case 1 and Case 2). In other instances, they created intense interactions between the supplier and other companies (Case 3). Finally, researchers generated positive externalities between suppliers by combining their technologies into new systems (Case 2).

In addition to the above described three conduits of direct influence among researchers and suppliers, our cases indicated the presence of further processes of direct contribution of researchers to firms manufacturing capabilities. Indeed, university laboratories can actively be involved with suppliers also at later stages of a product development process, i.e. the stages that we would normally expect to be part of firms' core business. Our empirical evidence shows indeed that, besides the pre-production testing as alpha and beta tests, researchers were also involved in the pre-series production phase. Pre-series production consists of building a limited number of a certain device so the supplier can share them with other companies that are going to perform the large-scale production of the system. These devices will then serve to the supplier to test the future production processes. The limited sample is subject to specific tests for ad hoc realisation. Suppliers need pre-series production as a quick alternative while actual series manufacturing is not yet in place. The pre-series production realized by the research unity enables suppliers to test both the production process and the products in a large-scale setting. Thus, suppliers acquire the experience and knowledge they need to decide whether to step back or move to the next level in their production phase. These pre-series are framed by a formal service agreement. Therefore, researchers and supplier switch roles in this setting: the researchers provide a service to the companies, thus in fact becoming their "suppliers".

4.6.2 Embeddedness and mutual learning

Beyond the above direct conduits of influence among researchers and suppliers, our three cases revealed that universities labs also favour learning in their industrial supplier companies in various indirect ways. These indirect learning channels are well explained by the notions of cognitive, structural and relational embeddedness that we highlighted in section 2 of this chapter.

Overall, our field studies indicate that at the beginning researchers' and suppliers' match according to complementary technological knowledge in certain domains. Researchers' clearly choose their industrial suppliers of instrumentation let by the desire to find companies able to help them in improving their instrumentation. In this sense, researchers with a clear vision about future developments of an instrument get in contact with companies that have capabilities to deliver technically sophisticated and advanced instrumentation and then who could be able to make the desired improvements. At the outset this matching is mainly technology-driven, as researchers have to rely on the most advanced instruments already developed by companies. However, once researchers integrate the instruments in their activities a new learning process is triggered. This process is driven by researchers' scientific agenda which determines the specific way in which the purchased systems is used. The in-depth scientific investigation in a particular field leads researchers to be confronted with unique technical problems whose resolution allows them to develop specific skills and knowledge. This technological knowledge acquired through practice plays then a fundamental role for the development of new instruments or the improvement of existing ones and can then be shared with companies through many channels. Some of these channels relate to the formation of a certain conduct of communication among researchers and suppliers leading to high level of social a cognitive interaction. This "cognitive embeddedness" generates a common language, symbols as well as common representations and models among the parties. The creation of such a shared vocabulary favours the coordination of researchers and suppliers on how a certain research field is expected to develop in future and about the consequences of these evolutions on equipment.

The building-up of such a common language is fairly well illustrated by each of the three cases we analysed. For instance, in Case 1 the company 1 had already a very solid scientific background, as it was created by an academic researcher and had its French branch managed by a University of Strasbourg PhD graduate. Accordingly, in this case, the common language between the company and the university existed because of the suppliers' university roots. Case 2 illustrates instead how common language can be developed through time via repeated interactions. This case also hints at the path-dependent and sometimes accidental nature of these developments. Indeed, common language developed out of initial technical and scientific expertise that both parties could put on the table. Practically, in Case 2, the supplier took a very pro-active approach in visiting the research unity already when this was still under construction. At this time the interest of the supplier was directed towards the laboratory as a potential purchaser of tools. Then, once the scientific activity of the imaging platform started, the company got conscious about a multitude of other reasons to remain in closer contact with the director of the research unity and its' staff.

Finally, the three cases altogether illustrate how interactions characterized by shared language trigger suppliers' interest to engage in a certain development and to exchange in informal ways with researchers. This is well summarized by one of our interviewees in Case 2: *"It must also be said that even for the industrialists we are very interesting. Why? Because we try to have a common dialogue. Classically when a scientific researcher has a need, he has his own dictionary which is not necessarily the dictionary of the industrialist. Languages by different actors are not necessarily the same. And the interests of each other are not necessarily the same. When they come here - they feel like we speak the same language and we have the same problems."* (interviewee 2, case 2). Also, the third case demonstrates, in a slightly different way, the potential of cognitive relations among researchers and suppliers. In this case, thanks to the common values between supplier 3 and ISIS, the supplier eventually overcame its initial reluctance to pursue the development of the hybrid device and they engaged in a completely informal manner in the development of the new device.

The progress of the relations between researchers and suppliers critically depends on the formation of the above-mentioned shared language. According to the theoretical discussion in Section 2 of this chapter, the researcher's knowledge about scientific instrumentation is codified but latent and its codebook is not manifest for all the members of the community because they have internalized it and it is a common knowledge. Thus, in order to grasp the latent part of their scientific knowledge which is also said to be the most valuable part of it, the suppliers should understand these codes of communications and be able to pass a "closed book" exam to enter in tight communication with researchers.

Once this initial phase is completed, shared language and symbols in a dyad represent a fertile ground for more intensive knowledge exchanges among researchers and suppliers and increased common understandings among them. In this process common language translates into the emergence of common vision and goals. In turn, such a common vision and goals trigger off investment by suppliers in the partner-specific assets and create self-reinforcing dynamics among researchers and suppliers. Each of the cases brings out these self-reinforcing dynamics in different ways. In the second case we observe that the co-invention of the macroscope began a longstanding alliance among the IGBMC and supplier 2.1 characterized by introduction of series of new microscopy solutions. In November 2017 the two institutions celebrated 20 years of collaborations with a workshop dedicated to presentations and scientific talks highlighting the successful projects stemming from the partnership (Supplier 1 Press release 2017). Interestingly, the day took place under the heading "From Micro to Macro" which emphasizes the truly transformational nature of the long-term ties among the suppliers and the research unity. At the event, the supplier 1 Vice President stated: *"A long partnership is based on passion for innovation. It is why we are partnering with IGBMC, an institute always innovating."* Compared to the second case, the first and the third cases appear as part of ongoing continuous relations among labs and supplying companies. Therefore, a common aspect among the three cases is that the exchanges among both parties take place in continuous way.

A second important channel of influence in researcher-supplier interactions is relational embeddedness. Relational embeddedness refers to the ability of interactions to generate trust, norms of reciprocity and credibility among the partners involved. The presence of mutual confidence and trust among researchers and suppliers creates a rich and solid foundation whereupon they build deeply rooted and complex relationships. On this ground, trust triggers off empowering interactions among counterparts and turns the knowledge transfer process smoother. In all the three cases trust between researchers and suppliers originated from previous positive interactions. Such previous experiences, motivated researchers' beliefs in suppliers' good-will, reliability and intentions to fulfil their obligations. For instance, in Case 2, the director of the imaging platform had a good experience working with the supplier at his previous research unity which was one of the reasons he preferred them as the main supplier when he was developing the imaging platform.

He motivated his decision as following: *"I was happy to be able to work with people I knew and trust and people who over time could better meet our needs and be more effective in meeting our needs."* (interviewee 3, case 2). These initial interactions subsequently turned into something more robust, as it is further described by an engineer at the platform: *"Jean-Luc* (the lab director) *created a relationship at that time. This relationship was interesting to such an extent that the director of the factory that made the confocal who was a scientist coming from Heidelberg made it a habit to come once or twice a year to talk to Jean-Luc about biology. So, these exchanges were very interesting, and they lasted for years. When they had a new confocal idea that came out, they came to consult with us to find out what was expected of a confocal in the future."* (interviewee 1, case 2).

This last statement illustrates how trustworthiness among individuals gives rise to rich informal exchanges and routines of communication. These routines are then essential later in the transmission of practical feedbacks, valuable pieces of knowledge and researchers' expectations about techniques and equipment.

Also, in Case 3 researcher's confidence towards the supplier company was based on a former informal collaboration between them that was not even related to equipment, but to a software. However, in contrast to Case 2, our interviewee's experience with the supplier did not took place with the same people he interacted in the past. This did not undermine the course of the relationship. Although our interviewee had never communicated with the same people of the supplier company, he was confident and did not feel like taking any risk or uncertainty by entering in informal exchanges with them: *"It was not with the same people, but we had already had this type of collaboration with supplier 3. So, we knew it was quite functional and we could proceed, and it would work very well."* (interviewee 1, case 3). This evidence suggests that trustworthiness does not concern specific dyad of people; it is not an interpersonal feature of researchers-suppliers relations but rather inter-organisational quality that characterizes interactions in general between the two types of organisations (Geneste and Galvin, 2015; Balboni et al., 2017). Even if trust is inspired by individuals, it can then become a stable trait of relations between organizations and facilitates interactions among their members.

Finally, all the three cases reveal how relationships of reciprocity and mutual trust occur largely outside contractual agreements. In this context, suppliers actively seek university expertise because they realize that they can benefit significantly from it in this informal way: "*They are lending us new products that have not even come out for testing yet, or the vendor has several ideas and the university says, that is not worth it; on the other hand that's good and they continue. All this is done only by the informal: when the Japanese company lent us the cameras, we did not sign anything. It was based on relationships that existed before.* " (interviewee 3, case 2).

A third and final channel of influence between researchers and suppliers that we could observe in our field study works via the establishment of new and useful interactions. In Section 2, we employed the concept of structural embeddedness to describe the willingness of researchers and suppliers to provide to each other access to their internal and external networks (McEvily and Zaheer, 1999; Uzzi, 1997). When a given researcher-supplier dyad has this structural component, industrial suppliers get access to the whole network of the university of Strasbourg through one particular research unity or team. The internal network represents all the other research unities and their equipment platforms and the external network - other universities and research organizations. Thus, one laboratory provides an access to the science community social network creating boundary-crossing links for the supplier. These researchers thus serve as a "bridging ties" (Granovetter, 1973) that are leveraged by suppliers to access direct and indirect sources of knowledge available within the university's network. These additional knowledge sources for suppliers then turn into ideas for new products; sources of feedback and assistance in R&D. Such mechanisms of knowledge access can take a multitude forms and ways of influence as shown by all the three cases we analysed. For instance, in Case 1 suppliers obtained access to the scientific production of the whole research unity. In this way the company could test its device using the newest synthesised samples, that tried to reply to the latest research questions and had completely different significance for the testing of equipment. Similarly, the second case shows how suppliers got access to the internal workshop of the university lab. This allowed suppliers' technicians to repair and adapt a device in a much shorter time than at the manufacturing site in Germany. These results confirm the importance of the access of firms to researchers' network: *"When an industrialist comes in our lab and we take him to the micromechanical workshop - he feels like at home ..."* (interviewee case 2). Lastly, the third case makes an important point by illustrating that the establishment of new network connections operates on both sides, i.e. also suppliers connect researchers to other firms across their industrial network. In the third case, the supplier company hesitated about engaging in the development of a hybrid device and for this reason put in contact the research unity with a small-scale firm manufacturing interface device for them.

4.6.3 Researchers-suppliers interactions and public procurement procedures

Finally, our case studies also provided evidence about the ways through which researchers-suppliers interactions take place within the framework of public procurement procedures. Informal interactions with suppliers are illegal during the procurement procedures. Nevertheless, our cases show that, within the boundaries allowed by legal procedures, researchers and suppliers interacted both before and after the end of the procurement bids. We observe a very similar approach followed by researchers and suppliers across the three cases. Researchers were involved in a rich communication, co-development (Case 3) and testing (Case 1) or both (Case 2) with the supplier before the public procurement procedure took place. The pattern that clearly emerges across the three cases is that researchers and suppliers exchange in various ways before the beginning of the procurement procedure in order to discuss possible technicalities concerning the future procurement. Once the procedure is official, they obey the rules of the procedure and researchers examine the offers by all possible providers. Furthermore, all cases indicate how interactions before the procedure allow researchers to obtain important advantages with respect to "ordinary" customers such as discounts and various added options for free. The uniformity and scale of these "gifts" across the three cases represent an additional evidence about the crucial role of researchers for suppliers and the significance of their contributions for the genesis of the final device. Sometimes the discount made by suppliers can be so important that the price of the equipment drops below the lowest bound subject to public procurement. For instance, Case 1 show how researchers purchased an equipment that initial price was 90 000 € and then were involved in the adaption/co-invention with the suppliers obtaining a final discount of 30 000 € which allowed them to avoid the public procurement procedure for this subsequent purchase. Similarly, in the third case the lab purchased an equipment costing 600 000 € for 240 000 € instead.

These examples illustrate well an important aspect of researcher-suppliers' relations: an equipment purchase is often followed by an whole stream of relations that unfold between researchers and suppliers both before and after moment of acquisition of a new device and that go beyond the initial formal context. [24]

4.6.4 From conduits of influence to innovation benefits

Altogether, our three case studies provided strong empirical evidence with respect to both direct and indirect learning processes that take place among researchers and suppliers. Our results are by and large in line with the prior research that has tried to evaluate the economic impact of public investments into scientific research (Schmied, 1982, 1987) as well as with studies on the economic value generated by public science centres (Autio et al., 2004; Castelnovo et al., 2018; Florio et al., 2018). These studies identify four large mechanisms through which the above value is created.

First, through their interactions with university researchers, suppliers acquire significant innovation benefits in terms of increasing turnover due to the ability to develop new and improved products. These products and the technologies that they embed are carefully described in section 5. As illustrated by the three cases, the conception of these products is impacted by university laboratories in various ways: from feedbacks about which direction to take for the research developments to detailed feedbacks about existing products or, finally, via the conception of new systems by the researchers themselves through the combination of existing devices. Second, keeping close relations with university laboratories yields significant commercial benefits to suppliers, as their turnover increases due to marketing reference value associated with the fact of being a supplier of an internationally recognized research unit. As shown in our field study, suppliers grasp this value in various ways. By diffusing information about their equipment that is used, tested or co-invented with research unities via user manuals; brochures; interviews with researchers published on their site and other communication means as well as by exploiting the researchers' scientific and academic network. A third possible benefit for suppliers stems from the positive financial impact of a contract with a university. Contrary to prior studies (Schmied, 1982,

[24] Furthermore, our cases indicate that interactions between researchers and suppliers can also unfold after the end of a formal procurement process. Even companies that do not win the bid, get in touch with researchers with the specific need to understand what the critical flaw of their product was and how it should be addressed.

1987; Autio et al., 2004), we do not find support for this channel. In contrast, our interviews show that University of Strasbourg laboratories are not considered important by companies because they are a big customer i.e., they purchase a lot, but rather because of their scientific distinction and reputation, which creates a significant positive externality for supplying companies.

Finally, it has been argued that public research contributes to suppliers' costs-savings through process improvements (Schmied, 1982, 1987). Our case studies reveal at least two channels through which such a process improvement takes place. First, laboratories build pre-series samples for the suppliers and provide them with precise information about the production process in large-scale environment and possible adjustments that might be required. On these grounds, suppliers take decisions whether to pursue with the large-scale production of the pre-series product or not. Often such pre-series production takes place once the suppliers have loaned the equipment to researchers to perform demonstration on it and test it. In addition, university laboratories carry out alpha, beta and field-testing which also generate relevant information for suppliers' production practices.

4.7 Conclusions

In this chapter, we provided field-study evidence about how university research influences the innovative performance of their suppliers. Technological learning among researchers and suppliers is determined by the processes and pace with which knowledge is diffused from its primary locus - the university - to the suppliers for which this knowledge has practical applications. We showed how, by sharing with suppliers' particular pieces of knowledge or technologies, researchers' help companies to develop new capabilities in the production of a certain device. These skills were then applied in the manufacturing of other types of devices, resulting in the expansion and diversifications of suppliers' activities. Thus, technical skills acquired during research activity at the university had direct applications in suppliers' production processes. In a nutshell the university effect on suppliers stems from the new capabilities and technologies that were developed or improved in response to researchers' specific, unprecedented requirements. In addition, once the knowledge acquired by universities was mastered, suppliers used it for other uses and applications.

The above-described process shares several characteristics with the unique historical account of the emergence of the machine-tool industry by Rosenberg (1963), scientific instruments being among the broad spectrum of machine-tool-using industries. According to Rosenberg's analysis (1963) the machine tool industry emerged out of intensive interactions among users (the industries which adopted new techniques of machine production) and producers. Machinery producers acted in response of a specific production requirements of different users and gathered knowledge about their needs with respect to broad range of technical solutions. Tapping into users' local knowledge and skills (accumulated through time with problem-solving of unique technical puzzles) that were essential for the machines' manufacturing process, allowed producers to introduce more efficient solutions.

Furthermore, our field-study shows that, even if the process governing researchers-producers interactions is mainly determined by the state of technology provided by suppliers at the beginning, it is heavily influenced by researchers demand thereafter. Indeed, researchers are in a position to communicate to suppliers' companies requirements that other kinds of organizations would be unable to impose and, in such a way, influence them significantly in their evolution within a certain technological paradigm (Dosi, 1982). In this sense, our evidence shows that public universities requirements are valuable because they are associated with the scientific and technological competences of researchers. However, the results of our field study go beyond the idea that researchers just act as mere customers and that manufacturers then take up the production processes and produce the final product. Indeed, our evidence shows that there is no clear-cut distinction among researchers' and manufacturers contributions. In addition, the role of researchers is not limited to the demand addressing a particular requirement. They also provide a variety of services for their suppliers. These services can vary from testing the equipment in various stage of its development, producing pre-series unities for the company to simply producing the prototype of equipment within a university lab. Therefore, researchers impact on suppliers' innovative performance through the procurement of instruments emerges as a combined effect of very sophisticated forward-looking demand and science-based technological knowledge and practical capabilities. Finally, our field-study illustrates that the transfer of knowledge among researchers and firms can happen in various stages of the procurement process but mostly via informal channels triggered by the formal procurement procedures. Altogether our field-study of researchers-suppliers interactions sheds light on the actual mechanisms through which university procurement exerts a significative and positive effect on companies innovation. More precisely, our evidence shows the presence of a "procurement-led" innovation phenomenon wherein university researchers provide companies with unique insights by acting both as equipment-demanders as well as suppliers of scientific knowledge about instruments, ultimately allow firms to explore new innovative trajectories.

Our study thus offers a new perspective about the role of universities than the one advanced by prior university-industry interaction studies. By focusing on the mutual learning processes unfolding through researchers-suppliers exchanges, we have been able to go further previous works as well as "input-output" studies that have attempted to quantify the secondary economic impact of universities. While valuable, these studies did not provide in-depth insights into how universities operate as a learning environment in a way different than other entities. The conjecture underlying our study, and that was confirmed by our case studies, is instead that there is something special about the relations among university researchers and suppliers that creates a knowledge development momentum and allows suppliers to become more innovative.

Our field-study has implications for researchers, university practitioners and policymakers. First and foremost, the present study suggests that the mains focus of science and technology policy should be to support public universities and allows them to pursue basic and applied topics of research with enough resources to purchase and access the most up-to-date and relevant equipment and machinery from industrials. Such public support should also allow to university labs to also purchase an appropriate maintenance contract for the equipment. By providing public universities with sufficient funds to procure such equipment, policymakers would support the organic emergence of by-products potentially valuable for the industry.

Our empirical evidence indeed suggests that interactions among universities and their industrial suppliers are multifaceted, involving a large number of different participants, and shows that universities possess some distinctive potential for acting as a learning environment compared to other types of public research institutions. However, the implications of a user-producer approach for industrial and technology policy recommendations are rather laborious. Science and technology policies should target both sides involved in the interactions, i.e. both universities and suppliers, in order to generate dynamic complementarities between them. According to our findings, the emergence of these complementarities is very much linked to the existence of a continuous dialogue between researchers and suppliers, so if one of them is not able to sustain the dialogue with the other the chain of effect will eventually be impaired. Furthermore, our field-study evidence clearly indicates that researchers-suppliers' dialogues are sustained by trust and informal practices of communication. Singular market transactions i.e. purchase of equipment are often embedded in a rich nexus of non-market, informal exchanges. It follows that encouraging knowledge exchanges and collaborations among university researchers and suppliers by settling more informal occasions would create space for non-market relations and enhance the quality and corresponding impact of the relationships among researchers and suppliers.

Furthermore, our field-study shows the presence of a close relationship between university equipment facilities, student training and the movement of skilled people. It turns out that the deterioration in the quality of university facilities would undermine the significant beneficial impact of knowledge streams arising from the close integration between well-equipped university laboratories and graduate training.

The present study could be extended in several ways. First, more research is needed for a broader and deeper examination of the effects of universities on second-tier suppliers and other actors of the supply-chain. Second, our current account of the researcher-suppliers' relations represents them as having solely positive effects to both sides. However, during our interviews we collected data that hints also to possible negative externalities for researchers as for example when they are obliged to accept equipment for free in their research unities just by convenience, neglecting their research agenda. Third, as shown by our cases, researchers match their expertise with suppliers that are able to assist them in the further development of instrumentation. Thus, only certain companies would be able to become university suppliers and benefit from the instrumentation knowledge at universities. This could raise questions over the truly public nature of knowledge created by universities through their demand.

Chapter 5

Concluding remarks

In 2017, the High Council for the Evaluation and Higher Education in France published an assessment report of the Institute of Supramolecular Science and Engineering (ISIS) stating that *"We all know that such institutions become powerhouses not only in terms of science but also in terms of economy and society."* (HCERES 2017 p. 7).

In this dissertation, we proposed a new approach to grasp the economic influence of universities by exploring the impact of academic research unities on the innovative capabilities of their industrial suppliers of instrumentation. To study the tricky nature of these relationships, and unlike the bulk of research on university-industry relations (Perkmann et al. 2013), we made use of a unique university data covering local administrative and financial records. Furthermore, with the aim to provide a more complete account of the complexity of university-suppliers interactions and of their effects on innovation, we combined quantitative and qualitative empirical methods.

We first set the stage by recalling sociological and historical studies on technology development. We showed that history, at least nineteenth-century technological history is highly relevant to what is going on at the end of the twentieth century and today (Patel and Pavitt, 1994). Then, we turn to the existing body of studies around the topics of public procurement and since the discussion of innovative public procurement is intrinsically links with the debate about the role and magnitude of demand as a source of innovation. We started by reviewing seminal studies related to demand-driven innovation since the 60s and 70s and the subsequent critiques addressed by Mowery and Rosenberg (1979) and Dosi (1982) that triggered a debate with respect to how supply and demand define the rate and direction of innovation. Finally, we focused on more recent studies on procurement that altogether find a positive and significant effect of government procurement on companies' capabilities to imitate (Czarnitzki et al., 2018) and innovate (Aschhoff and Sofka 2009; Guerzoni and Raiteri, 2015; Ghisetti 2017). Our review shows that procurement has been recognized and often mentioned as a relevant channel of public action to influence industrial innovation as part of mission-oriented programs (Mazzucato 2015, 2016), or as tool for government major influence in product development in sectors as military equipment, public transport and energy (Pavitt, 1998), or alternatively as strategic investment creating positive externalities in the case of big public research infrastructure as CERN (Castelnovo et al., 2018). At the same time, we highlighted how the analysis of the impact of university procurement on innovation has mostly been overlooked by scholars in the economics of technical change and how both quantitative evaluations as well qualitative field-studies are still lacking.

In the second chapter of the dissertation, we analysed the impact of researchers' demand on suppliers in terms of new-to-the-market products and sales due to such products. For this purpose, we tested the conjecture that being university supplier has, other things being equal, a positive and significant effect on the innovation performance of companies. We approached the status of university supplier as a treatment that companies receive, and we employed propensity score matching techniques to select an appropriate control group of untreated firms based on the probability that they become suppliers to the university. We then carried out a quasi-experimental analysis using a novel micro dataset composed of unique expenditures data at the project-level from the University of Strasbourg (2011-2014) that we blended with firm-level innovation (CIS) and financial (FARE) data. The average treatment effect (ATT) on the treated supports our initial conjecture and it indicates that being a supplier to the university of Strasbourg increases significantly company's propensity to open new markets and enjoy higher sales of new products.

The above empirical evidence also suggests that research fortuitous by-products such as instruments, techniques and problem-solving abilities bring into play real and substantial economic benefits (Salter and Martin, 2001; Rosenberg, 1992). In this way, the first chapter of the thesis provides quantitative evidence about a new knowledge transmission channel existing between academic researchers and manufacturers of equipment, whose existence has been conjectured by a wide range of scholars from various disciplines such as sociologists (Shinn, 1998; Shinn and Ragouet, 2005); economic historians (Teissier 2010; Rosenberg, 1976) and by scholars in science and technology (Joerges and Shinn, 2001; Gaudilliere, 1998) .

In the third chapter of the thesis we complemented the empirical results of the second chapter with an extensive robustness analysis. We followed a dual approach. As a first step, to tackle a number of issues that could possibly undermine the robustness of the main ATT findings, we carried out a nine sensitivity tests that can be sorted into three categories: sensitivity checks that controlled for further relevant characteristics; restricted the sample size according to different criteria; and experimented with the matching algorithms. ATT estimates exhibited a consistent and stable pattern of significance across the various specifications. As a second step, we revisited our initial empirical study by performing an alternative analysis of the university effect on supplier companies, this time questioning weather suppliers patent more than other similar companies. To this end, we coupled our original data with standard firm-level (AMADEUS) and patent (PATSTAT) data, exploring the effect of being a supplier on firms' patent activity by a Zero-Inflated-Negative-Binomial (ZINB) regression analysis. This additional sensitivity analysis corroborates the positive and significant effect of the University of Strasbourg on its suppliers' by showing that the latter exhibit a higher propensity to introduce new patents than similar non-supplier companies.

The quantitative evidence of the these two chapters provides several insights about the possible effects of universities research labs on the innovation of their suppliers. At the same time, these studies are unable to fully grasp the role that universities play in shaping the innovative capabilities of their industrial suppliers. Motivated by the desire to overcome this hurdle in chapter 4 we turned to a field-study that explores in a finer detail the processes underlying the above empirical results. The main goal is to provide a more in-depth characterization of how university research unities turn to serve as a rich learning environment for their suppliers. We carried out three case studies that describe the processes of technologies co-development that took place between researchers and engineers belonging to three academic labs and their industrial suppliers. Our field-study revealed a multitude of patterns through which researchers exchange back and forth pieces of valuable technological knowledge with their suppliers. In practical terms, our cases illustrated that by combining existing pieces of technology in an uncommon way to set up new devices, researchers introduce extensions that enlarged the field of application of devices, opening new markets for their manufacturers. As an alternative, replacing certain keys elements of systems with a cheaper one made these systems more desirable by other users, allowing firms to sell more from them. Furthermore, as shown in the case study of the macroscope fluorescence (co-developed by the University of Strasbourg in collaboration with an industrial supplier in Case 2) researchers' expertise played a key role in allowing their suppliers to discover market opportunities in the field of macroscopy instrumentation, by keeping companies updated about the evolvement of users' requirements.

Finally, co-inventing among researchers and suppliers is clearest illustration of how new tools and technologies are a joint product of researchers' and suppliers' efforts to overcome certain technical limitations that emerged in the course of scientific problem-solving and then had an immediate and significant impact on suppliers manufacturing capabilities. The three cases illustrated that researchers assume the role of "bridging ties" (Granovetter, 1973) that are leveraged by supplier to tap into direct and indirect sources of knowledge within university's network. Following, researchers-supplier interactions are mainly informal and are based on a ground of common values and goals.

All these processes are animated by various practices that acted as natural communication bridges and created appropriate conditions for rich knowledge transfers to take place. Among these practices we observed personnel mobility; co-directed thesis which aim is the experimental development of technology; large-scale events as forums, congresses and workshops are another way of intensive face-to-face, informal interactions among researches and suppliers that spark knowledge transfer within the scientific community while promoting integration of new skills.

The last chapter provided field-study evidence of the kinds of the requirement that university imposes to stimulate innovation among their suppliers – requirements that other kinds of organizations would be hard-pressed to impose. Exploring this interpretation let us to discover that the overall impact of the university over manufacturers goes beyond their mere role of customers i.e. the effect of demand. Furthermore, we showed that public research labs act also as providers of science-based knowledge about instrumentations and ready-made technologies for the companies throughout different steps of the procurement procedures and afterwards. The provision of such a valuable knowledge is deeply rooted in the nature of the research activity and functioning of scientific communities and it allows companies to explore new trajectories of research and innovation, that we label "procurement-led" trajectories. An important normative implication of our findings is that the transfer of academic ideas into practice is best achieved when universities are given the freedom and resources to conduct high-quality research and to make long-term investments into their facilities. In these instances, technologies appear as a natural side-effect of public research and follow their inherent trajectories of diffusion, instead of purposefully pre-conceived frameworks imposed over universities that do not take into consideration how those technologies are created in public universities. Therefore, the transfer of knowledge towards industry appears as a by-product of well-equipped public laboratories.

Needless to say, a lot of work is still needed to grasp a good understanding of the influences that universities exert over their industrial suppliers and their respective conduits of diffusion into substantial enhancement of companies' innovation capabilities.

As far as the patent analysis in Chapter 3 is concerned, one could attempt to extend the analysis to all French universities over all technological fields. However, this extension cannot be based on the same kind of data retrieved for the University of Strasbourg. One could instead adopt a different approach, that is to estimate the impact of academic users on firm innovation products as captured by patent data. To this end, one could take advantage of rich available data on academic patenting and scientific publications.

A second research path could involve the investigation of the emergence and development of specific type of equipment: artificially intelligence powered minimally invasive surgery devices. At the beginning of the 90s, surgery has been disrupted by new techniques, that led to the introduction of minimally traumatic, and by consequence, minimally invasive procedures, leading to the emergence of entirely new philosophy and paradigm in healthcare – minimally invasive surgery (MIS, see Satava, 1999; Thune and Mina, 2016). Contrary to open surgery, the MIS approach require thin instruments to penetrate the human body through small incisions and the use of sophisticated optical systems to observe the internal anatomy of the patient on a screen (Diana and Marescaux, 2015). This new paradigm gave rise to the development of entirely new kinds of medical instrumentation and equipment. The ensuing MIS techniques and treatments display practical challenges as they require a hand-eye disconnection of the surgeon and impaired depth perception. These are among the challenges that have been effectively tackled by the emerging discipline of computer-assisted therapies i.e. computer-assisted surgery and artificial intelligence techniques that were coupled with basic minimally invasive techniques. Since then, minimally invasive therapy is an extremely dynamic area of innovation, as shown by the constitution of new medical journals, growing number of publications, and the rapid entry of medical device firms into the market (Gelijns and Rosenberg, 1995). The case of minimally invasive surgery suggests that major developments in medical instrumentation have been intensely complemented by other innovations with origins beyond the boundaries of the medical world namely information, computer and communication technologies (Rosenberg, 2009). Despite the fact that the rise of artificial intelligence allows technology to empower the medical industry in the form of medical image analysis, machine reading and intelligent diagnosis it also brings up many ethical questions as for example to what extent artificial intelligence should be allowed to influence medical technologies and patients.

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Appendix

BETA
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Informations Personnelles Concernant le Chercheur/la Chercheuse

Dans cette partie nous vous posons quelques questions générales sur votre identité et votre implication dans l'achat d'équipement.

1. Nom du chercheur/de la chercheuse
   ……………………………
2. Unité de Recherche
   ……………………………..
3. Votre domaine de recherche
   ……………………………
4. Votre domaine de recherche
   ……………………………
5. Equipement acheté
   …………………………….
6. Fournisseur de l'équipement
   ……………………………

7. Quelle est l'institution qui a encadré le processus d'achat ?
   - ☐ L'Université de Strasbourg
   - ☐ CNRS
   - ☐ La fondation
   - ☐ INSERM
   - ☐ Autre, veuillez préciser :

8. L'équipement sert surtout :
   - ☐ Aux activités pédagogiques (enseignement etc.)
   - ☐ Aux activités de recherche
   - ☐ Les deux

9. Etiez-vous directement impliqué(e) dans la commande de ce matériel ?
   - ☐ Oui
   - ☐ Non

10. Une autre personne était-elle impliquée dans l'achat de cet équipement ?
    - ☐ Oui
    - ☐ Non

11. Pouvez-vous fournir quelques informations à propos de cette personne afin qu'on puisse lui adresser le présent questionnaire (nom)

………
………………………………………………………………..

Relation avec le Fournisseur

Nous cherchons maintenant à comprendre les principaux critères guidant le choix du fournisseur et la fréquence des interactions avec ce dernier.

12. Sur quels critères vous appuyez-vous lorsque vous choisissez un fournisseur ?
    - ☐ Coût
    - ☐ Qualité
    - ☐ Prestation générale
    - ☐ Service
    - ☐ Profil du fournisseur
    - ☐ Confiance mutuelle et interactions fluides
    - ☐ Propension du fournisseur à faire du sur-mesure/personnalisé
    - ☐ Qualité de la relation avec le vendeur
    - ☐ Spécificité unique du matériel
    - ☐ Autre (veuillez préciser)

13. Combien de temps avez-vous travaillé avec ce fournisseur au moment d'effectuer l'achat ?
    - ☐ Quelques mois mais moins d'un an
    - ☐ 1 à 3 ans
    - ☐ 4 à 5 ans
    - ☐ Plus de 5 ans
    - ☐ Je ne sais pas

14. A quelle fréquence avez-vous interagi avec votre fournisseur ?
    - ☐ Jamais
    - ☐ Toujours
    - ☐ Souvent
    - ☐ Parfois
    - ☐ Rarement

Interactions Informelles

15. Avez-vous eu l'occasion d'interagir avec le fournisseur en dehors le processus d'achat public ?
    - Toujours
    - Souvent
    - Parfois
    - Rarement
    - Jamais

16. Avez-vous échangé fréquemment lors de réunions planifiées ?
    - Jamais
    - Rarement
    - Parfois
    - Souvent
    - Toujours

17. Des réunions ont-elles été convoquées lorsque cela était nécessaire ?
    - Toujours
    - Souvent
    - Parfois
    - Rarement
    - Jamais

18. Comment avez-vous communiqué avec ce fournisseur ?
    - Face à face
    - Par téléphone
    - Par visio-conférence
    - Autres (veuillez préciser) :

19. Y a-t-il eu un travail d'équipe entre vous et votre fournisseur ?
    - Toujours
    - Souvent
    - Parfois
    - Rarement
    - Jamais

20. La possibilité de sur-mesure proposée par le fournisseur fait-elle partie de raisons pour lesquelles vous l'avez choisi pour cet achat ?
    - Oui
    - Non

Interactions Formelles

21. Pouviez-vous contacter de manière direct un contact privilégié du côté fournisseur or fallait-il passer par une procédure formelle de prise de contact ?
    - ☐ Autorisé à contacter n'importe quel représentant du côté du fournisseur
    - ☐ Invité à ne contacter qu'une seule personne, qui communiquait ensuite la requête à un niveau supérieur de hiérarchie
    - ☐ Autres (veuillez préciser) :

22. Les échanges avec le fournisseur se font via les supports suivants :
    - ☐ Lettres
    - ☐ Courriels
    - ☐ Rapports confidentiels
    - ☐ Autres (veuillez préciser) :

23. Le fournisseur proposait-il :
    - ☐ Des services de conseil
    - ☐ Documentation
    - ☐ Formation
    - ☐ Des démonstrations d'utilisation
    - ☐ Des services de maintenance de l'appareil
    - ☐ Autres (veuillez préciser) :

24. Le fournisseur a-t-il utilisé des descriptions de produits, des brochures d'information ou des rapports d'entreprise ?
    - ☐ Toujours
    - ☐ Souvent
    - ☐ Parfois
    - ☐ Rarement
    - ☐ Jamais

25. Les échanges d'informations impliquaient-ils l'utilisation de bases de données ou de données en général ?
    - ☐ Toujours
    - ☐ Souvent
    - ☐ Parfois
    - ☐ Jamais
    - ☐ Rarement

Fiabilité du Fournisseur

Nous sommes maintenant amenés à vous poser de questions sur votre évaluation de la fiabilité du fournisseur.

26. Lorsque vous partagez vos problèmes avec le fournisseur, le fournisseur répond avec compréhension.
    - ☐ D’accord
    - ☐ Plutôt d’accord
    - ☐ Indifférent
    - ☐ Plutôt pas d’accord
    - ☐ Pas d’accord

27. Vous êtes confiant sur le fait que le fournisseur ne prendra jamais de décisions qui pourraient vous affecter négativement.
    - ☐ D’accord
    - ☐ Plutôt d’accord
    - ☐ Indifférent
    - ☐ Plutôt pas d’accord
    - ☐ Pas d’accord

28. Le fournisseur est honnête dans ses échanges avec vous.
    - ☐ Pas d’accord
    - ☐ Plutôt pas d’accord
    - ☐ Indifférent
    - ☐ Plutôt d’accord
    - ☐ D’accord

29. La compétence du fournisseur dans l’exécution de son travail est bonne.
    - ☐ D’accord
    - ☐ Plutôt d’accord
    - ☐ Indifférent
    - ☐ Plutôt pas d’accord
    - ☐ Pas d’accord

30. Vous-avez confiance dans les compétences du fournisseur.
    - ☐ D’accord
    - ☐ Plutôt d’accord
    - ☐ Indifférent
    - ☐ Plutôt pas d’accord
    - ☐ Pas d’accord

Processus d'Achat Publique

31. Etiez-vous impliqué(e) au processus de commande publique ?
    - ☐ Oui
    - ☐ Non

32. Comment étiez-vous impliqué(e) au processus de commande publique ?

……
…………………………………………………………

Co-Développement

La suite des questions concerne votre activité collaborative avec les fournisseurs.

33. À quelle fréquence effectuez-vous les activités suivantes avec vos fournisseurs ?
    - ☐ Des essais alpha des prototypes des fournisseurs
      - o Toujours
      - o Souvent
      - o Parfois
      - o Rarement
      - o Jamais

    - ☐ Des essais beta des produits des fournisseurs
      - o Toujours
      - o Souvent
      - o Parfois
      - o Rarement
      - o Jamais

    - ☐ Essais sur le terrain des produits des fournisseurs
      - o Toujours
      - o Souvent
      - o Parfois
      - o Rarement
      - o Jamais

34. En cours de votre activité de recherche, a quelle fréquence avez-vous développé un prototype ou d'autres articles en partenariat avec vos fournisseurs ?
   - ☐ Toujours
   - ☐ Souvent
   - ☐ Parfois
   - ☐ Rarement
   - ☐ Jamais

35. Avez-vous déjà acheté un équipement ou accessoire issue de l'activité collaborative avec des fournisseurs ?
   - ☐ Toujours
   - ☐ Souvent
   - ☐ Parfois
   - ☐ Rarement
   - ☐ Jamais

36. Les interactions susmentionnées avec le fournisseur ont-elles mené à d'autres formes de relations ? Si oui, lesquelles :
   - ☐ Travail de conseil de la part de l'université
   - ☐ Projets de R&D en collaboration
   - ☐ Formation d'étudiants/étudiants diplômés (ex. Alternance, stage)
   - ☐ Echange temporaire de personnel
   - ☐ Programme spécifique de formation pour les employés de l'entreprise (fourni par l'université)
   - ☐ Utilisation/location de locaux ou d'équipements
   - ☐ Exploitation d'un brevet ou d'un modèle d'utilité/brevets conjoints
   - ☐ Création d'une nouvelle entreprise (spin-off ou start-up)
   - ☐ Participation à un projet commun de centre de recherche hybride
   - ☐ Autres relations informelles
   - ☐ Autres types d'activités collaboratives
   - ☐ Activités de diffusion de connaissances non académiques
   - ☐ Autres (veuillez préciser) :
   - ☐ Je ne sais pas

Coordonnées du Fournisseur

Enfin, dans le cadre de cette étude nous souhaitons contacter les fournisseurs de l'Université de Strasbourg pour leur adresser une enquête similaire.

37. Afin de contacter la personne la plus approprié pourriez-vous nous indiquez le nom de l'agent principal de côté fournisseur avec lequel vous étiez en contact pour cet achat ? (Au cas où cette personne ne travaille plus à la même entreprise, nous vous prions de nous indiquer un autre contact utile dans l'entreprise.)
   ………

STATEMENT OF CONFIDENTIALITY: All information you provide will be used in the strictest confidence. We will neither publish, release, nor disclose any information on, or identifiable with, individuals or their organizations or companies, business units, or R&D units.

INSTRUCTIONS: This survey is designed to be responded by the scientific equipment suppliers of the University of Strasbourg. Your company has been pointed out as a supplier of equipment by one of the researchers included in our sample. The survey refers to a particular equipment that your company has provided to the University of Strasbourg.

PERSONAL INFORMATION OF THE SUPPLIER

In this part, we ask you some general questions about your involvement in the production of the equipment.

38. Name of the firm ………………………………..
39. Sector of activity ……………………………….
40. Supplied equipment …………………………………
41. Indicate your position at the firm …………………………..
42. Were your firm directly involved in producing this item?
    - ☐ Yes
    - ☐ No

43. Was anyone else involved in producing this item?
    - ☐ Yes
    - ☐ No

44. Who else was involved, could you specify the company's name?
    ……………………………………………………

45. How long have your company been a supplier to the University of Strasbourg?
    - ☐ Few months but less than a year
    - ☐ 1 to 3 years
    - ☐ 4 to 5 years
    - ☐ More than 5 years
    - ☐ Do not know

RELATIONSHIP WITH THE RESEARCHER

We now seek to investigate the main criteria in the selection processes between the supplier and the researcher, as well as the frequency of interactions between them.

46. What criteria do you think the researcher used when selecting your company as supplier?
    - ☐ Quality
    - ☐ Service
    - ☐ Supplier's Willingness to Customize
    - ☐ Cost
    - ☐ Mutual Trust and Easy Communication
    - ☐ Delivery
    - ☐ Supplier's Profile
    - ☐ Quality of Relationship with Vendor
    - ☐ Unique specificity of the material
    - ☐ Other

47. How long had you been working with this researcher (research unity) at the time of the purchase?
    - ☐ Few months but less than a year
    - ☐ 1 to 3 years
    - ☐ 4 to 5 years
    - ☐ More than 5 years
    - ☐ Do not know

48. How often did you interact with the researcher while working on this purchase?
    - ☐ Always
    - ☐ Often
    - ☐ Occasionally
    - ☐ Rarely
    - ☐ Never

INFORMAL INTERACTIONS

49. Have you had the opportunity to interact with the researcher outside of the public procurement process?
    - ☐ Always
    - ☐ Never
    - ☐ Rarely
    - ☐ Occasionally
    - ☐ Often

50. Did you communicate regularly through planned meetings?
- Always
- Often
- Occasionally
- Rarely
- Never

51. Were meetings called when necessary?
- Always
- Often
- Occasionally
- Rarely
- Never

52. How did you communicate with this researcher?
- Face-to-face
- Telephone
- Video conferencing
- Other, please specify: ……………………………….

53. Was there teamwork between you and the researcher?
- Never
- Rarely
- Occasionally
- Often
- Always

54. According to you, was your willingness to customize part of the reason the researcher chose your company for this purchase?
- Yes
- No

FORMAL INTERACTIONS

55. Were you able to contact the researcher that demanded the equipment directly or you were obliged to pass through a formal procedure or other university structure?
- Could contact directly the researcher
- Regulated to communicate through an established procedure related to the public procurement bids
- Other, please specify: …………………………………..

56. Communication with researcher consists of using:
- ☐ Letters
- ☐ Emails
- ☐ Confidential Reports
- ☐ Other, please specify: ………………………………..

57. Did the researcher provided:
- ☐ Consulting
- ☐ Documentation
- ☐ Training
- ☐ Demonstrations
- ☐ Other, please specify: ………………………………………………

58. Did you used product descriptions, information booklets, or company reports?
- ☐ Always
- ☐ Often
- ☐ Occasionally
- ☐ Rarely
- ☐ Never

59. Did information exchanges involve using data bases or data in general?
- ☐ Always
- ☐ Often
- ☐ Occasionally
- ☐ Rarely
- ☐ Never

RESEARCERS' TRUSTWORTHINESS

Now we are interested in asking you about your evaluation of researchers' trustworthiness.

60. When you share your problems with the researcher, the researcher responds with understanding.
- ☐ Agree
- ☐ Somewhat agree
- ☐ Neither agree nor disagree
- ☐ Somewhat disagree
- ☐ Disagree

61. You are confident that the researcher will never make decisions that could affect your company negatively.
    - Agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Disagree

62. The researcher is honest in dealing with you.
    - Disagree
    - Somewhat disagree
    - Neither agree nor disagree
    - Somewhat agree
    - Agree

63. This researcher's competence in performing their job is good
    - Agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Disagree

64. You feel confident about the researcher's skills.
    - Agree
    - Somewhat agree
    - Neither agree nor disagree
    - Somewhat disagree
    - Disagree

PUBLIC PROCUREMENT PROCESS

65. Were you involved in the public procurement process?
    - Yes
    - No

66. How were you involved public procurement process?
    (Open ended question)

CO-DEVELOPMENT

In this section, we would like to know about your collaborative work with researchers.

67. How often do you perform the following activities with university researchers?
    - Alpha-testing of prototypes
        - Always
        - Often
        - Occasionally
        - Rarely
        - Never
    - Beta-testing of products
        - Never
        - Rarely
        - Occasionally
        - Often
        - Always
    - Field-testing of products
        - Always
        - Often
        - Occasionally
        - Rarely
        - Never

68. In the course of your activity, how often have you developed a prototype or other accessories related to research equipment in partnership with researchers from the University of Strasbourg?
    - Always
    - Often
    - Occasionally
    - Rarely
    - Never

69. Did these partnerships lead to any of the following for your company?
    - Product Innovation
    - Process innovation
    - Customization / Adaptation / Improvement of an existing product
    - I do not know
    - Other, please specify: …………………………

70. Have you already introduced commercial products through collaborative activity with researchers?
    - Always
    - Often
    - Occasionally
    - Rarely
    - Never

71. Did the above-mentioned interactions with the researcher lead to other forms of relationships? Please select the items that correspond to these relationships:
- Consultancy work from the university
- R&D Projects
- Training of postgraduates and internships at the firm
- Temporary exchange of personnel
- Specific training of the firm workers provided by the university
- Use or renting of facilities or equipment
- Exploitation of a patent or utility model/joint patents
- Creation of a new firm (spin-offs and start-ups)
- Participation in a joint venture of hybrid research center
- Informal relationships
- Other types of collaborative activities
- Non-academic knowledge diffusion activities
- Other, please specify:…………………………………………

RELATIONSHIP OUTCOME

Finally, we are interested to evaluate what are the outcomes for your company of these partnerships.

72. To what extent do you agree or disagree with the following statements regarding the outcomes for your company through the interactions with researchers of the University of Strasbourg?

In the last years, we have continued to be able to improve products design performance through these partnerships

- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree

In the last years, we have continued to be able to improve process design through these partnerships.

- Agree
- Somewhat agree
- Neither agree nor disagree
- Somewhat disagree
- Disagree

In the last years, we have continued to reduce lead time through these partnerships.

- Agree
- Somewhat agree

- ☐ Neither agree nor disagree
- ☐ Somewhat disagree
- ☐ Disagree

In the last years, we have continued to obtain higher sales/profitability from new products through these partnerships.

- ☐ Agree
- ☐ Somewhat agree
- ☐ Neither agree nor disagree
- ☐ Somewhat disagree
- ☐ Disagree