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**ORGANIZATIONAL BEHAVIOR AND HUMAN RESOURCES MANAGEMENT FOR PUBLIC TO
PRIVATE KNOWLEDGE TRANSFER: AN ANALYTIC REVIEW OF THE LITERATURE**

STI Working Paper 2012/1

By Branco Ponomariov (University of Texas at San Antonio) and Craig Boardman (Ohio State University)

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ORGANIZATIONAL BEHAVIOR AND HUMAN RESOURCES MANAGEMENT FOR PUBLIC TO PRIVATE KNOWLEDGE TRANSFER: AN ANALYTIC REVIEW OF THE LITERATURE**Branco Ponomariov¹¹****Craig Boardman²²****Abstract**

This paper reviews the current academic thinking on knowledge transfer channels between universities and private industry, from a human resource perspective. It also offers a general framework for “re-organising” the literature, so as to identify gaps in the understanding of organisational behavior and human resource management for university-industry knowledge transfer. The review highlights that knowledge transfer channels with highest “relational intensity” are also most valued by industry, and that most knowledge transfer channels are not currently institutionalized or formalized. It concludes that knowledge transfer between universities and industry is characterized by important management challenges, which require an understanding of the extent and nature of individuals’ involvement. However, the existing literature emphasises the outcomes rather than processes of knowledge transfer. Future research looking at knowledge transfer processes at the individual and organizational level of analysis would provide valuable information for better policy-making.

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**COMPORTEMENT DES ORGANISATIONS ET GESTION DES RESSOURCES HUMAINES
DANS LE CADRE DES TRANSFERTS DE CONNAISSANCES DU PUBLIC VERS LE PRIVÉ :
REVUE ANALYTIQUE DE LITTÉRATURE**

Branco Ponomariov¹

Craig Boardman²²

Abstract

Ce document donne un état des lieux de la réflexion universitaire sur les différents canaux utilisés pour les transferts de connaissances entre les universités et l'industrie, sous l'angle des ressources humaines. Il propose également un cadre général pour « réorganiser » la littérature existante afin de mettre en évidence les points d'ombre qui subsistent quant au comportement des organisations et à la gestion des ressources humaines dans le cadre des transferts de connaissances du monde universitaire vers l'industrie. L'étude souligne que les canaux de transfert de connaissances caractérisés par une forte « intensité relationnelle » sont aussi les mieux appréciés par l'industrie, et que la plupart des canaux de transfert de connaissances ne sont actuellement pas officialisés ou formalisés. Elle conclut que les transferts de connaissances posent des problèmes en termes de management, qui requièrent une meilleure compréhension de la nature et de la portée de l'engagement des individus. Or, la littérature existante est focalisée sur les résultats et non sur les processus de transfert de connaissances. Des recherches analysant les processus de transferts de connaissances aux niveaux individuel et organisationnel permettraient de produire des informations utiles pour l'élaboration des politiques.

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Executive summary

Without a good understanding of the logic and structure of various channels for knowledge transfer (KT) between universities and industry (U-I), public policy efforts may miss their targets. This document provides an overview of the current academic thinking on U-I KT channels and presents a general framework that identifies gaps in our knowledge of organizational behaviour and human resource management as it applies to U-I KT.

One way to describe and compare U-I KT channels is to look at their key characteristics. An important dimension is the level of knowledge transformation that takes place in the transfer and the relational intensity (*i.e.* the extent of direct personal involvement) of the KT interaction. Knowledge is not just “information” but also incorporates more intangible aspects (*e.g.* tacit “know-how”); as such, most KT channels involve some degree of interaction with the knowledge creators to allow the transfer to be successfully realised. The extent to which the transfer process is dependent on assistance from the knowledge creator directly affects the form KT adopts. For instance, clarification of a minor point in a scientific paper would be characterized with low relational intensity, while joint research would have high relational intensity. The question for policy is whether the appropriate conditions exist for relationships to occur in the KT channels that need them.

Another dimension by which KT channels differ is their importance or significance to industry. Surveys of industry representatives yield similar and robust overall rankings of channels; for example, scientific publications and collaborative research are some of the highly significant KT channels for industry, while commercialisation of property rights and exchange of personnel are rated low. Considering the significance for industry can help indicate the potential pay-offs of different policy choices. It also informs assessments of “goal congruence”, or the alignment of individual with organizational goals. Channels with high goal congruence will generally require less extensive and complex interventions to foster.

Two further dimensions are knowledge finalization and the degree of channel formalization. Knowledge finalization refers to the degree to which a project can be contained in discrete deliverables or is more open-ended, and it approximates the type of knowledge involved in KT. The appropriability and complexity of knowledge will influence the type of KT channel that is used. Channel formalization refers to the extent to which the interaction is institutionalized and/or guided by formal rules and procedures. The extent of formalization applies mainly to the relationships between universities and industry, and less so to individual scientists, for whom industry engagement remains a discretionary behavior. In fact, the radical change in U-I interactions is not their increased prevalence but the increased rate of institutionalization of such relations.

At the level of individual KT channels, the most commonly mentioned in the literature are: scientific publications; professional meetings and conferences; informal interactions with faculty; collaborative research and research partnerships; contract research; academic consulting; hiring of recent graduates; institution building/boundary institutions/creation of physical facilities; commercialisation of property rights; and personnel exchanges/mobility. These channels differ according to their relational intensity, industry significance, degree of finalization and their formalization, and the motivations for academics to engage in the different channels ranges from prestige to access to resources.

Measurement of these activities is difficult and most efforts have focused on channels for which easily quantifiable data is available (such as publications and patents) or which are easily institutionalized (such as licensing or spin-off company formation). The chief disadvantage of such measures is that they are often an indirect measure of KT activity and may be confounded with KT impact. Studies that capture the actual process of KT typically must rely more on qualitative data and narratives. Future analyses of KT need to capture such elements as discovery, acquisition and communication of knowledge; such issues currently

appear to be more intensely researched in the context of business and management literature on inter- and intra-firm KT. Measures of KT impact tend to be measures of economic impact and value-added, and tend to under-emphasize the indirect impact of KT, such as learning and improvements in human capital and research capacity. It would be useful to distinguish between organizational outcomes, knowledge outcomes, technological outcomes and financial outcomes when designing measures of KT.

Overall, all U-I KT channels can be influenced to some degree by human resource management strategies, but the viability and impact of interventions will vary according to channel characteristics. It appears that channels important to industry also have high relational intensity, and from a policy perspective it could be interesting to look more closely at informal contacts, conferences and professional meetings, consulting and collaborative research. These channels also have low to medium levels of finalization, suggesting possibly high goal congruence, since the interactions may involve more complex knowledge and new problems that are of interest to academics.

Given that individual involvement in KT is essential for most KT channels, especially those important for industry, it is useful to better understand the determinants of this behavior. Researchers' behaviors are likely to be influenced by their mindset (*e.g.* their motivation to participate in commercialization) and their competences (*e.g.* understanding the needs of industrial partners). They are also influenced by the institutional culture in which they work and the leadership/management skills in their organization. These variables interact, so that performance and success in KT are dependent on many factors.

However, the literature pertaining to mindset, competence, institutional culture and leadership tends to emphasize outcomes, rather than the individual factors and organizational processes that helped facilitate these outcomes. Studies show that researcher seniority, prior industry experience and gender are related to their industry involvement, and that reward structures and organizational priorities may influence behavior. But the issue of intensity and type of involvement would benefit from further study. Similarly, there are few direct assessments of researchers' motivations and mindsets regarding U-I KT activities or of their relevant competencies. At the level of institutional culture, some studies suggest academic prestige and tenure considerations may dampen motivation for KT activity, while the degree of government requirement for interdisciplinary work may stimulate new types of U-I KT. However, in sum, only a limited amount of literature addresses the role of institutional culture in U-I KT. There are also few studies on leadership in U-I KT, although it is an important issue, particularly given the social goals of many research institutions and the management constraints that may hinder leaders' actions.

Future research should emphasize processes at the individual and organizational levels of analysis, informed by broader literature on organizational behavior and strategic human resource management. Without systematic investigation into the processes of U-I KT at these levels, policy making for U-I KT will continue to be characterized by high levels of uncertainty regarding the production of intended and unintended outcomes of and returns on investment from these policies.

Synthèse

Faute d'une bonne compréhension de la logique et de la structure des différents canaux du transfert de connaissances (TC) entre universités et industrie (U-I), politiques publiques risquent de manquer leur cible. Ce document offre un panorama de la réflexion universitaire actuelle sur les TC U-I, et présente un cadre général permettant de mettre en évidence des zones d'ombre dans notre appréhension du comportement des organisations et de la gestion des ressources humaines dans le cadre des TC U-I.

Pour décrire et comparer les canaux de TC U-I, on peut considérer leurs caractéristiques clés. Le niveau de transformation des connaissances qui intervient au cours du transfert et l'intensité relationnelle de l'interaction de TC (l'importance des relations directs) forment une première dimension importante. La

connaissance ne se limite pas à de l'information : elle comporte des aspects moins tangibles (comme le « savoir-faire »); ainsi, la plupart des canaux de TC supposent un certain niveau d'interaction avec les créateurs du savoir, interaction qui est une des conditions du succès de ce transfert. Le degré de dépendance du processus de transfert vis-à-vis cette interaction avec le créateur des connaissances a un impact direct sur la forme que prend le TC. Par exemple, la clarification d'un point de détail dans une communication scientifique entraîne une faible intensité relationnelle, alors qu'une recherche conjointe correspond à une forte intensité relationnelle. La question pour les politiques publiques est de savoir si les conditions sont réunies pour que le bon niveau de relations s'établisse pour les différents canaux de TC.

Autre dimension par laquelle les canaux de TC diffèrent entre eux : leur importance ou leur pertinence pour l'industrie. Les enquêtes auprès de représentants de l'industrie donnent des résultats fortement convergents dans le classement global des canaux : les publications scientifiques et la recherche collaborative sont des canaux de TC extrêmement valables aux yeux des entreprises, alors que la commercialisation de droits de propriété intellectuelle et l'échange de personnel le sont moins. Tenir compte de la valeur attachée aux différents TC par les entreprises peut donner une indication sur les résultats des différentes politiques publiques possibles. C'est aussi utile pour évaluer la « congruence des objectifs », c'est-à-dire l'alignement des objectifs des individus avec ceux des organisations. Favoriser les canaux caractérisés par une forte congruence des objectifs nécessitera généralement des interventions moins appuyées et moins complexes.

Deux autres dimensions sont à noter : le degré de complétude des connaissances et le degré de formalisation des canaux. La complétude des connaissances caractérise la mesure dans laquelle un projet peut être divisé en livrables autonomes ou si ses limites sont plus ouvertes ; cette dimension est liée, peu ou prou, à la nature des connaissances concernées. L'appropriabilité et la complexité des connaissances auront une influence sur le type de canal de TC qui sera utilisé. La formalisation des canaux caractérise la mesure dans laquelle l'interaction est officielle et/ou encadrée par des règles et procédures formelles. Le degré de formalisation s'applique principalement aux relations entre universités et entreprises, mais beaucoup moins au niveau des chercheurs, car leur engagement aux côtés des entreprises relève encore largement de comportements individuels. De fait, la transformation radicale des interactions U-I tient non à leur multiplication mais à leur formalisation accrue.

S'agissant des canaux de TC, les plus fréquemment cités dans la littérature sont les suivants : publications scientifiques ; congrès et conférences professionnelles ; relations informelles avec des universitaires ; recherches collaboratives et partenariales ; recherches contractualisées ; consultants universitaires ; recrutement de jeunes diplômés ; renforcement d'universités, établissements limitrophes, construction d'infrastructures physiques ; commercialisation de droits de propriété intellectuelle ; échanges de personnel et mobilité. Ces canaux diffèrent en termes d'intensité relationnelle, d'importance attachée par l'industrie et de degré de complétude et de formalisation, et les raisons qui motivent les universitaires à en choisir tel ou tel canal peuvent être multiples : prestige ou accès à certaines ressources, par exemple.

La mesure de ces activités est difficile et la plupart des travaux en ce sens se limitent aux canaux pour lesquels on dispose de données facilement quantifiables (publications et brevets, par exemple) ou qui sont facilement formalisés (vente de licences ou création d'entreprises dérivées). Le principal inconvénient de ces mesures est qu'elles ne constituent souvent qu'une mesure indirecte de l'activité de TC, et qu'il ne faut pas les confondre avec l'impact des TC. En règle générale, les études visant à cerner le processus même des TC devraient s'appuyer davantage sur des données qualitatives et des explications narratives. Les analyses des TC devraient rendre compte d'éléments tels que la découverte, l'acquisition et la communication des connaissances ; or, d'après la littérature existante, il apparaît que ces questions sont plus souvent examinées dans un contexte d'entreprise et de management, dans les études sur les TC inter- et intra-entreprises. Les mesures de l'impact des TC évaluent généralement l'impact économique et la valeur ajoutée, et n'attachent pas suffisamment d'importance à des retombées indirectes des TC, comme

l'apprentissage, l'amélioration du capital humain et de la capacité de recherche. Il serait utile, dans la conception de la mesure des TC, de faire la distinction entre les résultats du point de vue des organisations, des connaissances, des technologies et de l'aspect financier.

Tous les canaux de TC U-I peuvent être influencés, dans une certaine mesure, par les stratégies de gestion des ressources humaines, mais la viabilité et l'impact des interventions vont varier selon les caractéristiques des canaux. Il semblerait que les canaux auxquels l'industrie attache le plus d'importance se caractérisent par une forte intensité relationnelle ; du point de vue des politiques publiques, il pourrait être intéressant de s'intéresser de plus près aux contacts informels, aux conférences et aux congrès professionnels, aux contrats de consultant et à la recherche collaborative. Ces canaux se caractérisent aussi par un niveau faible ou moyen de complétude, ce qui pourrait indiquer une congruence des objectifs élevée car peut-être que les interactions concernent des connaissances plus complexes et des problèmes nouveaux qui intéressent les universitaires.

Comme l'implication individuelle est essentielle pour la plupart des canaux de TC, en particulier pour ceux auxquels l'industrie attache de l'importance, il est utile de mieux comprendre les déterminants de ce comportement. Les comportements des chercheurs peuvent être influencés par leur mentalité (par exemple, leur motivation à participer à la commercialisation) et par leurs compétences (par exemple leur compréhension des besoins des partenaires industriels). Ils sont aussi influencés par la culture de l'institution dans laquelle ils travaillent, ainsi que par les compétences de leadership et de management qui existent au sein de l'organisation à laquelle ils appartiennent. Toutes ces variables vont agir en interaction les unes avec les autres : les performances et le succès des TC dépendent donc d'une multitude de facteurs.

Pourtant, au vu de la littérature, les recherches sur les mentalités, les compétences, la culture institutionnelle et le leadership sont souvent axées sur les résultats et non sur les différents facteurs et les processus organisationnels qui ont contribué à amener ces résultats. Des études montrent que l'ancienneté des chercheurs, le fait qu'ils aient eu ou non une expérience en entreprise, la structure de rémunération et les priorités des organisations peuvent influencer les comportements. Mais la question de l'intensité et du type de participation mériterait d'être étudiée plus avant. De même, il n'existe pas, ou quasiment pas d'évaluations directes des motivations et des mentalités des chercheurs vis-à-vis des activités de TC U-I, pas plus que de leurs compétences en ce sens. Pour ce qui est de la culture institutionnelle, certaines études montrent que des considérations liées au prestige universitaire et aux titularisations tendraient à diminuer la motivation pour les activités de TC, alors que les obligations imposées par les gouvernements en matière de travaux interdisciplinaires tendraient à stimuler l'apparition de nouvelles formes de TC U-I. Cela étant dit, il existe très peu de recherches sur le rôle de la culture institutionnelle dans les TC U-I. De même, le rôle du leadership dans les TC U-I a été assez peu étudié, alors que c'est un aspect important, particulièrement en ce qui concerne les objectifs sociaux qu'ont un grand nombre d'établissements de recherche et les contraintes de gestion qui peuvent empêcher les leaders d'agir comme ils le souhaitent.

Des recherches ultérieures devraient mettre l'accent sur l'analyse des processus, aux niveaux individuel et organisationnel, à la lumière de travaux plus généraux sur le comportement des organisations et la gestion des ressources humaines stratégiques. Sans une investigation systématique des processus de TC U-I à ces niveaux, l'élaboration des politiques sur les TC U-I restera marquée par l'incertitude quant aux résultats recherchés et fortuits et au retour sur investissement de ces politiques.

1. Introduction

This paper first provides an overview of the current academic thinking on knowledge transfer (KT) channels between public research organizations (PROs) and private industry. The literature reviewed primarily focuses on university-industry (U-I) links: the discussion of public research institutes that are not universities is relatively limited, thus the discussion is mainly centered on the role of universities, with additional clarifications inserted if appropriate (*e.g.* in cases when more specialized studies discuss new institutions such as university-based research centers or knowledge organizations such as public research institutes). Related, the most common units of analyses are universities, individual scientists, firms and offices of technology transfer. Following the overview, a general framework for organizing current knowledge and identifying knowledge gaps in the understanding of organizational behavior and human resource management for university to industry knowledge transfer (hereafter “U-I KT”) is developed and applied to the main themes in the literature.

The aim of the review is to draw out information and issues from the academic literature for governments considering their HR-related policies for knowledge transfer between PROs and industry.¹ The overarching message of this exercise is that U-I KT is characterized by important management (especially HR management) challenges, and that addressing these challenges must consider not only the constraints resulting from policy and institutional choices, but also, importantly, the extent and nature of individuals’ involvement (*i.e.* of knowledge workers, of managers/leaders, of policy makers) in the different types of KT channels.

2. Overview of public-private KT channels

2.1 Introduction to the section

The general contribution of university knowledge to industrial innovation has long been acknowledged (*e.g.* Gibbons & Johnston, 1974; Mansfield, 1998), but only recently have there been systematic efforts to develop taxonomies differentiating U-I KT processes along analytically meaningful dimensions (*vis-à-vis* a holistic discussion of university-industry links) and systematic investigation of the internal structures and logics of these various links (*e.g.* Perkmann & Walsh, 2007). The emerging work on KT is suggestive of a wide variety of U-I KT channels in the innovation system, institutional and individual levels of analysis, each with different stakeholders, incentives, opportunities and constraints, governance mechanisms, outputs, and outcomes – but none which have been explored systematically and in detail sufficient to understand the roles and behaviors of knowledge workers and administrators in U-I KT so as to inform human resource (HR) management strategy and practice.

The task of differentiating the logics and structures of various U-I KT channels is challenging because it requires disaggregation of the general and ambiguous concept of university-industry linkages into an analytical framework that both describes and distinguishes each discrete channel in a valid and reliable manner, while at the same time addressing the fact that that each link, despite its structural and logical

¹ This paper was commissioned by the OECD Secretariat (Science and Technology Policy Division) as an input to the Working Party on Research Institutions and Human Resources’ (RIHR) project on Human Resources for Knowledge Transfer and Exchange.

variation when compared to alternate linkages, is a specific manifestation of a single general, complex phenomenon: U-I KT. Variation in the logics and structures of university-industry linkages are predominantly a function of the nature of the knowledge to be transferred and the context of the KT, including individual, institutional as well as economic, policy and political influences. An additional challenge to the task of differentiating the logics and structures of various U-I KT channels is not to confound these two dimensions (type of knowledge and context) of KT.

Without systematic investigation of the logics and structures of the various U-I KT channels, public policy and management efforts (*e.g.* changes to the intellectual property (IP) systems to stimulate university patenting, licensing, or spin-off formation; institution building for co-ordinated problem solving by universities and business) will be handicapped. Lack of understanding of the underlying KT structures and mechanisms, instead of leading to genuinely new policy and management levers, may lead to simply elaborating the spillover-based linear model of U-I KT – *i.e.* the provision to businesses by universities of codified knowledge (*e.g.* publications) and human capital (*e.g.* trained graduate students) – in ways that are eventually beneficial to economic competitiveness (Bush, 1945) but not conducive to strategic public policy decision making (beyond providing sufficient resources for science and education).

This is not to deemphasize the criticality of U-I KT via new knowledge creation and human capital development to economic competitiveness for regions and nations. These public policy outcomes rightly constitute the primary goals of universities and the governments funding universities, from both educational and economic perspectives. These goals have not changed dramatically in centuries, nor should they. But the evolving socio-economic context in which universities operate now requires substantive understanding of the variable processes by which U-I KT occurs – to inform strategic public policy decision making in ways that make the production of knowledge and human capital by universities and its transfer to industry more predictable and therefore more efficient and effective (Feller, 1990).

Currently there is some, albeit limited, understanding of the processes governing various U-I KT channels. Today it is accepted, for instance, that the fundamental roles of universities in national and regional (and, increasingly, global) innovation systems is as producers of scientific and technical research for expanding knowledge frontiers, applied research for proof-of-concept prototype (*e.g.* methods, instruments) development and testing, and human capital both through the education of students and through personnel mobility (Smith 1995). But these are just preconditions for U-I KT and do not themselves exhibit the processes by which universities can have direct influence on the rate and direction of technological change in industry.

A common approach to understanding U-I KT channels essentially equates to what economists would characterize as a “trickle down” or “supply-side” approach. This has some appeal as a simple analytical tool, but ignores critical “demand-side” and “boundary-spanning” procedural/process considerations that can affect whether or not the knowledge capital supplied by universities is utilized optimally by businesses. These considerations range from the need for absorptive capacity (Cohen & Levinthal, 1990) and downstream industry investments (Callon & Bowker, 1994), to boundary-spanning issues of process and institution building.

Ideally, policy makers need to approach U-I KT as a problem of reducing the discrepancy between industry-relevant knowledge that is available in the public domain and the actual knowledge that is applied

by businesses in their current operations and in their strategic decisions for future operations. The way to do this is not to accumulate a laundry list of “best practices” for university-industry interactions, but rather to develop an understanding of the direct and indirect relationships between public policy goals, knowledge types, U-I KT contexts, and U-I KT channels. Doing this will help to supplant the oftentimes imprecise and incorrect spillover heuristic (Bozeman, 2000) that has guided past public policies and industry strategies for U-I KT with an empirically-based, contingency understanding of U-I KT. Currently, attempts to institutionalize KT are driven primary by the idea to enhance the efficiency of the transfer process (Geuna & Muscio 2009). However, institutionalization efforts so far have only encompassed a limited range of KT channels amenable to formalization and institutionalization – patenting, spinoff formation, and licensing. The vast majority of the KT between university and industry is not yet institutionalized, and therefore alternative strategies must be sought to influence it.

The analytic purpose of this literature review is not to “fill in the gaps” in understanding of U-I KT channel processes *per se*, but instead to identify what contingencies are addressed by scholarship on U-I KT and what is left unknown. This requires an analytic framework for re-organizing and analyzing the literature on U-I KT as a collective body of knowledge, which we present in the sections below. But the first steps of any literature review are to provide an overview of the “raw data,” here the existing scholarship on U-I KT, before applying the framework to make sense of the scholarship as a collective body of knowledge.

This section (2) inventories the literature in terms of the various KT channels that are evidenced by past practice and study of U-I KT. The following section (3) uses a framework for the roles and behaviors of knowledge workers, groups thereof, and leaders/managers and how these may contribute to (or impede) desired KT outcomes. It aims to identify the available scholarship that contributes to a contingency (versus “best practice”) understanding of U-I KT (which is important for strategic public policy decision making) and also to identify gaps in understanding (for which there is no current scholarship).

2.2 *Characteristics of U-I KT channels*

There are two approaches towards inventorying U-I KT channels and understanding the differences across them. The first approach (section 2.2) is to review the literature from the general perspective of how KT channels can vary; the second approach (2.3) is to address the literature on specific U-I KT channels. Necessarily there is overlap/redundancy in these reviews.

Accordingly, this section (2.2) addresses the general ways by which different U-I KT channels vary. There are potentially a large number of other, uninvestigated dimensions to characterize KT channels. For the purpose of this part of the review, the attention will be limited to assessing the variables and dimensions addressed by current scholarship and not speculating about alternate, uninvestigated variables for KT channels.

Section 2.3 reviews the discrete KT channels as addressed in available scholarship and necessarily draws on the general overview of variables discussed in the current section (2.2). In the section that follows (3), with the assistance of a framework for organizing the literature, “pressure points” are identified for the successful implementation of HR management strategies in U-I KT.

2.2.1 *Knowledge transformation and relational intensity*

The most fundamental, yet under-appreciated, characteristic of U-I KT is that in reality any knowledge transfer from university to industry involves not just transmission or “transfer,” of “deliverables” (Mowery & Sampat, 2006) but also – and indeed predominantly – knowledge transformation (Faulkner & Senker, 1994). In the context of industrial innovation, new knowledge is very often a creative combination of already existing knowledge (Schartinger *et al.* Rammer, Fischer & Fröhlich, 2002). However, the ability of firms to engage in such knowledge transformation is limited by their absorptive capacity (Cohen & Levinthal, 1990), which by itself is sufficient to question the utility of simple transfer of codified knowledge from universities to firms (*e.g.* via IP protection and licensing).

A more realistic picture in the context of the increased dependence of technology on science, paints corporate innovation as increasingly reliant on “open innovation” models, which involve the (interactive) utilization of external sources of knowledge, such as PROs (Perkmann & Walsh, 2007; Tasse, 2007). With the shift towards outside sources of knowledge, inevitably the process of knowledge transformation has also spilled over outside the firm boundaries and has become entangled in institutional and social interactions with outside knowledge producers in channels such as joint research, contract research or consulting. Conceptually, this is the fundamental reason why the label “transfer” only partially conveys the processes that occur in university-industry interactions. They are far more interactive and relationship-dependent than typically acknowledged (Agrawal & Henderson, 2002; Thursby & Thursby, 2004). In the process of KT, knowledge is understood not merely as “information” (which if it were, it could be easily and cheaply transmitted and utilized), but as also incorporating more intangible artifacts (*e.g.* instrumentation, social relationships, human capital, tacit knowledge). Insofar as many aspects of knowledge (*e.g.* context, relationships to prior and adjacent knowledge, experimental/technical peculiarities, *etc.*) are difficult to codify and transmit easily, most KT channels involve some degree of interaction with the knowledge creators because much of this knowledge remains “latent” (Agrawal, 2006) in the knowledge creator/inventor due to the limitations in all “transfer media” (Bozeman, 2000). Therefore, some type of engagement with the inventor is necessary if the potential of the “transfer object” (Bozeman, 2000) is to be fully and successfully realized.

Currently, it is recognized that all scientific and technological knowledge is characterized with tacitness (Rosenberg & Nelson, 1994). Tacitness however does not imply “insufficient” codification, but simply that the transfer object is difficult to separate from its environment (Bozeman, 2000) – simply because the environment itself (*e.g.* the scientists involved, the organizational and cognitive processes in a certain institutional setting, the knowledge and technology) contains elements that are fundamental for the ability of a third party (*e.g.* a private company) to be able to utilize the knowledge. In earlier studies of technology transfer, such environmental contingencies were limited to a firm’s internal expertise and ability to use external knowledge – “absorptive capacity” (Cohen & Levinthal, 1990). However, in the context of “open innovation”, the concept of an internal capacity to “absorb” has become less useful because technologies involved in KT are less likely to be discrete and defined, and more likely to be diffuse, external to the firm, and dependant on multiple sources of knowledge and actors. Hence, one of the tasks in designing KT channels is in recognizing the relevant aspects of the environment that need to be maintained for a successful transfer to occur.

The process of knowledge transformation applies, though to a different extent, in all forms of KT, *e.g.* consulting, contract research, or informal relations, because all knowledge is tacit to some extent, and thus its transfer between different parties is likely to require some degree of assistance from the knowledge creator (Rossi, 2010). The extent to which the process is dependent on such assistance directly affects the form KT adopts. Thus a relationship can be established between the “relational intensity” of a KT channel and the extent of knowledge transformation involved (*i.e.* the transmission of tacit knowledge contingent on the knowledge creator’s assistance), whereby the complexity of knowledge may mediate the relationship between tacitness of knowledge and the extent and type of scientists’ personal involvement. For example, the more complex and tacit a knowledge base is, the more likely it is that its transfer necessitates the establishment of more complex, stable structures (*e.g.* university research centers) to ensure its transfer. On the other hand, a knowledge transfer of tacit knowledge characterized with lower complexity may be suitably accommodated by other mechanisms (*e.g.* consulting, contract research).

“Knowledge transformation” may take many forms, and this is the reason why it is a concept closely related to the “relational intensity” and the “complexity” of the knowledge involved. For example, if a firm contracts with a university scientist to conduct research to solve a specific technological problem identified by the firm, the resulting KT (“contract research”) will be characterized with medium or high relational intensity, the knowledge uncertainty and complexity will be low or medium; in essence, the university scientist will provide direct assistance in combining outside knowledge with the firm’s knowledge by transforming available knowledge inputs and transferring them to the firm as a deliverable. However, this is only one possible scenario. In the context of open innovation, some firms may have needs necessitating other forms of KT. For example, if a technological area is extremely complex and uncertain, and firms have to manage multiple innovation processes, it may be the case that an ongoing collaborative relationship (*e.g.* collaborative research, membership in university research centers) may be necessary. In this context, the firm’s needs no longer involve simply adding onto its existing knowledge base, but engaging in a process of joint discovery that necessitates at least a medium degree of relational intensity and an ongoing commitment to the interaction.

Since the process of knowledge transformation is by definition dynamic and social (David & Foray, 1995), and it is carried out through personal interactions and communications between individuals (Schartinger *et al.*, 2002), the concept of “relational intensity” (Perkmann & Walsh, 2007) describes the extent to which a particular KT channel is inherently dependent on such direct personal involvement of the participants. As outlined above, the source of such dependency is related to the tacitness of the knowledge involved, and as a result, the extent to which a “relation” with the knowledge creator may be necessary for a successful transfer. While all KT channels may be characterized with (or benefit from) some degree of relational involvement, the required levels of intensity will vary widely. For example, an unsolicited inquiry to a university scientist for a clarification of a minor point in a scientific paper or patent will be characterized with a very low relational intensity (and therefore better classified as a “transfer mechanism” – Perkmann & Walsh, 2007), while activities such as joint research, research partnerships and services will be characterized with a high relational involvement (thereby better classified as “relationships”). Channels with intermediate relational involvement may include academic entrepreneurship or human mobility/exchanges (Perkmann & Walsh, 2007), and institutional collaborations (*e.g.* university research centers with industrial participation). It should be noted that levels of “relational intensity” are not *a priori* desirable or undesirable – the policy- and management-relevant issue is simply whether the appropriate conditions for “relationships” to occur in KT channels that may necessitate them (*e.g.* as a result of

contingencies such as the firm's needs or the properties of the underlying knowledge) exist. For example, policy efforts emphasizing the legal transfer of IP from universities to private companies via patenting and licensing are likely to have limited impact unless they also consider the fact that most university inventions are embryonic (*i.e.* embody complex and uncertain knowledge) which often necessitates the collaboration of the inventor. In this example, better understanding of the process of knowledge transfer points to a need to develop mechanisms and incentives for "relational involvement".

Thus the concept of "relational intensity" is an important descriptor of KT channels because it is a suitable (if partial) proxy for the extent of "knowledge transformation" that takes place in a particular channel. The importance of "relational intensity" has been documented in multiple studies (Agrawal & Henderson, 2002; Roessner, 1993; Scharfing, *et al.*, 2002; Thursby & Thursby, 2004). The emphasis on "relations" is a better approximation of the knowledge dynamics in KT channels than transmission of "tacit knowledge", because tacit knowledge is rarely, if ever, passively "transmitted". Instead, it is conveyed and/or created in a process characterized with some degree of "learning by doing" (*e.g.* joint research), or "learning by observing" (*e.g.* contract research or consulting) or interacting in some other way. Since this type of learning is a primary motivation both for companies and faculty to participate in KTs, its extent is an essential element for understanding the dynamics of the different KT channels. "Relational intensity" is also a relatively easily measurable concept, since a variety of quantitative and qualitative measures (for example, recording the type, occasions, and frequency of actual interaction and communication events between collaborators) can capture the degree of personal involvement and interaction that partners in a KT channel engage in.

2.2.2 *Relative significance of KT channels and goal congruence*

A second dimension by which U-I KT channels can vary concerns the relative importance of different KT channels for industry. This is an external constraint on KT channels, insofar as the "perceived importance" of a KT channel does not directly influence the logic of a KT channel but can inform policy and HR strategic choices. The "significance" of different KT channels for industry has been primarily measured by surveys of industry representatives, *e.g.* by asking them to rank the relative importance of different KT channels for their products and innovation processes (*e.g.* Arvanitis, Sydow & Woerter, 2008; Bekkers & Bodas-Freitas, 2008; Cohen, Nelson & Walsh, 2002; Library House, 2008; Scharfing, *et al.*, 2002). The relative rankings of the different channels are quite similar and robust in studies conducted in different contexts and countries (see Table 1 for an aggregate assessment).

The reason it is important to consider the significance of different KT channels to industry² (as well as to academics) early on has to do with the diversity and complexity of the different channels and the divergent implications of pursuing them without considering the likely outcomes and payoffs. A KT channel being "useful" or "significant" for industrial innovation is an obvious and important general payoff that is not always reflected in policies designed to encourage U-I interactions. For example, the recent controversies regarding the increasing entrepreneurial orientation of universities have focused on

² Of course, there is always substantial sectoral variation in the relative importance of different KT channels. However, such variation is not of direct interest for the current overview which aims to summarize the overall findings across a broad set of science-dependent industries. For detailed overviews of sectoral variation see *e.g.* Cohen, *et al.*, 2002; Scharfing, *et al.*, 2002.

knowledge transfer channels that are least common, and least important to industry: patenting, licensing, and spin-off formation (*e.g.* Cohen *et al.*, 2002). Indiscriminate efforts to scale up these types of KT channels at universities are probably misguided since they involve the biggest change in academic norms and expectations (D’Este & Perkmann, 2011), yet at the same time studies have repeatedly shown that IP, licensing, and commercialization activities are among the least important for industrial firms interacting with universities (Cohen, *et al.*, 2002; Mansfield, 1998; Pavitt, 1991; Schartinger, *et al.*, 2002). Thus understanding what KT channels are actually most significant for industry, combined with knowledge about the nature of the channels, will simplify strategic and policy planning for fostering such channels. Table 1 broadly characterizes the different channels as having “high”, “medium” or “low” importance based on studies assessing the full spectrum of U-I KT interactions.

The second, and more important reason why the relative importance of KT channels is essential has to do with a key constraint in managing personnel in any organization: goal congruence, or the alignment of individual with organizational goals (university scientists and private firms and universities, respectively). KT channels involving activities with higher goal congruence – *i.e.* perceived as significant by both private firms and university scientists – will generally require less extensive and complex (all else equal) interventions to foster, while channels with high goal incongruence will require substantial HR and institutional efforts to address the implications of goal incongruence (*i.e.* situations where industrial and faculty collaborators may have different goals and expectations from the co-operation). In general, recent studies (D’Este & Perkmann, 2011; Perkmann & Walsh, 2008) suggest that contrary to the emerging stereotype that universities’ embracing of the entrepreneurial mission will cause faculty to abandon scholarly norms in the pursuit of commercialization, faculty motivations for engaging in the most common KT channels (such as consulting, contract research, and joint research) are in fact highly congruent with their traditional missions and these motivations primarily include learning opportunities, joint exploration, and securing research support. Such congruence does not mean that all U-I interactions for KT that could naturally occur already occur without intervention: involvement with industry is a discretionary behavior for academics, and both scientists and industry partners may be deterred from engaging in such activities by inappropriate organization or regulation of such activities.

The question of KT channels’ significance for industry and the attendant degree of goal congruence is better understood once the questions of the nature of KT channels (previous section) and the role of interactions in knowledge transformation are considered. It appears that across a broad range of KT channels, the primary motivation for industry to engage in KT is access to advanced knowledge and learning, rather than procuring “deliverables”. In the words of Rosenberg and Nelson (1994, p. 340), “What university research most often does today is to stimulate and enhance the power of R&D done in industry, as contrasted with providing a substitute for it”, and the process of such stimulation typically involves both actual research and some level of informal knowledge exchanges.

To better capture the problem of relative importance of the different channels, Table 1 includes a column listing the primary motivations for university scientists to participate in different KT channels.

2.2.3 *Degree of knowledge finalization*

The concept of finalization of research refers to the degree to which a project realistically can be contained in discrete deliverables or pursues a specific goal, as opposed to more general, complex, and/or

curiosity driven research whose outcomes are difficult to anticipate and measure ex-ante such as open-ended, more general improvements in research capacity and knowledge (Perkmann & Walsh, 2007).

This is an ambiguous – but useful – concept that approximates various aspects of the type of knowledge involved in KT. Since knowledge has multiple characteristics (*e.g.* cumulateness, tacitness, interdependency, diversity *etc.*), a measure that could provide a holistic (if tentative) assessment of the level of its complexity can be valuable, especially since the nature of knowledge in KT is one of the primary determinants of the appropriate mechanism or organizational form. The concept of finalization provides contextual information for the interactions taking place within a KT channel by putting them on an imaginary continuum as to how finalized a research effort is and can range from broad exploratory activities to explicitly commissioned research and consulting services with specified deliverables and outcomes. For example, KT channels such as consulting and contract research are typically characterized with a high degree of finalization, since most commonly they are commissioned to accomplish a specific goal. Alternatively, KT channels such as collaborative research and university-industry research centers can be characterized with a low degree of finalization, since they primarily involve exploratory activities to produce uncertain, potentially useful knowledge, without necessarily having explicitly articulated ideas about its application.

A richer and more nuanced elaboration of the concept of finalization is provided by Rossi (2010) who proposes that “governance mechanisms” of university-industry interactions (which are equivalent to what we refer to as “knowledge transfer channels” throughout this review), are a function of two aspects of the underlying knowledge: its appropriability, and its complexity and uncertainty. While the issue of appropriability of knowledge in science policy is well understood, Rossi’s interpretation is innovative and useful in discussing properties of KT channels. Specifically, knowledge pursued and gained through university-industry interactions may be characterized with different degrees of complexity, or the extent to which it is dependent on a recombination of external (to the firm) sources of knowledge. For example, knowledge needs may vary according to the degree to which knowledge involves complementarity (*i.e.* requires the integration of different complementary types of knowledge), cumulativeness (*i.e.* requires building on pre-existing knowledge), or compositeness (*i.e.* requires the combination of different bits of knowledge that are held by many agents). This set of features broadly describes the complexity of relevant knowledge (Rossi, 2010) and moreover represents a useful guide for considering “appropriate” knowledge transfer channels. Rossi’s general proposition is that degree of appropriability and complexity determine “best” governance mechanisms. For example, knowledge with high appropriability and high complexity may be best provided by contract research or consulting, while high complexity accompanied with low appropriability may be best served by collaborative research or university research centers – *i.e.* ongoing interactions with substantial joint commitment. The research outputs in each governance form vary accordingly (*e.g.* discrete, more “finalized” deliverables in consulting or contract research context *vis-à-vis* joint knowledge production in collaborative research center context).

Thus the concept of finalization usefully approximates the broad characteristics of knowledge pursued in a given KT by encompassing scope (*e.g.* goals) and complexity of the knowledge base. Table 1 classifies all KT channels listed in terms of degree of finalization. This distinction is chiefly useful for loosely demarcating a boundary between commercialization and transfer vs. “relationship” activities. It also provides useful contextual information regarding the extent to which an on-going open-ended

commitment may be required of participants. It also can provide insight regarding the appropriate degree of structuration and formalization of the activity (Ouchi, 1980).

2.2.4 *Degree of formalization of the KT channel*

The final dimension of KT channels considered at this stage is the degree of formalization of the KT channels, understood as the extent to which the interaction is institutionalized and/or guided by formal rules and procedures. This dimension is important insofar as it sets the context for viable ways to influence participant behavior. For example, formalized contexts (*e.g.* university research centers or licensing arrangements, where the nature, scope, and extent of interactions between universities and industry are well-specified) will generate different HR strategies than will informal contexts of KT transfer which by definition occur outside of the realm of formal institutional relationships.

However, at bottom, even in KT channels characterized with some degree of formalization, engaging directly with industry or participating in different KT channels remain discretionary behavior for academics (Boardman & Ponomarev, 2012, forthcoming; D'Este & Perkmann, 2011). The extent of formalization applies predominantly to regulating the institutional relationships between universities and industry, and less so to individual scientists. The extent to which individual behavior can be regulated through formal rules and procedures is contingent on the primary affiliation of the scientists. For example, in evaluating faculty (*e.g.* in tenure and promotion decisions) in traditional academic departments, the emphasis is typically on the production of basic knowledge and publication in specialty journals; any emphasis on industry-related activities is typically informal, and a function of the organizational culture of the department or the university (Bercovitz & Feldman, 2008), rather than formal requirements to interact with industry.

Individual scientists' involvement with KT activities (and particularly patenting, one of the most researched relevant behaviors), can also be affected indirectly, by university rules and policies regulating technology transfer. Studies have found that universities providing stronger royalty incentives encourage faculty to disclose their inventions (Lach & Schankerman, 2008), while perceived red tape in interacting with offices of technology transfer may deter invention disclosures (Owen-Smith & Powell, 2001).

Finally, formal rules may also directly affect faculty behavior in some settings (*e.g.* in university research centers where faculty may have formal appointments, including partial or full funding of their salary, or in large grants where the funding agency requires and specifies certain type of industrial interaction). The problem of formalization is also related to the issue of institutionalization of U-I KT (Geuna & Muscio, 2009) – an under-researched and extremely important area insofar as Geuna and Muscio argue, the radical change in U-I interactions is not the increased prevalence, but the increased rate of institutionalization of such relations. Hence, the need to pay close attention to which different KT channels are formalized and/or institutionalized.

2.3 *Inventory of U-I KT channels*

There are multiple inventories of the range of interactions in which universities and industry engage, and the spectrum of interactions ranges from “passive” mechanisms of transfer (such as through scientific publishing, patenting and licensing), through formal or semi-formal partnership relations (such as research partnerships or services and contract research), to informal interactions and communication, as well as

personnel mobility-based links (Arvanitis, *et al.*, 2008; Cohen, *et al.*, 2002; D'Este & Patel, 2007; Meyer-Krahmer & Schmoch, 1998; Perkmann & Walsh, 2007; Scharfetter, *et al.*, 2002). These studies show a remarkable degree of agreement on what are the most significant/important KT channels. Table 1 lists the common channels, based on the above sources, along with rankings of the different KT channel characteristics consistent with the underlying studies. The table synthesizes existing inventories. The “high”, “medium” and “low” rankings of the level of individual KT characteristics directly reflect the original authors’ assessments/findings, except for cases where more nuanced rankings have been collapsed into the three categories (high, medium and low) to facilitate comparison.

Accordingly, Table 1 contains suggested values for the descriptive dimensions of the different KT channels discussed above (section 2.2) for each of the discrete KT channels. This section briefly discusses all channels individually, and attempts to derive a taxonomy relevant for thinking about viable HR interventions to foster establishment and development of some of these KT channels. One of the primary goals of Table 1 is to highlight the fact that it is possible to talk about different KT channels, precisely because they have different goals, structures, constraints and requirements, which in turn enable the building of different taxonomies (*e.g.* based on outcomes, knowledge and management requirements, *etc.*). While it is possible to conceive of different KT channels as complements in some cases and substitutes in others, such complementarity or substitution is likely to be contingent on available organizational resources to manage a spectrum of channels. For example, the presence of a university research center may create the conditions for synergies between publishing, training, collaborative research and consulting, while in the absence of management support, all else equal, interactions through such KT channels may happen sporadically or involve tradeoffs. Similarly, different ways of managing university intellectual property may or may not facilitate joint work on further development of university inventions, the inherent complementarity of both notwithstanding; initial informal contact may or may not lead to formalized interactions, depending on conditions, *etc.* Undoubtedly, considerable complementarity may exist between university-industry KT and university-based activities such as research and teaching (Hughes *et al.*, 2010).

2.3.1 *Scientific publications*

This channel is the most traditional, and widespread mode of transmission of knowledge from universities to society and the private sector. Scientific findings produced in universities are made available in the public domain, from where they can be applied and further developed by any company with the inclination and resources to do so. Generally, this KT channel is characterized with a low degree of formalization, low relational intensity and a high degree of knowledge codification, and it is routinely ranked by industry as highly important. Additionally, it is highly important for university scientists since the allocation of credit for new findings is the primary reward mechanism in science, thereby also exhibiting a high degree of goal congruence.

It is difficult to conceptualize the role of people in a Weberian “ideal type” (*i.e.* independent of any further contingencies) model of this transfer mechanism. A publication can inform many different processes of knowledge transformation and utilization. Perhaps most commonly, scientists/workers in firms with in-house R&D routinely scan scientific journals and use them to inform their own work. However, one can envision other dynamics – for example, publications may trigger and complement other KT channels, such as informal contacts. Nevertheless, such activities would represent a different type of KT, thus they are not considered as a part of the definition of publications as a KT channel *per se*.

Additionally, the cases of jointly co-authored publications between industry and academic scientists should also be considered as a separate case, since they represent the outcome of collaborative research, rather than a separate case of publication-based knowledge transfer.

2.3.2 *Professional meetings / conferences*

Professional conferences – academic, industry, or ones with both academic and industry participation – represent an important channel for transmitting knowledge and establishing informal contacts between academic and industry representatives. Professional meetings are among the KT channels that are routinely ranked as some of the most important KT sources by industry (Cohen, *et al.*, 2002; Meyer-Krahmer & Schmoch, 1998), and they are a routine and expected part of the activities of most scientists (D'Este & Patel, 2007). The exact nature of the exchanges taking place via conferences and meetings is not studied in sufficient detail, but is rather inferred based on the format of such meetings – researchers from academia and industry presenting their latest work and having the opportunity to identify collaborators of interest and discuss developments at the research frontier (D'Este & Patel, 2007; Nelson, 1986). The importance of this KT for both industry and academia justifies more careful study. In addition, this is a highly informal KT channel, involving medium face-to-face contact, capable of transmitting tacit knowledge (Schartinger *et al.* 2002) at low financial, relational, and institutional cost. Therefore, it is a KT channel characterized with a relatively high degree of goal congruence and, given its dependence primarily on individual scientists' motivations and activities, an appropriate and feasible target for HR interventions.

2.3.3 *Informal interactions with faculty*

“Informal relations”, “conversations”, and “casual contact” are consistently among the KT channels routinely ranked as most important by industry (Agrawal & Henderson, 2002; Cohen, *et al.*, 1998; Cohen, *et al.*, 2002; Meyer-Krahmer & Schmoch, 1998). As with conferences, the systematic study of informal contacts has been neglected until recently relative to investigations of patenting and transfer of IP, and no in-depth research exists on the exact nature of these informal contacts other than estimating determinants of individual and disciplinary propensity to engage in informal contacts (*e.g.*, Grimpe & Fier, 2010; Link, Siegel, & Bozeman, 2007). What is known is that they typically accompany and complement other forms of interaction (Ponomariov & Boardman, 2008), that informal contacts may be a precursor to more formal involvement (Druihe & Garnsey, 2004; Abreu *et al.*, 2010), and that unlike other KT channels, informal contacts appear to be invariantly important across different industrial sectors (Bekkers & Bodas-Freitas, 2008).

Table 1. Summary of U-I KT channels as addressed in the literature

Knowledge transfer channel	Relationship formalization	Degree of finalization	Relational intensity	Motivation for faculty	Significance for industry
Scientific publications	Low	High	Low	Academic prestige, peer review	High
Professional meetings and conferences	Low	Low	Medium	Exchange of ideas and concepts with colleagues and peers in their respective fields	High
Informal interactions with faculty	Low	Low	Medium	To establish additional interpersonal connections based on individual preferences	High
Collaborative research and research partnerships	Medium	Low	High	To have access to resources that may not have been available through the university alone	High
Contract research	High	High	High	To have access to resources that may not have been available through the university alone	High
Academic consulting	Medium	High	High	Done to acquire additional expertise and for personal gain, <i>i.e.</i> money, notoriety	High
Hiring of recent graduates	Medium	Low	Medium	Transfer of their tacit knowledge and their expertise in industry	Medium
Institution building / boundary institutions/ creation of physical facilities	High	High	High	Learning through knowledge sharing with industry	Medium
Commercialisation of property rights	High	High	Low	To develop relationships with firms for use of equipment or technology, finding the best partner to develop and market the patent	Low
Personnel exchanges / mobility	High	Low	Medium	To further the facilitation of learning within the organisation via experienced personnel	Low

Source: Adapted from Cohen *et al.* (2002), Scharinger *et al.* (2002), Perkmann and Walsh (2007) and others.

By definition, such contacts are not formalized, can be *ad hoc* and sporadic or ongoing. Depending on the context, informal relations can be important for ensuring the continuity of a relationship, including

during periods when no formalized activity/KT exchange is taking place. The internal logic of “informal contacts” is difficult to discern outside of the context of any of the other forms of collaboration, and it may be useful to consider the concept of informal relations in conjunction with the “relational intensity” dimensions of KT channels. While informal relations certainly can be specified as a KT channel in its own right, it is unclear how to realistically demarcate it from other channels such as consulting, collaboration, and joint research (D’Este & Perkmann, 2011), especially given that many actual collaborations emerge from pre-existing informal ties (Thune, 2007). For the purpose of this review it will be understood as forms of informal knowledge exchanges that persist even while there is no other more specific, discrete, or formalized form of collaboration taking place at a given moment. Such a definition is consistent with the dominant motivations of both companies and university scientists to engage in informal relations – to learn about industry problems and research (and respectively – about promising relevant academic developments), to receive feedback from industry, and maintain networks (D’Este and Perkmann, 2011). Such motivations are shown to relate to university scientists’ likelihood of engaging in informal relations.

Regardless of the difficulties of conceptualizing and measuring informal interactions, this is an essential concept in studying university-industry KT because such interactions develop “social and technical human capital” (STHC)³ (Bozeman, *et al.*, 2001) and sustain existing, or promote the development of, future, more involved collaborations (*e.g.* consulting, collaborative, joint, or contract research), as shown indirectly by some studies (Ponomariov & Boardman, 2008). Furthermore, personal interactions develop around, and describe, the socially embedded process of knowledge transformation (Schartinger *et al.*, 2002), which is considered essential in all innovative activities. Related, access to university personnel, which is a by-product of many of the other KT channels, is among the most important industry motivations to enter research partnerships and collaborative research (Leyden & Link, 1992).

2.3.4 Collaborative research and research partnerships

Collaborative research describes a broad set of situations where university scientists and private companies jointly commit resources and research efforts to projects (D’Este & Patel, 2007). Collaborative research is research carried out conjointly, may be co-funded by both partners, and may or may not be institutionalized in a designated entity – these characteristics distinguish it from contract research (section 2.3.5, below). More precisely, research partnerships can be defined as an innovation-based relationship that involves a significant joint R&D effort (Hagedoorn, Link, & Vonortas, 2000). There is a potentially large variation within this type of KT since the joint commitment can be at the individual scientist level or at the institutional level, but generally it involves a degree of reciprocity of commitment (*vis-à-vis* contract research) or public-private partnership (Audretsch *et al.*, 2002). University-industry partnerships range from small-scale temporary projects to large-scale organizations with multiple members and stakeholders (Perkmann & Walsh, 2007) that can overlap with structured institutional research partnerships (centers) as reviewed in section 2.3.8 below.

Research partnerships can be classified based on their membership composition and on the structure of the relationship – *e.g.* public *vs.* private (Hagedoorn, *et al.*, 2000), although this is a seemingly insufficient distinction. Similarly, *per* Hagedoorn and colleagues, the structure of the relationship can be

³ Understood as “the sum of an individual researcher’s professional network ties, technical knowledge and skills, and resources broadly defined” (Bozeman, Dietz, & Gaughan, 2001, p. 636).

described on the basis of its formality/informality, which also may not be a sufficient distinction, especially given that virtually nothing is known about informal partnerships, in spite of evidence suggesting that this type of partnership may be the most common (Link & Bauer, 1989).

Consistent with D'Este and Perkmann (2011), Bozeman and Corley (2004) suggest that collaborations are primarily motivated by strategies to enhance “scientific and technical human capital”, *i.e.* learning and social network building. In addition, researchers with more diverse collaborations (including with industry) tend to receive larger amounts of grant funding, though the direction of causality is ambiguous, since securing industry support for research is one of the important motivators for engaging in collaborative research with industry (D'Este & Perkmann, 2011).

2.3.5 *Contract research*

Contract research is commissioned by a private firm to pursue a solution to a problem of interest to the firm. The distinction with consulting (below) can be somewhat blurry and is often contingent on university policies, but in general contract research may be implemented by an institutional sub-unit (*e.g.* a laboratory or research center), while consulting engagements are typically individual. Furthermore, consulting engagements are typically negotiated directly between the individual faculty and a private firm, while contract research is usually heavily or exclusively governed by university rules and may have some university management or administration involvement. In addition, contract research may also have somewhat broader and diffuse goals *vis-à-vis* consulting, which tends to be a KT channel suitable for smaller, focused problems and deliverables. The distinction between contract research and most types of consulting also includes that contract research involves creating new knowledge *per* the specifications or goals of the client, while consulting tends to exploit existing knowledge (Perkmann & Walsh, 2008), albeit most types of consulting involve problem solving and related research. Regardless, contract research involves some type of deliverable that can be codified formally (*e.g.* in a contract) or agreed upon informally. The degree of finalization and formalization is usually moderate to high.

Alternatively, the difference between collaborative research (above) and contract research is that in the latter case, the company purchases a service for a fee, without necessarily committing personnel and other resources to the underlying research. In addition, the work performed in contract research is usually more applied than the type of activities in collaborative research (Van Looy *et al.*, 2004).

The primary motivations for faculty to engage in contract research include learning and, to the same or larger extent, securing industry resources to conduct research, while commercialization is not necessarily a major motivator (D'Este & Perkmann, 2011). This is verified in a US study estimating that university scientists who had industrial grants and contracts were far more likely to interact with industry through a variety of KT channels than scientists without (Bozeman & Gaughan, 2007). Similar results have been obtained by Gulbrandsen and Smeby (2005). Thus, similar to “informal relations”, consulting and contract research may be channels with somewhat high relational intensity and instruments to ensure continuity, rather than classic “arm’s length” contracts.

2.3.6 *Academic consulting*

Consulting is one of the most widespread – yet least institutionalized – activities in which academics and industry engage. Consulting refers to research or advisory services provided by individual academic

researchers to industry clients (Perkmann & Walsh, 2008). This is also one of the most important from industry's point of view (Cohen, *et al.*, 2002; Schartinger, *et al.*, 2002), yet least researched (Hall, 2004) KT channels, with the notable (theoretical) exception of Perkmann and Walsh (2008). They identify three types of consulting, with somewhat distinct motivations and dynamics: research-, opportunity-, and commercialization-driven consulting. While opportunity-driven consulting is chiefly motivated by personal income opportunities, commercialization-driven consulting is motivated by the inventor's desire to commercialize their inventions (Thursby & Thursby, 2004). In research-driven consulting, activities are directly linked to academics' research projects, where they maintain links to firms supporting their research. Such consulting activities are often complementary with firms' usage of other open science mechanisms, such as publications. Plausibly, a firm may identify a promising research publication and then hire the author as a consultant to assist in the implementation of some of the downstream research activities.

Consulting activities are typically informal or semi-formal, and they are characterized with high relational intensity (Schartinger *et al.*, 2002; Perkmann & Walsh, 2008). There is generally substantial goal congruence between university faculty and industry's motivations, with the possible "boundary case" of opportunity-driven consulting. Perkmann and Walsh (2008) speculate that research- and commercialization-driven consulting may be motivated by learning opportunities and D'Este and Perkmann's operationalization and analysis (2011) detect a weak effect of learning motivations on the likelihood of engaging in consulting, along with commercialization motivations. This prompts them to label consulting as a natural "boundary" of university-industry interactions, up to which faculty motivations are congruent with the traditional Mertonian motivators of scientific activity where most academics are motivated by the pursuit of solutions to interesting problems, rather than economic opportunities. Thus they identify consulting and contract research as potentially the most significant sources of industrial benefits, which also do not compromise the university mission.

2.3.7 *Hiring of recent graduates*

Access to qualified graduates as future employees is considered to be one of the major motivations for firms to engage in university-industry collaborations (Feller & Roessner, 1995; Slaughter *et al.*, 2002), and one of the main benefits that universities produce for industry in general (Martin & Salter, 1996; Pavitt, 1991). This typically occurs in the context of some other form of interaction, *e.g.* joint supervision of graduate theses (Schartinger, *et al.*, 2002), or collaborative research (Ponomariov, 2009). Generally, recent graduates are considered to be highly (Feller & Roessner, 1995; Schartinger, *et al.*, 2002) to moderately (Cohen *et al.*, 2002) important KT channels by industry. The hiring of recent graduates in the context of another, more general, ongoing relationship (*e.g.* collaborative research) affords benefits relative to hiring on the general labor market, because it provides reliable information regarding the graduate's specific knowledge, skills and abilities *vis-à-vis* much more general competencies conveyed in a degree: graduates hired in the context of an ongoing relationship with a faculty or a center have typically worked on specific projects of interest to the hiring firm, and thus indicate the possession of knowledge, skills and abilities of direct relevance to the company, in addition to their core training. Such relationships can be informal or semi-formal, and they are well suited for transferring tacit knowledge with low degree of finalization and reliant on personal interaction. They are characterized with medium relational intensity, and relatively high goal congruence as far as faculty and industry motivations are concerned.

As in all “mobility” based KT (Perkmann & Walsh 2007), the relational intensity of the various scenarios through which recent graduates are recruited in industry can be characterized as “medium”, insofar as the training and availability of graduates is generally viewed as a by-product of other activities, *e.g.* collaborative research, informal contacts. The role of university scientists in such interactions is as catalysts of both human and social capital, insofar as they are involved both in maintaining the informal relationships with students and industry partners and in organizing and managing the research efforts in which students are involved.

2.3.8 *Institution building / boundary organizations / creation of physical facilities*

Another channel for U-I KT is the establishment of new “boundary organizations.” Many of these organizations have formed in response to calls for increased productivity and integrity in science (Guston, 2000). Others formed in response to the call for enhanced competitiveness in the global marketplace (Geiger, 1990). Other new institutional forms have emerged due to the increasing complexity and expense of scientific and technical research (Ziman, 1994). While perhaps still in the minority relative to total U-I KT activity, it appears that such new institutions will be increasingly important, and must be a subject of intense study considering that they are among the few actually institutionalized U-I KT interactions (Geuna & Muscio, 2009).

These new institutions represent changed expectations for U-I KT, including increased expectations for formalization, institutionalization and effectiveness of KT. For example, technology licensing offices provided the expertise and resources necessary for university scientists to act as entrepreneurs and explore the commercial potential of their projects. Research parks, by bringing science- and technology-based firms in close proximity to university campuses, enabled university scientists to act as consultants and “transfer agents” (Bozeman, 2000). Offices of research integrity encouraged university scientists to act as proctors and ethicists, helping them to understand and adhere to the laws, regulations and policies to which they are subject.

The most prevalent bridging institution is the boundary-spanning research center, which goes by many names (Boardman & Gray, 2010). According to the Research Centers Directory, there are more than 30 000 centers worldwide. Large universities often have more than sixty centers, some have as many as two hundred (Dresser, 1989). In the United States context, perhaps the best known centers are those associated with the US National Science Foundation (NSF), including Engineering Research Centers and Science and Technology Centers, which focus on research topics rather than disciplines, implement strong inter-institutional and cross-sector ties, and play a major role in the conduct of “big science” in the United States (Bozeman & Boardman, 2004).

Centers have been shown to provide numerous benefits. They aid industrial partners, if they have them, by way of a number of U-I KT channels, including increased patenting and research (Adams *et al.*, 2001), enhanced access to students for potential hire (Feller & Roessner, 1995), enhanced access to “upstream” modes of knowledge (Feller, Ailes & Roessner, 2002), and also by way of technological problem solving and competency building (Santoro & Chakrabarti, 2002). Centers also benefit the university scientists who affiliate with them, through increased opportunities for research (Corley & Gaughan, 2005), enhanced access to industrial research partners (Bozeman & Gaughan, 2007), enhanced access to resources (including funds, equipment and infrastructure, and collaborators), enhanced

publication rates and co-authorship diversity (Ponomariov & Boardman, 2010), and also by offering an opportunity to “do good” for society (Friedman & Friedman, 1982).

Understanding how different types of centers affect U-I KT is imperative as governments and universities seek to become more strategic with regard to joint research and related interactions with industry (National Academy of Science, 2007). Though centers often generate industry-related outputs and outcomes (Gray *et al.*, 2001; Feller *et al.*, 2002; Santoro & Chakrabarti, 2002; Dietz & Bozeman, 2005), little is known about the extent to which center characteristics are related to differences in university-industry interactions – for instance in terms of the intensity (Schartinger *et al.*, 2002) and character (Bhattacharya & Arora, 2007) of academic researchers’ exchanges with private companies. University research centers, though unlikely the sole authors of these exchanges, may influence and structure them based on their organizational characteristics (Boardman, 2009).

An important observation to make about existing research on centers is that they are as known for their management challenges as for their successes. Though many centers (at present) are similar to collaborative networks and thus it is typically assumed at the policy level that conventional governance mechanisms such as resource interdependence are the impetus for implementation of centers (much as occurs in networks for public service provision), the assumption that participants engage with one another because none individually has the resources needed to achieve its own goals generally does not hold for centers. The research conducted by NSF centers in many instances does not constitute the core activities for academic (Boardman & Bozeman, 2007; Boardman & Ponomariov, 2007) or industry (Feller *et al.*, 2002) participants. In contrast to conventional networks, the balance of resource dependence in centers is weighted towards management (Bozeman & Boardman, 2003). Though center participants typically can pursue their respective research agendas without center resources, the center typically cannot do so without the involvement of particular participants.

Related, another observation to make is that centers often lack the governance mechanisms that typically work for formal organizations (*versus* networks). Center managers cannot exercise formal personnel authority and are precluded from meaningful engagement in a number of organizational design activities, including the articulation of enforceable rules and procedures for governing behavior and the use of contracts to formalize personnel obligations to the center (Crow & Bozeman, 1998). Even if center leaders had increased authority, the non-routine nature of scientific and technical research limits options for internal structuration. Therefore a fundamental objective of center management should be to facilitate goal congruence and/or resource interdependence to assure participant contributions (Ouchi, 1980), which can prove challenging when organizational environments are “complex” (Meyers, Riccucci, & Lurie, 2001).

Hence a central issue for policy makers and administrators is developing an understanding of how different types of centers affect U-I KT. What little scholarship there has been on this topic shows government-sponsored centers to be more conducive to faculty affiliates’ industry involvement than industry-sponsored centers (Boardman, 2009) and low levels of resource dependence and goal congruence on the part of faculty participating in centers to be associated with more formal and more complex organizational strategies to HR management in centers (Boardman & Ponomariov, 2012, forthcoming).

Finally, in regards to factors critical for the success of such centers, one prior study has established that the co-operation/commitment of the host university, and the personal characteristics and managerial abilities of the center director, are critical factors for success (Geisler, Furino & Kiresuk, 1990).

2.3.9 *Commercialization of property rights*

Universities have been increasingly encouraged to patent and commercialize the fruits of their research. As a result, university patenting, licensing and spinoffs have received a very substantial attention in the literature (Mowery, Sampat & Ziedonis, 2002; Mowery & Ziedonis, 2002; Rothaermel, Agung & Jiang, 2007; Sampat, 2006; Thursby & Thursby, 2003; Valentin & Jensen, 2007). That attention does not seem justified from the standpoint of its significance for industry, but is understandable considering that this type of KT is one of the few that are institutionalized at present (Geuna & Muscio, 2009). From the standpoint of both industry and academic scientists, patents are consistently ranked among the least important KT channels (Agrawal & Henderson, 2002; Cohen, *et al.*, 2002; Scharfetter, *et al.*, 2002). As a KT channel, IP transfers (*e.g.* patenting, licensing, spin-off formation) are characterized with a high degree of formalization since such activities are codified and governed at the university level, typically by a designated technology transfer office (TTO). (University spin-offs are discussed in Box 1 below).

The commercialization KT channels are also the most incongruent with the norms of open science. Faculty who are involved in commercialization are primarily motivated by the prospect of bringing their invention to market, as well as monetary rewards (D'Este & Perkmann, 2011). In some cases, faculty may have motivations to pursue intellectual property rights (IPR) out of concern for preserving their flexibility for doing future research by protecting it from patent litigation or claims (Owen-Smith & Powell, 2001), and substantially affected by institutional environment and policies, which may be cumbersome enough to discourage invention disclosure altogether and even disincentivize faculty to commercialize their inventions (Siegel, Waldman & Link, 2003).

Similar to publications, the “inherent” relational intensity of this KT is low: generally, a patent is supposed to be a bit of codified knowledge, a “recipe” that others may use for a fee. However, in reality substantial follow-on involvement of the inventor in assisting firms in commercializing the licensed invention is necessary: a majority of licensed inventions rely on assistance from the inventor for follow-on research (Agrawal, 2006; Agrawal & Henderson, 2002; Thursby & Thursby, 2004).

Box 1. University spin-off companies

The process of spin-off company creation is nominally a KT channel, although it does not actually involve direct transfer of knowledge to the private sector in the same sense as the other KT channels discussed here; instead universities or university faculty choose to pursue their invention by establishing a company for that specific purpose. In other words, spin-offs are a mechanism for exploitation of publicly developed R&D in a newly established commercial entity, rather than a mechanism for transfer – the “transfer” in this case is nominal. Consequently, the majority of research in this area is concentrated on the individual and institutional factors that may predict startup formation, rather than on any underlying KT processes (see O’Shea *et al.*, 2005, for a systematic review of the literature). The area of spin-off creation has received substantial attention, although this remains one of the more rare forms of U-I KT: on average, US universities produce 1.9 startups per year, with a very skewed distribution (O’Shea *et al.*, 2005). Similar to patenting and licensing, one of the reasons why spin-off company formation has received large attention is that it is one of the few forms of U-I interactions that have actually been institutionalized recently (Geuna & Muscio, 2009).

One of the robust findings in the literature on university spin-off companies is that university policies and rules have pronounced effects on the rate of spin-off formation (Di Gregorio & Shane, 2003). Although locational factors are important, the primary organizational factor that positively influences startup formation at universities is the flexibility of the licensing contract policy. Others suggest that organizational rules may have differential impacts depending on the KT channel: Caldera and Debande (2010) suggest that large and more experienced TTOs lead to a greater volume of contract research, but not necessarily to a greater volume of licensing and spin-offs. This should not be surprising considering that contract research and consulting opportunities are more easily identified, while university patents significant enough to spin off are high-reward, but low probability events in general.

In addition to organizational-level factors, individual scientists’ characteristics are related with the likelihood of establishing or joining a spin-off. Researchers who are motivated to a greater extent by opportunities to commercialize research are also more likely to be involved in spin-off companies (D’Este & Perkmann, 2011), and the most prominent scientists are more likely to engage in spin-off company activity (Zucker, Darby & Brewer, 1999). Commercialization orientation is, however, less common among scientists: although most US scientists are enthusiastic about knowledge and technology transfer activities in general, they are reportedly less enthusiastic about explicit commercial schemes such as spin-off company formation (Lee, 1996). Even when it comes to spin-off creation, many scientists are primarily motivated by enhancing their academic standing, rather than just the potential for profit or commercialization (Fini, Grimaldi & Sobrero, 2009)

However, university level and contextual characteristics also shape the likelihood of individual scientists’ establishing startups: Müller (2010) found that usually the main impediment for establishing firms by academics is the need to acquire complementary skills and assemble the appropriate teams; however, this process is greatly facilitated if the founders have access to university infrastructure/services and receive formal and informal support through their networks. University characteristics/services that appear significant in facilitating the creation of spin-offs include sufficient TTO staff, relationships between TTO and external organizations, and support services provided by TTOs to faculty (Fini, *et al.*, 2009; Nosella & Grimaldi, 2009).

2.3.10 Personnel exchanges / mobility

As a KT channel, personnel exchanges may take many forms, formal and informal, explicit and implicit, temporary and permanent. This is a KT channel with a typically moderate to high degree of formalization, which involves university or industry scientists spending time in the alternate setting. Explicit personnel exchanges between academia and industry seem rare, though may be more common

between federal laboratories and defense contractors. Informal personnel exchanges, particularly through students, seem far more common and are highly valued by industry, indeed representing one of the main motivations to join university research centers (Feller, *et al.*, 2002). Another form of personnel exchange can be simply professional training/lectures provided by universities to industry. However, this KT has not been studied and is only mentioned by Schartinger *et al.* (2002), and was judged as having a low importance by industry. It appears that a main contingency in this KT channel is the degree of formalization/institutionalization, which can range from completely informal to heavily formalized.

Perhaps the most studied and/or important form of “personnel mobility” in the context of university-industry KT are cases when university inventors either start spin-off companies or are employed by industrial firms. Zucker, Derby & Torero (2002) suggest that important scientific breakthroughs are characterized by “natural excludabilities” (since they are embodied in their creator), which in turn means that one of the best ways to transfer such knowledge is to employ the knowledge creator part- or full-time. Other studies (Zucker, Darby & Armstrong, 2002) find direct linkages between scientists’ human capital and the innovative performance (*e.g.* number of and citations to firms’ patents) of biotechnology firms they join or collaborate with – as long as the human capital is “commercially oriented” (Toole & Czarnitzki, 2009).

2.4 Other KT channels

Table 1 represented the most commonly discussed KT channels across multiple studies. In addition, several less prominent types and subtypes of KT channels can be studied. These include:

2.4.1 Research training of graduate students in industry

In general, graduate students are considered an essential and multi-faceted asset in the process of university-industry relations (Feller & Roessner, 1995; Ponomariov, 2009; Slaughter, *et al.*, 2002), although until recently such involvement has been viewed as a by-product of U-I interactions. A designated journal (“Industry and Higher Education”) explores various aspects of the education-industry interface. Increasingly, graduate training in collaboration with industry is institutionalized. Examples include the Engineering Research Center program in the United States, which must include educational components (Bozeman & Boardman, 2004), and collaborative educational programs in Europe (Borrell-Damian *et al.*, 2010). The majority of the studies still focus on the implications or impacts of industrial collaboration on graduate education and students themselves (Behrens & Gray, 2001; Harman, 2002; Kolmos, Kofoed & Du, 2008), but studies have become increasingly specific and at present focus on the impact of industrial collaboration on the type of knowledge produced (Chiang, 2011) and more positive attitudes towards industrial R&D and careers with industry (Kay, 2004).

Relatively less common are studies of the specific role of graduate students in KT. When the focus is not on the effect of U-I relations on students, studies discuss broad policy changes pertaining to the role of graduate education in U-I interactions (Thune, 2007). For a current overview of the literature on graduate students in the university-industry interface, see Thune (2009, 2010).

2.4.2 *Services to industry*

The issue of providing services to industry fits with a specific type of “innovation market failure” (Martin & Scott, 2000) – situations where the key driver of innovation is the application of inputs/technologies developed elsewhere (e.g. suppliers, universities, *etc.*). In such cases, especially if barriers to entry include small firm size and limited appropriability (Martin & Scott, 2000), bridging institutions (e.g. extension services) may provide an adequate policy response. Similar logic applies in cases where the driver of innovation is the development of complex systems, though in these cases extension services provision may blur with more sophisticated and complex institutions such as university research centers and research consortia. The latter are arguably more interesting and important from a KT perspective, insofar as policy makers and universities strive to assist private industries without compromising the core activities of universities (e.g. advanced research). Considering that one of the motivations for firms to join research centers is access to advanced equipment – in addition to access to faculty and students (Feller & Roessner, 1995) – future research should consider the issue of services to industry in the broader context of collaborative research, rather than in the context of traditional manufacturing extension programs.

2.5 *Measurement of KT*

Accurate measurement of KT activities is difficult, in large part due to the importance of “soft”, “tacit”, informal interactions. As discussed above, all KT channels involve some degree of knowledge flow and transformation, and unless the extent and nature of such flows and transformations can be captured, the measurement of KT quantitatively involves validity trade-offs. Not surprisingly, most efforts to measure KT have been centered on activities for which easily quantifiable data is available, such as bibliometric methods and financial analyses – *i.e.* the KT channels characterized with high degree of codification such as co-authorships and financial flows (Carlsson & Fridh, 2002).

One of the straightforward measures of knowledge transfer activities of universities – patents – piqued researchers’ interest after the enactment of the Bayh-Dole Act in the 1980s. This Act provided US universities with permission to patent inventions resulting from federal funding, based on the premise that providing IP protections and opportunities for licensing will provide incentives for the private sector to develop university inventions – *i.e.* transfer university knowledge into commercializable products. Accordingly, several studies have estimated the impact of the Bayh-Dole Act on university patenting (Mowery *et al.*, 2001). The evidence of positive impacts on patenting is mixed (Mowery, *et al.*, 2001), and suggests that the trend for increased patenting was already underway before the enactment of Bayh-Dole. While the passage of the Act has generally spurred the production of patents across a broader set of universities, the patents of the “newcomers” are generally of lesser quality (Mowery & Ziedonis, 2002) causing some researchers to doubt that emulating Bayh-Dole in other countries will have any significant positive impact (Mowery & Sampat, 2005).

Another indirect measure of KT is volume or proportion of industry funding to universities, considered a proxy indicator for “meeting the research needs of industry” (Turk-Bicakci & Brint, 2005). While university patents and industry funding to some extent measure knowledge transfer, such measures are indirect insofar as university patents describe the potential for transfer, and perhaps university commitment to KT. However, unless private companies use (e.g. license university patents) or universities

develop them themselves (*e.g.* by assisting in the creation of spin-off companies), no actual transfer is taking place. Analyses of university licensing, citations to university papers, and spin-off company formation are more direct measures of knowledge transfer. Specifically, number of executed licenses and licensing income are two other common measures of U-I KT at the institutional level (Turk-Bicakci & Brint, 2005).

A shortcoming of the general patenting or licensing variables above is that they do not reveal much information regarding any substantive impact of university knowledge on commercialization. In an attempt to capture the contribution of academic knowledge to industrial innovation, Narin and colleagues (1997) estimated that 73% of the citations provided on US patents are to papers produced by universities (thereby indicating that private sector patents have substantial basis in university science), though the validity, directness and scope of this link has been questioned (Meyer, 2000).

The chief disadvantage of the types of measures outlined above is that they measure KT indirectly at best, or confound it with the problem of KT impact (below). Very few studies attempt to capture the actual process of knowledge transfer, as such studies are costly and typically need to intensely rely on more difficult-to-analyze qualitative data and narratives (*e.g.* Colyvas *et al.*, 2002). When conducted, such studies of KT usually uncover a nuanced and complex process with different expectations, interests and conflicts, even in KT channels that may seem straightforward by any other measurements, such as university patenting and licensing (*e.g.* Siegel, Waldman, Atwater & Link, 2003).

The only present alternative to using existing data sources (*e.g.* bibliometrics, transaction records) is directly surveying the participants in KT (*e.g.* firms, managers, scientists). The survey approaches are characterized with both reliability (subject-dependent answers) and validity (difficult to elicit detailed information on processes) challenges. Several approaches attempt to measure the broader spectrum of less codified KT behaviors through surveys, mostly for the purpose of ranking the different channels (*e.g.* in terms of importance). In many cases (*e.g.* studies at the individual level) simple discrete variables (*e.g.* asking survey respondents whether or not they engage in a certain KT activity/channel) are utilized. Others attempt to be more specific, *e.g.* by asking scientists about their time allocations (percentage of time) on different types of research, *e.g.* with industry collaborators (Boardman, 2009).

This approach (attempting to capture the incidence of different KT channels) can be extended at the institutional level, by counting the volume of activity in each KT channel – *e.g.* numbers and monetary value of consulting agreements, number and monetary value of contract and collaborative research agreements, numbers, survival rate, and market capitalization of spinouts, *etc.* In addition to measuring the quantity of activity in these common channels, it is also possible to approximately measure the quality of interactions, *e.g.* by studying the amount of “repeat business”, private sector feedback, private sector assessments of the contributions of the PRO, *etc.* (For a full overview see the Library House report (2008).) Such assessments can be implemented at different organizational levels, either as a survey or by aggregation and analysis of organizational records, or through a combination. Schartinger and colleagues (2002) proposed a number of such measures at the academic department level, including: *i*) number of collaborative projects with firms, *ii*) number of papers written jointly with firms; *iii*) number of faculty with part-time or full-time employment arrangements with private firms; *iv*) number of startups originating from the department; *v*) number of theses jointly supervised with industrial firms; *vi*) number of lectures

given by firm representatives; *vii*) number of training courses for firm representatives offered; and *viii*) number of research assistants financed by firms.

Finally, some studies, mostly in the business literature, focus on individual firms or inter-firm interactions in an attempt to directly measure the learning aspects of knowledge transfer. Foos and colleagues (2006) operationalized KT in a survey instrument where items elicited managers' assessments of their knowledge acquisition goals and their organization's ability to integrate and utilize knowledge, and found that an important element of successful KT is trust and pre-existing relationships – something that has been highlighted in U-I KT as well (Thune, 2007).

Future studies of KT need to explicitly capture the constituent elements and processes that take place in KT, including, but not limited to, discovery, articulation, acquisition, communication, internalization, application and absorption of knowledge, among others. It appears that such issues are more intensely researched in the context of the business and management literature on inter- and intra-firm KT, than it is in the context of university-industry relations. (For an overview, see Tsai-Lung Liu, 2001.) Some of the approaches to studying KT in the business sector may be applicable in the university-industry context.

2.6 *Impact of KT*

As noted in section 2.5 above, in the present literature the distinction between measures of KT and measures of KT impact can be somewhat blurry. Even when studies purportedly attempt to measure the extent of KT transfer, the direct process of KT is almost never directly measured, but rather inferred on the basis of occurrence of certain outcomes such as funding, patents and licenses, which can just as easily be conceived of as outcomes/impacts, and even inputs (Caro, de Lucio & Gracia, 2003). Some of the commonly studied outcomes/impacts are presented in this section.

Virtually all measures of the impact of KT are measures of economic impact/value added, either at the firm level (*e.g.* new products, processes) or the social level (*e.g.* social returns). This is expected, considering that knowledge is a primary driver of economic growth and that this understanding lies behind all policy efforts to intensify U-I KT. However, it has also led to an under-emphasis on indirect/intermediary impacts of KT such as learning and improvements in human capital and research capacity, which are important intermediary impacts of KT at the firm level and may be part of the mechanisms for the overall economic impacts of KT.

The absence of well-developed measures of the intermediary processes of KT results in KT impact being inferred indirectly, either by collecting aggregate innovation/financial data, or by soliciting information from industrial companies about specific contributions made by KT activities on firms' activities, products and profits. There is a considerable research tradition in the measurement of knowledge impacts of universities on firms. The oldest in this tradition are studies of "social impact" of university research, *e.g.* Griliches (1958) compared the cost of hybrid corn research with the value of increases in corn production that resulted from advances in hybrid corn research, and estimated a rate of return of 700%.

Rather than attempting to detect the social returns (arguably the "ultimate" measure of impact) from KT, some studies attempt to estimate more directly the role of KT on firm performance. Based on the responses to a survey of 76 US firms, Mansfield (1998) estimated that about 10% of new products and

processes would have been introduced with a great delay without contributions from academic research. Various newer studies (*e.g.* Beise & Stahl, 1999; Monjon & Waelbroeck, 2003) have used the same or similar measures of impact, *i.e.* the self-reported contribution of academic knowledge to the invention of new products or improvements in existing ones, and generally find positive relationships. Such information is gleaned through surveys, which makes it somewhat unreliable due to its dependency on identifying a specific person within an organization who can provide this information (typically a R&D manager or a business owner in the case of SMEs).

Some studies relying on existing data attempt to capture intermediary impacts of public research on private companies. Nelson (1986) uses firms' ratings of significance of university research in general and finds that more R&D intensive firms tend to value university research higher, which Nelson interprets as evidence that one of the primary impacts of university research is to increase the productivity of private R&D thus facilitating the discovery and exploitation of opportunities for innovation (rather than generate new technology *per se*), a point further explored elsewhere (Pavitt, 1998; Rosenberg & Nelson, 1994).

An extension of this line of reasoning and a modified dependent variable is proposed by Kaufmann and Tödtling (2001) who show that firms who interact with universities improve their ability to innovate, defined as introduction of products that are new for the firm; in addition, the effect was stronger for radical rather than incremental innovations. A variety of KT impact variables is proposed by Adams and colleagues (2003) in a study of the effects of Cooperative Research and Development Agreements between firms and federal laboratories in the United States. The variables include: in-house company financed R&D budget (*i.e.* in-house R&D spending) and number of patents.

An indirect approach to study the impact of public science and particularly the impact of university-industry collaborations is to study the characteristics of award winning inventions (Block & Miller, 2008). Specifically, Block and Miller discover that the proportion of award-winning innovations that involve some form of public-private collaboration has drastically increased since the 1970s.

One of the recent attempts to measure the impact of U-I KT (Arvanitis, *et al.*, 2008) aims to differentiate the impacts that different KT channels may have on firm performance. The dependent/impact variables are: *i*) sales of new products as a percentage of total sales; and *ii*) sales of significantly improved existing products as a percentage of total sales, modelled as a function of the full spectrum of KT activities that firms may engage in. The results suggest that firms with primarily research-oriented collaboration with universities perform better on those variables.

Other approaches (Cohen, *et al.*, 2002; Schartinger, *et al.*, 2002), shift the focus from products in general, and instead ask companies to rank the importance of different stakeholders (*e.g.* suppliers, customers, public research institutes) or types of KT channels for their innovation activities. Cohen and colleagues (2002) differentiate between the contribution of public research to new project ideas and contributions to solving existing problems, and find that public research is more useful in the latter than the former. That finding is qualified by a separate study (Meyer-Krahmer & Schmoch, 1998), which suggests a moderating effect of sectoral differences: in science-intensive fields, private companies primarily value public research as a general knowledge source, while in less science-intensive industry, the primary value of public research is in problem solving.

Overall, the generic types of impacts of KT can be grouped in four broad categories: organizational outcomes, knowledge outcomes, technological outcomes and financial outcomes (Tsai-Lung, 2001). Such distinctions should be kept in mind when designing measures of KT, insofar as these categories can be confused with each other: for example, while the improvement of a firm's knowledge base may (and ideally should) improve its competitive position, financial or technological improvements may be an indirect effect of a KT interaction specifically aimed at augmenting a firm's knowledge base (which is one of the leading motivations for firms to enter U-I KT). Becker (2003) applies a useful and simpler distinction: universities can influence either or both:

- Firm-level innovation inputs (*e.g.* learning, absorptive capacity, internal R&D investments)
- Firm-level innovation outputs (*e.g.* products, sales, patents, *etc.*)

This distinction will be useful to consider when analyzing different KT channels, and indeed, whether a KT channel targets a firm's innovation outputs or inputs is conceptually useful as one of the major dimensions characterizing KT channels.

Similarly, the issue of the role of HR management practices in KT (see next section) has been much more intensively researched in the firm/private sector context than in the U-I context (for a recent overview, see Smale, 2008). Many of the business literature lessons may be applicable in the university-industry context, although it should be emphasized, again, that unlike private companies who have direct authority over their personnel, U-I KT remains a discretionary behavior and thus not all traditional HR management practices are directly applicable.

2.7 *Synopsis of the literature on U-I KT channels from a strategic HR management perspective*

The characteristics of the knowledge transfer process and the importance of individual behaviors, as highlighted above, strongly suggest that systematic study of HR strategies to influence KT may be warranted. In the abstract, all of the U-I KT channels outlined above can be influenced at least to some degree through HR management strategies. However, the viability and the impact of such interventions will vary *per* contingencies brought by the KT channel dimensions of relational intensity, finalization and goal congruence.

Analysis of the "relational intensity" dimension of the different KT channels highlights two important KT features: first, that the KT channels that are self-reported by industry to be the most important are also among the ones with the highest relational intensity; and second, that faculty involvement is an essential part of the U-I KT process regardless of specific channel, though the degree, nature and importance of this involvement may vary. The channels identified as most important to industry included: informal contacts, conferences, scientific publications, consulting and collaborative or contract research. Activities related to commercialization of IP and personnel exchanges are ranked as somewhat less important. Thus, many KT channels important to industry are heavily dependent on the activities, motivations and choices of individual faculty.

From a policy perspective, it could be interesting to focus further analysis on the group of KT channels with high relational intensity and importance to industry. The initial short list noted above of KT channels to be singled out for KT interventions can be narrowed even further: scientific publications have

very low relational intensity (unless they trigger further informal interactions) and, moreover, the production of scientific articles is the main output desired of university scientists and is already reflected in the organization of academic research at PROs. This reduces the list of relevant channels to informal contacts, conferences and professional meetings, consulting and collaborative research (Box 2 presents arguments for a possible further, narrower focus on academic consulting and collaborative research).

Box 2. A potential focus for further policy-analysis work

For analytical purposes, it could be interesting to focus on collaborative research and academic consulting.

The rationale for singling out these channels is a derivation from the synthesis of the KT channel characteristics presented in this paper. Both consulting and collaborative research rank high in terms of perceived relative significance for industry, and both require a certain degree of direct interaction with university scientists, thereby facilitating the process of “knowledge transformation.” The channels are also complementary. Consulting activities satisfy industrial needs that may be shorter term, discrete and characterized with a high degree of finalization – in short, consulting is an efficient way to harness existing faculty expertise for industrial needs without compromising the core functions and missions of university faculty. Collaborative research covers a much broader spectrum of possible joint commitments to research that range from specific projects to research conducted within new organizational forms, such as university-industry research centers. (Although university research centers were listed as a separate KT channel due to their size, clearer boundaries and increasing importance, they often do fall within the broader concept of collaborative research). Thus collaborative research can satisfy other types of industrial needs, namely the needs of learning, monitoring disparate technologies and trends, accessing cutting edge research, and maintaining and developing absorptive capacity.

The two channels are also theoretically complementary: while consulting is an important source of KT for industry, it is by definition sporadic, dependent mostly on individual faculty idiosyncrasies. Considering that the current trend is towards increased institutionalization and formalization of KT channels to increase KT efficiency (Geuna & Muscio, 2009), future research on U-I KT should consider both the potential and the limits for formalization and institutionalization. The various forms of collaborative research represent multiple avenues for possible institutionalization and formalization that need to be well understood, and a first step in that direction can be the study of the HR implications of collaborative research settings in universities at present. Related, although consulting appears to be least amenable to institutionalization, understanding faculty involvement in consulting may shed light on possible organizational levers to further encourage, and perhaps even institutionalize, some forms of consulting.

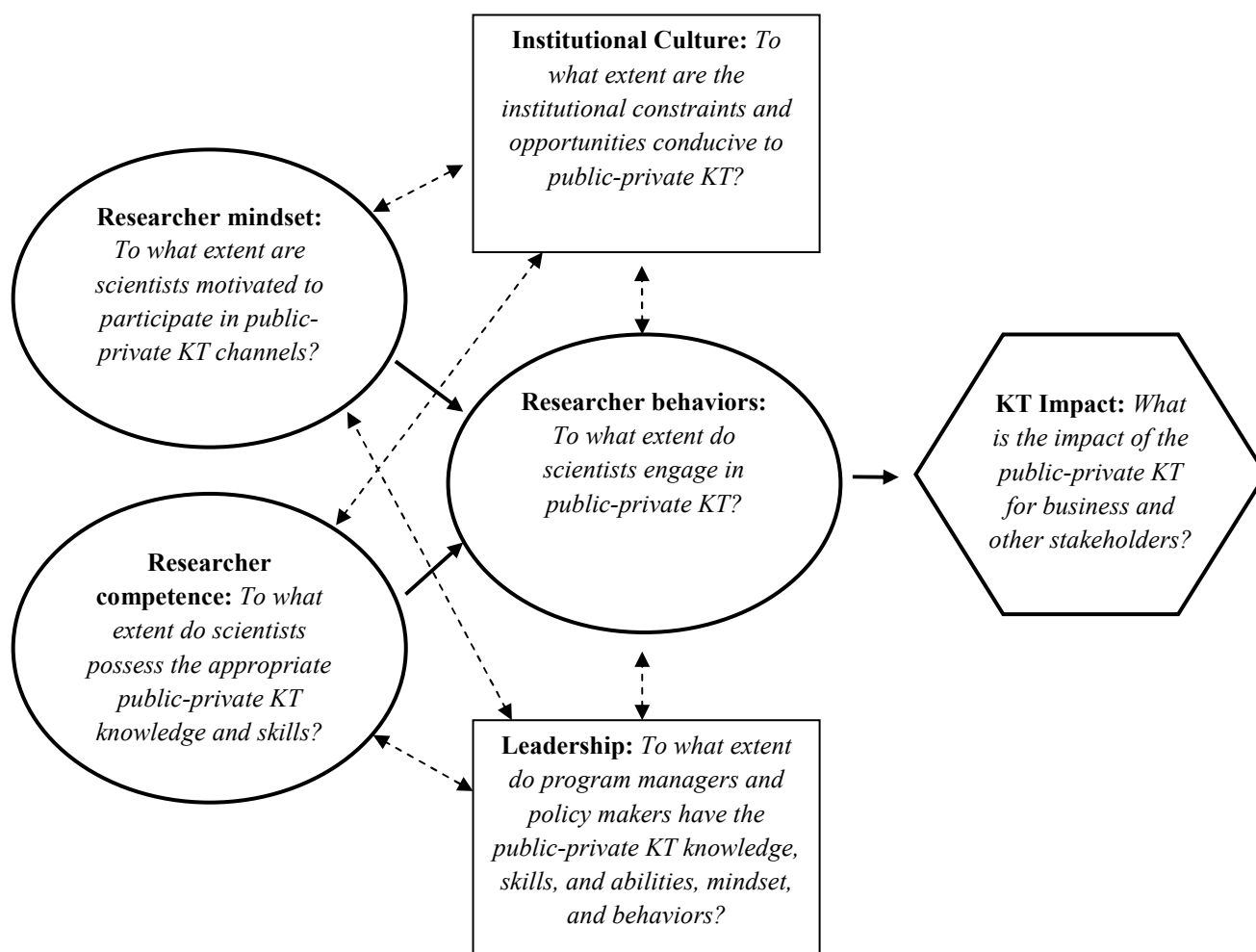
In terms of the finalization of the final product, the four KT channels singled out above are characterized with low to medium finalization. This is also related to the motivations of university scientists to engage in KT: by and large, the motivations of university scientists to participate in KT with industry are congruent with the traditional norms of science – commercialization and monetary rewards are generally weaker motivators than access to new problems, instrumentation, *etc.* From an HR perspective, this is also important because it suggests that the most common, and most important, KT channels are also the most congruent with the traditional university missions and faculty motivations. However, such a potentially high degree of goal congruence does not imply that all mutually beneficial KT transactions that could occur, do occur. The likelihood of participation is contingent on other characteristics of KT (*e.g.* type and complexity of knowledge) and, especially, on contextual factors such as organizational policies, reward systems, policies and regulations, *etc.* Finally, the four channels suggested above are also characterized with medium to high goal congruence, which further delimits the range of appropriate strategies (Boardman & Ponomariov, 2012, forthcoming).

This overview simplifies the task of conceptualizing HR interventions since it limits the focus to altering individual behaviors (versus more complex institutional and organizational interventions that are required to manage activities such as transfer of IP). The above taxonomy should not be taken as “final”, but as a framework to assist in conceptualizing the process of knowledge transfer / knowledge generation as integrating knowledge characteristics, individuals and organizational forms. Until recently (Lam, 2000), there have been relatively few attempts at such analysis. Section 3 provides a framework to assist with the derivation of appropriate HR strategies. The framework will utilize insights gleaned from the preliminary taxonomy above and will suggest viable policy and management levers in the context of U-I KT.

3. Making sense of the U-I KT literature using an organizational behavior framework

The framework in Figure 1 below aims to highlight individual and group contributions towards U-I KT goals. It is an adaptation of Philips and colleagues’ (2001) “HR scorecard” approach, expanded to include contingencies specifically relevant to KT (*i.e.* leadership and institutional culture). After identifying that individual involvement in KT is essential for most KT channels, it follows that a systematic understanding of the determinants of this behavior will be useful. Since involvement with industry remains predominantly discretionary behavior for most university-employed faculty, the behavioral aspect of the framework needs to incorporate measures of whether or not faculty engage in any KT channels, and if so, whether their activities within KT channels are congruent with the internal logic and needs of each channel. This framework also implicitly recognizes that at present most KT channels are not institutionalized and formalized, and therefore alternative levers (*e.g.* leadership behaviors and organizational development) need to be explored.

Figure 1. Organisational behaviour framework for identifying the knowledge base for the strategic management of HR in U-I KT



Faculty behaviors are likely to be determined by their mindset (e.g. their motivation to engage in commercialization), and competences (e.g. understanding the needs of industrial partners). Finally, the relationship between mindset, competencies and behaviors can be mediated or moderated by leadership and institutional culture. Multiple configurations of these factors are possible (and amenable to management interventions).

For example, while some university faculty and groups of researchers and other stakeholders designated to participate in U-I KT may have the knowledge, skills and abilities appropriate to perform this task and make the intended contributions towards KT goals, other individuals and groups with the same knowledge and training can underperform when it comes to KT goals (Boardman & Ponomariov, 2012, forthcoming). Why? One of the most valuable outcomes of an analytical review of the literature on U-I KT channels is to address this question systematically, drawing on and structuring the relevant insights to make clear what we understand about organizational behavior as it pertains to U-I KT and what we do not

understand about this process. The framework here considers the numerous factors or variables that may affect individual and group performance, including not just knowledge and training, but additional factors or variables, such as worker motivation and understanding of organizational goals and strategy, worker behaviors and leader behaviors (Phillips, *et al.*, 2001; Vasu, Stewart & Garson, 1998).

The framework emphasizes the multivariate nature of individual and group performances in U-I KT. Performance and success are dependent not just on individual and group competencies, but additionally on individual and group mindsets and behaviors. Note that the example questions in each part of the framework addressing researchers (denoted by an oval) ask about the extent to which researchers and/or groups of researchers exhibit particular characteristics. Individuals and groups can vary greatly in terms of their mindsets, competencies and behaviors, and therefore in terms of their individual and group performance and success at contributing towards U-I KT goals.

The framework also addresses institutional and managerial factors or variables that are manipulable by policy, law and organizational development and/or design (denoted by rectangles) and that can affect individual and group performance and success at U-I KT. For example, leadership responses at the program or agency level to a deficiency in knowledge and abilities (see the competencies part of the framework) may be worker training and development or the recruitment of new talent; managerial responses to unmotivated workers (see the mindset part of the framework) may be to alter leadership styles or, if feasible given environmental constraints, to restructure incentives; responses to a lack of coordination and communication within an organization (see the behaviors part of the framework) may include organizational design and culture development.

Thus, there are three levels of analysis considered by the framework. It begins with individuals and groups thereof and then addresses policy and administrative responses when individuals and groups are not contributing to U-I KT goals. Environmental constraints such as economic conditions are excluded from the framework because these seldom are immediately or directly manipulable by policy makers and administrators for the implementation of U-I KT processes.

The next step is to address each component of the framework and to describe which components (if any) of the above reviewed literature (section 2) informs that component. Consistent with our observation at the beginning of section 2, about heavy emphasis on U-I KT outcomes in the U-I KT literature and limited emphasis on U-I KT processes, the reorganization of the U-I KT literature highlights major gaps in understanding in the U-I KT literature pertaining to: *i*) individual researcher mindsets/motivations and knowledge and skills as these pertain to U-I KT; and *ii*) leadership and institutional culture as these relate to U-I KT.

3.1 Individual and group levels of analysis

Here, the framework is used to provide suggestions for “reorganizing” the literature on U-I KT reviewed in section 2. This subsection addresses the issues contained in the ovals in the framework (Figure 1), which are focused on researchers themselves. Because the framework is based not on the relatively narrow literature on U-I KT, but rather on the very broad literature on organizational behavior and strategic HR management (*e.g.* Vasu *et al.*, 1998), the reorganization sees some components of the framework (*e.g.* on worker motivations and mindsets) “empty” or without much (or any) relevant literature on U-I KT. Nevertheless, as the broader organizational behavior and strategic HR management literature is

focused almost exclusively on knowledge-based work, the framework based on this broad literature is most appropriate for thinking about knowledge and knowledge gaps regarding researchers' competencies, mindsets and behaviors as they pertain to U-I KT (which, too, is knowledge-based work).

3.1.1 *Researchers' behaviors*

This portion of the framework describes the numerous ways and the extent to which scientists engage in U-I KT channels, as identified in Section 2. The relevant measures of their activity can range from the very simple, such as asking scientists if they have engaged in any KT activities during a given period, to the more granular, such as asking about the amount of time allocated to relevant activities, as well as about the nature of the specific tasks they undertake. A study by D'Este and Patel (2007) provides useful estimates about the general prevalence of such behaviors: they estimate that about 65% of scientists engage in meetings and conferences, about 56% reported engaging in consultancy and contract research, and 44% in joint/collaborative research. At the individual level, all of these activities can be tracked either through surveys or through university information systems, annual reviews, *etc.* Other studies (*e.g.* Bozeman & Gaughan, 2007, and the majority of papers based on the Research Value Mapping program's data) estimate that about 50% of university scientists are engaged in some form of interaction with industry, though with varying intensity and in varying ways depending on personal (Boardman & Ponomariov, 2007) and institutional factors (Boardman, 2009).

Seniority (*e.g.* as approximated by being tenured), is generally positively associated with the likelihood to engage in interactions with industry (Link, *et al.*, 2007), and in general researchers increase their interactions with industry as they get older, even if their overall scientific productivity flattens (van Rijnsouwer, Hessels & Vandeberg, 2008). In addition, the nature of the scientists' career trajectories appears to matter: industry experience prior to accepting an academic appointment is associated with a higher likelihood of patenting in their academic careers (Dietz & Bozeman, 2005), while there may be some gender inequities – women were less likely to engage in some types of collaborations, such as university research centers (Corley & Gaughan, 2005).

The significance of seniority/rank as a predictor of commercial involvement goes beyond experience and accumulated human and social capital, and is also the result of the reward structures in academia, which induce scientists to invest in developing their scientific reputation early in their career by making research contributions upon which they can capitalize later in their careers (Agrawal, 2001).

Beyond the issue of discrete information on whether university scientists are engaged in some form of U-I KT, the issue of intensity and type of involvement has not been sufficiently studied, although advances in its operationalization have been made in the context of university research centers (Boardman, 2009). The scale and scope of relevant changes in researcher behaviors has been successfully measured indirectly (Ponomariov & Boardman, 2010), by using publication data, which allows to discern if scientists collaborative behavior and research content have changed in accordance to the priorities of a university research center with which they affiliate.

Additionally, the studies discussed in sections 2.3.2-2.3.6 and 2.3.10 constitute empirical analyses of researchers' behaviors. The extent to which this component of the broad literature on U-I KT satisfactorily provides useful knowledge of researchers' behaviors as they pertain to KT is discussed in the concluding subsection (3.4) below.

3.1.2 *Researcher mindset*

This portion of the framework describes the extent to which scientists are motivated to engage in U-I KT activities, and their attitudes and beliefs regarding U-I KT and the attendant work activities. However, the existing literature on the motives of researchers to work with industry has limited, mostly general, insights on institutional (*e.g.* university research centers), disciplinary (*e.g.* engineering, life sciences), and personal/professional (*e.g.* gender, tenure status) characteristics. In general, there is anecdotal evidence of an increasing, if sometimes uneasy (Glaser & Bero, 2005; Lee, 1996), acceptance among university scientists that interactions with industry are beneficial both to individual careers and to institutions and economies, but there are few if any direct assessments of researchers' motivations and mindsets regarding U-I KT activities (though some studies no less claim, incorrectly, to have made such direct assessments). General characteristics of researcher mindsets, such as trust and personal motivation (Gibson & Smilor, 1991), do matter in KT, but it is unclear how to cultivate them other than acknowledgements that the local organizational and leadership environments influence these mindsets (Bercovitz & Feldman, 2008). Regardless, changes in scientists' mindset (*e.g.* propensity to disclose inventions and to patent) has tangible effects on university patenting output (Thursby & Thursby, 2000), and therefore is a viable lever for HR interventions.

Accordingly, hardly any of the studies discussed in section 2 constitute empirical analyses of researchers' motivations and mindsets as they pertain to U-I KT specifically, although there are some general assessments of university scientists general beliefs in "open science" (*e.g.* Anderson, 2000) or general attitudes towards commercially relevant research (*e.g.* Boardman & Ponomariov, 2007). This gap in the literature on U-I KT is discussed in the concluding subsection (3.4) below.

3.1.3 *Researcher competencies*

This portion of the framework describes the extent to which scientists possess the necessary knowledge, skills and abilities to engage in U-I KT channels. This is not to be confused with their general scientific professional competencies, although studies suggest that general scientific excellence of faculty facilitates interactions with industry (Perkmann, King & Pavelin, 2011). It describes their general ability to identify and work with industry partners, and their knowledge of the relevant university rules and procedures. The existing work on the topic of industrial competencies has focused mostly on institutional level background and competencies, not on individual researchers. For example, Freier (1986) shows that a university can become a center of a local technological hub without altering its "character" and core missions. One study, indirectly studying the issue of competencies (Dietz & Bozeman, 2005) found that individuals with industry experience were likely to be more productive and have more patents upon transitioning into an academic career, thereby suggesting that industrial experience equips them with competencies relevant to pursuing industry-relevant activities in academia.

Finally, while technology transfer activities require somewhat different mindsets and competencies (Bercovitz & Feldman, 2008), scientists tend to adopt these behaviors if the local organizational and leadership contexts favor or emphasize commercialization-oriented activities.

Accordingly, hardly any of the studies discussed in section 2 constitutes empirical analyses of researchers' competencies as they pertain to U-I KT. This gap in the literature on U-I KT is discussed in the concluding subsection (3.4) below.

3.2 *Policy and management levers*

This subsection addresses the rectangles in the framework (Figure 1), which are focused on actions that policy makers and administrators in government, academia and industry can take to facilitate U-I KT under the present circumstances. The primary utility of the framework is to provide a systematic overview of the relevant components of a system affecting scientists' behaviors in regard to KT, and thus to also derive guidelines for altering this system to elicit change in individual behaviors, attitudes and skills as they pertain to U-I KT (summarized in 3.1). Putting this general conceptual map into the specific constraints brought by the context of KT further clarifies what are the realistic "levers" that can be adjusted to influence individual researchers' behaviors, mindsets and skills for U-I KT, directly and indirectly.

3.2.1 *Institutional culture*

Only a limited amount of the literature reviewed in section 2 assesses the role of institutional culture in U-I KT. Institutional culture can be affected either at the university level, or (more likely) at the departmental or organized research unit (*e.g.* university research center) level. It can address informal norms and expectations for behavior (*i.e.* culture), formal structural elements (*e.g.*, organizational complexity and centralization), or both (Vasu *et al.*, 1998). Institutions may be addressed at the organizational as well as the individual levels of analysis (Vasu *et al.*, 1998).

Some studies (*e.g.* Kenney & Goe, 2004; Berkovitz & Feldmann, 2008) demonstrate that being embedded in an academic department and disciplines in which cultures are supportive of interaction with industry can help counteract any disincentives that may be created by an unsupportive university environment. Broader university climate can also affect individual propensity (or lack of) to interact with industry (Ponomariov, 2008). Ponomariov (2008) found that researchers in universities with higher academic prestige exhibit somewhat lower propensity to interact with industry. This finding is consistent with the premium placed on advancements in basic research at the most elite universities. However, similar dynamics also operate in many departments. Boardman & Ponomariov (2007) found at the individual level that junior (*i.e.* untenured) scientists were less likely to approve of and engage in industry-relevant activities, likely because such activities are not considered as relevant or important in awarding tenure decisions.

There is also a growing literature on institutional heterogeneity and how this may affect U-I KT on the part of university researchers. Boardman (2009) finds that researchers affiliated with university research centers sponsored by government programs with industry-relevant goals produce more, and more varied, types of U-I KT when compared to university researchers affiliated with centers sponsored by industry but not government. Boardman concludes (speculatively, given data limitations) that government requirements for interdisciplinary work in centers is facilitative of new types of U-I KT, whereas the industry-only centers facilitate KT on the part of university researchers that was part of their respective, usual repertoires before they participated in their centers. The institutional culture of government-sponsored centers is different due to its disciplinary diversity when compared to industry-sponsored centers. Regardless of the setting, institutional culture and procedures are likely to play an increasingly important role in KT – as some (*e.g.* Abreu *et al.*, 2010) have reported, the vast majority of university-industry interactions are initiated by organizations or individuals external to the university. If so, the ability to acknowledge,

accommodate and account for such efforts at the institutional level is likely to affect the likelihood of such interactions occurring at the individual level.

Accordingly, only the studies discussed in sections 2.3.2 and 2.3.8 constitute empirical analyses of institutional culture as it pertains to U-I KT. This gap in the literature on U-I KT is discussed in the concluding subsection (3.4) below.

3.2.2 *Leadership*

Only a limited amount of the literature reviewed in section 2 assesses the roles of leaders and managers in U-I KT. This is not surprising considering that universities and university departments are highly decentralized, and that university scientists have a large degree of autonomy regarding what types of tasks and projects to pursue.

The few existing studies on leadership in U-I KT concern hybrid institutions, such as university research centers, which require a higher degree of co-ordination and where leadership behavior can thus have a more discernible direct impact. One study (Boardman & Ponomariov, 2012, forthcoming) evaluates the leadership strategies of university center directors as a function of resource dependencies (or the lack thereof) and of goal alignment (or the lack thereof). Related, a study by Boardman and Ponomariov, 2012 (forthcoming) assesses the relationship between university researchers' management knowledge (not knowledge management, *e.g.* industry experience, past experiences leading industry contracts) and their approaches to leading university-industry research centers sponsored by the US National Science Foundation. Another study (Geisler, *et al.*, 1990) reported that the qualities and behaviors of center leaders are an important factor determining the success or failure of co-operative research centers. Also, Geisler and colleagues (1990) established that having "champions" for the center in the university administration is an important factor affecting its viability.

Despite the limited research on U-I KT leadership in centers, it is especially important due to the social goals of these centers (*e.g.* innovations for curing cancer, surveillance of terrorism) and to the confluence of management constraints that often hinder leadership in centers. Case studies suggest that most centers lack the governance mechanisms required for co-ordinated problem solving among diverse actors, including but not limited to goal congruence and resource interdependence among participants, and have limited managerial discretion for the internal development of formal structures and authorities (Boardman & Bozeman, 2007). The deficit in this literature is perhaps one of the most important to address with the development of new cases and data sets because numerous national governments and many regional governments implement policies and programs addressing problems requiring scientific and technical remedies by establishing such centers (Bozeman & Boardman, 2004).

Accordingly, only some of the studies discussed in section 2.3.8 constitute empirical analyses of leadership as it pertains to U-I KT. This gap in the literature on U-I KT is discussed in the concluding subsection (3.4) below.

3.2.3 *Structure / Procedures*

Given the above discussion of "relevant and important" KT channels and the discretionary nature of most KT interactions, organizational design approaches have limited relevance. However, some aspects

have been discussed in prior study, primarily in regards to regulating the transfer of IP from universities. Prior studies have found that royalty distribution formulas and efficiently functioning TTOs generally positively affect the propensity of faculty to disclose inventions (Lach & Schankerman, 2008) and the rate of creation of spin-off companies (DiGregorio & Shane, 2002). Additionally, perceived inefficiencies and costs associated with interacting with offices of technology transfer are found to be deterrents to faculty desire to disclose inventions (Owen-Smith & Powell, 2001).

But the presence of TTOs does little to inform policy and management pertaining to U-I KT. Some of the literature on leadership in university research centers addresses structure and procedure (see 3.2.2), but only as outcomes themselves. There is little understanding of how structural variations relate to U-I KT outcomes, for which there is a relatively rich empirical literature (see 3.3).

Accordingly, only some of the studies discussed in section 2.3.8 constitute empirical analyses of leadership as it pertains to U-I KT. This gap in the literature on U-I KT is discussed in the concluding subsection (3.4) below.

3.3 *U-I KT Impact*

This subsection addresses the hexagon in the framework (Figure 1), which is focused on outcomes that may be characterized as U-I KT. Because of the heavy emphasis on U-I KT outcomes in the U-I KT literature, most of the studies reviewed in section 2 fall under this category, specifically sub-section 2.6 on the impact of KT. Of somewhat peripheral importance are studies of the indirect impact of KT on universities and related unintended consequences (*e.g.* Behrens & Gray, 2001) and concerns over too much industrial influence on universities and their core missions. Such studies were outside the scope of this review, but theoretically it appears that their messages and concerns are unwarranted considering that the recent literature on U-I KT is suggestive of a high level of congruence between university and private sector goals and expectations, and the relative importance of different KT channels (*e.g.* Bekkers & Bodas Freitas, 2008). Others suggest that commercially-relevant and academic activities in KT may be mutually reinforcing both at the individual (Gulbrandsen & Smeby, 2005; Mitchell & Rebne, 1995; Owen-Smith, 2003; Van Looy, *et al.*, 2004) and the institutional (Owen-Smith, 2003) levels.

3.4 *Concluding remarks*

As a result of the framework application to the literature on U-I KT, our commentary at the beginning of this report on the heavy emphasis in the literature on outcomes rather than processes is validated. Whereas from the literature we can identify policy and program instances in which particular KT outcomes (*e.g.* patents, informal contacts, publications, student transfer) have been achieved, the literature tells us very little about the individual factors and organizational processes that helped to facilitate these outcomes. Without systematic investigation into the processes of U-I KT at the individual and organizational levels of analysis, which the application of the framework reveals has yet to occur, policy making for U-I KT will continue to be characterized by high levels of uncertainty regarding the production of intended and unintended outcomes of and returns on investment from these policies. Future research must emphasize processes at the individual and organizational levels of analysis, informed by the broader literature on organizational behavior and strategic HR management.

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