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Evidence on how academics manage their portfolio of knowledge transfer activities

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ABSTRACT

The purpose of this paper is to explore whether six broad categories of knowledge transfer activities undertaken by academics: the creation and diffusion of knowledge through publications, transmission of knowledge through teaching, informal knowledge transfer, patenting, spin-off formation and consulting activities, are complementary, substitute, or independent, as well as the conditions under which complementarities, substitution and independence among these activities are likely to emerge. This investigation relied on data regarding 1554 researchers funded by the Natural Sciences and Engineering Research Council of Canada. Contrary to prior studies which have examined complementarities and the determinants of knowledge transfer activities in separate models, this study relied on a multivariate path model to reflect the fact that in practice, academics consider simultaneously whether or not to undertake multiple knowledge transfer activities. Overall, the results point to the existence of three very different types of knowledge transfer portfolios of activities: a first portfolio made up of complementary activities which are interdependent and reinforce each other. This portfolio includes publications, patenting, spin-off creation, consulting and informal knowledge transfer. A second portfolio includes teaching activities and publication outputs which are substitute for each other. A third portfolio comprises teaching activities and other activities independent from teaching, namely, patenting, spin-off creation, consulting and informal knowledge transfer. Each of these three portfolios of knowledge transfer activities emerged under different conditions. Implications are derived for managerial practice and future research.

1. Introduction

The way academics perform their different knowledge transfer activities has been the focus of unresolved debates as university administrators and public policy makers seek to improve faculty performance. Academics engage in six broad categories of knowledge transfer activities: the creation and diffusion of knowledge through publications, transmission of knowledge through teaching, and informal knowledge transfer represent three forms of non-commercial knowledge transfer activities, while getting granted patents, engaging in spin-off formation and consulting services constitute three forms of commercial knowledge transfer activities (Perkmann and Walsh, 2007; Upstill and Symington, 2002). Given a free choice, the involvement in multiple forms of knowledge transfer activities is likely to exhibit differences from one academic to another. This issue raises a question dealt with by portfolio management (Cooper et al., 2006): how do academics decide what knowledge transfer activities to get involved in? Portfolio management of knowledge transfer activities refers to the idea that, like entrepreneurs, academics constantly update and revise their list of activities and the projects composing these activities. In doing so, new activities are assessed, selected and prioritized; on-going activities may be accelerated, cancelled or de-prioritized; and resources may be allocated and re-allocated to and between the different knowledge transfer activities. In practice, however, academics may make joint decisions for multiple knowledge transfer activities rather than treating them independently, due to the presence of complementarities that arise from interrelated knowledge transfer activities. University administrators and policy makers who fail to take into account such interdependencies by treating complementary knowledge transfer activities atomistically are likely to prevent academics from exploiting opportunities for cost saving in knowledge transfer activities, as well as to prevent them from drawing on tacit interrelated skills.

When considering the performance of academics in different knowledge transfer activities, three hypotheses emerge (Azoulay et

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al., 2007; Colbeck, 1998; Grimpe and Fier, 2009; Mitchell and Rebne, 1995; Walckiers, 2004). The first hypothesis suggests that complementarity arises when doing more of one knowledge transfer activity increases the returns to doing more of another knowledge transfer activity. According to Milgrom and Roberts (1995), complementarity effects generally involve benefits that arise from making joint decisions about multiple activities. The second hypothesis suggests that substitution arises when doing more of one knowledge transfer activity reduces the performance of another activity; for example, it would be the case if teaching more would reduce the publication performance of academics. Finally, independence among knowledge transfer activities arises when changes in one knowledge transfer activity do not change the performance of other knowledge transfer activities. This study has two purposes. First, it explores whether six knowledge transfer activities, specifically publishing, teaching, informal knowledge transfer, getting granted patents, engaging in spin-off formation and consulting services, exhibit complementarity, substitution or independence effects. Second, it explores the conditions under which complementarity, substitution or independence is likely to emerge. By investigating empirical evidence, we aim to derive implications regarding complementarities among knowledge transfer activities and to lay the basis for some future theoretical work on knowledge transfer activities.

This paper makes four contributions in extending our understanding of the links between knowledge transfer activities undertaken by academics. First, prior studies on knowledge transfer have examined the role of institutions, especially universities and university transfer offices, in fostering knowledge transfer. Such an institutional unit of analysis is appropriate to capture formal knowledge transfer activities that are disclosed to university administrators. This paper contributes to advance knowledge by using the individual scientist as its unit of analysis in order to integrate, in a single study, formal and informal knowledge transfer activities in order to take into account both disclosed and undisclosed knowledge transfer activities. Such a perspective is appropriate to shed a more comprehensive light on knowledge transfer activities undertaken in universities, as well as to contribute to advance knowledge on the interplay between formal and informal knowledge transfer activities undertaken by academics.

Second, there is a growing empirical literature that has adopted the individual knowledge transfer activity interaction approach to investigate the one-on-one relationships among individual knowledge transfer activities. Hence, prior studies show that publications and patents are not substitute for one another, but that they may even be complementary (Azoulay et al., 2009; Czarnitzki et al., 2007; Fabrizio and Di Minin, 2008; Godin and Gingras, 2000; Landry et al., 2006, 2007a; Meyer, 2006; Van Looy et al., 2004, 2006). Similarly, Mitchell and Rebne (1995) have shown that consulting and publication performance are complementary up to a certain extent. Other studies suggest that formal commercial and informal non-commercial technology transfer are complementary (Grimpe and Hussinger, 2008; Link et al., 2007; Siegel et al., 2003). No study, however, has relied, like this study does, on a system perspective to simultaneously investigate the relationships among six major commercialized and non-commercialized knowledge transfer activities that may be undertaken by academics. Applying a system perspective yielded evidence on the presence of complex interactions among multiple knowledge transfer activities. As suggested by Ennen and Richter (2010), the individual knowledge transfer activity interaction approach might fail to detect complementarity effects between two knowledge transfer activities, due to interactions or absence of interaction with other knowledge transfer activities outside the focus of studies based on the one-on-one relationship approach between knowledge transfer activities. The results of this study contribute to uncover complementarity effects among multiple forms of commercial and non-commercial knowledge transfer activities that capture more adequately the knowledge transfer activities of academics than studies based on a few selected knowledge transfer activities.

Third, prior studies on complementarities and substitution among a few knowledge transfer activities have also tended to focus attention on single fields, like biotechnologies (Gittelman and Kogut, 2003; Murray, 2004), or nanotechnologies (Meyer, 2006). Other prior studies on complementarities and substitution between knowledge transfer activities cover many research fields, but they have focused on individual universities (Ranga et al., 2003; Van Looy et al., 2004, 2006). This study contributes to advance knowledge and improve the generalization potential of findings by exploring complementarities, substitution and independence between knowledge transfer activities across six research fields in natural sciences and engineering, and by looking at a large sample of academics operating in small, medium and large research universities.

Fourth, prior studies have examined the determinants of knowledge transfer activities in separate models. No study has investigated the conditions under which academics will be active concurrently in multiple knowledge transfer activities. This paper uses a multivariate path model to reflect the fact that in practice, academics simultaneously consider whether or not to undertake concurrently multiple valuable knowledge transfer activities rather than treating them independently. The multivariate path model includes six equations referring to the six knowledge transfer activities mentioned above. To the extent of our knowledge, the multivariate path model approach to data analysis has never been used to address the issue of how academics decide what academic activities to get involved in. The multivariate specification allows for systematic covariances between choices for the different types of knowledge transfer activities. Such covariances may be due to complementarities (positive covariances) or substitution (negative covariances) between these activities. The six knowledge transfer activities included in this study are: teaching, publishing, patenting, spin-off formation, consulting and informal knowledge transfer. The explanatory variables included in the multivariate path model are the following: financial assets (private funding and internal funding), knowledge assets (research fields and novelty of research results), network assets, organizational assets (research unit size and research university size), and personal assets (experience and academic rank).

The paper is organized as follows. First, we review the arguments supporting the complementarity, substitution and independence hypotheses. Secondly, we review studies reporting evidence regarding the determinants of the different knowledge transfer activities included in this study. Thirdly, we provide information about the data and descriptive statistics. The next section discusses the estimation results, and the final section concludes with a discussion of implications from the results for the management of knowledge transfer activities.

2. Complementarities, substitution and independence among knowledge transfer activities

We first identify and define knowledge transfer activities that academics may undertake, and outline arguments concerning complementarities, substitution and independence among knowledge transfer activities. We argue that the transfer of knowledge from academics to knowledge users may involve commercial and non-commercial knowledge transfer activities (Perkmann and Walsh, 2007; Upstill and Symington, 2002). Commercial knowledge transfer activities are based on formal commercial agreements between academics and knowledge users. The major commercial knowl-

Table 1
Commercial and non-commercial knowledge transfer activities undertaken by academics.

Commercial knowledge transfer activities based on formal commercial agreements between academics and knowledge users:	
Granted patents	Patents refer to a right granted to anyone who invents or discovers any new and useful process, machine, article of manufacture, or composition of matter, or any new and useful improvement thereof
Spin-off formation	Development and commercialization of technologies undertaken by academic inventors through the creation of a spin-off company they own at least in part
Consulting services	Activities commissioned by industrial clients or government agencies including contract research and consulting activities
Non-commercial knowledge transfer activities taking place without any contractual agreements between academics and knowledge users:	
Scientific publications	Publication of codified scientific knowledge transferred in the pool of open science
Teaching	Knowledge transfer achieved when students graduate and are hired by companies and other types of employers
Informal knowledge transfer	Informal pathways through which knowledge is exchanged across academic and members of companies and other types of organizations

edge transfer activities undertaken by academics include patenting, spin-off formation and consulting services. As for non-commercial knowledge transfer activities, they take place without any contractual agreements between academics and knowledge users. They usually take three major routes: publications, teaching and informal knowledge transfer. Table 1 defines these six knowledge transfer activities.

As pointed out by Link et al. (2007), commercial knowledge transfer has attracted much attention in the academic literature. By comparison, with a few exceptions (Grimpe and Hussinger, 2008; Grimpe and Fier, 2009; Landry et al., 2001, 2007a; Link et al., 2007), informal knowledge transfer has received little attention in the empirical literature. Informal knowledge transfer refers to activities undertaken by academics to foster the flow of knowledge through informal communication processes, such as sending technical reports to knowledge users outside the scholarly milieu, giving presentations in a technical seminar organized by firms or other types of organizations, participating in industry expert groups or expert committees that are involved in efforts to directly apply research knowledge, etc. (Landry et al., 2007a). According to Grimpe and Fier (2009), informal knowledge transfer appears to be a dominant mode of collaboration between academics and knowledge users. Many, if not most academics, do not disclose their informal knowledge transfer activities to their university administrators. Similarly, as shown by Hall et al. (2003), Siegel et al. (2003), and Thursby et al. (2007), and many academics in the United States do not disclose their commercial knowledge transfer activities to their university administrators, although prescribed by law. In order to capture as comprehensively as possible the knowledge transfer activities undertaken by academics, we conducted a survey asking them to report on the knowledge transfer activities that they have personally (in order to cover non-disclosed activities), or their university on their behalf (to cover disclosed activities), engaged in (see Appendix A for operational definitions of the six knowledge transfer activities used as dependent variables).

Let us now turn our attention to the notion of complementarity by addressing three questions: when do complementarities arise? Why do complementarities arise? How to approach the study of complementarities? According to Milgrom and Roberts (1995, p. 181), complementarities arise when "doing more of one thing increases the returns to doing more of another". Milgrom and Roberts (1995) suggest that most generally, complementarities generate benefits that arise when joint decisions are made about multiple activities. Hence, the notion of complementarity suggests that performance in one knowledge transfer activity predicts performance in that activity as well as in the other activities associated with it (Mitchell and Rebne, 1995; Walckiers, 2004). Each knowledge transfer activity generates outputs that become inputs for other knowledge transfer activities. More concretely, it suggests that the outputs of certain knowledge transfer activities may become the asset base upon which other knowledge transfer activities may build. As a consequence, performance in certain knowledge transfer activities may generate a leverage effect on other activities. According to Ennen and Richter (2010), Roberts (2004), and Tzabbar et al. (2008), complementarities generate system effects such as that "the whole becomes more (or less) than the sum of its parts". In other words, the total effects on knowledge transfer performance that are generated from increasing all the knowledge transfer activities together are greater than the sum of the impacts of the individual knowledge transfer activities.

The complementarity hypothesis is recurring in the literature on knowledge transfer activities, as exhibited by the following claims:

- "Being active in research might improve teaching skills and vice versa" (Colbeck, 1998; Layzell, 1996; Walckiers, 2004).
- The increase in interactions between science and technology (Azoulay et al., 2009; Etzkowitz and Leydesdorff, 1997; Narin et al., 1997) suggests that certain knowledge transfer activities may be complementary.
- The Triple Helix model of knowledge exchange between university, industry and government also points to the idea that research, knowledge and technology transfer activities may be complementary (Etzkowitz, 2003; Etzkowitz and Leydesdorff, 1997).

Although quantitative studies investigating complementarities are still scanty, there is a growing number of studies supporting the complementarity hypothesis between:

- Teaching, research and consulting (Mitchell and Rebne, 1995).
- Entrepreneurial and academic activities (Carayol, 2003; Owen-Smith, 2003; Van Looy et al., 2006).
- Patenting and publications (Azoulay et al., 2007; Breschi et al., 2008; Czarnitzki et al., 2007, 2009; Fabrizio and Di Minin, 2008; Stephan et al., 2007).
- Formal commercial and informal non-commercial knowledge transfer activities (Grimpe and Hussinger, 2008; Link et al., 2007; Siegel et al., 2003).

The benefits that may arise from complementarities are due to economies of scope. It suggests that academics might create economies of scope that reduce the costs of knowledge transfer activities by becoming more efficient due to the fact that they jointly coordinate multiple knowledge transfer activities. Hence, academics can reduce the costs of their knowledge transfer activities when they make a more efficient utilization of resources that can be shared among multiple knowledge transfer activities, when they leverage the outputs of one knowledge transfer activity over multiple knowledge transfer activities, when they share their expert knowledge and skills for multiple knowledge transfer activities.

In a recent literature review of the empirical literature on complementarities in organizations, Ennen and Richter (2010) differentiated studies based on the interaction approach from those relying on the systems perspective. As indicated above, prior studies on complementarities of knowledge transfer activities based on the first approach focus on one-on-one relationships among a limited set of knowledge transfer activities. In contrast, the systems perspective involves extensive systems of knowledge transfer activities. Ennen and Richter (2010, p. 225) suggest that future empirical studies on complementarities "should avoid walking the beaten tracks of the interaction approach versus the systems approach and seek to explore the middle ground between them". The system approach is adopted in this study by focusing attention on six knowledge transfer activities.

The notion of complementarity coexists with the notion of substitution. The notion of substitution rests on the idea that academics are resource-constrained and therefore, involvement in one knowledge transfer activity comes at the expense of involvement and performance in the other activities (Mitchell and Rebne, 1995; Walckiers, 2004). The substitution hypothesis implicitly assumes that knowledge transfer activities are separate, dissociated, and "fragmented", and that doing more of one activity reduces the performance of doing another activity (Colbeck, 1998). Azoulay et al. (2007) and Geuna and Nesta (2006) have recently discussed possible substitution effects between publishing and patenting, and between publishing and teaching.

Other empirical studies pointed to the fact that knowledge transfer activities were actually separate activities that were independent from each other (Godin and Gingras, 2000; Meyer, 2006). In their study on the relationship between teaching and research, Hattie and Marsh (2004) concluded that "there is zero relationship between teaching and research at the individual level and at the departmental level".

To sum up, there is no definitive answer to the complementarity, substitution and independence hypotheses. However, although prior empirical studies appear to generally support the complementarity hypothesis, there are as yet no empirical studies that have simultaneously considered publishing, teaching, informal knowledge transfer, patenting, spin-off formation, and consulting activities in a single econometric model like in the present study.

3. Determinants of knowledge transfer activities

There are as yet no studies that have compared the determinants of these different activities like in the present study. A better understanding of these determinants is likely to shed new light on the factors that contribute to reinforce or attenuate complementarity and substitution effects. In order to explain why academics engage in various knowledge transfer activities, we draw on the resource-based theory of firms (Conner and Prahalad, 1996; Grant, 1996; Kogut and Zander, 1992; Landry et al., 2006, 2007a) to assume that, like entrepreneurs, academics control bundles of idiosyncratic resources and capabilities which are deployed and mobilized in the accomplishment of their knowledge transfer activities. However, it is important to point out that previous studies on the determinants of knowledge transfer activities tend to focus on the determinants of publications, patents and spin-off formation, with much less attention paid to the determinants of the other activities. In the literature on knowledge transfer activities, resources that enable academics to undertake knowledge transfer activities include financial, knowledge, organizational, network, and personal assets.

3.1. Financial resources

The creation, transmission and transfer of knowledge require a large variety of resources, notably financial resources (Stephan, 1996). Prior studies showed that the publication record of academics is strongly influenced by their funding structure (Gaughan and Bozeman, 2002; Landry et al., 2006, 2007a; Lee and Bozeman, 2005). Patenting and spin-off creation are also strongly influenced by the funding structure of knowledge transfer activities (Azagra-Caro et al., 2006; Baldini et al., 2007; Breschi et al., 2008; Krabel and Mueller, 2009; Landry et al., 2007b; O'Shea et al., 2005). The level and variety of funding controlled by academics may also provide an indication of the magnitude of the equipment they can deploy, not only in the creation and commercialization of research, but equally in other knowledge transfer activities such as teaching and informal knowledge transfer. Most academics may rely on three sources of funding: internal university sources, funding from university research granting councils, and industry sources. To capture the variety of funding sources, we relied on information regarding each of these three funding sources. Every respondent had funding from the Natural Sciences and Engineering Council of Canada because it was used as an inclusion criterion in the population targeted by this study. The importance of internal university funding and the importance of private funding were used to capture the two other constitutive elements of funding variety. The variable research unit size is also used as a proxy to assess the importance of funding (see Section 3.4 for a discussion of this variable). In this paper, we hypothesize that the greater the importance of internal university financial support to the success of knowledge transfer activities is, the higher the likelihood of influence on teaching and publications, and the lower the likelihood of influence on the other activities. Likewise, we hypothesize that the greater the importance of industry financial support to the success of knowledge transfer activities is, the higher the likelihood of influence on entrepreneurial activities such as patenting, spin-off creation and consulting, and the lower the likelihood of influence on teaching, publications, and informal knowledge transfer. The assumption behind these hypotheses is that internal university financial support induces academics to select research projects for their intrinsic academic merit while, by comparison, industry financial support induces them to select research projects on the basis of their commercial potential. Internal university funding includes seed money, matching grants and small research grants. However, internal university funding usually involves much smaller grants than the average grants obtained through research granting councils and industry (see Appendix A for operational definitions of internal and industry financial support).

3.2. Knowledge attributes

The literature on diffusion of innovation shows that attributes of innovation, in particular the degree of novelty of the knowledge embodied in innovation, influence the transferability of knowledge (Rogers, 1995). Studies on knowledge transfer activities all point to the importance of research fields as another attribute that influences the transferability of knowledge from the academic milieu to the practice milieu (Landry et al., 2006, 2007a). We will now turn our attention to each of these two knowledge attributes.

3.2.1. Novelty of research

Prior studies on the relationship between knowledge transfer activities and novelty of research results are very scanty. We suggest that the direction and significance of this relationship may vary from one knowledge transfer activity to the next. On the one hand, one may hypothesize that higher degrees of research novelty carry a higher potential for publications, higher incentives to protect intellectual property through patents (Landry et al., 2006). On the other hand, one may hypothesize that as degrees of research novelty increase, so does the distance between research results and applicability in market products and production processes, as well as in teaching products. Therefore, increasing the distance between research results and their applicability contributes to decrease the short term potential of research results and, as a consequence, the incentives to create spin-offs and the incentives to use such research results in teaching and consulting activities. Landry et al. (2007a) have shown that novelty of research results has a negative and significant impact on informal knowledge transfer. Based on this rationale, we tentatively hypothesize that novelty of research results of the researchers' projects is positively related to publishing and patenting, and negatively related to spin-off creation, informal knowledge transfer, consulting and teaching (see Appendix A for operational definition of novelty of research results).

3.2.2. Research fields

The bibliometric and scientometric literature on productivity showed that there are significant differences across research fields with respect to the production of publications (Rinia et al., 2002). Likewise, opportunities for entrepreneurial activities appear to be higher in some research fields than in others (Bercovitz and Feldman, 2003). More specifically, the literature on spin-offs and patenting suggests that research fields are a determinant of spin-off creation and patenting (Carayol and Matt, 2006; Fontes, 2003; Landry et al., 2006, 2007b; Lubango and Pouris, 2009; Owen-Smith and Powell, 2003). A recent study showed that researchers in engineering are significantly more involved in informal knowledge transfer than their counterparts in other natural sciences (Landry et al., 2007a). Based on this rationale and prior empirical studies, we hypothesize that researchers in certain disciplines, like engineering, will exhibit a higher likelihood than their peers in natural sciences of becoming involved in consulting, spin-off creation, patenting, informal knowledge transfer, as well as in publishing. Furthermore, we think that the direction and significance of the relationship between research fields and teaching are ambiguous and that it should be resolved through empirical investigation. In this paper, research fields were measured with a series of binary variables defined in Appendix A.

3.3. Network assets

There is a vast literature pointing to the fact that network capital or network assets create opportunities that facilitate the creation and exploitation of knowledge, and influence the patterns of professional careers, including the patterns of academic careers (Bozeman et al., 2001; Bozeman and Corley, 2004; Burt, 1997; Dietz and Bozeman, 2005). Previous studies showed that network assets do not exert the same impact on all knowledge transfer activities. Based on prior empirical studies, we hypothesize that the greater the knowledge assets that researchers have with people based in industry and government agencies, the higher the likelihood of spin-off creation (Grandi and Grimaldi, 2003; Landry et al., 2006, 2007b), the higher the likelihood of getting involved in informal knowledge transfer (Landry et al., 2007a). Similarly, we hypothesize that there is a positive relationship between network assets and consulting, as well as between networks assets and publishing. In this paper, the level of network assets was measured by using an index assessing the intensity of the linkages that the researcher had with managers and/or professionals from three types of organizations: (1) private firms; (2) government departments; and (3) university communications department (media relations, public affairs).

3.4. Organizational assets

Several empirical studies showed that academics affiliated to prestigious universities are more productive than their peers in less prestigious universities (Allison and Long, 1990; Cole and Cole, 1973). Other studies investigated the relationship between academic productivity and research university size by assuming that academics located in large research universities benefit from economies of scale that generate higher productivity (publications) than their counterparts in smaller research institutions. Prior studies regarding the relationships between research institution size and productivity have generated mixed results (Bonaccorsi and Daraio, 2003; Carayol and Matt, 2004a,b). Furthermore, one may also argue that the larger the research institution size, the higher the access to research funds and resources (Bercovitz and Feldman, 2004; Feldman et al., 2002), and star scientists' expertise (Zucker et al., 2002), and the higher the academic productivity. Overall, prior studies suggest that large research university infrastructures provide more resources to facilitate the undertaking of knowledge transfer activities, as well as giving rise to norms and incentives that give recognition and facilitate the undertaking of knowledge and technology transfer (Landry et al., 2006, 2007a). Theoretically, there is no clear answer to the question of the relationship between research university size and teaching. It is therefore an empirical question that we will investigate later with econometric models. As for the other knowledge transfer activities, we hypothesize a positive relationship between research university size and publications, patenting, spin-off creation, consulting, and informal knowledge transfer.

However, one may also argue that the performance of academics is related to idiosyncratic resources located in their immediate laboratory environment rather than to generic resources located at the university level (Landry et al., 2006, 2007a). Prior studies have documented the importance of university laboratories in the commercial exploitation of research university knowledge (Azagra-Caro et al., 2006; Carayol and Matt, 2004a,b, 2006). Based on this rationale and prior studies, we hypothesize a positive relationship between laboratory size and publications, patenting, spin-off creation, consulting, and informal knowledge transfer (see Appendix A for operational definitions of research unit size and research university size).

3.5. Personal assets

Several empirical studies showed that personal factors may affect the researcher's knowledge transfer activities. As mentioned by Moutinho et al. (2007), many studies found that factors such as career status and experience influence the level of implication of researchers in different knowledge transfer activities (Carayol, 2004; Stephan et al., 2007; Wallmark, 1997).

In this paper, the experience of researchers was measured as the number of years between 2002 and the year of completion of PhD. The level of seniority was measured with a series of binary variables referring to the researcher's academic rank (see Appendix A for their operational definitions).

The control variable gender was added and measured as a binary variable coded 1 if the researcher is a man and coded 0 if the researcher is a woman.

4. Methods

4.1. Data

The population of the present study consists of 8191 university researchers funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). NSERC is the primary funding organization for university researchers in these disciplines in Canada. Moreover, NSERC-funded researchers accounted for 85% of all papers from Canadian universities, and the majority of active researchers in natural sciences and engineering in Canada

(Godin and Côté, 2002). The population included faculty members from a wide variety of research fields and universities, including small-sized research universities as well as large-sized research universities. A random sample of 4000 university researchers was prepared by NSERC for this study, in order to represent 25 research field categories. All individuals included in the sample were funded by NSERC during the 1997–2002 period. A questionnaire and the 4000 names were sent to a survey firm using CATI, a computer-assisted telephone interviewing technology, which can embed data coding and data entry simultaneously in the data collection phase. The survey was conducted by telephone between 18 February and 27 March 2002. Of the 4000 people included in the sample, 2075 were excluded from the sample for the following reasons: no response after 25 calls ($n = 1637$), inability to respond ($n = 2$), residential phone number ($n = 66$), discontinued phone number ($n = 194$), ineligible respondent ($n = 8$), and other reasons such as being retired, wrong number, etc. ($n = 168$). The final sample thus comprised 1925 people. Of these 1925 people, 19 did not complete the questionnaire, 274 refused to participate (after a recall) and 78 asked to be interviewed later, but were never reached. Finally, the survey generated 1554 usable questionnaires for a net response rate of 81% (1554/1925). The possibility of non-response bias was verified by comparing the number of respondents to that of the original population sample for 25 categories of research fields. Every research field category is statistically well represented in the completed questionnaires, except for the pure and applied mathematics category, which is under-represented. With the help of NSERC staff, we merged the 25 research fields into the following six categories: Physics, Mathematics and Statistics; Chemistry; Computer Sciences; Earth Sciences; Life Sciences; and finally, Engineering. This procedure allowed us to have enough observations to conduct comparative analyses.

4.2. Instruments and measures

As indicated earlier, the explanatory variables are regrouped in the following six categories: (1) financial resources; (2) knowledge attributes; (3) networks assets; (4) organizational assets; (5) personal assets; and (6) control variables. The operational definitions of the explanatory variables are presented in Appendix A. Appendix B provides results of a principal components factor analysis (PCFA) and internal reliability coefficients (Cronbach's alpha) for the dependent and independent variables with a multiple-item scale. These results indicate that all the multiple-item scale variables satisfy the unidimensionality criterion. Moreover, the values of Cronbach's α indicate that the items forming each index are reliable.

Furthermore, we used the probability plots to determine whether the distribution of each of the four independent continuous variables included in the model matches a normal distribution. More specifically, we used the *Q*–*Q* plots procedure, which plots the quintiles of a variable's distribution against the quintiles of a normal distribution. In doing so, we found that only the variables network capital index and research novelty index seem to match a normal distribution. In fact, the observations of these variables are clustered around a straight line, corresponding to normal distributions. For the other two continuous variables included in the model, namely laboratory size, and experience of researchers, we have found that the observations are not clustered around a straight line corresponding to normal distributions. For these two variables, we used a square root transformation; the probability plots for the transformed values indicated that the transformed variables did not differ significantly from a normal distribution.

Finally, we checked the correlation matrix between the independent variables used in the regression models (Appendix C). This correlation matrix indicates that almost all the coefficients are weak. This last finding ensures that no multi-collinearity problem can arise in the estimations of the regression models.

4.3. Analytical plan

The analytical plan contains two stages. First, we simultaneously estimated six regression equations (i.e., by using M*plus* 3, a structural equation-modeling package, see Muthén and Muthén, 1998–2004) to explore the correlates of the six activities considered in this study, namely, patenting (PATENT), spin-off creation (SPINOFF), consulting (CONSULT), informal knowledge transfer (INFTR), publishing (PUBL) and teaching (TEACH). We used the weighted least squares mean and variance adjusted estimator (WLSMV) as it allows estimating simultaneously different types of regression equations (i.e., ordinary least squares, binay probit, ordered probit, tobit, zero-inflated tobit, Poisson, zero-inflated Poisson). A recent utilization of the WLSMV estimator can be found in Ouimet et al. (2007). Technical details about the WLSMV estimator are provided in Muthén (1998–2004, pp. 17–20).

In this study, the WLSMV estimator was used to estimate a path model including the six above-mentioned dependent variables, that is, PATENT, SPINOFF, CONSULT, INFTR, PUBL and TEACH. PATENTING and SPINOFF were measured on dichotomous scales (see Section 2), so the regression equations with these variables as the dependent variables are binary probit regressions. The number of patents (PATENT), which constitutes a typical example of count data, was not treated as such (it was rather dichotomized as mentioned above), as M*plus* does not allow estimating negative binomial regressions and as the distribution of PATENT was not a Poisson distribution because the assumption of equality between the mean and variance of the random variable is not satisfied in this case.

For its part, CONSULT was measured on a 5-point ordinal scale, so the regression equation with this variable as the dependent variable is an ordered probit regression. Finally, INFTR, PUBL and TEACH were measured on normal continuous scales (see Section 2), so the regression equations with these variables as the dependent variables are ordinary least square regressions. Note that both PUBL and TEACH were normalized by using the square root transformation.

The path model is thus similar to six separate regression models (i.e., two binary probit, one ordered probit and three OLS), except that it applies to six simultaneously estimated equations with free error-term covariances. These error-term covariances will serve as proxies of the complementarities or substitution effects between the various knowledge transfer activities. To the extent of our knowledge, our approach to data analysis has never been used to address the issue of how academics decide what knowledge transfer activities to invest their resources in. Most previous studies attempted to identify the determinants of involvement in knowledge transfer activities by using separate models. This latter approach implicitly discards the occurrence of complementarities or substitution between the various activities. The major issue raised from the use of standard models when estimating separate equations is related to the possibility of getting inefficient estimators if some equations' disturbances are correlated (Belderbos et al., 2004). The multivariate path model estimated in this study is an extension of the separate models that allows to jointly estimate several equations while controlling for the existence of mutual covariances between the equations' disturbances (Amara et al., 2008).

Finally, the second stage consisted in estimating the same model, but by fixing insignificant regression coefficients (i.e., those with $p > .10$, two-tailed) at 0. Unlike the first path model, the second one can be assessed for model fit, as fixing parameters (i.e., insignificant parameters found in the first model) allows estimating the

Table 2
Descriptive statistics.

Variables	Type of variables	α de Chronbach	Minimum	Maximum	Mean	S.D.
Continuous variables:						
CONSULT	Ordinal: number	NA	1	5	2.63	1.19
INFTR	Index: 4 items	.807	1	5	2.61	.95
PUBL	Continuous: number	NA	0	200	17.15	15.77
TEACH	Continuous: number	NA	0	100	31.40	14.84
NOVELT	Index: 4 items	.735	1	5	2.94	.77
NETASS	Index: 3 items	.649	1	5	2.54	.93
LABSZ	Continuous: number	NA	0	60	4.14	4.32
EXPR	Continuous: number	NA	2	51	21.22	11.01
Dichotomous variables:						
PATENTING	21.7 % (Yes)					
SPINOFF	16.3 % (Yes)					
PRVFND	24.32% ((Private funding was *important, very important* or *extremely important* to the success of the research projects))					
INTFND	35.65% (Internal funding was *important, very important* or *extremely important* to the success of the research projects)					
FIELD	8.24% (CHEM)	15.83% (PHMST)	8.11% (COMP)	8.11% (EARTH)	30.82% (ENGIN)	28.89% (LFSC)
LARGEUNV	69.76% (Large)					
SENIORITY	7.6% (Grantee researchers)	19.0% (Assistant professors)	20.6% (Associate professors)	52.8% (Full professors)		
GENDER	87.54% (male)					

path model with degrees of freedom. Saturated path models like the one estimated in the first stage always fit perfectly as they typically have 0 degree of freedom. As mentioned in Ouimet et al. (2007), Golob and Regan recommend fixing insignificant parameters, as "saturated models are difficult to interpret, because statistically significant effects can be diminished due to multicollinearity with insignificant effects" (2002, p. 217).

5. Results

The descriptive statistics of the variables used in this study are reported in Table 2. The results of the path models are summarized in Tables 3 and 4. Table 3 shows the results for the saturated model (i.e., with 0 degree of freedom). The results of the unsaturated path model, which takes into account only the significant coefficients, are summarized in Table 4. The results specifically regarding the complementarity/substitution/independence between knowledge transfer activities are summarized in Table 4.

As mentioned in Section 4.3, the saturated path model estimated in the first stage could not be assessed for model fit as it typically has zero degree of freedom. We therefore only present the fit of the final model, which excludes the insignificant parameters found in the saturated model estimated in stage 1. Note that an interesting aspect of the WLSMV estimator implemented in M*plus* "is that the value for the model degrees of freedom is estimated from the empirical data . . . rather than being determined directly from the specification of the model" (Flora and Curran, 2004, p. 470). The unsaturated path model had 33 degrees of freedom and an insignificant Chi-square statistic of 24.701 ($p > .10$). The insignificant Chi-Square indicates that the final unsaturated path model has a very good fit. We also estimated the same unsaturated path model, but with the covariances between equations' error-terms fixed at 0. The computed value of the chi-square for this nested path model is significant at the 1% level (i.e., Chi-square 279.401; 45 degrees of freedom; $p \leq .01$), which indicates a poor model fit. This suggests that a path model with free error-terms covariances better reflects the data than a path model with error-terms covariances fixed at 0. In other words, this specific finding provides evidence, at least for our data, that the use of separate regression models is not appropriate to estimate the determinants of the researchers' involvement in the various knowledge transfer activities.

The covariances between error-terms of the six regression equations are presented at the bottom of Table 4. Most of these covariances are significant and positive. Moreover, all covariances between patenting, spin-off creation and consulting are significant and range from .083 to .357. This last finding suggests that there are complementarities between these activities. The positive and significant covariances between informal knowledge transfer and patenting, between spin-off creation and consulting, as well as between informal knowledge transfer and consulting, also suggest complementarities between these activities. Moreover, the positive covariance between publications and informal knowledge transfer, and the positive covariance between publications and consulting, also suggest complementarities between these pairs of activities. However, the negative and significant covariance between publications and teaching suggests that there is a substitution effect between these activities. The remaining statistically insignificant results suggest that publications are independent from patenting and spin-off creation, while teaching is independent from patenting, spin-off creation, consulting and informal knowledge transfer.

Let us now consider the determinants of the researchers' involvement in the various knowledge transfer activities. The likelihood of patenting (Panel A) increases as academics rely on private funding, as the novelty of their research increases, as their network assets increase, as their research unit size gets greater, as their experience rises, and when they are affiliated with large research universities rather than small and medium ones. Conversely, the likelihood of patenting decreases when academics rely on internal funding, when they are active in physics, mathematics and statistics rather than in life sciences, and when they operate in earth sciences rather than in life sciences. Secondly, the results show that eight variables significantly and positively influence the likelihood of spin-off creation (Panel B). These variables are the novelty of the research, network assets, research unit size, experience, affiliation to the engineering field rather than to the life sciences field, affiliation to the computer sciences field rather than to the life sciences field, affiliation to large research universities rather than small and medium ones, and being a man rather than a woman. Thirdly, the

Table 3
Saturated multivariate path model results explaining the knowledge transfer activities.

Independent variables	Commercial knowledge transfer activities						Non-commercial knowledge transfer activities					
	Panel A		Panel B		Panel C		Panel D		Panel E		Panel F	
	Patenting		Spin-off		Consulting		Informal knowledge transfer		Publications		Teaching	
	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value
Intercept							.624***	3.635	1.720***	4.804	8.050***	22.424
Threshold 1	3.541***	8.401	4.031***	8.672	1.073***	4.024						
Threshold 2					1.630***	6.078						
Threshold 3					2.785***	10.322						
Threshold 4					3.934***	14.350						
Financial and partnership assets												
Internal funding *[INTFND]*	–.067*	–1.900	–.028	–.766	–.048*	–1.768	–.006	–.376	.069*	1.928	.050	1.364
Private funding *[PRVFND]*	.156***	3.972	.014	.335	.083***	2.812	.123***	7.286	.001	.031	–.126***	–2.924
Attributes of knowledge assets												
Novelty of the research *[NOVELTY]*	.350***	5.806	.172***	2.876	.021	.507	–.030	–1.186	.100*	1.853	–.004	–.059
Field (ENGIN = 1) *[FIELD]*	.050	.457	.246**	2.066	.188**	2.110	.105**	2.025	–.456***	–4.351	.442***	3.261
Field (CHEMIST = 1) *[FIELD]*	.113	.692	–.002	–.009	–.206	–1.598	–.230***	–3.130	.382**	2.485	–.050	–.309
Field (PHYSMATH = 1) *[FIELD]*	–.561***	–3.244	–.101	–.597	–.104	–1.037	–.128**	–1.990	–.049	–.354	.323**	2.220
Field (COMPUT = 1) *[FIELD]*	–.192	–1.057	.694***	4.039	–.322***	–2.647	–.151**	–2.081	–.856***	–5.217	.517**	2.414
Field (EARTH = 1) *[FIELD]*	–1.102***	–4.154	.011	.055	–.087	–.683	–.037	–.445	–.374**	–2.028	.052	.301
Network assets												
Network capital *[NETASS]*	.105*	1.803	.218***	3.617	.507***	11.938	.528***	21.893	.069	1.255	–.052	–.904
Organizational assets												
Research unit size *[SrUNTSZ]*[a]	.207***	4.711	.158***	3.098	.120***	3.411	.127***	5.985	.543***	13.068	–.160***	–2.880
Large-sized university *[LARGEUN]*	.244**	2.458	.229**	2.129	.167**	2.380	.019	.424	.265***	2.938	–.251**	–2.395
Personal assets												
Experience *[SrEXPR]*[a]	.134**	2.558	.172***	3.024	.020	.531	.041*	1.722	.123***	2.757	–.418***	–9.586
Grantee *[GRANTEE]*	–.067	–.436	–.076	–.452	–.136	–1.107	–.088	–1.193	–.130	–.915	–.322**	–2.167
Assistant *[ASSIST]*	.104	.639	.242	1.375	–.179	–1.406	–.044	–.581	–.892***	–5.818	–.670***	–4.565
Associate *[ASSOC]*	.184	1.385	.108	.754	–.108	–1.118	–.076	–1.164	–.511***	–3.794	–.007	–.039
Control variables												
Gender (Man = 1) *[GENDER]*	.152	.958	.626***	3.125	.146	1.438	.097*	1.648	.271*	1.898	–.155	–.932

Covariances between disturbances	Commercial knowledge transfer activities						Non-commercial knowledge transfer activities				
	Panel A		Panel B		Panel C		Panel D		Panel E		Panel F
	ε_1	*t* value	ε_2	*t* value	ε_3	*t* value	ε_4	*t* value	ε_5	*t* value	
ε_2	.357***	6.899									
ε_3	.083*	1.849	.170***	3.608							
ε_4	.055**	2.049	.089***	3.256	.251***	14.684					
ε_5	.066	1.240	.008	.160	.080**	2.124	.097***	4.019			
ε_6	–.037	–.652	–.028	–.464	–.031	–.800	.004	.163	–.115**	–2.115	
Number of cases	1229										
R-square	.310		.200		.302		.514		.286		.134

Note: For the variables Field and Seniority, the reference categories are Life sciences (LIFE) and Full professor (FULL), respectively.
[a] Sr indicates a square root transformation.
* The coefficient is significant at the 10% threshold.
** The coefficient is significant at the 5% threshold.
*** The coefficient is significant at the 1% threshold.

Table 4
Unsaturated multivariate path model results explaining the knowledge transfer activities.

Independent variables	Commercial knowledge transfer activities						Non-commercial knowledge transfer activities					
	Panel A		Panel B		Panel C		Panel D		Panel E		Panel F	
	Patenting		Spin-off		Consulting		Informal knowledge transfer		Publications		Teaching	
	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value	Coeff. (β)	*t* value
Intercept							.624***	3.634	1.721***	4.805	8.049***	22.423
Threshold 1	3.542***	8.405	4.030***	8.670	1.073***	4.024						
Threshold 2					1.630***	6.078						
Threshold 3					2.785***	10.323						
Threshold 4					3.934***	14.349						
Financial and partnership assets												
Internal funding *[INTFND]*	−.067*	−1.900			−.048*	−1.768			.069*	1.928		
Private funding *[PRVFND]*	.156***	3.972			.083***	2.812	.123***	7.286			−.126***	−2.921
Attributes of knowledge assets												
Novelty of the research *[NOVELTY]*	.350***	5.807	.172***	2.877					.100*	1.851		
Field (ENGIN = 1) *[FIELD]*			.246**	2.066	.188**	2.109	.105**	2.025	−.456***	−4.351	.442***	3.261
Field (CHEMIST = 1) *[FIELD]*							−.230***	−3.127	.382**	2.484		
Field (PHYSMATH = 1) *[FIELD]*	−.561***	−3.245					−.128**	−1.988			.323***	2.221
Field (COMPUT = 1) *[FIELD]*			.694***	4.039	−.322***	−2.644	−.151**	−2.077	−.856***	−5.215	.517**	2.413
Field (EARTH = 1) *[FIELD]*	−1.102***	−4.154							−.374**	−2.028		
Network assets												
Network capital *[NETASS]*	.105*	1.802	.218***	3.618	.507***	11.938	.528***	21.893				
Organizational assets												
Research unit size *[SrUNTSZ]*[a]	.207***	4.711	.158***	3.096	.120***	3.411	.127***	5.985	.543***	13.068	−.160***	−2.883
Large-sized university *[LARGEUN]*	.244**	2.457	.229**	2.132	.167**	2.382			.265***	2.939	−.251**	−2.395
Personal assets												
Experience *[SrEXPR]*[a]	.134**	2.555	.172***	3.023			.041*	1.722	.124***	2.758	−.418***	−9.586
Grantee *[GRANTEE]*											−.322**	−2.167
Assistant *[ASSIST]*									−.892***	−5.817	−.670***	−4.566
Associate *[ASSOC]*									−.511***	−3.794		
Control variables												
Gender (Man = 1) *[GENDER]*			.626***	3.124			.097*	1.648	.271*	1.899		

Covariances between disturbances	Commercial knowledge transfer activities						Non-commercial knowledge transfer activities				
	Panel A		Panel B		Panel C		Panel D		Panel E		Panel F
	ε_1	*t* value	ε_2	*t* value	ε_3	*t* value	ε_4	*t* value	ε_5	*t* value	
ε_2	.357***	6.901									
ε_3	.083*	1.847	.171***	3.610							
ε_4	.055**	2.049	.089***	3.256	.251***	14.684					
ε_5	.066	1.238	.008	.161	.080**	2.124	.097***	4.019			
ε_6	−.037	−.652	−.028	−.464	−.031	−.798	.004	.163	−.115**	−2.115	
Number of cases	1229										
R-square	.302		.205		.283		.515		.283		.124

Note: For the variables Field and Seniority, the reference categories are Life sciences (LIFE) and Full professor (FULL), respectively.
[a] Sr indicates a square root transformation.
* The coefficient is significant at the 10% threshold.
** The coefficient is significant at the 5% threshold.
*** The coefficient is significant at the 1% threshold.

Table 5
List of factors that significant explain the knowledge transfer activities.

	Commercial knowledge transfer activities			Non-commercial knowledge transfer activities		
Independent variables	Patenting	Spin-off	Consulting	Informal knowledge transfer	Publications	Teaching
Financial and partnership assets						
Internal funding *[INTFND]*	−		−		+	
Private funding *[PRVFND]*	+		+	+		−
Attributes of knowledge assets						
Novelty of the research *[NOVELTY]*	+	+			+	
Field (ENGIN = 1)		+	+	+	−	+
Field (CHEMIST = 1)				−	+	
Field (PHYSMATH = 1)	−			−		+
Field (COMPUT = 1)		+	−	−	−	+
Field (EARTH = 1)	−				−	
Network assets						
Network capital *[NETASS]*	+	+	+	+		
Organizational assets						
Research unit size *[SrUNTSZ]*[a]	+	+	+	+	+	−
Large-sized university *[LARGEUNV]*	+	+	+		+	−
Personal assets						
Experience *[SrEXPR]*[a]	+	+		+	+	−
Grantee *[GRANTEE]*						−
Assistant *[ASSIST]*					−	−
Associate *[ASSOC]*					−	
Control variables						
Gender (Man = 1) *[GENDER]*		+		+	+	

Note: For the variables Field and Seniority, the reference categories are Life sciences (LIFE) and Full professor (FULL), respectively.

results show that (Panel C) five variables have a significant positive impact and two variables have a significant negative impact on the intensity of consulting activities. Hence, the intensity of consulting increases as academics rely on private funding, as their network assets get greater, as their research unit size increases, when they are affiliated with large research universities rather than small and medium ones, and when they are in engineering rather than in life sciences. Conversely, the intensity of consulting decreases as academics rely on university internal funding, and when they are active in computer sciences rather than in life sciences. Fourthly, informal knowledge transfer is significantly influenced by nine variables (Panel D). While private funding, network assets, research unit size, experience, affiliation to the engineering field rather than the life sciences field, and being a man rather than a woman are variables that are positively correlated with informal knowledge transfer, the affiliation of the respondents to the fields of chemistry, computer sciences, and physics, mathematics and statistics rather than to life sciences decreased the likelihood of involvement in informal knowledge transfer. Fifthly, the results (Panel E) show that 12 variables exert a significant impact on the publication activity. The production of scientific papers is positively influenced by the reliance on internal funding, novelty of research, research unit size, experience, affiliation to the field of chemistry rather than to life sciences, affiliation with large research universities rather than small and medium ones, and being a man rather than a woman. Conversely, publishing is negatively influenced by being in the fields of engineering, computer sciences and earth sciences rather than in life sciences, and by being an assistant or an associate professor rather than a full professor. Finally, the percentage of time allocated to teaching activities (Panel F) is influenced by nine independent variables. The degree of involvement in teaching is positively influenced by being in engineering, computer sciences and physics, mathematics and statistics rather than in life sciences. The remaining six variables that negatively influence the time dedicated to teaching activities are private funding, research unit size, experience, affiliation with large research universities rather than small and medium ones, and being a grantee or an assistant professor rather than a full professor. Table 5 summarizes the previous findings regarding the factors that significantly explain the various forms of knowledge transfer activities.

6. Discussion and conclusion

The first purpose of this study was to explore whether six knowledge transfer activities, specifically publishing, teaching, informal knowledge transfer, getting granted patents, engaging in spin-off formation and consulting services exhibited complementarity, substitution or independence effects. The results of this study suggest that there are complex interactions among multiple forms of mutually reinforcing knowledge transfer activities that lead to an enhanced performance in the knowledge transfer of academics. Indeed, complementarity effects among multiple knowledge transfer activities arise because once the level of one activity increases, the impact of augmenting the level of another activity is greater than would have been the case if the first activity would not have been increased. Thus, the total effect on the knowledge transfer performance of individual academics that results from increasing all the knowledge transfer activities together is greater than the sum of increases in the individual knowledge transfer activities.

Consistent with many prior studies which pointed out the presence of complementarities between pairs of knowledge transfer activities such as publications and patenting, publications and spin-off creation, publications and consulting, publications and informal knowledge transfer, the results of this study suggest that publications, patenting, spin-off creation, consulting and informal knowledge transfer are complementary. These results suggest that complementarities emerge through complex interactions among a much larger number of knowledge transfer activities than demonstrated in prior studies that relied on one-on-one interactions among individual knowledge transfer activities. Indeed, the results of this study suggest that the complex interactions that emerged among the six knowledge transfer activities considered in this study better represent a knowledge transfer system made up of interdependent and mutually reinforcing activities that lead to the enhanced knowledge transfer performance of academics. Thus, the results of this study provide insight into the boundaries between the different forms of knowledge transfer as well as into the overlap between the boundaries of these different forms of knowledge transfer activities. Hence, the results of this study suggest that the outputs of some of these knowledge activities may become the resource base upon which other activities may build, and, as a consequence, the performance in some activities may generate a leverage effect on the performance of other activities. These complementarities mean that publication, patenting, spin-off creation, consulting and informal knowledge transfer are interdependent and reinforce each other and that, in order to improve our understanding and our policies, we should approach these activities jointly rather than independently. Hence, we hypothesize that there may be a virtuous cycle in which publications produce knowledge, expertise and skills that are redeployed into informal knowledge transfer activities, thereby augmenting the knowledge base that academics have about knowledge users in firms and other organizations, which, in turn, enhances the ability of academics to get involved successfully in commercial knowledge transfer activities such as patenting, spin-off creation and consulting. In turn, formal commercial knowledge transfer activities give rise to a mutual informal exchange of knowledge (informal knowledge transfer) between academics and knowledge users that increases the knowledge base, expertise and skills that enhance the ability of academics to become more successful in publishing and informal knowledge transfer. We may hypothesize that such a type of virtuous circle may emerge only when multiple forms of knowledge transfer activities occur simultaneously because it requires the exchange of codified and non-codified knowledge between academics and knowledge users.

However, contrary to claims pointing to the existence of complementarities between teaching activities and publication outputs (Colbeck, 1998; Walckiers, 2004), our results suggest that teaching and publication activities are substitute for each other. In other words, it means that increasing teaching activities comes at the expense of increasing publication outputs and vice versa. Substitution effects between teaching and publications suggest that in general, increasing the knowledge, expertise and skills developed in teaching activities reduces the knowledge, expertise and skills developed in research activities, and vice versa. This negative relation might be explained by the fact that teaching tends to deal with topics that are general and introductory, whereas research tends to deal with specialized topics generating knowledge, expertise and skills that cannot be reused and shared with teaching activities. As a consequence, increasing the time dedicated to teaching activities reduces the time that can be dedicated to produce publications and vice versa. The results suggest that this is the case for researchers in natural sciences and engineering. Again, these results carry important implications for our understanding and for the management of universities, both at the level of the individual academic and at the level of the university managers and policy-makers who should approach these activities independently as separate activities, and not as joint activities which reinforce and consolidate each other.

Surprisingly, the results did not support the substitution hypothesis between teaching and patenting, spin-off creation, consulting and informal knowledge transfer. Indeed, our results suggest that there is independence between teaching and patenting, spin-off creation, consulting and informal knowledge transfer. This result implies that patenting, spin-off creation, consulting and informal knowledge transfer neither have positive nor adverse effects on teaching, meaning that the knowledge, expertise and skills created in teaching are not outputs that can be leveraged, reused and shared with these other knowledge transfer activities to create a virtuous circle of beneficial effects, and vice versa.

Overall, these results point to the existence of three very different types of knowledge transfer portfolios: a first portfolio made up of complementary activities which are interdependent and reinforce each other. This portfolio includes publications, patenting, spin-off creation, consulting and informal knowledge transfer. A second portfolio includes teaching activities and publication outputs, which are substitute for each other. A third portfolio comprises teaching activities and other activities independent from teaching, namely, patenting, spin-off creation, consulting and informal knowledge transfer. Fig. 1 illustrates these portfolios of interactions.

The second purpose of this study was to explore the conditions under which complementarities, substitution or independence were likely to emerge. The results show that these three portfolios of knowledge transfer activities are explained by different sets of factors. Hence, with few exceptions, private funding, novelty of research results, network assets, laboratory size, research university size and experience have a positive and significant impact on most of the knowledge transfer activities (publications, patenting, spin-off creation, consulting and informal knowledge transfer) included in the portfolio of complementary activities. Internal university funding obtained for research projects is either not related or negatively related to the activities included in this first portfolio of complementary knowledge transfer activities. It suggests that such internal funding is either too small to exert any impact or that it is a tool that should not be used to foster complementary knowledge transfer activities. Novelty of research involving significant changes in materials, production techniques, and significant financial investments for the development of new or improved products, processes or services is positively related to patenting activities, spin-off formation and publications, but has no relations with consulting activities and informal knowledge transfer activities. It suggests that the research results involved in patenting, spin-off formation and production of publications carry a higher degree of novelty than is the case for the research results mobilized in consulting and informal knowledge transfer which might rely on less novel and well-established research knowledge. Furthermore, the results of this study show that commercial knowledge transfer activities and informal knowledge transfer activities are all associated with the size of network assets, whereas the size of network assets is not related to publications. This result might be explained by the fact that our measure of network assets attempted to capture linkages with companies and government organizations rather than linkages with other researchers. The results also show that although research university size is positively associated with patenting, spin-off creation, consulting and publications, it has no relation with informal knowledge transfer. It may mean that informal knowledge transfer does not depend on the various types of institutional resources that characterize large research universities. Interestingly, like for the other types of commercial knowledge transfer activities, informal knowledge transfer is positively associated with research unit size, which may mean that resources closer to academics, like is the case for those resources linked to their research units, might be more customized and hence more useful in informal knowledge transfer than those less customized resources located at the university level. However, these results suggest that even informal knowledge transfer might require an organizational base which is located at the level of the research unit rather than at the university level. In short, generally speaking, complementarity effects among patenting activities, spin-off formation, consulting, informal knowledge transfer and publications emerge under four conditions: financial conditions linked to private funding, attributes of knowledge assets linked to the degree of novelty of research findings, network assets, and organizational assets linked to the size of research units and the research intensity of universities.

The two substitute knowledge transfer activities included in the second portfolio, that are the level of teaching activities and publication outputs, are explained by very different factors. Hence, internal university funding has a positive impact on publications, but no impact on teaching; private funding positively influences publications, while it has a negative impact on the level of teaching activities; the novelty of research results exerts a positive influence on publications, but has no impact on teaching; as for the laboratory

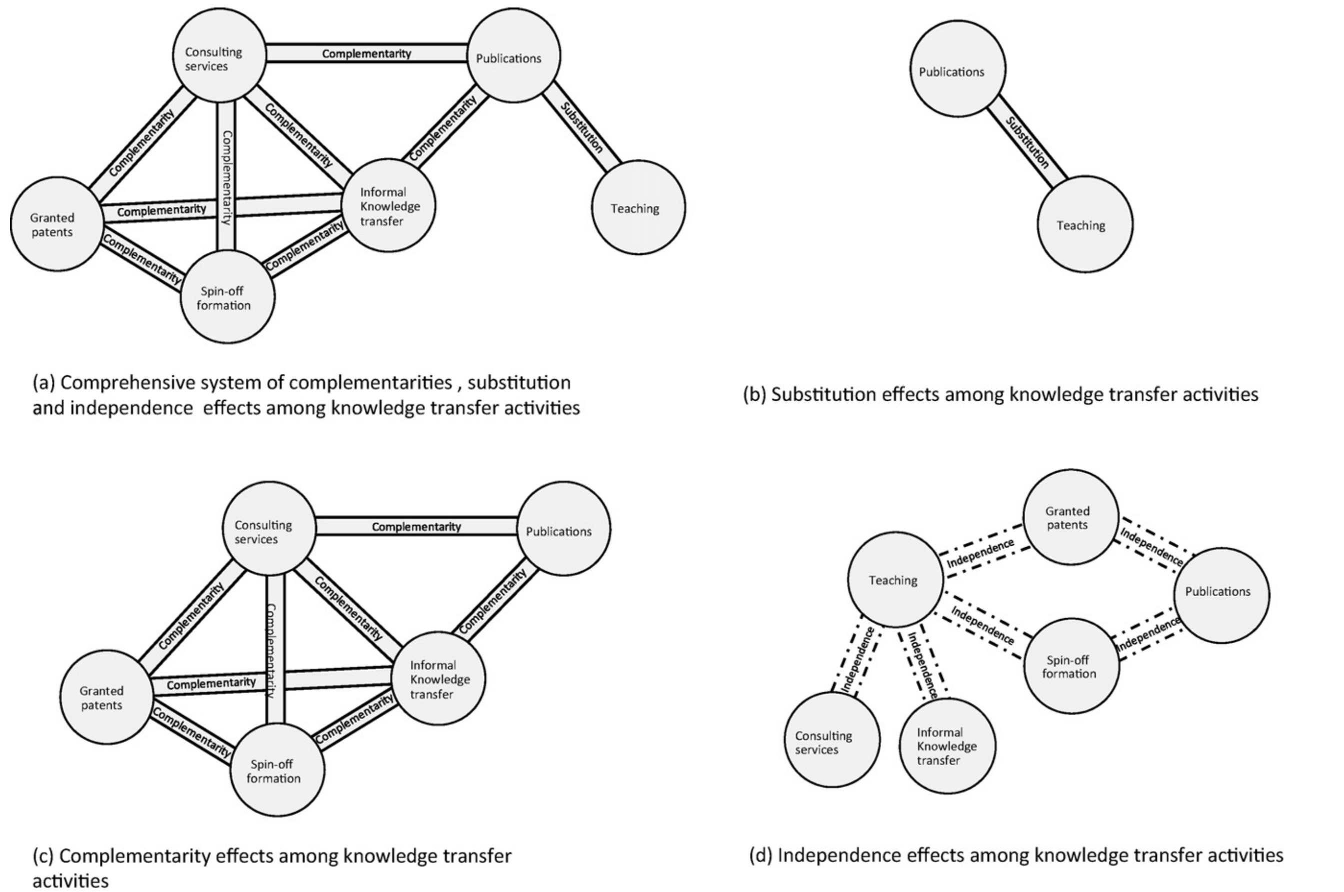

Fig. 1. (a–d) Patterns of complementarities, substitution and independence among knowledge transfer activities.

size and the research university size, they have a positive impact on publications, but again a negative impact on teaching activities; finally, years of experience that academics have positively influence publication outputs, but negatively teaching activities. In short, the conditions under which substitution effects among publications and teaching emerge are associated with either different factors and even factors that appear to have opposite effects on each activity.

As for the third portfolio regarding the independence between teaching and all other activities but publications, the results show again that the variables that exert a positive and significant influence on patenting, spin-off creation, consulting and informal knowledge transfer tend to have a negative influence or no influence on teaching. Such heterogeneities in the determinants of the different portfolios of knowledge transfer activities suggest that in order to increase the performance of academics, university managers and policy makers should devise policies that take into account that performance in the different portfolios is influenced by different factors.

6.1. Implications for managerial practice

What do our results suggest regarding the portfolio management of knowledge transfer activities at the level of the individual academic and at the level of the university managers and policy makers? As pointed out by Ennen and Richter (2010, p. 226), "The complementarity perspective is sceptical of the notion of "best practices", which supposedly enhance performance regardless of the circumstances in which they are applied. It suggests that decision makers have to manage complex social systems whose constituents and interactions are usually incompletely understood and whose benefits may only become apparent post hoc". It is nevertheless possible to derive some implications for the management of knowledge transfer. Hence, failing to take into account interdependencies by treating decisions regarding knowledge transfer activities independently would mean that policy makers and university administrators misinterpret boundaries among knowledge transfer activities and formulate knowledge transfer strategies based on individual knowledge transfer activities rather than on the joint coordination of multiple knowledge transfer activities. Devising such knowledge transfer strategies might lead to a loss of performance.

The results of this study also suggest that the existence of complementary activities may facilitate the entry and successful performance into other activities while, on the other hand, the existence of substitution effects may hamper the entry in some activities and come at the expense of successful performance in these activities (see Siggelkow, 2002; Stieglitz and Heine, 2007, for a detailed discussion on complementarities and substitution in organizations). The management of complementary, substitute and independent knowledge transfer activities is important if one aims to facilitate the entry and derive the benefits resulting from involvement in the different knowledge transfer activities. Hence, a failure to recognize complementarities between publications, patenting, creation of spin-offs, consulting and informal knowledge transfer may lead to the under-exploitation of synergies, and therefore revenues and performance. Therefore, university managers and policy makers should attempt to provide incentives that would induce academics to use the outputs of their complementary activities as inputs for other activities, instead of attempting to prevent the entry in new and complementary activities. In many universities, different offices, for instance the research offices and the technology transfer offices, manage research, patenting and spin-off creation by focusing on the performance of individual activities, thus ignoring synergies and complementarities between activities. We can extend Siggelkow's (2007) analysis from firms to universities to hypothesize that: the greater the emphasis on isolated activity performance is, the greater the degree to which the complementary interaction between the activities is ignored or misperceived. Likewise, not taking into account the substitutability between research and teaching activities may lead to the under-exploitation of resources and inefficiency, because some academics make an inefficient use of resources contributing to increase research performance, while other academics could make a more efficient use of these resources and vice versa for resources contributing to increase teaching performance. Therefore, a failure to take into account substitutability may lead to a loss of performance at the level of the individual academic and at the university level. University managers and policy makers could take substitutability into account by implementing policies based on a modulation of activities that would induce some academics to invest more time in teaching activities, while others would be induced to invest more time in research activities.

6.2. Limitations and further research

This study has limitations in context and methods that inform the interpretations of results and suggest further research. Hence, the findings of this study establish convincingly that there are complementarities, substitution and independence between multiple knowledge transfer activities. The complementarity theory suggests that knowledge transfer derives benefits from the interplay among multiple knowledge transfer activities. However, further research should investigate, both at the theoretical and empirical levels, how the virtuous circle among multiple knowledge transfer activities may emerge and may become sustainable over time. Difficult empirical and theoretical issues are at stake in this regard: while the results of this study rely on the complementarity theory to deal with the coordination of multiple knowledge transfer activities with cross-sectional survey data, further research should also consider the dynamics of joint coordination of multiple knowledge transfer activities over mid and long time periods.

Furthermore, the findings of this study might well describe and explain the interplay that emerged among multiple knowledge transfer activities undertaken by researchers in natural sciences and engineering. However, it would be informative to investigate how researchers in biomedical sciences and social sciences coordinate the interplay among their different knowledge transfer activities. Such additional empirical research would provide a platform of evidence that would facilitate the development of a general complementarity theory regarding multiple forms of knowledge transfer activities undertaken by academics.

Further research is also required at the measurement level. More and more studies claim that many academics do not disclose, to their university administrators, a more or less significant part of their knowledge transfer activities. Most prior studies focused their attention on knowledge transfer activities that are disclosed to university administrators. Furthermore, academics are not expected to disclose, to their university administrators, their involvement in informal knowledge transfer activities. This study attempted to capture both the disclosed and undisclosed knowledge transfer activities by asking academics to report about the knowledge transfer activities they have been personally involved in, as well as those in which they have been involved on behalf of their universities. Such an approach is required when one wants to investigate the interplay between commercial knowledge transfer activities based on contractual agreements and informal knowledge transfer activities undertaken outside of any formal contractual agreements with knowledge users. The results of this study suggest that informal knowledge transfer activities appear to play a central role in establishing a virtuous circle among the different knowledge transfer activities. Further studies should aim to better understand, at the theoretical and empirical levels, how informal knowledge transfer activities fit in the larger picture of the other knowledge transfer activities.

Like many social sciences and management studies based on micro-data, this study relied on self-reported data. Such data may include some bias related to social desirability. However, as pointed out by Podsakoff and Organ (1986, p. 535), "To the extent that this problem causes only an upwards within the distribution of responses, it is not a serious concern, at least in the interpretation of correlations involving the scale. Even if the effect of social desirable responses were to compress the range of responses around the end of the scale, the damage would occur mainly in the attenuation of the correlations". A meta-analysis based on a sample of 126 studies investigating the correlation between self-reported and explicit measures found that these measures are systematically related to one another and that correlations between these measures may be high for mundane topics like consumer preferences, but low for socially sensitive topics like prejudice against minority groups (Hofmann et al., 2005). Although knowledge transfer activities do not represent socially sensitive topics, we attempted as much as possible to control potential biases in developing scales that were tested for unidimensionality and internal consistency. However, further research should, whenever possible, attempt to obtain multiple measures of conceptually important variables from multiple sources using multiple methods of data collection.

These limitations notwithstanding, we believe that our results contribute to establish a more complex system of mutually reinforcing knowledge transfer activities than prior studies based on the study of the interplay between two knowledge transfer activities. The results of this paper show that complementarity matters, but further studies will be necessary to better establish and better understand the entire system of knowledge transfer activities in which academics are involved.

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Appendix A. Definitions of dependent and independent variables.

Dependent variables	Measure	Sub-items	Method (range)
Patenting [PATENT]	Dichotomous variable: coded '1' if the researcher had at least one granted patent during the past 5 years, and 0 otherwise.		
Spin-off creation [SPINOFF]	Dichotomous variable: coded '1' if the researcher has created a spin-off during the past 5 years, and 0 otherwise.		
Consulting [CONSULT]	Measured using a 5-point scale of frequency ranging from 1 (never) to 5 (very often) regarding the provision of consulting services to private firms, government agencies or organizations associated with the research field of the respondent. Consulting activities refer to commercial activities that exclude university-industry research collaboration projects.		Ordinal
Involvement in teaching [TEACH]	Measured as the percentage of time spent by the researcher during the last 5 years on teaching activities. This variable was matched with the normal distribution using a square root transformation.		Ratio
Publication assets [PUBL]	Measured as the total number of articles published in scholarly journals during the last 5 years. This variable was matched with the normal distribution using a square root transformation.		Ratio
Informal knowledge transfer [INFTR]	Measured as an index on a Likert scale of frequency ranging from 1 = *Never* to 5 = *Very often* regarding the four following statements. The scores of the respondents, which initially ranged from 4 to 20, were weighted in order to take into account "does not apply" answers. Thus, for each respondent, the sum of the score was divided by the number of applicable item(s). Even though the initial index has integer values from 1 to 5, once weighted, it can take on non-integer values.	I have sent my research results to private firms, government agencies and other users outside the academic milieu; I have been invited to present my research results to groups and organizations which could make direct use of them; I have been asked to sit in on working groups that were involved in efforts to directly apply new knowledge including my own research; The use of my research results has contributed to the development of new or improved goods or services.	Sum of the four items divided by the number of applicable items (the index ranges between 1 and 5)

Independent variables	Measure	Sub-items	Method (range)
Continuous variables			
Degree of novelty of research results [NOVELTY]	Measured by using a four-item index regarding the distance between research results and their applicability. For each of the four following statements, the respondents were asked to assess what would be required for their research results to be used in the development of new or improved products, processes or services, using a 5-point scale ranging from 1 (Strongly disagree) to 5 (Strongly agree).	The use of new materials; The use of radical new technology; The use of new production techniques; Significant financial investments.	Sum of the four items divided by the number of applicable items (the index ranges between 1 and 5)
Level of network assets [NETASS]	Measured as an index on a Likert scale of frequency ranging from 1 = Never to 5 = Very often assessing the intensity of the linkages that the researcher had with managers and/or professionals from three types of organizations. For each type of organization, the respondents were asked to assess how frequently they had person-to-person contact with managers and/or professionals, using a 5-point scale ranging from 1 (Never) to 5 (Very often).	Private firms Government departments University communications department (media relations, public affairs)	Sum of the three items divided by the number of applicable items (the index ranges between 1 and 5)
Research unit size [SrUNTSZ]	Measured as the number of equivalent full time research personnel (excluding administrative support) supported by the researcher's research grants and contracts. This variable was matched with the normal distribution using a square root transformation.		Ratio
Experience of researcher [EXPR]	Measured as the number of years between 2002 and the year of completion of PhD. This variable was matched with the normal distribution using a square root transformation.		Ratio
Categorical variables			
Internal funding [INTFND]	Dichotomous variable: coded '1' if the researcher considered that funding from his university was Important, Very important, or Extremely important to the success of his research projects over the past 5 years, and 0 otherwise. We have not included funding from university research granting councils because there was no significant difference in this respect between the academics surveyed in this study who all had research grants from the Natural Science and Engineering Council of Canada.		
Private funding [PRVFND]	Dichotomous variable: coded '1' if the researcher considered that funding from private firms was Important, Very important, or Extremely important to the success of his/her research projects over the past 5 years, and 0 otherwise.		
Gender [GENDER]	Dichotomous variable: coded '1' if the researcher is a man and coded 0 if the researcher is a woman.		
Seniority	The level of seniority in the academic ranks was measured as follows: grantee researcher (GRANTEE) is a binary variable coded 1 if the researcher is not tenured and if his salary is supported by research grants, and coded 0 otherwise; assistant professor (ASSIST) is a binary variable coded 1 if the researcher is an assistant professor, and coded 0 otherwise; associate professor (ASSOC) is a binary variable coded 1 if the researcher is an associate professor, and coded 0 otherwise; finally, full professor (FULL) is a binary variable coded 1 if the researcher is a full professor, and coded 0 otherwise. This last category was used as the reference category in the econometric models.		
Large-sized university [LARGEUNV]	Dichotomous variable: coded '1' if the researcher is affiliated with a large-sized research university, and 0 otherwise. The categorization of universities in Large, Medium and Small sizes was developed by the staff of the Natural Sciences and Engineering Research Council of Canada (NSERC), based on the levels of the total funding received by the various universities from national and provincial research councils. In this paper, the large-sized research universities represent what is frequently referred to in the literature as the elite universities.		
Research fields	Research fields were measured with a series of dichotomous variables defined as follows: Engineering (ENGIN) is a binary variable coded 1 if the respondent is a researcher in engineering, and 0 otherwise; Chemistry (CHEMIST) is a binary variable coded 1 if the respondent is a researcher in chemistry, and 0 otherwise; Physics, mathematics and statistics (PHYMAT) is a binary variable coded 1 if the respondent is a researcher in physics, mathematics and statistics, and 0 otherwise; Computer (COMPUT) is a binary variable coded 1 if the respondent is a researcher in computer sciences, and 0 otherwise; Earth (EARTH) is a binary variable coded 1 if the respondent is a researcher in earth sciences, and 0 otherwise; finally, Life (LIFE) is a binary variable coded 1 if the respondent is a researcher in life sciences, and 0 otherwise. This last category of researchers was used as the reference category in the econometric models. These mutually exclusive categories are based on the NSERC's database and they refer to the names of the peer review committees selected by the researchers when they submit applications for research grants.		

Appendix B. Test of constructs' unidimensionality and internal reliability coefficients (Chronbach's alpha) for variables including multiple-item scale.

Items:	Communalities	Item score
Informal knowledge transfer		
1. I have sent my research results to private firms, government agencies and other users outside the academic milieu	.640	.800
2. I have been invited to present my research results to groups and organizations which could make direct use of them	.696	.834
3. I have been asked to sit on working groups that were involved in efforts to directly apply new knowledge including my own research	.573	.757
4. The use of my research results has contributed to the development of new or improved goods or services	.618	.786
Explained variance		63.455%
Eigenvalue		2.54
Chronbach's alpha	.807	
Degree of novelty of research results		
The use of new materials	.579	.761
The use of radical new technology	.621	.788
The use of new production techniques	.613	.783
Significant financial investments	.518	.646
Explained variance		55.88%
Eigenvalue		2.24
Chronbach's alpha	.735	
Level of network assets		
Private firms	.784	.885
Government departments	.739	.860
University communications department (media relations, public affairs)	.656	.810
Explained variance		59.20%
Eigenvalue		1.78
Chronbach's alpha	.649	

Appendix C. Correlation matrix.

Non-parametric correlations between independent variables

	PRVFND	INTFND	NOVELT	ENGIN	CHEMIST	PHYMAT	COMPUT	EARTH	NETASS	SrLABSZ	LRGUNV	SrEXPR	GRANTEE	ASSIST	ASSOC
INTFND	.036														
NOVELT	.124	.122													
ENGIN	.365	.032	.079												
CHEMIST	.008	.043	.117	−.200											
PHYMAT	−.287	.002	−.018	−.289	−.130										
COMPUT	−.001	−.002	−.120	−.198	−.089	−.129									
EARTH	.029	−.066	−.087	−.198	−.089	−.129	−.088								
NETASS	.552	.001	.166	.330	−.040	−.237	−.022	.123							
SrLABSZ	.346	−.035	.180	.121	.075	−.249	−.039	−.001	.352						
LRGUNV	.044	−.101	−.028	.036	−.032	.002	−.015	.001	.025	.132					
SrEXPR	−.099	−.231	−.069	−.109	.071	.117	−.136	.094	−.027	−.085	.123				
GRANTEE	.067	−.060	−.005	.077	.021	−.018	−.041	−.032	.049	.055	.020	.048			
ASSIST	.024	.293	.094	.054	−.007	−.057	.067	−.078	.006	.006	−.014	−.564	−.139		
ASSOC	−.027	.004	−.044	−.047	−.013	−.015	.053	−.011	−.069	−.045	−.074	−.260	−.146	−.247	
GENDER	.093	−.067	.031	.086	.028	.071	−.032	.066	.077	.017	.006	.206	.018	−.133	−.138

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