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Technology commercialization intelligence: Organizational antecedents and performance consequences

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ABSTRACT

External technology commercialization, e.g., by means of technology licensing, has recently gained in importance. Despite imperfections in technology markets, out-licensing constitutes a major technology commercialization channel. Although the identification of licensing opportunities represents a significant managerial challenge, prior research has relatively neglected these activities. Therefore, we develop the concept of 'technology commercialization intelligence' (TCI), which refers to the observation of a firm's environment with particular focus on identifying technology licensing opportunities. Grounded in a dynamic capabilities perspective, we test hypotheses regarding organizational antecedents and performance consequences of TCI, drawing on data from a survey of 152 companies. The empirical findings provide strong support for the importance of the TCI concept. The findings deepen our understanding of the discrepancies between successful pioneering firms active in technology licensing and many others being less successful. The results have major implications for technology exploitation in open innovation processes.

1. Introduction

External technology commercialization has recently emerged as a major trend in industrial firms [1,2]. It refers to commercializing technologies exclusively or in addition to their application in a firm's own products, e.g., by means of out-licensing [3,4]. Thus, it goes far beyond a marginal activity of commercializing residual technologies [5,6]. In particular, firms often license technology because of limited complementary assets for internal technology exploitation [4,7]. Accordingly, outward technology transfer often constitutes a key dimension of corporate strategy [1,8]. A significant example is a biotechnology company that collaborates with large pharmaceutical firms to commercialize new technologies [9]. By means of technology licensing, firms attempt to achieve various strategic and monetary benefits. Previously, this potential had often been neglected because outward technology transfer was limited to specific situations, e.g., foreign market entry through licensing [10].

Regarding strategic benefits, external technology exploitation may help firms to set industry standards or gain access to external knowledge. Concerning monetary benefits, various pioneering firms, e.g., IBM and Dow Chemical, have generated hundreds of millions of dollars in annual licensing revenues [11]. Thus, technology licensing may substantially contribute to firm performance. For instance, Texas Instruments received as much as 50% of its net income from licensing over multiple years, and this number is likely even higher in some small companies [8,11]. Despite the benefits of some pioneering firms, most firms experience major managerial difficulties in external technology exploitation. Many companies do not achieve their objectives in technology

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licensing because of the managerial challenges in the imperfect markets for technology [12]. As an effect, the technology markets could be almost 70% larger than what they currently are [13].

The discrepancy between some successful firms in technology licensing and the many unsuccessful others cannot be explained by prior research. Therefore, this article sets out to study interfirm heterogeneity in executing external technology exploitation strategies and not to examine the consequences of technology licensing on firm performance, i.e., whether the benefits of such a strategy outweigh the detriments. Various researchers have recently suggested open technology exploitation strategies, which imply minor restrictions on external technology commercialization [6,10]. While these scholars focus on the opportunities of externally leveraging technological knowledge, the managerial challenges associated with these activities have often been neglected. These limitations underline the strong research deficit, especially concerning the identification of technology commercialization opportunities. The recent increase in technology licensing is a trend mainly from p[illegible], however, and it has insufficiently been reflected upon by academic research.

Internal technology application in new products, which represents the complementary mode of technology exploitation [14,15], and inward technology transfer, which constitutes the opposite type of technology transactions [16,17], has received a lot of attention. Research into university technology transfer [18] and some recent studies into corporate technology licensing [1, 19] have deepened our understanding of outward technology transactions. These studies have emphasized the increasing importance of technology licensing, but they have focused on the outcome of licensing activities and [illegible] external determinants of licensing, e.g., a firm's competitive environment [1,20]. However, a complementary analysis of internal managerial activities, which opens up the black box of corporate out-licensing behavior, is lacking [7,19]. This lack of research constitutes a significant gap in our understanding because external determinants likely affect a firm's internal processes, which in turn influence its licensing behavior [11,21].

Although the identification of licensing opportunities has been highlighted as a central managerial challenge in external technology exploitation, managerial responses to this challenge have hardly been addressed in prior research [11,12]. Prior work on technology intelligence [22–24] has focused on the observation of a firm's technological environment to support internal innovation. In response to the increasing acquisition of external technology, some studies have additionally pointed to the need of technology acquisition intelligence, i.e., the observation of technology acquisition opportunities and technology sources [9,25]. In a similar vein, research into technology-based alliances, which has usually taken a technology acquisition perspective, has frequently emphasized the need for identifying appropriate partners [26,2[illegible]]. By contrast, the insights into identifying technology commercialization opportunities in the context of imperfect technology markets are limited [11,28–30].

The present article is aimed at bridging these gaps in [illegible] by developing and subsequently testing empirically the new concept of '*technology commercialization intelligence*' (TCI), which is defined as the scanning and monitoring of a firm's environment with particular emphasis on the identification of technology licensing opportunities and potential licensees. In light of an increasing interest in external technology commercialization, the article provides various new insights, and it contributes to the literature in several ways. First and foremost, the article [illegible] to explain the discrepancies between some leading firms in outward technology transfer and many others. As such, it constitutes a first step towards a theory of technology licensing. Successful TCI appears essential to achieve [illegible] avoiding the risks of transferring proprietary technology. As TCI contributes to effective technology exploitation, it may constitute a major determinant of performance in technology-based firms [11]. Because of interdependencies between internal and external technology exploitation, e.g., technology licensing to gain access to external knowledge, the study's implications go beyond outward technology transfer. The article addresses a central dimension of corporate strategy in technology-based industrial firms [11]. In particular, this article deepens our understanding of capturing value from technology in open innovation processes [14,31]. Moreover, it helps to explain market mechanisms in knowledge markets, which differ from product markets [[illegible]2].

Grounded in a dynamic capabilities perspective, this article is among the first quantitative success factor studies of technology licensing. We test multiple hypotheses regarding antecedents and consequences of TCI with data from a large sample of industrial firms in Germany, Austria, and Switzerland. In particular, the data underscore the importance of different organizational mechanisms in intelligence processes. Because of our focus on organizational antecedents of TCI, we do not examine specific methods for [illegible] technologies and markets [33]. Finally, the study has implications for emerging themes in technology management, e.g., organizational boundaries [34]. As technology boundaries may mismatch organizational boundaries, our study provides support for [illegible]ency perspectives in boundaries research, which go beyond efficiency-based analyses, e.g., transaction costs [35]. These issues have been highlighted as areas ripe for further study in recent works on opportunity identification [3[illegible]], knowledge management [34], technology intelligence [25], technology licensing [37], organizational boundaries [35], and open innovation [8].

2. Theory and hypotheses

2.1. Technology commercialization intelligence

As a result of the imperfections in the markets for technology, external technology commercialization is more complex than the commercialization of goods or services [13,30]. However, firms may reduce transaction costs in technology markets by developing a dynamic capability of identifying technology transfer opportunities [11,17]. Successfully managing internal technology exploitation, i.e., new product development, has often been used as an example of a dynamic capability [38,39]. In that field, prior research has found positive effects of intelligence processes on performance [40,41]. Despite the differences between internal and external technology exploitation [37,42], their complementary nature points to a positive influence of intelligence activities in outward technology transfer.

To identify technological opportunities and threats in a firm's environment, many companies have established technology intelligence processes, which are directed at becoming aware of technological trends in time [43–45]. Furthermore, technology intelligence fulfills additional roles, such as organizational learning [25,46,47]. Because of the growing acquisition of external technology, many technology-based companies have systematized their search processes by building up additional technology acquisition intelligence activities [48,49]. These activities are specifically designed to identify potential technology sources, to support 'make or buy' decisions, and to monitor existing external technology acquisition projects [16,25]. For the external commercialization of technologies, by contrast, no specific intelligence processes have been described in prior research.

This research deficit is surprising as the identification of technology commercialization opportunities constitutes the essential managerial challenge in outward technology transfer [12,13]. Accordingly, proficient TCI processes should be an essential starting point for enhancing a firm's performance in this field. Following research into new product development, proficiency is here understood as the quality of executing the TCI tasks [41,50]. Basically, the proficiency level reflects to what degree a firm has set up high-quality TCI activities instead of considering them as marginal ad-hoc operations with limited quality of execution [51,52]. As external technology exploitation does not constitute the core business of most industrial firms, previous research has shown that there are major differences between successful pioneering firms and many others with regard to proficiently managing TCI [2,10,53].

TCI comprises the scanning and monitoring of a firm's environment with particular focus on licensing opportunities and potential licensees. Basically, the role of TCI is to provide relevant information for external technology commercialization. Besides the identification of opportunities, TCI also includes the identification of potential risks and the analysis of the environment, e.g., competitors in technology markets [54,55]. Moreover, TCI not only refers to information search but also to the prior identification of information needs and to the subsequent information evaluation and communication [25,56]. The identification of the information needs limits the search for internal and external information to avoid information overflow [57,58]. On this basis, information is collected for the needs that have been identified [[illegible],58]. Subsequently, the relevance of the information is determined, which positively impacts on organizational learning [48,[illegible]]. Finally, the results of information search and information evaluation are transferred to the relevant persons in the organization [[illegible]7,59].

Hence, TCI refers to the scanning and monitoring of a firm's environment with a particular focus on opportunities for licensing and the identification of potential licensees. In external technology exploitation, a firm owns a potential technological solution for specific problems. The firm faces the difficulty of identifying profitable applications, which may be in completely different industries than its own current product markets. Accordingly, the [illegible] challenge is the identification of applications for a technology, which has been developed or will be developed [[illegible]]. Thus, TCI not only refers to the observation of a firm's technological environment [25]. By contrast, it also goes beyond developing a market orientation because market orientation refers to a strategic focus on a firm's product markets, which does not include the markets for technology [60]. In addition, TCI exceeds competitor intelligence activities because many licensing opportunities arise across industries [13]. As a consequence, TCI activities go beyond the observation of a firm's competitive environment, which mainly refers to the industries of a firm's product business [54,61].

The identification of licensing opportunities comprises the examination of internal technologies that may be licensed and the observation of the environment regarding potential licensees. Similar to general intelligence processes [25], TCI may therefore follow two strategic approaches. In the 'inside-out' approach [59], a firm screens its technology portfolio to find technologies that could be licensed based on its corporate strategy. Then, the firm monitors its environment to find possible applications of these technologies. According to the 'outside-in' approach [59], a firm scans broad application areas, which could have some connection to its technologies. Subsequently, the firm analyzes if it has technologies that fit the particular application. These two modes represent 'ideal types', and because of interdependencies between these two complementary approaches, firms usually combine them in their intelligence processes [25]. Thus, TCI activities are usually situated at a continuum somewhere in between these two approaches.

2.2. Organizational antecedents of technology commercialization intelligence

Early works on technology intelligence has primarily suggested establishing a centralized technology intelligence unit, but recent works have shown that technology intelligence processes require more complex solutions [25,31,62]. In particular, technology intelligence activities comprise informal and project-based organizational mechanisms in addition to formal organizational structures [47,56]. To arrive at a comprehensive view of managing TCI, we follow prior technology intelligence research and study three complementary organizational mechanisms, which may indeed co-exist within any given firm. First, firms may rely on structural organization, i.e., particular organizational structures for coordinating intelligence tasks [56,63,64]. Second, a firm may use project-based organization, which refers to temporary projects for coordinating intelligence activities [65–67]. Third, different intelligence tasks may be carried out informally [67–69]. In the following, these three organizational mechanisms are addressed in detail.

2.2.1. Structural organization

Structural organizational mechanisms are based on organizational rules, and they are part of a firm's formal organizational structure [64,67]. By establishing and maintaining these structures, a company institutionalizes its TCI activities. The most obvious of these actions is to allocate resources, particularly dedicated employees, exclusively to TCI. Although too much institutionalization in the form of rules and formality may hamper proficiency in TCI, the extant literature suggests several positive effects of structural organization. First, because of the continuity that often results from assigning specialized employees, the systematic organizational approach constitutes a key factor for improving TCI [48,56]. In particular, formal organizational structures enhance the possibility to achieve learning effects that help firms enhance their proficiency in these activities over time [70,71]. As dedicated TCI employees do not possess all relevant knowledge to ensure the success of a firm's TCI, they do not carry out all tasks on their own. Instead, they have a coordinating role and serve as contact persons for issues regarding TCI, thus forming a communication hub [25,70].

Second, and beyond performing a pure coordinating role, formally dedicated employees may directly extend a firm's relevant knowledge for identifying applications of its technologies. The easiest way of developing knowledge ab[illegible]itional markets for a firm's technologies is to hire persons that have previously worked in the relevant application are[illegible]his de[illegible]n constitutes a substantial investment, which may be justified only if a firm sees a high commercialization potent[illegible]or its techn[illegible]gies. However, this investment may already pay off if it leads to one or two major technology transactions because a[illegible]ional expe[illegible]itures tend to be relatively low, whereas the potential revenues are high [5]. Dedicated TCI employees need[illegible]have su[illegible]nt i[illegible]ght into a firm's technologies and into potential markets for these technologies. Thus, firms may bene[illegible]rom the T-s[illegible]skills of selected employees [72]. However, an initial learning period appears to be inevitable unti[illegible]e inve[illegible]ents in [illegible]ssigning dedicated employees materialize.

While hiring employees from other industries may be considered the most dire[illegible]nd e[illegible]ive wa[illegible] building up application knowledge for a particular industry, there are other ways, which require less res[illegible]es. A comp[illegible] assign internal employees, who already have sufficient prior knowledge about the firm's technologies [17[illegible]nalyze parti[illegible]ar markets and to accumulate relevant knowledge about these markets. As these initiatives may cover a va[illegible]ty o[illegible]tries, formally dedicated employees may learn to become familiar with new markets more easily by developing experience-base[illegible]wledge regarding the analysis of new applications, the matching of possible applications with a firm'[illegible]ologies, and [illegible]e assessment of these technology commercialization opportunities. Grounded in the arguments abov[illegible]we posit the following hypothesis.

Hypothesis 1. Activities associated with structural organization ar[illegible]sitively re[illegible]ed to a firm's proficiency in TCI.

2.2.2. Project organization

Project-based organizational mechanisms refer to [illegible]s that may not clearly be classified as formal or informal organization [66,69]. Thus, project-based organization co[illegible]utes [illegible]organizational mechanism for conducting TCI [25]. TCI projects are officially set up by a firm's management, but the[illegible]lo[illegible]t result in continuous organizational structures. In technology intelligence, project-based organization is gainin[illegible]popular[illegible]nd it represents an essential complement to formal technology intelligence structures, which are relatively [illegible]n many[illegible]ms [47,56]. Despite their popularity, however, project-based organization may impose negative constr[illegible]s on [illegible]ns trying to implement them. For instance, structures and procedures employed in projects need to be understoo[illegible]relat[illegible]us and simultaneous courses of activity [73]. Utilizing projects may also lead to problems with communica[illegible]n a[illegible]rdination [74]. These problems seem indeed unfavorable for proficiency in TCI but as with structural organization, h[illegible]ever, the p[illegible]ive effects of project organization on proficiency in TCI seem to outweigh the negative ones.

First and foremost, projects[illegible]ay b[illegible]d to pool the capabilities of various individuals from different functional units and business units to benefit fro[illegible]the potentia[illegible]ergies of combining different knowledge bases [40,75]. In particular, these projects may help firms to integrat[illegible]e knowledge o[illegible]icated TCI employees on the one hand and of R&D and marketing experts on the other. A multi-business[illegible]t co[illegible]osition of the project teams may further help to successfully use a firm's knowledge about potential applications[illegible]s te[illegible]ologies. This application knowledge may result from business activities in different product areas [37], and it may constit[illegible]ajor ad[illegible]tage in TCI.

Concerning th[illegible]cus a[illegible]irec[illegible] of TCI projects, they may follow either the 'inside-out' perspective or the 'outside-in' perspective th[illegible]av[illegible]en dis[illegible]above [59]. Thus, the project team may start with screening a firm's technology portfolio and later identif[illegible]otenti[illegible]applications for the relevant technologies. Alternatively, it may scan broad application areas to identify interestin[illegible]plica[illegible]hich the firm may have appropriate technologies. Therefore, projects to identify technology commerciali[illegible]pportunities also help firms to address specific topics and to benefit from the distinct expertise of multiple employees. Acco[illegible]ly, the potential benefits of TCI projects go beyond the knowledge of dedicated employees, and they help firms to ensure suff[illegible]t flexibility in managing TCI. For these reasons, projects represent an essential complement to structural organization, and due to the possibility of enhancing TCI proficiency by carrying out specific projects, we posit the following hypothesis.

Hypothesis 2. Activities associated with project-based organization are positively related to a firm's proficiency in TCI.

2.2.3. Informal organization

Beyond dedicating specific resources to TCI by building up organizational structures and carrying out projects, a company may rely on informal modes of organizing. Such a mode is not part of the formal organizational structure, and it is not or only to a very limited degree based on formal rules and regulations [67,69]. Results of research into internal technology exploitation, technology intelligence, and strategic alliances point to the relevance of informal mechanisms in TCI [47,61,76]. The importance of informal organization for TCI is also supported by research on technological gatekeepers, who provide a link between an organization or organizational unit and its external environment. One key characteristic of gatekeepers is that they are able to understand and translate contrasting languages, conceptual frameworks, and coding schemes [77–79]. To identify potential applications of a firm's technologies, the knowledge about technologies and applications has to be communicated across the organization, which may be regarded as a distributed knowledge system [80].

Thus, proficiency of a firm's TCI not only depends on its interfaces with the external environment but also on knowledge transfers across and within its subunits [17,80]. Therefore, informal activities, e.g., gatekeepers' activities, are likely beneficial for a firm's proficiency in TCI. If every subunit only uses its own knowledge, the opportunities of knowledge sharing across subunits remain unrealized [81]. Apart from the communication between different business units, the pooling of the knowledge bases has to overcome functional barriers, e.g., the R&D and marketing interface, which may represent considerable communicational challenges [75,80]. To access the distributed knowledge bases, it seems beneficial to rely on informal approaches to TCI, which will result in broader knowledge bases [80,81].

As the resources of dedicated employees are limited, an active involvement of the organization's other members seems reasonable. Researchers in the fields of technology intelligence and absorptive capacity have called for a broad range of potential receptors [17,25]. Regarding TCI, this corresponds to a large number of persons that actively try to identify licensing opportunities. In addition to marketing staff, it appears to be particularly beneficial to draw on the knowledge of R&D employees. These technology experts have often developed the new technologies, and they may have interesting ideas for their potential external commercialization, either exclusively or in addition to their internal application [18]. Although we suggest an active involvement of these persons, their limited resources for TCI are acknowledged because external technology exploitation does not constitute the core business of most firms. However, the identification of technology commercialization opportunities may be realized by these persons along with their ongoing work without major resource requirements [77,78]. One may argue that informal activities may imply negative consequences as well, as these are outside the formal control of management, but as these informal approaches may considerably enhance a firm's TCI, they constitute a major complement to formal organizational structures. Accordingly, the following hypothesis is proposed.

Hypothesis 3. Activities associated with informal organization are positively related to a firm's proficiency in TCI.

2.3. Performance consequences of technology commercialization intelligence

Multiple reasons lay behind the fact that we should expect proficiency in TCI to be positively related to performance in externally commercializing technology. First, by developing proficiency in TCI activities, firms may cope with the challenges of identifying licensees [11,13]. Thus, firms will be able to identify a higher number of technology commercialization opportunities. In most cases, only a part of the additional opportunities that are identified by means of proficient TCI will finally lead to technology transactions [13,30]. Nevertheless, TCI may provide firms with options to externally leverage technology that they would not have identified otherwise. Accordingly, it seems reasonable to believe that proficient TCI leads to a higher quantity of technology transactions. Second, TCI may lead to a higher quality of external technology exploitation. Firms with limited TCI lack sufficient information to successfully take 'keep-or-sell' decisions [12]. In firms with proficient TCI, by contrast, 'keep-or-sell' issues are addressed more successfully based on detailed information about the benefits and drawbacks of a particular technology transaction. As a result, firms with proficient TCI may achieve the opportunities of external technology commercialization, which may provide an important source of competitive advantage [8,13].

Third, firms with high proficiency in TCI should be better positioned to control the risks of transferring proprietary technology [5,11]. In a similar vein, they are likely better at identifying these risks because environmental threats may be analyzed more thoroughly. For instance, the licensing potential of a particular technology may be substantially reduced by the development of a new competing technology. In contrast, insufficient TCI may have severe negative consequences. Among them are the incomplete exploitation of a firm's technology portfolio and the underutilization of the monetary and strategic opportunities of technology licensing. An example of the inability to achieve the strategic benefits is the failure to establish an industry standard based on a firm's own technology. However, insufficient TCI may also result in strengthening competitors because of underestimating the risks of transferring technologies [5]. These potential negative effects of insufficient TCI illustrate that TCI likely has a positive impact despite the additional costs that result from these activities. Because of the relatively high volume of many licensing deals, a few successful technology licensing transactions will usually be enough to overcompensate the limited costs of TCI [37].

Finally, in external technology acquisition, many firms have established intelligence processes to support the identification and absorption of external knowledge [9,48]. Thus, investing in these activities is beneficial, and similar effects can be expected in technology commercialization. As TCI reduces the uncertainty concerning a potential technology transfer, it may lower a firm's transaction costs in technology markets. The larger numbers of technology transactions that result from high TCI may in turn enhance a firm's knowledge of potential applications of its technologies. These effects underline that proficient TCI processes are built up in path-dependent learning processes [17], which may finally lead to a self-reinforcing cycle. The self-reinforcing tendencies may be intensified by the fact that a critical level of technology commercialization is necessary for investments in TCI to pay off. For instance, establishing dedicated structures may only be reasonable in firms that enter a substantial number of technology transactions. In sum, there are strong theoretical reasons for why we should expect a positive influence of TCI on performance in external technology exploitation. Accordingly, we posit the following hypothesis.

Hypothesis 4. Proficiency in TCI is positively related to a firm's performance in external technology commercialization.

One can assume that the positive effect of TCI on performance in external technology commercialization may vary with environmental conditions, as external contingency factors affect the markets for technology [11,30]. Therefore, we consider the degree of technological turbulence, which reflects the major dimension of environmental uncertainty in the technology markets. Technological turbulence, i.e., the rate of technological change [60], has been considered in numerous prior studies e.g., [82]. Some authors e.g., [53], have suggested that capabilities are path-dependent and hence very difficult to change, while environmental conditions are often described as transient, a fact which speaks against the assumption of moderation effects. Other results indicate, however, that the importance of TCI increases in situations of high technological turbulence. In settings that are characterized by relatively stable conditions, firms may identify promising licensing opportunities [illegible] without establishing professional TCI processes. A firm's technologies are replaced less rapidly, and the firm has more time to identify licensees [13,30].

In situations of high technological change, by contrast, complexity increases [38]. It becomes increasingly difficult to have an overview of promising technology commercialization opportunities because of rapid changes in the different technology fields [83]. Accordingly, proficient TCI appears to be essential. Besides strengthening the performance impact of TCI, higher technological turbulence may also require a more active acquisition of external technologies because firms are unable to [illegible] all technological developments by internal inventive activities [11,83]. A more active acquisition of external technology enhances the licensing potential of a firm's technologies [12,13]. As this higher potential may be achieved by firms with proficient TCI, its positive impact tends to increase further. Hence, key findings of prior works suggest a positive moderating effect of technological turbulence on the relation between TCI and performance. Thus, our fifth and final hypotheses state that:

Hypothesis 5. Technological turbulence positively moderates the relationship between proficiency in TCI and a firm's performance in external technology commercialization.

3. Methods

3.1. Sample and data collection

The study focused on medium-sized and large industrial companies. In most of these firms, external technology commercialization is considered a strategic activity, which complements their main business, i.e., product marketing [4,11]. Accordingly, these firms actually take 'keep-or-sell' decisions because they are able to internally exploit technologies and are not forced to externally commercialize them. Therefore, a sample of medium-sized and large firms appears to be more appropriate for studying TCI than a sample of small firms or of firms that mainly provide R&D services. After conducting interviews in 25 firms, a questionnaire-based study was carried out. To boost the response rate, this study was supported by the Licensing Executives Society (LES), an organization of practitioners in the field of intellectual property management. Therefore, we directly contacted all LES industry members in Germany, Switzerland, and Austria. The LES is directed at intellectual property management in general, and only one of its numerous committees addresses out-licensing. Accordingly, it comprises members from firms that actively commercialize technological knowledge and members from firms that are relatively passive in this respect.

To reach a cross-sectional sample of medium-sized and large firms, we additionally considered all industrial companies ranked among the 500 largest firms in Germany, among the 100 largest firms in Switzerland, and among the 100 largest firms in Austria based on revenues. Thus, the sample is not representative of all companies. It comprises medium-sized and large firms from Germany, Switzerland, and Austria, and a part of these firms are LES members. Because of our focus on industrial firms and a considerable overlap between the LES members and the top 500 firms in Germany and the top 100 firms in both Switzerland and Austria, a total number of 412 companies could be identified as potential participants. 155 firms participated in the study, corresponding to a response rate of 37.6%. If the confidentiality of the questions is taken into account, this response rate can be considered high. A *t*-test for non-response bias and for a bias resulting from LES membership showed no significant differences regarding different variables, e.g., firm size. Of the 155 questionnaires, [illegible] were sufficiently complete for 152 firms. Despite our assurances of complete anonymity and confidentiality, however, 16 firms did not disclose their licensing revenues. The number of observations is therefore slightly lower for the analyses [illegible] measure. Additional analyses keeping only the 136 companies show no significant changes in the findings as reported below on the basis of the full sample of 152 firms. A profile of the sample shows a reasonable spread across industries: automotive/machinery 42%, chemicals/pharmaceuticals 28%, electronics/semiconductors 18%, and other 12%.

Based on the interviews, we identified the heads of the firms' corporate intellectual property departments as key informants. In firms with a dedicated external technology commercialization unit, e.g., licensing function, the head of this unit was our key informant. Because of the importance of patents in knowledge transactions [21], a firm's intellectual property department is involved in nearly all of these transactions. Because of the specificity of most questions, these persons were the only informants with a sufficient level of knowledge to answer the survey questions. Apart from their detailed understanding of a firm's current technology commercialization activities, the informants were able to assess the potential benefits that a firm may achieve from externally leveraging technology. Moreover, these persons strongly interact with other employees along the out-licensing process. Therefore, it is feasible to assume that they possessed detailed insights into the issues that were relevant in this study.

Data collection was undertaken via questionnaires administered in English, given that the literature base from which measurement scales were derived was exclusively in English. Most of the firms in the sample are international companies with headquarters in one of the three countries included in this study. In addition, pretests indicated that the language did not compromise a homogeneous understanding of the items among the informants. The measurement scales were specifically generated for this study based on descriptions and measures of related constructs in the literature e.g., [58,60]. In developing these scales, we followed suggestions in the literature for developing valid measures. The complete measurement scales are included in the appendix of this article. Informants rated all items on 7-point scales. The anchor points for the items were 'I strongly disagree' = 1 to 'I strongly agree' = 7.

3.2. Measures

3.2.1. Technology commercialization intelligence

TCI has been measured on a three-item scale. The construct (Cronbach's alpha = .79) describes the proficiency of a firm's activities to observe the environment and to identify technology commercialization opportunities and potential technology customers. Accordingly, the items capture to what degree a continuous observation of a firm's external technological environment takes place, particularly with the aim of identifying technology commercialization opportunities. The items have been developed based on prior research into technology intelligence and information search [56–58].

3.2.2. Organizational antecedents

Regarding *structural organization* of TCI, we have measured the number of dedicated employees, who represent the major organizational resource that is specifically assigned to external technology commercialization. Accordingly, we have asked for the number of persons in a firm that are occupied full-time with external technology exploitation. *Process-based organization* has been measured on a three-item scale (Cronbach's alpha = .91). It captures if a company sets up particular projects to identify technology commercialization opportunities. Thus, it considers if the technology portfolio is regularly checked for commercialization opportunities, if particular resources are employed, and if different employees collaborate to identify external technology exploitation opportunities. *Informal organization* has been measured on a three-item scale (Cronbach's alpha = .90). It considers if, in addition to dedicated employees, a large number of persons try to identify commercialization opportunities. Because of the importance of marketing and R&D employees in these activities and to facilitate the understanding of the items by the informants, the construct focuses on the participation of marketing and R&D experts.

3.2.3. Performance consequences

To capture the monetary and strategic aspects of external technology exploitation, we have used a firm's revenues in this field and its success relative to competitors as dependent variables. A firm's *annual revenues from externally commercializing technology* refer to the revenues from licensing and selling technological knowledge. Because of the high confidentiality of this information in most firms, which had been emphasized in the pretests, the revenues were measured in the following five categories: EUR 0–5 million, EUR 5–20 million, EUR 20–50 million, EUR 50–100 million, over EUR 100 million. In the factor analysis, this measure formed one factor with the subjective measure 'The return on our investments in external technology exploitation is high', which was measured on a 7-point scale. The correlation coefficient between these variables is .82 $p<01$. However, we decided to focus on revenues as an objective success variable to limit common method bias.

The variable *success relative to competitors* (Cronbach's alpha = .92) was measured using three items capturing a firm's performance in external technology commercialization relative to the firm's direct competitors. Thus, the construct considers strategic aspects in addition to monetary issues. It shows that companies which are successful in external technology commercialization from a monetary perspective also tend to successfully achieve the strategic potential and vice-versa. The relatively high correlation between the success variables of .47 $p = .001$ highlights the importance of monetary aspects when comparing external technology commercialization among firms. At the same time, however, it demonstrates the importance of strategic issues because otherwise the correlation would have been still higher.

The measurement scale of *technological turbulence* (Cronbach's alpha = .71) is based on Jaworski and Kohli [60], who developed the items as a moderating construct in their study of market orientation. Subsequent empirical studies into new product development relied on these scales, e.g., [82]. The final construct in the present study consists of three items, and it captures the importance of technological change for a firm's business processes. Moreover, it takes into account the difficulty of forecasting technological change, and the need for closely observing the technological environment, which may be considered equally important for internal innovation processes and for externally commercializing technology.

3.2.4. Controls

Four sets of control variables have been taken into account. Firm size may affect the proficiency of TCI. Moreover, it may be related to performance because it affects the technology commercialization potential, i.e., the volume of technology that may be externally leveraged. Accordingly, the firms' *revenues* in billions of Euros have been included as a measure of their size. Because of the higher commercialization potential, *R&D intensity*, i.e., R&D expenditures as a percentage of sales, has been considered as another control variable. By influencing the size of a firm's technology portfolio, it may also have an impact on TCI. As a result of our cross-industry approach, we also controlled for any *industry* effects on the relationships investigated. Based on prior works [2,11,21], which reported different motives for external technology commercialization in these industries, we grouped the companies into the following four classes: automotive/machinery, chemicals/pharmaceuticals, semiconductors/electronics, and other. For the first three classes, we included a dummy variable (1 = pertaining to this industry 0 = not pertaining to this industry) in our analyses. The same method was applied to the firms' *country of origin* in the OLS analyses with controls for Austria and Switzerland. However, we could not include dummy variables for both countries in the ordered logit analyses. Because of the limited number of firms from these countries, the ordered logit analyses failed to converge [84]. Therefore, these categories were combined into one dummy variable (1 = headquarters in one of these countries; 0 = headquarters not in these countries).

3.3. Analytical procedures

Because of analyzing the antecedents and consequences of TCI, we had to take into account the antecedents when analyzing the consequences. Although mediation effects do not constitute the main focus of this article, we applied the most common method for testing mediation and performed three regression models: (1) the mediator on the independent variables; (2) the dependent variable on the independent variables; (3) the dependent variable on both the independent variables and the mediator [85,86]. Mediation can be established if the regression coefficient of the independent variables in the third type of model is insignificant (full mediation) or less than in the second type of model (partial mediation) given that the mediator and the independent variables are significant in the third type of model. This method is considered the most appropriate procedure for studying mediation in samples that are smaller than 200 observations, and the significance of the partial mediation effect was tested by applying Sobel's test [85].

When analyzing the consequences of TCI, we could not use OLS regressions in the analysis of licensing revenues because these revenues were measured on an ordinal scale. Since OLS analyses can provide misleading results in this case, we applied ordered logit analyses [84]. For the second dependent variable, i.e., success relative to competitors, we used linear OLS regression models. To analyze the influence of technological turbulence, moderated multiple regression analyses have been applied. To reduce multicollinearity between the interaction term and the original variables, we have used the mean centering procedure [87]. In the moderated regression analyses, the potential moderator has been entered into the basic model. Then, the cross-product term has been entered. The regression coefficient and the partial F associated with the resulting change in R^2 have been examined to test whether or not a moderating effect exists. To understand the form of the interaction, we have analyzed simple slopes at one standard deviation below and above the mean [87]. Finally, the significance of the regression coefficients at the two levels has been examined to ensure the significance of the effect at all levels.

For all models, we calculated the variance inflation factor to check for potential multicollinearity. The highest value across all models and variables refers to 'automotive/machinery' in model 12 and amounts to 2.88. This value is well within an acceptable range [88]. In addition, the residuals have been checked for normal distribution applying the Komolgorov–Smirnov test [88]. Despite the 'quasi-objective' measure 'licensing revenues' as one indicator of activity, we cannot fully rule out the existence of a common method bias because the same key informant per firm was used in independent and dependent variables. Therefore, we analyzed the extent of a potential common method bias by applying the procedure recommended by Lindell and Whitney [81]. The results of this analysis suggest that our findings are not due to common method bias, but rather are substantial [89].

4. Results

Table 1 shows the descriptive statistics and correlations. For TCI, we find a relatively low mean of 2.95, which reflects that TCI is usually considered a major challenge in external technology commercialization. Moreover, this result points to managerial deficits

Table 1
Descriptive statistics and correlations

Variables	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TCI (1)	2.95	1.45														
Licensing revenues (2)	1.43	.96	[illegible]***													
Success relative to competitors (3)	3.45	[illegible]	.39[illegible]	.47***												
Revenues (4)	3.88	9.[illegible]	[illegible]	.59[illegible]	.27**											
R&D intensity (5)	[illegible]	6.63	[illegible]	[illegible]	−.10	−.05										
Automotive/ machinery (6)	[illegible]	.50	−.[illegible]	[illegible].12	.10	−.03	−.20*									
Chemicals/ pharma (7)	.28	[illegible]	[illegible]**	.17†	.05	−.02	.15	−.53***								
Electronics/ semiconductors (8)	[illegible]	.38	−.08	.10	−.14†	.10	.18†	−.40***	−.29***							
Austria (9)	.11	.31	.01	−.16†	.05	−.12	−.06	.01	.03	−.05						
Switzerland (10)	.20	.40	−.08	−.07	.04	−.11	−.05	.05	−.01	.03	−.17*					
Austria/ Switzerland (11)	.31	.46	−.07	−.17*	.07	−.17*	−.08	.05	.01	−.01	.52***	.75***				
Structural organization (12)	2.49	4.92	.37***	.76***	.38***	.49***	.01	−.19*	.24**	.07	−.03	−.06	−.08			
Hybrid organization (13)	2.87	1.66	.61***	.41***	.43***	.24**	.04	−.14†	.28***	−.19*	.05	−.08	−.03	.42***		
Informal organization (14)	3.79	1.60	.45***	.33***	.37***	−.04	−.01	.01	.32***	−.23**	−.05	.06	.02	.26**	.54***	
Technological turbulence (15)	4.35	1.17	.13	.15†	.20*	.04	.12	−.15†	.12	.14†	.02	−.08	−.06	.11	.32***	.28**

†$p<.1$; *$p<.05$; **$p<.01$; ***$p<.001$.

Table 2
Results of OLS analyses

Variables	Model 1	Model 2
Dependent variable	TCI	TCI
Control variables		
Revenues	.03* (.01)	.00 (.01)
R&D intensity	−.02 (.02)	−.03† (.02)
Automotive/machinery	−.64* (.37)	−.61* (.31)
Chemicals/pharmaceuticals	.27 (.39)	−.34 (.34)
Electronics/semiconductors	−.55 (.43)	−.22 (.36)
Austria	.02 (.38)	−.06 (.31)
Switzerland	−.19 (.29)	−.19 (.24)
Independent variables		
Structural organization		.04* (.02)
Hybrid organization		.38*** (.07)
Informal organization		.19** (.08)
R^2	.11	.43
R^2 adjusted	.07	.39
F	2.61*	10.76***
Number of observations	152	152

†$p<.1$; *$p<.05$; **$p<.01$; ***$p<.001$.
Unstandardized coefficients with standard errors in parentheses.

in TCI. In addition, the data show that the firms in the sample have assigned 2.[illegible]9 employees to TCI on average. Thus, the dedicated resources for technology licensing are limited in most firms. Informal organizational mechanisms have a relatively high mean of 3.79. Thus, firms do not exclusively rely on dedicated employees, but they additionally use the expert knowledge of R&D and marketing employees. The correlation coefficient between structural and informal organization is .26 at $p<.01$, which shows that the knowledge of other employees is used as a complement rather than as a substitute for the knowledge of dedicated TCI employees. Similar results may be found for project-based organizat[illegible]

In the regression analyses, 12 models have been tested. The models that [illegible] include the controls are all highly significant at $p<.001$ and explain a considerable part of the variance in the dependent variables. Regarding the antecedents of TCI, model 1 only includes the four sets of controls (Table 2). In model 2, we find the ex[illegible]positive effect of all three modes of organizing for TCI, and the adjusted R^2 increases to .39. Accordingly, Hypothesis 1, Hypothesis 2, and Hypothesis 3 are supported by the data. Thus, the proficiency in TCI can be enhanced by relying on activities associated with structural, project-based, and informal modes of organizing.

In models 3–7, the licensing revenues are used [illegible] dependent variable (Table 3). Model 3 only includes the controls. We find a significantly positive effect of firm size, which considerably contributes to the high Pseudo R^2 of .28. In addition, model 4 considers the independent variables. It shows positive effects [illegible] and informal organization, whereas project-based organization does not have a significant direct effect on lic[illegible]revenues. In model 5, we find a significant and positive influence of TCI. The

Table 3
Results of ordered logit analyses

Variables	Model 3	Model 4	Model 5	Model 6	Model 7
Dependent variable	Ext. tech. commercial. revenues	Ext. tech. commercial. revenues	Ext. tech. commercial. revenues	Ext. tech. commercial. revenues	Ext. tech. commercial. revenues
Control variables					
Revenues	[illegible] (.03)	.20*** (.05)	.21*** (.05)	.22*** (.05)	.23*** (.05)
R&D intensity	.05† [illegible]	.12** (.04)	.12** (.04)	.12** (.04)	.12** (.05)
Automotive/machinery	.45 (.74)	−.54 (.94)	−.39 (.94)	−.39 (.95)	−.41 (.94)
Chemicals/pharmaceuticals	[illegible] (.77)	−1.70† (1.07)	−1.66† (1.07)	−1.67† (1.07)	−1.60† (1.05)
Electronics/semiconductors	[illegible]2)	.13 (1.07)	.20 (1.09)	.02 (1.12)	−.06 (1.09)
Austria/Switzerland	−.76† (.54)	−1.11† (.69)	−.99† (.70)	−1.03† (.71)	−.98† (.70)
Independent variables					
Structural organization		.32*** (.07)	.27*** (.07)	.31*** (.07)	.34*** (.07)
Hybrid organization		.00 (.20)	−.14 (.22)	−.21 (.23)	−.28 (.23)
Informal organization		1.21*** (.29)	1.07*** (.30)	1.16*** (.30)	1.12*** (.30)
Mediator variable					
TCI [a]			.37* (.24)	.64* (.35)	.97* (.41)
Interaction variables					
Technological turbulence [a]				.33 (.34)	.62 (.38)
TCI × tech. turbulence					−.63* (.34)
Pseudo R^2 (Nagelkerke)	.28	.53	.58	.59	.62
Chi-square	24.09***	105.04***	107.88***	108.95***	112.51***
Number of observations	136	136	136	136	136

†$p<.1$; *$p<.05$; **$p<.01$; ***$p<.001$; unstandardized coefficients with standards errors in parentheses.
[a] Variables mean centered in models 6 and 7.

Table 4
Results of OLS analyses

Variables	Model 8	Model 9	Model 10	Model 11	Model 12
Dependent variable	Success rel. to competitors	Success rel. to competitors	Success rel. to competitors	Success rel. to competitors	Success rel. to competitors
Control variables					
Revenues	.04*** (.01)	.02† (.01)	.02† (.01)	.02† (.01)	.02† (.01)
R&D intensity	−.01 (.02)	−.01 (.02)	−.01 (.02)	−.01 (.02)	−.01 (.02)
Automotive/machinery	.37 (.34)	.31 (.32)	.40 (.32)	.40 (.32)	.45 (.32)
Chemicals/pharmaceuticals	.34 (.37)	−.23 (.35)	−.18 (.35)	−.21 ([illegible])	−.13 (.35)
Electronics/semiconductors	−.24 (.40)	−.14 (.37)	−.11 (.36)	[illegible]	−.17 (.37)
Austria	.37 (.35)	.34 (.32)	.35 (.32)	[illegible]	.34 (.31)
Switzerland	.27 (.27)	.26 (.24)	.29 (.24)	[illegible] (.24)	.33† (.24)
Independent variables					
Structural organization		.06** (.03)	.04** (.03)	.06* [illegible]	.06* (.03)
Hybrid organization		.19** (.08)	.14† (.08)	.10† (.09)	.11 (.09)
Informal organization		.17* (.08)	.14* (.08)	[illegible] (.08)	.11† (.08)
Mediator variable					
TCI [a]			.15* (.09)	.25* (.13)	.26* (.13)
Interaction variables					
Technological turbulence [a]				.15 [illegible]	.11 (.11)
TCI × tech. turbulence					−.14† (.10)
R^2	.11	.31	[illegible]	[illegible]	.38
R^2 adjusted	.07	.26	[illegible]	.28	.32
F	2.54*	6.20***	6.40***	5.63***	6.40***
Number of observations	152	152	152	152	152

†$p<.1$; *$p<.05$; **$p<.01$; ***$p<.001$; unstandardized coefficients with standards err[illegible] in parentheses.
[a] Variables mean centered in models 11 and 12.

positive effects of structural and informal organization remain signifi[illegible] but they [illegible]e less strong in model 5 than in model 4. Thus, the influence of these variables is partially mediated by TCI.

In models 8–12, the relative performance measure is use[illegible]ependent variable (Table 4). Again, there is a significant and positive influence of firm size. With regard to the impact of TCI, mode[illegible] and [illegible] results that are similar to the findings in models 4 and 5. The only major difference is the significant and positive effect o[illegible]oje[illegible]ased organization. In model 10, we find a significant and positive impact of TCI, partially mediating the influence of all three organ[illegible]nal antecedents. Accordingly, proficient TCI considerably enhances the monetary and strategic performance of firms [illegible]ally lev[illegible]ing technological knowledge. Therefore, Hypothesis 4 is supported by the data.

To analyze the moderating effect of te[illegible]logic[illegible], we have introduced the interaction variables in models 6–7 and 11–12. For both performance variables the [illegible] of technological turbulence is insignificant, whereas the effect of the cross-product term is significant and negati[illegible] The fac[illegible] it is only moderately significant in model 12 may be explained by the relative nature of the dependent variable [illegible]chnological [illegible]lence may affect the activities of direct competitors in a similar way. To

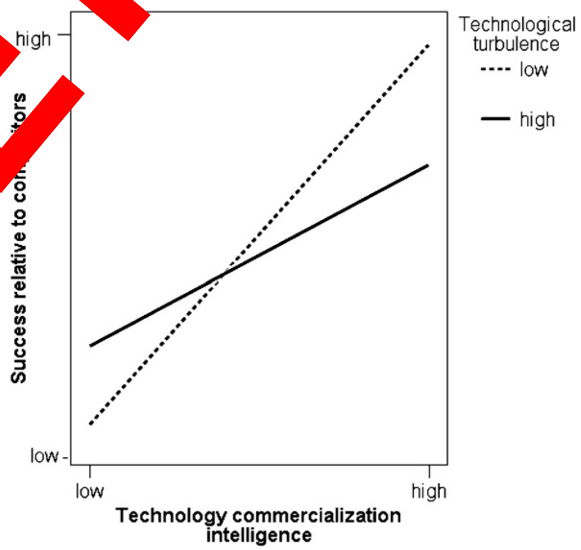

Fig. 1. Illustration of simple slope analyses.

understand the type of interaction, simple slope analyses have been performed. TCI has a positive impact on both performance variables for all levels of technological turbulence. However, an increase in technological turbulence reduces the strength of the positive relation between TCI and performance. This finding is illustrated in Fig. 1 for the relative performance measure. As the negative moderating effect of technological turbulence is contrary to our expectations, Hypothesis 5 has to be rejected.

5. Discussion

In this study, we have first developed and then subsequently tested empirically the theoretical concept of TCI as an extension of general technology intelligence activities in light of increasing outward technology transfer. The empirical results have provided strong support for the importance of the theoretical concept. Despite actively addressing external technology exploitation, many firms experience major difficulties in TCI, which constitutes a major challenge in active technology licensing. Moreover, TCI represents a major success factor of external technology commercialization. Therefore, the concept may deepen our understanding of the discrepancies between some successful firms in technology licensing and many others. Proficient TCI activities clearly help firms to capitalize on their technology portfolios by realizing the monetary and strategic benefits of outward technology transfer. By analyzing structural, project-based, and informal organizational mechanisms, this study is also the first study that has provided quantitative evidence for the importance of these different organizational mechanisms for intelligence processes.

5.1. Theoretical implications

The empirical findings have underscored that the identification of technology commercialization opportunities constitutes an essential problem in outward technology transfer [12,13]. While the analysis of the organizational antecedents has demonstrated that firms actively address TCI, the low mean of TCI underlines most firms' major managerial deficits in this field. Insufficient TCI constitutes a major barrier to active technology licensing. Accordingly, the capability-based concept of TCI has received strong empirical support, and it constitutes a first step towards a theory of technology licensing. Many firms capture the value of their technology portfolios to a limited degree because they have difficulties in identifying licensees [[illegible]90]. Thus, the imperfections in the technology markets limit the size of these markets, and they constitute a severe barrier to the diffusion of new technological knowledge.

Technology boundaries may mismatch a firm's organizational boundaries, and this leads to major licensing opportunities [27]. By developing proficiency in TCI activities, firms may reduce their transaction costs in technology markets [17]. Thus, our study provides support for capability-based perspectives in boundaries research that go beyond efficiency-based analyses, e.g., transaction costs [35]. As such, the concept of TCI deepens our understanding of appropriating [illegible] technological knowledge in open innovation processes [6,31]. In particular, our capability-based analyses suggest that researchers should not oversimplify the realization of technology commercialization opportunities by excessively focusing on a firm's degree of openness [2,10]. Beyond being open, firms need to establish and maintain proficient TCI activities to achieve the benefits of external technology commercialization. Although we have not specifically taken into account the costs of TCI activities, an additional exploratory analysis to cross-validate the positive effects of TCI shows a significant and positive correlation between TCI and return on sales of .25 at $p<.05$. This finding provides some preliminary evidence that TCI is positively related to firm performance beyond its positive effects on the extent of technology licensing.

Moreover, our study has provided support for the distinction between structural, project-based, and informal organization, which has recently been suggested in the literature on technology intelligence [25]. While the formal TCI structures are usually limited, many firms actively rely on project-based and informal organization. Regarding formal structures, dedicated employees have a positive direct impact on a firm's external technology exploitation performance. Because of coordination requirements, it could be argued that the number of employees rises with the volume of external technology exploitation. However, the strong positive effect of dedicated employees on TCI shows that the identification of licensing opportunities constitutes an essential task of these persons. Thus, firms may enhance their licensing performance by improving their TCI activities through assigning dedicated employees. This view of the causal relation between dedicated employees and licensing performance is supported by the examples of various pioneering firms, e.g., IBM, which first initiated a proactive licensing strategy including dedicated employees before the extent of these activities rose significantly [5,6]. As a result of the path-dependent nature of TCI and the need to understand technologies and applications, however, an initial learning period appears to be inevitable until the positive effects of dedicated employees materialize.

Similarly, informal approaches to identifying technology commercialization opportunities have a positive impact on TCI and performance. Accordingly, participatory processes seem to be important for identifying potential licensees and for realizing licensing transactions. Thus, the findings have underlined that the relevant prior knowledge for identifying technology commercialization opportunities is not resident in some individual employees who are dedicated to TCI. Instead, it is usually dispersed across the organization. Accordingly, the results provide strong support for the view of firms as distributed knowledge systems [75,80]. By contrast, the impact of project-based organization is fully mediated by TCI when considering monetary performance. Although prior research has usually regarded technology transactions as a single project [70,71], this finding shows that two types of projects may be distinguished from an individual firm's perspective. First, projects that are directed at identifying licensing opportunities affect the proficiency of TCI, and they may be directed at numerous potential licensing agreements. Second, projects that are directed at actually transferring technology to the licensees will mainly affect the final results of individual licensing transactions instead of TCI.

Moreover, the study has provided empirical support for a negative moderating effect of technological turbulence in the markets for technology [60]. Contrary to our expectations, a high degree of technological turbulence tends to reduce the positive effect of TCI on licensing performance. Thus, the argumentation that firms may identify promising technology commercialization opportunities in relatively stable conditions without establishing professional TCI has not been supported. Moreover, the positive effects of enhanced demand in the technology markets do not overcompensate the additional managerial challenges derived from an increase in complexity. The negative moderating effect may be explained by this high complexity and a lower market transparency in turbulent settings [11,38,60]. Furthermore, the benefits of technology licensing may be reduced in these situations because of shorter time horizons and a more rapid substitution of technologies, which limits potential revenues.

5.2. Managerial implications

It is beneficial for firms to establish proficient TCI activities, which constitute a major success factor of externally leveraging technology. Accordingly, technology intelligence should not be limited to the general observation of the firm's environment or the identification of potential technology sources [25,44]. A proficient identification of technology commercialization opportunities may enhance a firm's returns on its technology portfolio and may additionally provide multiple strategic benefits. The strength of TCI's impact varies for different levels of technological turbulence, but its positive nature remains unchanged. The positive relation between TCI and performance is robust across contexts characterized by different levels of technological turbulence. Therefore, firms should actively manage their TCI. A major way of enhancing TCI is to assign dedicated employees. However, it is insufficient to merely assign some persons because dedicated TCI employees need to have sufficient understanding of their own technologies and of potential markets for these technologies.

Despite the positive impact of establishing formal organizational structures by assigning dedicated employees, the necessary knowledge for TCI is not resident in a small number of employees. Instead, the knowledge is distributed across the organization. Accordingly, companies should try to benefit from this knowledge by addressing TCI informally. Firms may encourage all employees, particularly R&D and marketing experts, to actively participate by making suggestions for technology licensing. Prior research has shown that these additional tasks may be carried out along with the ongoing work [25,78]. Only the participation of the technology and market experts will help firms to successfully leverage their technologies. In addition, companies should initiate specific TCI projects instead of merely carrying out projects to implement technology transactions. In particular, these projects may help firms to combine the knowledge of dedicated TCI employees and of other experts. These TCI projects do not have to be managed in an isolated way. They may be integrated into general technology intelligence projects or into a firm's intellectual property management [91].

5.3. Limitations and outlook

Some limitations of this study are worth noting. The monetary performance measure has focused on a firm's revenues from licensing agreements and technology sales as an objective performance variable. Accordingly, it has not captured a firm's technology transactions in alliances and other contractual forms for which a similar impact of TCI should be expected. In the analysis of the antecedents of TCI and of the relative performance measure, a potential common method bias may exist because only one key informant per firm could complete the detailed questionnaire. By using objective data for one of the antecedents and for the monetary performance variable, the influence of any bias has been limited. Apart from cross-validating the variables, we have applied the procedures suggested by Lindell and Whitney [81] confirming that common method bias was not an issue. Moreover, we have not addressed specific methods for matching technologies and markets, e.g., database, network, or matrix approaches [92]. A thorough examination of this type of tools is highlighted as an important avenue for further research. In addition, we have not taken into account the costs of TCI activities because we have focused on explaining a firm's success in external technology commercialization rather than firm performance, which has only been used to cross-validate the findings. Finally, the empirical study has focused on medium-sized and large firms from three European countries, and a part of these firms are LES members.

Therefore, future works may analyze the TCI activities of smaller companies or even of other types of organizations, e.g., research institutes. Here, the concept of TCI may provide new insights into the managerial challenges of academic technology transfer organizations. Besides developing a deeper understanding of TCI processes, additional antecedents could be studied. In particular, the integration of external experts, e.g., by means of informal networks, could help firms to reduce their managerial challenges in TCI. Moreover, the relation between technology intelligence, TCI, and potential technology acquisition intelligence could provide interesting insights into the right point to organizationally integrating these activities [93]. In addition, future works could simultaneously analyze the identification and implementation of technology licensing transactions to study potential interdependencies between these tasks. These studies could also specifically consider the costs incurred by establishing proficient TCI activities. Accordingly, there are great opportunities for future research into TCI, whose results may help firms to overcome the imperfections in the technology markets and to optimally utilize their technological knowledge.

Appendix A

Technology commercialization intelligence ($\alpha = .79$)

- An effective identification of external technology commercialization (=ETC) opportunities is carried out.
- A continuous observation and intelligence of the technological environment takes place, especially regarding ETC opportunities and potential ETC customers.
- We seek to identify ETC opportunities also in other industries than in our own industry.

Project-based organization ($\alpha = .91$)

- In certain time intervals, we check our technology portfolio for ETC opportunities.
- For particularly valuable technologies, additional resources are employed to identify ETC opportunities.
- For particularly valuable technologies, different employees collaborate in a project to identify potential ETC customers.

Informal organization ($\alpha = .90$)

- Many ETC transactions that are initiated by the company are based on ideas from R&D or marketing employees.
- For identifying ETC opportunities, the ETC employees closely collaborate with R&D or marketing employees.
- R&D or marketing employees often propose technologies for potential ETC.

Success relative to competitors ($\alpha = .92$)

- In relation to our direct competitors, we are successful in the ETC activities.
- Our ETC revenues are considerably higher than the ETC revenues of our direct competitors.
- We use the ETC more successfully for strategic objectives than our direct competitors.

Technological turbulence ($\alpha = .71$)

- It is very difficult to forecast where the major technologies in our industry will be in 3 years.
- A large number of new product ideas have been made possible through technological breakthroughs in our industry.
- Closely observing the technological development is important for long-term success in our industry.

$\alpha =$ Cronbach's alpha.

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