PhD THESIS DECLARATION

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Date 31 January 2015

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Contents

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Abstract

In this dissertation I address different topics in Economics of Innovation. In the first two chapters, I focus on delegation of autonomy and decision rights in knowledge-intensive projects. In chapter one, I link delegation to the *fit* between the inventor and her assigned project. I argue that besides the objective to improve the decision-making quality in projects, autonomy is delegated as an instrument to motivate inventors in projects where there are high agency concerns. The empirical results confirm that companies delegate higher levels of autonomy, when projects do not fit with the inventors, for the sake of motivating them and correcting agency issues. The second chapter analyzes the impact of delegation on the direction and quality of innovative output. Since knowledge workers typically have different objectives with respect to companies, delegating to them may shift the direction of the project far from the company's scope. In the second chapter, I show that delegation of autonomy to inventors, while increasing the scientific value of patents, may have a negative impact on their commercial value, and discuss the reasons that companies may decide to bear this cost for delegation.

Besides micro-foundations of innovation, I have studied patent pools and especially inefficiencies involved with their formation. While the literature has mostly focused on the role of IP holders in the patent pool formation, I investigate the potential role of "pool administrators". By developing a formal model of pool formation in chapter three, I show that despite their initial purpose, patent pool administrators may contribute to inefficiencies in the pool formation process including failures and pool inflations.

Chapter 1

AUTONOMY IN KNOWLEDGE-INTENSIVE ACTIVITIES: EFFICIENCY OR INCENTIVES?[1]

Abstract

Delegation is a key dimension of knowledge-intensive projects. Literature reports delegation to have a variety of impacts on the employee and on the project, yet it is not clear how it relates to their characteristics, and to the *fit* between them. In this paper, we focus on the determinants of autonomy in knowledge-intensive projects and propose *employee-project fit* as a key factor. On this basis, we discuss two main reasons for which companies may delegate autonomy: for efficiency purposes and to better motivate their key employees. Using a novel dataset based on a survey of inventors, we provide evidence for our theory highlighting the role of delegation as a strategic incentive instrument in knowledge-intensive contexts.

Introduction

Delegation of autonomy to employees has become an increasingly hot and important topic in the effective engagement and utilization of human capital. Various streams of literature have long studied this issue and yet *'...autonomy is often at the heart of heated debates'* (Gagné and Bhave, 2011). Employee autonomy is considered a more relevant issue in innovative and knowledge-intensive projects, where employees' assigned tasks are typically less routine and

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scheduled. Therefore, project goals are achievable through a range of approaches and methods and thus, there is much room for employee autonomy within the project. This aspect makes delegation a crucial dimension for the organization of activities in knowledge-intensive contexts.

Delegation is reported to have variety of impacts at the individual and project level such as loss of control (Aghion & Tirole, 1997; Christie, Joye & Watts, 2003; Jensen & Meckling 1976; Shimizu, 2012), improving decision-making efficiency (Grant, 1996; Jensen & Meckling, 1992) and satisfying employees' motivational needs (Bénabou & Tirole, 2003; Gagne & Deci, 2005, Horngren, et al., 2013). These effects and their magnitude may very well depend on the factors from employee-side, as well as the ones from company- or project-side (Gambardella, Panico & Valentini, 2015). Therefore, the level of delegation for each employee at a given project, would be a strategic decision for the company that shall be made considering the employee and project related factors. Nevertheless, prior studies while being insightful have not fully linked this decisions to the characteristics of the project and the employee (Morgeson & Humphrey, 2008). This is surprising since a vast literature has already demonstrated that the complementarity between the characteristics of employees and their job accounts for a variety of outcomes in companies (Kristof, 1996; Kristof-Brown, Zimmerman, & Johnson, 2005). The questions thus still remain: *To whom, in which project, how much* and *for what reason* should companies delegate? In this paper, we intend to address the above questions by differentiating between distinct functions of delegation and linking them to the congruence between the employee and the project; borrowing from person-environment fit literature, we introduce the *employee-project (EP) fit* as a main moderator for delegation effects and their magnitude. On this basis, we theorize two mechanisms explaining why autonomy is delegated to an employee in a given project: for efficiency reasons and for incentive purposes. By doing so, we link the individual and project characteristics to companies’ delegation decisions. Furthermore, we provide empirical evidence for our theory and investigate the extent at which companies leverage delegation when managing their key human capital in knowledge-intensive contexts.

Knowledge-intensive tasks typically require certain levels of congruence between the employee and the project. From the employee-side, prior knowledge, experience, and background broadly define their project-level expertise. From the company side, levels of relevant resources and assets define their project-level competence. We define EP fit as the level aforementioned factors that for a given unit of employee's effort i) increase the productivity in the project, and ii) increase employee’s motivation, initiative and satisfaction. Accordingly, factors such as more relevant experience from the employee-side or higher levels of advanced equipments from the company-side can improve the EP fit. As knowledge-intensive companies typically engage in variety of innovative and non-routine activities, their projects' requirements - both from the employee and from the company-side - may be closer or further to the ideal condition; poor fits in some cases may be inevitable due to companies' limited capacity to provide relevant resources or to find and hire the ideal fit employees for their projects. Therefore, the EP fit may vary across company's projects for the same employee. We propose this variable as a main moderator for autonomy outcomes, and consequently, a key determinant for delegation decisions in knowledge-intensive projects.

It has been widely established that knowledge workers have peculiar preferences and objectives in their activities, e.g. intellectual challenge, satisfying their scientific curiosity and visibility and reputation (Cohen & Sauermann 2007, Giuri et al., 2007). On the other hand, companies have different objectives such as higher profits or faster commercialization of the innovative outputs. These two objectives may not align perfectly, causing a conflict of interest between the company and the knowledge worker. As a result, delegation of autonomy to the knowledge worker will create a cost for the company since she would use it to shift the project towards her preferred direction rather than the company's (Aghion & Tirole, 1997). However, there are certain reasons that because of them, company may find it worthy to bear the delegation cost and give autonomy to knowledge workers. The first reason that we study is delegating for decision quality improvements (Grant, 1996; Jensen & Meckling, 1992). We discuss that the size this effect will be dependent on the EP fit quality; knowledge workers whose background and knowledge fit better with the project, have higher expertise about the project technicalities and are generally are more capable of making right decisions regarding the project (Vroom and Jago, 1988; Yukl and Fu, 1999). Also when companies provide higher levels of relevant and advanced resources for a project, knowledge workers typically can make better decisions than managers about the use of resources, due to their higher levels of knowledge about technicalities. Based on this argument, delegating higher autonomy to an employee in better EP fit is more efficient for the project. This is the basis for the common premise which assumes that to a *better* fit, corresponds a *higher* autonomy (Clegg & Spencer, 2007, Ouchi, 1979, Grant & Parker 2009, Vroom & Yetton, 1973). We label this mechanism of delegation as the *efficiency channel of autonomy*.

Besides the decision efficiency, delegation has strong motivational consequences that neglecting them can be misleading in understanding companies' decisions. We discuss that leveraging the motivational impact of autonomy is another reason that companies may decide to bear the cost of delegation. It has been established that intrinsic motivations are extremely important for knowledge workers and autonomy supports these motivations (Benz & Frey, 2008a & 2008b; Frey, Benz & Stutzer, 2004, Sauermann & Cohen, 2010; Stern, 2004). Therefore, knowledge workers - besides being more productive- gain greater personal benefit from working in environments with higher autonomy. We argue that EP fit plays a moderating role on this relation as well; a poor fit between an employee and her assigned project triggers two outcomes: the first is that the project productivity drops and as the second outcome, she becomes less motivated (Werbel and DeMarie, 2005). In these cases, the company is concerned for two reasons: low productivity and agency issues, especially considering the imperfections in monitoring and measuring the innovative output. It is argued that in these situations, delegating more autonomy and decision rights can significantly improve employee's motivation and mitigate the agency issues (Gambardella et.al, 2015). On the contrary, when the fit between the employee and the project is good, the productivity is high in the project and the employee is already motivated. In this case, there is no need for company to bear the cost of delegation and lose control over the project. Thus, company will keep the project direction on its preferred path (i.e. delegates less) and still benefits from productivity by the employee. Via this mechanism, companies delegate *more*, when they face *poor* EP fits, for the sake of motivating their employees. We denote this mechanism as the *incentive channel of autonomy*, which goes in the opposite direction of the efficiency channel.

To test the implication of the theoretical framework, we use a novel dataset which is based on a specifically designed survey of inventors of the European Patent Office (EPO) granted patents with priority dates between 2003–2005 in twenty European countries, U.S., Japan, and Israel. For the purpose of our study, we combine the survey data with other complementary resources to get a wide range of information at the company, project and individual level. Our results confirm the role of EP fit as a significant determinant of delegation. Moreover, the findings provide empirical evidence consistent with the existence of the two channels, underlining the role of delegation as a strategic incentive instrument in environments where motivation is a major concern.

We believe this study targets an important and relevant issue in the strategic management of innovative capital. We highlight a crucial dimension in the effective utilization of key employees in knowledge-intensive projects, a factor which is considered to be among the ultimate determinant of competitive advantage for companies (Campbell, Ganco, Franco & Agarwal, 2011; Coff, 1997 & 1999; Youndt, Snell, Dean & Lepak, 1996). Our empirical investigation moves in the direction of better understanding the antecedents of autonomy and contributing to research in strategy in several ways: first, we address a relevant issue for both scholars and practitioners by extending the theory and employing a novel and unique dataset. Second, by introducing the incentive channel next to the efficiency channel of autonomy, we improve our understanding of the outcomes of delegation. Third, by relating employee's autonomy to companies' projects and resources, our work complements relatively recent streams of literature suggesting a potential role for a firm's capabilities on its governance decisions and strategy (see e.g. Hoetker, 2005; Leiblein & Miller, 2003; Martin & Salomon, 2003; Mayer & Solomon, 2006; Wright & Snell, 1998). Fourth, by linking autonomy to employee characteristics, we offer clear managerial insights for the delegation decisions at the project level. Finally, by highlighting and addressing an important understudied issue, we point toward a gap in the literature and seek to advance the theory.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical background, whereas the empirical setting, data, and the sample employed in the study are described in section 3. Section 4 reports and discusses the results, and section 5 concludes.

Employee-Project Fit and the Role of Autonomy

Employee-project fit

Theories based on person-environment fit have been prevalent in the fields of organization, human resource management, industrial relations, and personnel psychology. Person–environment fit is related to the compatibility between characteristics of a person and those of an environment (Kristof-Brown & Guay, 2011). The *complementary perspective* is the crucial basis for person–environment fit. Borrowing from the person-environment fit literature, in this study we focus on the congruence between an employee and her assigned *project*. Since the concept of fit has been used in strategy research very broadly (Venkatraman, 1989), we further clarify the definition of EP fit that we employ in this study; EP fit is defined as the degree of employee-side and project-side features that for a unit of effort by the employee i) increase the productivity in the project, AND ii) increase employee's motivation and initiative (reduce the disutility of the effort). As noticed from the definition, the notion of EP fit is a bilateral concept based on the complementarily perspective. Therefore, it can be improved from both sides. For example, the employee-side can improve the fit by increasing project relevant knowledge and expertise, while from the company-side, fit can be improved by providing higher and more advanced levels of project relevant resources.[2] Also, it is important to notice that *both* company and employee benefit from this congruence (Werbel and DeMarie, 2005). While company gains higher productivity and efficiency, the employee will enjoy higher motivation and satisfaction (Holland, 1985). A low fit may instead exacerbate agency costs such as hidden action by the employees, especially in the environments where measuring the employee performance is more difficult (e.g. innovative tasks).

Since both company and employees are negatively impacted by poor fits, a question may arise as why should these cases happen in the first place? Poor EP fits typically happen due to variety of reasons: knowledge-intensive companies are active in dynamic environments and

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[2] It is sensible to assume that higher provision of state-of-the-art equipments and resources improve the EP fit since it increases the project productivity and employee motivation. In this regard, we have implicitly assumed that knowledge workers gain higher personal benefits from working in projects with higher levels of relevant and advanced resources.

engage in different projects. These projects may require different types of expertise from the employee side, and resources from the company side. On the other hand, employees and the company have finite context-specific expertise and resources. It would not be realistic to assume that companies spot and hire the ideal employees for each and every project. Also, it is not likely that the companies provide top and advanced resources for *all* of their projects (e.g. projects far from their core business). Therefore, a knowledge-intensive company may face different fit levels among different projects assigned to its employees. Note that this is a project-level construct, such that a good-fit employee for one project, may be unfit for another (for cases of similar discussion see: Brousseau, 1983; Carpenter, Sanders & Gregersen, 2001; Gupta & Govindarajan, 1991).[3] Thus, having poor EP fits would be inevitable in some projects.

Using this notion in the next sections, we argue that EP fit is an important dimension of employers' job setting as it affects the impacts of delegation and thus, the project performance (Hamel, 1994). Next, we theorize how the fit between a knowledge worker and her assigned project can explain the level of autonomy delegated to her.

The efficiency channel of autonomy

The literature on autonomy has mostly addressed it as a key feature of the workplace which affects the performance of the employee; following the pioneering work of Hackman and Oldham (1975) in job setting literature, autonomy has been introduced as one of the five core job characteristics. However, this line of literature does not clearly relate autonomy's impacts to the employee or project-side characteristics. In another line of literature, improvement of decision quality and attaining higher efficiency is mentioned among the impacts of delegation

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[3] In the sample of our study, a quite considerable portion of respondents reported medium and lower fit levels with their projects. Also, among a small number of respondents accounting for multiple projects, the reported measure for fit was mostly varying across projects for the same employee.

(Jensen & Meckling, 1992; Grant, 1996). Thus, employees who have better expertise in specific tasks and projects are considered more capable of making the better decisions in those projects. A similar rationale as in leadership literature suggests that leaders delegate more tasks and give more autonomy to subordinates who are more capable and skilled (Yukl and Fu, 1999). Obviously, the efficiency of employees will depend on their own characteristics and the characteristics of their tasks and so, the *fit* between them. From the employee-side, when the characteristics fit better with the project, their knowledge becomes more instrumental for the tasks, and decision quality and performance improves; this has been empirically confirmed for the case of R&D professionals (Chen, Chang & Yeh, 2004; Igbaria, Greenhaus & Parasuraman, 1991) and CEOs (Chen & Hambrick, 2012). Also from the company-side, when higher levels of advanced and state-of-the-art resources are provided (i.e. the EP fit is improved), it is more likely that knowledge workers - comparing the managers- take better decisions about the use of advanced resources. Therefore, it is reasonable to assume that companies would delegate higher autonomy levels when EP fit is higher. However, as mentioned in the previous section, the fit may change for each employee-project pair. So the level of autonomy in a company shall vary across projects for the same employee. Therefore, it is reasonable to assume that for the performance concerns, company delegates more, when the EP fit is higher, to achieve higher efficiency. This mechanism, assumes a higher autonomy levels for better EP fit quality. We name this as the *efficiency channel of autonomy*. According to this channel, we expect *a positive relation between EP fit quality and employee's autonomy in the project* (Figure 1).

The incentive channel of autonomy

The efficiency channel neglects the motivational effects of delegation on individuals, focusing only on their decision quality and efficiency improvement. Nevertheless, studies have already highlighted that autonomy serves as an important motivation and initiative facilitator in companies (Bénabou & Tirole, 2003; Gagné & Deci, 2005) through its effect on their well-being (Deci *et al*.,2001; Gagné and Bhave, 2011) and job satisfaction (Benz and Frey, 2008a; Sousa-Poza and Sousa-Poza, 2000). In this paper, we analyze motivational purposes- besides efficiency considerations- as another reason that companies may bear the cost of delegating and losing control over the project. Although the motivational effects of delegation are established in the literature, there is not much research on the factors determining the size of the effect and its link to the employee/job characteristics. We argue that also the size of motivational effects of autonomy will vary with the EP fit quality. Therefore, the extent of delegation by the company for this purpose will be influenced by the EP fit.

As previously stated, poor EP fit levels are inevitable for the employers across projects. Lower fits can lead to lower productivity and diminished interest and engagement at the workplace (Barnett, 1999, Holland, 1985, Werbel & DeMarie, 2005), factors that negatively impact the company and the employees and trigger agency costs.

Solving the motivational concerns raised by poor EP fit can be very challenging in knowledge-intensive contexts. The main reason is that the standard incentive instruments including pay-for-performance schemes, while working well for tasks such as physical effort, are not functional for creative activities (Ederer and Manso, 2013). Difficulties in measuring employee's input and output make it hard for the company to establish compensation based on employee's contribution to project; it is not easy to observe the employee's effort in contexts such as R&D compared to simpler tasks. Also, the value of innovative output is extremely difficult to be measured in short-term and usually becomes clear in commercializing phases which can take years. Finally, knowledge-intensive activities require creativity and exploration, while their output is uncertain. So, rigid pay-for-performance schemes that punish failures in fact can have adverse effects on the innovative performance and hinder innovation (Ederer & Manso, 2013; Manso, 2011). Therefore these standard instruments are not considered effectual in motivating employees for innovative tasks (Amabile, 1996; Kohn, 1993). For all the reasons above, companies may seek alternative instruments to deal with motivational concerns caused by poor EP fit in innovative tasks.

Delegation of decision rights and control over the project's resources have been theoretically proposed as an alternative instrument that can be used to motivate knowledge workers and mitigate agency issues (Gambardella et. al, 2015). As in our definition, good EP fit is associated with two effects: high productivity and high employee motivation. Therefore, in these cases there is no concern for the company either from the performance or agency issues perspective. Accordingly, in the absence of the efficiency arguments, company does not need to bear the cost of delegation and lose the control over the project. Thus, in a good EP fit, it delegates lower autonomy levels to the employee and still has her motivated and productive. In this case, low levels of autonomy do not discourage much the employee since she is already motivated. On the contrary, when there is a poor EP fit case, the productivity in the project is low and the employee is not motivated. Therefore, the agency concerns are very high. In this case, it is not likely that the project leads to any significant output. Therefore, in the absence of efficiency mechanism, company might find it optimal to bear the cost of delegation and give higher autonomy levels to motivate the employee. Obviously in this case, the company loses more control over the direction of the project and the output will not be perfectly in line with the company's scope (delegation cost), but it is better than having no or very poor output (which is the likely outcome when the employee is neither productive nor motivated). This is the essence of what we denote as the *incentive channel of autonomy*. Via this channel –and absent of the efficiency channel- we expect employers to offer *more* autonomy when there is a *poor* EP fit. In the other words, for the motivation purposes, we expect *a negative relation between the EP fit quality and employee's autonomy in the project* (Figure 1).

[Insert Figure 1 here]

Efficiency and incentive; the overall effect

The two channels discussed in the previous sections point towards different directions between autonomy and EP fit. This is represented graphically in Figure 1, where each line depicts company's optimal delegation with respect to fit, in the absence of the other mechanism. The overall effect will depend on companies' decision facing the combination of the effects. Although in reality, we would not observe each channel independently, yet, we can discuss two extreme cases on the EP fit axis to better demonstrate the conditions.

On the far right of the horizontal axis, we have the cases with high EP fit levels. According to the efficiency channel, delegation of job autonomy will generate efficient outcomes for the company (efficiency channel). Also due to the good fit, the employees will already be motivated to work in these projects. So the employer is not required to lose her control over the project direction (i.e. delegate autonomy) for motivational purposes. Therefore, if we observe higher autonomy in the far right side of the fit axis, this would imply that gains from efficiency mechanism become increasingly higher in a way that they cover the costs of delegation.

On the contrary, for the left side of the horizontal axis in Figure1, we have cases where EP fit is poor and there are low efficiency gains from delegating (efficiency channel). So, from this perspective, company prefers to keep the control (i.e. delegate less). However, employees in this case are not much motivated and through the incentive channel, we expect company to give autonomy for motivational reasons. Therefore, observing greater autonomy levels for poor EP fit cases implies that agency concerns become important such that for correcting them, company is ready to pay the cost of delegation.

In next sections we empirically investigate the autonomy-fit relation in reality and discuss its implications in testing our arguments.

Method

Data and Sample

The empirical study is based on a sub-sample of the PatVal-2 dataset, which is a part of a European Commission funded project (*InnoS&T*: '*Innovative S&T indicators combining patent data and surveys: Empirical models and policy analyses*'). This dataset is based on a survey of inventors in 20 European countries plus the US, Japan and Israel on inventors associated with a EPO granted patents with priority dates between 2003 – 2005. An invitation was sent to the first inventor of randomly chosen patent applications, asking to fill out an online survey questionnaire offered in 10 languages. 50% of the invited inventors were from Europe and Israel, 13% from Japan, and 37% from the U.S. In the end, 22,557 responses were received yielding a response rate of 18.2%. The questionnaire covered a wide range of complementary indicators at the level of individual, project, company, region and technology. At the individual-level, the survey included personal characteristics (e.g., age, gender, education, motivations and etc.). At project-level, it collected data on the dimensions related to the process leading to invention (e.g. project size, project autonomy level, project resources, etc.). At the firm-level, the survey included data on the characteristics of the organization such as company’s type, age, size, activities, governance and etc. Other complementary indicators have been matched with the survey data using Amadeus, Orbis and Compustat datasets. More details about the survey, methodology and the primary indicators are described in Gambardella et al. (2014).

As the main sample of this study, we focused on subsample of the PatVAl-2 regarding inventors employed in private companies and exclude the employees of non-commercial institutions (e.g. research centers and universities, governments and etc.). This rule of selection besides excluding the missing values dropped our main sample to about 9,000 observations (since we use different proxies for our theoretical measures, the sample size changes slightly across specifications). Also, one of the EP fit measures (fit from employee-side) is based on inventors' knowledge from the previous employer. Thus, it is calculated on inventors who have moved at least once during their career. In the analyses using this measure, the number of observations in our sample drops to around 3,000. All the empirical tests in this study are conducted on the main sample described above, unless it is clearly noted; for robustness checks, we also use other subsamples within the PatVal2 (e.g. employees of non-commercial institutes) to compare the results with the ones of our main sample.

Key Measures

Autonomy. Autonomy is the central to our analysis and the main dependent variable in the empirical section. By the autonomy in the project, we intend to capture the degree to which the employee is provided with '*...substantial freedom, independence, and discretion [...] in scheduling the work and in determining the procedures to be used in carrying it out*' (Hackman & Oldham, 1980). Our focus is the autonomy within the boundaries of the project.

The constructs we use in this paper are based on a question from the survey asking respondents to rate their autonomy level at the time of the invention, on a Likert scale from one ('no autonomy') to six ('very high autonomy') on the items:

(a) *'selection of your tasks or projects'*, (b) '*allocation of your working time among different tasks or projects'*, (c) '*flexibility of your working hours*'

We use the responses to the questions above to build three alternative measures of autonomy (AUT1, AUT2 & AUT3). To build a broad measure of employee's autonomy (AUTONOMY), we simply sum up the responses over the items above. In the regressions, we use each of the alternative three measures independently to check the robustness of our results.

Employer-project fit. The quality of fit between the employee and the project is the key explanatory variable in our theory. To capture this concept, we needed variables that could account for both project-side and employee-side factors impacting the fit. As mentioned in the theory section, the complementarily is the crucial element for this construct, therefore we choose two questions from the survey on factors impacting the company (higher productivity) and the employee (higher motivation).

Employee-side: we employ a question from survey, asking the inventors to consider their knowledge and experience from their prior organization and to indicate whether their experience matched the inventive activity. We build this measure using a question from the survey asking inventors to which extent they agree or disagree with the following statements:

'... the combination of your previous experience with the knowledge of your new employer was instrumental in enhancing the inventive activity at the new organization.'

The statement captures a broad concept of PE fit from the employee side features. We make use of this item to build the variable FIT. To check for nonlinearities in the effect of PE fit on autonomy, we generate the square of our fit measure (FIT_SQ). Since this question is only applied to the employees who have moved at least once during their career, in the empirical section, we check for the potential selection bias in our analysis.

Project-side: as discussed in the theory section, companies may improve the EP fit by providing higher levels of advanced and relevant resources to the project, since this will increase the productivity and the motivation. To capture this dimension of EP fit, we use a question from the survey asking inventors to which extent they agree or disagree with the following statements:

(a) *'The organization had all the right instruments and technical equipment for this invention'.*

(b) *'The organization had all the complementary resources to make the invention a technical success'.*

(c) *'The organization had all the resources to turn the invention into something economically valuable (e.g., new product, process or else)'.*

We use the above to build the measures ASSET_FIT1 (*Technical Instruments*), ASSET_ FIT2 (*Complementary Resources*) and ASSET_FIT3 (*Commercializing Resources*) respectively. Again we generate the squared of these variables to check for the non-linear effects in the specification.

Intellectual Motive. The idea behind the incentive channel is leveraging the intrinsic motives and motivational impacts of delegation. Therefore, employee's motivation is a central notion in our analysis. Motivation towards a project can have different origins and sources (e.g. caused by monetary reward, reputation effect or intellectual challenge). For testing our theory (especially the assumption on the positive motivational impacts of delegation), we were interested to measure the level which employee was motivated towards the project due to the intellectual attractions that the project provides. To build the variable capturing this dimension, we use a question in the survey which asks the respondents about different factors contributing to their motivation for making the corresponding invention. Among these items, we use the item asking *the importance of intellectual challenge* in *"motivations for making this particular invention".* The respondent could answer to the question on a Likert scale, ranging from one ('not so important') to five ('very important').

Controls

We control for a wide range of variables at the level of individual, project, company, region and technological area. At the individual level, we control for the gender, age and gross income of the employee. Moreover, we control for the inventor's level of education and rank in the project's structure. At the project and firm level, we control for the project size (project man-month) and firm size (measured by number of employees). Finally, due to potential role of technology-specific and geographical factors, we control for the location of the employee and technological areas.

A brief variable definition and summary of their statistics and correlations are presented in Tables 1, 2a and 2b.

[Insert Table 1, Table 2a & 2b here]

Empirical Strategy

In the empirical analysis, we first estimate the determinants of employee autonomy in projects. Our dependent variables (measures of autonomy) are reported in levels, which would typically require the use of an ordered regression model. We postulate an ordered logit model as follows with robust standard errors:

$$\mathbf{P}(AUTONOMY_i=j) = \boldsymbol{\Phi}(\theta_j-\beta_1 FIT_i - \beta_2 FIT\_SQ_i - \mathbf{X}'_i\boldsymbol{\gamma}) - \boldsymbol{\Phi}(\theta_{j-1}-\beta_1 FIT_i - \beta_2 FIT\_SQ_i - \mathbf{X}'_i\boldsymbol{\gamma}) \quad (1)$$

In the equation above *j* is one of the *J* categorical levels of autonomy for the employee *i*. θ_j is a cutoff point, estimated by the model (with $\theta_0= -\infty$ and $\theta_J =\infty$) and Φ is a logistic CDF. **X** in equation (1) is a vector of controls and $\boldsymbol{\gamma}$ is a vector of estimated coefficients. The firm level controls are matched with the employee level controls, so all can be controlled at the individual level.

Also, for the ease of interpretation gained from OLS - especially in calculating the turning points in non-linear relations- we estimate the specification above with a simple OLS model as follows:

$$AUTONOMY_i=\beta_1 FIT_i+\beta_2 FIT\_SQ_i+X'_i\gamma + \varepsilon_i \quad (2)$$

We estimate equations (1) and (2) using alternative constructs for the *autonomy*. In the both specifications above, β_1 and β_2 account for the effect of PE fit quality on the employee’s autonomy (aggregate of efficiency and incentive channels). The sign and statistical significance of β_1 and β_2 can imply the overall shape of the effect.

As another test for our theory, we use employee's intellectual motive for the project as dependent variable and empirically investigate its determinants. This enables us to test some of the assumptions regarding how in reality employees' motivation is shaped. We include the constructs for FIT, AUTONOMY and their interaction in an ordered logit model (equation 3). The estimated coefficient in the equation (3) can provide implication for testing our theory. Also estimating β_3 can imply whether or not, delegation of autonomy to poor EP fits, impacts their motivation more than good EP fit cases.

$$\mathbf{P}(MOTIVE_i=j) = \boldsymbol{\Phi}(\theta_j - \beta_1\, FIT_i - \beta_2\, AUTONOMY_i - \beta_3\, AUTONOMY_i * FIT_i - \mathbf{X}'_i\gamma)$$
$$- \boldsymbol{\Phi}(\theta_{j-1} - \beta_1\, FIT_i - \beta_2\, AUTONOMY_i - \beta_3\, AUTONOMY_i * FIT_i - \mathbf{X}'_i\gamma) \qquad (3)$$

Results

Main Findings

Table 3, presents the results of the estimates for equations (1) and (2), where the dependent variables are the measures of autonomy. We report the determinants of autonomy in the projects using four measures of *autonomy in selection of tasks* (AUT1), *time allocation among tasks* (AUT2), *determining the working time* (AUT3) and the *broad* measure of autonomy (AUTONOMY). For each measure, we report the estimated coefficients of ordered logit and OLS model as in equations (1) and (2). Also, we include a wide set of controls at the employee level (such as gender, age, education, and income) and the work/ project level (including firm and project size). All specifications include geographical, technological, and firm fixed effect controls. The coefficients of the ordered logit model in table 3 can be interpreted as log odds-ratios.[4] The key variables of interest in table 3 are the PE fit measures from the employee side (FIT & FIT_SQ). The estimated coefficients of FIT and FIT_SQ can determine the relation between PE fit and autonomy.

In all the specifications in table 3, FIT exerts a significant negative sign while FIT_SQ shows a positive and significant effect on the autonomy measures. This implies a U-shape relation between autonomy and the EP fit quality. The relation is robust to for all alternative autonomy

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[4] Since the dependent variable and the main predictors in our study are ordinal responses and do not correspond to tangible units, we mainly focus on the sign and statistical significance of the results rather than their magnitude. Accordingly, we do not report the marginal effects in the tables.

measures. Also, in the columns (7) and (8), when we use the broad measure of autonomy, fit demonstrates an identical effect.

[Insert Table 3 here]

Also the OLS specifications in table 3 - columns (2), (4), (6) and (8) - can be used for a simple check of the turning point of the U-shape relation (equation 2). Calculating for the three specifications, we observe that the turning point of the U-shape is almost in the middle of the range for FIT, slightly inclined towards lower fit values (around 2.8 in the range of 1-5). This implies that the full range of the EP fit variable is not dominated by a positive slope - as the efficiency arguments suggest. Without accounting for the incentive channel, high levels of autonomy that poor fit employees receive would be difficult to be explained. We interpret this as an evidence for the existence of another channel of delegation, working in the opposite direction of the efficiency channel which we have labeled as the incentive channel.

In the framework of efficiency and incentive channels, the U-shaped relation suggests that companies face sever motivational challenges when their projects fit poorly with the employees. Therefore, higher levels of autonomy are delegated to incentivize the employee - without the objective to increase the decision-making quality. On the contrary, when the EP fit quality improves, companies are not required to delegate autonomy in order to motivate. However, in high EP fits, delegation becomes increasingly efficient for the project. So, companies delegate higher autonomy for another objective -i.e. to improve the decision-making quality in the project. This is our interpretation on how EP fit generates a U-shaped effect on the autonomy.

Looking at some of the control variables also gives interesting results. Gender does not affect employee's autonomy level significantly in projects. However, employee's age generally relates positively to autonomy delegation. Employee's autonomy seems also to depend significantly on the rank in the project. In our results, employees with higher positions in the projects' structure enjoy higher autonomy levels. The only exception is the case of flexibility in the working hours -columns (5) and (6) - which higher ranks negatively relate to autonomy. The results on the firm size and project size also suggest that employees receive less autonomy in larger companies, however, bigger projects typically provide higher autonomy for the employees.

Table 3 checks for the relation of autonomy and fit, using different measures of autonomy. As the next step, we run equation (1) with alternative EP fit measures, this time from the company-side factors. In the specifications reported in table 4, we use the broad measure of autonomy (AUTONOMY) as the main dependent variable. As the key explanatory variable, we include ASSET_FIT1, ASSET_FIT1 and ASSET_FIT3 and their squared. Checking the reported coefficients in table 4, it shows the U-shape relation is highly robust to use of alternative EP fit measure (from the company side). Also, the turning point of the U-shape relation is still in the range of the independent variable. This provides stronger evidence for the curvilinear relation between autonomy and fit, regardless of their measures.

[Insert table 4 here]

In the estimations in tables 3 and 4, our analysis investigates the determinants of autonomy as the dependent variable. As another evidence for our theory, this time we investigate the factors impacting intellectual motives of employees in projects. Based on equation (3), we regress the role of intellectual motivation on the level of autonomy in the project, the EP fit variable and their interaction. Table 5 reports the estimation results. Since the dependent variable (MOTIVE) is reported in levels, equation (3) is formulated as an ordered logit model.

As previous estimations, we use a wide range of controls besides our main explanatory variables which are FIT, AUTONOMY and most importantly, their interaction. In the specifications in table 4, we first report the model without including the interaction term -column (1) -and then estimate it including the interaction- column (2). This procedure is repeated for alternative measures of autonomy in the proceeding columns.

In all of the specifications, FIT enters significantly with a positive sign which is intuitive and in line with our definition of fit; in a better EP fit, there is more personal advantage and for the employee towards the project. Thus, intellectual motivation plays a more significant role. Also in all the specifications, employees' autonomy -regardless of the measure- shows positive and highly significant impact. This confirms our assumption that delegation increases employee motivation.

[Insert table 5 here]

The most interesting part in table 5 is the coefficient for the interaction between fit and autonomy. In three out of four specifications which the interaction term is included - columns (2), (4) and (8) - the coefficient exerts a negative and significant sign. We find this very meaningful for our theory; the negative interaction term implies that when there is a poor fit, delegating more autonomy boost the role of intellectual motivation much more than the case where EP fit is good. As previously explained, in good EP fits, the employee is already motivated, thus, delegation cannot increase much the motivation. However, when there are poor EP fit cases, the employee is not motivated much and that is why delegation can jump the intellectual motives towards the project.

[Insert Figure 2 here]

To have a better intuition of the results in table 5, we plot the estimated interaction coefficients of column (2) in Figure 2. The slope of the lines in figure 2 indicates the impact of autonomy on the role of intellectual motivation for the project. The solid line represents poor EP fit cases (FIT=1), while the dotted line is the case for good EP fits (Fit=5). As depicted in the figure, intellectual motivation for poor fit employees (the solid line) remains always below the good fit case (the dashed and dotted lines). However, higher levels of autonomy motivate poor EP fits much more than good EP fit employees (i.e. the slope of the solid line is bigger). These results, confirm two important aspects of our arguments: first, as we discussed, employees in good EP fits need not receive autonomy for motivational purposes. So, if company delegates autonomy to them, it should be due to other purposes (namely efficiency). Secondly, delegation has the potential to be used as a powerful instrument in mitigating agency concerns in knowledge-intensive activities.

Further Checks

Our results in tables 3, 4 and 5 provide evidence for the existence of another mechanism besides the efficiency channel. Based on our theory, we believe that the negative slope around poor EP fits is generated by the mechanism of delegation for motivational purposes - i.e. the incentive channel. In this section, we present robustness checks which provide further evidence for our argument. We test and refute alternative explanations which may have generated the U-shape relation. Also we test for potential selection bias in our results. Finally, we investigate the existence of the two mechanisms in a context which we expect them to be absent.

[Insert table 6 here]

Employee's autonomy in our theory is a result of delegation via both channels. In the data, we only observe the effect under co-existence of the two channels. Although, we are not able to disentangle each channel and estimate them independently, we can check for alternative explanations which may generate a U-shape relation. We discuss to cases of this sort below.

It might be argued that high autonomy levels for poor EP fits are driven by explorative approaches in the workplace. In this scenario, a knowledge-intensive company may start a fully explorative project without pre-defined targets by assigning fresh employees and delegating high levels of autonomy to them in order to reach ground-breaking results. This approach can cause low EP fit employees to receive high autonomy levels inside projects and generate a U-shape relation between EP fit and autonomy. To refute this alternative explanation, we repeat our analysis on a subsample of *targeted* projects. For this purpose, we use a question in the survey asking about the "*creative process that led to the invention"* and limit our sample for the cases where the patent was a "*targeted achievement of a research or development project*". These cases account for approximately half of the main sample in table 3. We estimate equation (1) based on the sample of targeted projects. The results are reported in the first three columns of tableb6. The magnitude and the significance level of FIT and FIT_SQ in all the specifications imply a U-shape relation. This proves our results to be robust for the subsample of targeted projects and refutes the alternative explanation that explorative projects are the cause for our main finding.

As another alternative scenario, one might argue that companies may organize the project activities as team-work and employees' autonomy level might be defined by the extent which company delegates to the *team*- rather than to the employee. In this scenario, an employee with low EP fit may receive high autonomy level in a team project if there are sufficient expert and fit members within her team. To check for this effect, this time we repeat the analysis on a subsample of projects which are reported as *individual work* -i.e. only one inventor involved with the invention process. Focusing on individual projects within the main sample, we estimate equation (1) for the three measures of autonomy and report the coefficients in columns (4) to (6) in table 6. As can be seen from table 5, for the measures of autonomy in *selection of tasks* and *time allocation among tasks*, the U-shape relation stays robustness for the subsample of individual-work projects. For the measure of *determining working time* in column (6), although not significant, the fit variables still exert similar signs as for the U-shape relation.

In building the EP fit variable, we have used the congruence between employees' previous job experience and the employer's knowledge for the project. This approach has limited our sample to employees who have moved at least once through their career. Considering this, there is a concern that our results are impacted by sampling bias of mobile employees. To check for the potential sampling effect, we repeat the analysis on the full sample of the survey data, adding employees who have not moved during their career. This increases the sample size to about 10,000 observations. To check for the effect of sampling, we generate a dummy variable indicating mobile individuals (MOBILITY). Since we have used previous job experience in building the fit measure, the EP fit values (FIT and FIT_SQ) are missing for the non-mobile employees. For these cases, we replace a zero instead of the missing value and include the modified fit measures together with the mobility dummy in our regression. With this specification, the estimated coefficient of mobility dummy (MOBILITY) will control for the sampling effect. Also, the coefficients of the fit will demonstrate if the effect of fit still holds after controlling for sampling. We estimate an ordered logit model for this specification on the whole sample of mobile and non-mobile employees.

[Insert table 7 here]

The first three columns in table 7 report the determinants of autonomy based on the full sample of mobile and non-mobile employees. According to the results, the mobility dummy (MOBILITY) enters the regression with a positive and significant sign, suggesting that the employees who have changed their job at least once typically gain more autonomy in the projects. Correcting for the sampling effect of mobility, the findings in the previous section completely hold for the effect of fit. For all the measures of autonomy, EP fit shows a significant U-shape pattern after correcting for the sampling bias. The magnitude of the effect is also comparable with the results on the main sample in table 3. Accordingly, we conclude that our findings are not limited to the sample of mobile employees which confirms our theoretical argument.

Our previous analyses are conducted over the sample of employees working in commercial companies (the main sample). As the final robustness check, this time we estimate the determinants of employee autonomy based on a sample employees working in non-commercial institutions. These mostly account for scientific centers and universities. We expect the two mechanisms of delegation to be absent in this context. The reason for this is that our theoretical framework is based on a setup of a profit-maximizing company. Many elements of this setup -such as conflict of interest between knowledge worker and employer- are absent for the case of non-commercial institutes. Therefore, autonomy is not likely to be used as an instrument to utilize and manage knowledge workers in these contexts. Based on this, we expect delegation in non-commercial contexts to happen through totally different mechanisms and not via our discussed channels. The results of our analysis in table 7 show that the U-shape relation disappears for the sample of non-commercial institutes. In any of the specifications in columns (4) to (6), EP fit does not significantly explain employees' autonomy level. This result also serves as another evidence for our arguments in the theory section.

Discussion and Conclusion

The purpose of this study is to theoretically and empirically examine the questions of to whom, how much and in which project shall the employer delegate autonomy? Our work develops new theoretical framework and presents empirical evidence to improve our understanding about the presence and antecedents of autonomy delegation in knowledge intensive activities.

Our key findings that stand out are as follows; we develop a framework which combines the distinct effects of delegation by proposing EP fit as a key determinant of employees' autonomy in knowledge intensive activities. Based on our theory, we provide evidence that companies delegate autonomy for motivational purposes besides efficiency reasons in projects where poor EP fit may give rise to agency concerns. Our results confirm the co-existence of both channels of autonomy delegation, showing that the aggregate of the effects depends on the EP fit quality. We believe that the theoretical advancement and empirical findings of our study make important contributions to strategic management research and practice.

Our work underlines the importance of fit instead of other common absolute measures such as employee's knowledge or experience. The literature has traditionally considered employee's knowledge and skill as key factors in employment related issues. The best demonstration for this approach is the vast empirical literature which mostly uses the employee's education or experience as a main predictor for various outcomes. Our results highlight that the functionality of experience and knowledge matters more when companies make decisions on the job setting. We believe bringing the *fit* into the framework in other areas of strategic human resource management may be promising.

Moreover- and unlike most previous works- our theoretical framework allows us to address employee autonomy at the project-level. We find this a crucial dimension, especially with respect to increasing complexity in knowledge intensive activities which may change EP fit substantially across projects. Empirically, we expect that this lens enables explaining autonomy variations across the projects and within/among firms for employees.

It is also insightful to discuss some limitations of this work. The empirical context of this study is a sample of inventors who have produced patented inventions. Some might question the generalizability of our findings for non-patenting contexts. However, there is no clear evidence that the mechanisms may differ for other knowledge-intensive contexts.

Also, though employing a survey data helps us to acquire directly the measures that we need for the theory, the variables in this case will correspond to the respondents self-estimation of these measures (e.g. perceived autonomy or fit). Although it might be beneficial to combine and check the data with other measures, however, ‘*there is no systematic evidence that people seriously distort reporting on their job characteristics*’ (Spenner, 1990).

Finally, in our empirical setting, we only observe the aggregate of two discussed channels and cannot empirically examine each channel independently. It would be valuable to find proxies which can isolate the two channels as a more reliable test for our theory. For now, this remains as a part of our future agenda.

References

Aghion, P. & Tirole, J. 1997. Formal and real authority in organizations. *Journal of Political Economy*, 1-29.

Amabile, T.M. 1996. *Creativity in Context*. Westview Press, Boulder, CO.

Barnett, R.C. 1999. A new work-life model for the twenty-first century. *The Annals of the American Academy of Political and Social Science*, 562(1), 143-158.

Benabou, R. & Tirole, J. 2003. Intrinsic and extrinsic motivation. *The Review of Economic Studies*, 70(3), 489-520.

Benz, M. & Frey, B.S. 2008a. Being independent is a great thing: subjective evaluations of self-employment and hierarchy. *Economica* 75: 362–383.
Benz, M. & Frey, B.S. 2008b. The value of doing what you like: Evidence from the self-employed in 23 countries. *Journal of Economic Behavior & Organization* 68(3): 445-455.

Brousseau, K.R. 1983. Toward a dynamic model of job-person relationships: Findings, research questions, and implications for work system design. *Academy of Management Review*, 8(1), 33-45.

Campbell, B.A., Ganco, M., Franco, A.M., & Agarwal, R. 2011. Who leaves, where to, and why worry? Employee mobility, entrepreneurship and effects on source firm performance. *Strategic Management Journal* 33(1): 65-87.

Carpenter, M.A., Sanders, W.G. & Gregersen, H.B. 2001. Bundling human capital with organizational context: The impact of international assignment experience on multinational firm performance and CEO pay. *Academy of Management Journal* 44(3) 493–511.

Chen, T., Chang, P. & Yeh, C.A. 2004. Study of career needs, career development programs, job satisfaction and the turnover intentions of R&D personnel. *Career Development International*, *9*, 424–37.

Chen, G. & Hambrick, D.C. 2012. CEO replacement in turnaround situations: Executive (mis) fit and its performance implications. *Organization Science*, *23*(1), 225-243.

Christie, A.A., Joye, M.P. & Watts, R.L. 2003. Decentralization of the firm: Theory and evidence. *Journal of Corporate Finance* 9(1), pages 3-36.

Clegg, C. & Spencer, C. 2007. A circular and dynamic model of the process of job design. J*ournal of Occupational and Organizational Psychology*, 80(2), 321-339.

Coff, R.W. 1997. Human assets and management dilemmas: Coping with hazards on the road to resource-based theory. *Academy of Management Review*: 374-402.

Coff, R.W. 1999. When competitive advantage doesn't lead to performance: The resource-based view and stakeholder bargaining power. *Organization Science* 10(2): 119-133.

Cohen, W. M. & Sauermann, H. 2007. Schumpeter's prophecy and individual incentives as a driver of innovation. F. Malerba, S. Brusoni, eds. *Perspectives on Innovation*. Cambridge University Press, Cambridge, UK, 73–104.

Deci, E.L., Ryan, R.M., Gagné, M., Leone, D.R., Usunov, J., & Kornazheva, B.P. 2001. Need satisfaction, motivation, and well-being in the work organizations of a former eastern bloc country. *Personality and Social Psychology Bulletin*, 27, 930–942.
Ederer, F. & Manso, G. 2013. Is Pay for Performance Detrimental to Innovation? *Management Science, 59*(7), 1496-1513.

Frey, B.S., Benz, M.A. & Stutzer, A. 2004. Introducing Procedural Utility: Not Only What but also How Matters. *Journal of Institutional and Theoretical Economics* 160(3): 377-401.

Gagné, M. & Bhave, D. 2011. Autonomy in the workplace: An essential ingredient to employee engagement and well-being in every culture. In *Human autonomy in cross-cultural context* (pp. 163-187). Springer Netherlands.

Gagné, M. & Deci, E.L. 2005. Self-determination theory and work motivation. *Journal of Organizational Behavior* 26(4): 331-362.

Gambardella, A., Giuri, P., Harhoff, D., Hoisl, K., Mariani, M. & Torrisi, S. 2014. Inventive Process and Economic Use of EPO Patents: Summary Evidence from the PatVal Surveys, *Working Paper*

Gambardella, A., Panico, C. & Valentini, G. 2015. Strategic incentives to human capital. *Strategic Management Journal*, 36(1): 37–52.

Giuri, P., Brusoni, S., Crespi, G., Francoz, D., Gambardella, A., Garcia-Fontes, W., Geuna, A., Gonzales, R., Harhoff, D., Hoisl, K., Lebas, C., Luzzi, A., Magazzini, L., Mariani, M., Nesta, L., Nomaler, O., Palomeras, N., Patel, P., Romanelli, M., & Verspagen, B. 2007. Inventors and invention processes in Europe. Results from the PatVal-EU survey. Research Policy, 36(8): 1107-1127.Grant R. 1996. Toward a knowledge-based theory of the firm. *Strategic Management Journal*, 17: 109–122.

Grant, A.M. & Parker, S.K. 2009. 7 Redesigning Work Design Theories: The Rise of Relational and Proactive Perspectives. *The Academy of Management Annals,* 3(1), 317-375.

Gupta, A.K. & Govindarajan, V. 1991. Knowledge flows and the structure of control within multinational corporations. *Academy of management review*, 16(4), 768-792.

Hackman, J.R. & Oldham, G.R. 1975. Development of the job diagnostic survey. *Journal of Applied psychology*, *60*(2), 159.

Hackman, J.R. & Oldham, G.R. 1980. *Work redesign*. Reading, MA: Addison-Wesley.

Hamel, G. 1994. The concept of core competence. In G. Hamel, & A. Heene (Eds.), *Competence based competition*. New York Wiley.
Hoetker, G. 2005. How much you know versus how well I know you: Selecting a supplier for a technically innovative component. *Strategic Management Journal* 26(1): 75-96.

Holland, J.L. 1985. Making vocational choices. *Englewood Cliffs*, NJ7 Prentice Hall.

Horngren, C.T., Datar, S.K., Foster, G., Rajan, M. & Ittner, C. 2013. *Cost accounting: A managerial perspective*. Upper Saddle River, NJ: Prentice Hall.

Igbaria, M., Greenhaus, J.H. & Parasuraman, S. 1991. Career orientations of MIS employees: An empirical analysis. *MIS Quarterly*, *15*, 151–69.

Jensen, M.C. & Meckling, W.H. 1976. Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics,* 3(4), 305-360.

Jensen, M.C. & Meckling, W.H. 1992. Specific and general knowledge and organizational structure. *Knowledge Management & Organizational Design*, 17-18.

Kohn, A. 1993. Punished by rewards: The trouble with gold stars, incentive plans, A's, praise, and other bribes. *Houghton Mifflin Co*., Boston.

Kristof, A.L .1996. Person-organization fit: An integrative review of its conceptualizations, measurement, and implications. *Personnel Psychology*, 49, 1-49.

Kristof-Brown, A.L. & Guay, R.P. 2011. Person-Environment Fit. In S. Zedeck (Ed.) *American Psychological Association Handbook of Industrial and Organizational Psychology*, Amy L. Kristof-Brown, Russell P. Guay, American Psychological Association, 3, 1-50.

Kristof-Brown, A.L., Zimmerman, R.D. & Johnson, E.C. 2005. Consequences of individuals' fit at work: A meta-analysis of person-job, person-organization, person-group, and person-supervisor fit. *Personnel Psychology,* 58, 281-342.

Leiblein, M.J. & Miller, D.J. 2003. An empirical examination of transaction-and firm-level influences on the vertical boundaries of the firm. *Strategic Management Journal* 24(9) : 839-859.

Manso, G. 2011. Motivating innovation. *The Journal of Finance*, 66(5), 1823-1860.

Martin, X. & Salomon, R. 2003. Knowledge transfer capacity and its implications for the theory of the multinational corporation. *Journal of International Business Studies* 34(4): 356-373.

Mayer, K. J. & Salomon, R.M. 2006. Capabilities, contractual hazards, and governance: Integrating resourced-based and transaction cost perspectives. *Academy of Management Journal* 49(5): 942-959.

Morgeson, F.P. & Humphrey, S.E. 2008. Job and team design: Toward a more integrative conceptualization of work design. *Research in Personnel and Human Resources Management*, 27, 39-91.

Ouchi, W.G. 1979. A conceptual framework for the design of organizational control mechanisms. *Management Science*, 25(9), 833-848.

Sauermann, H. & Cohen, W.M. 2010. What makes them tick? Employee motives and firm innovation. *Management Science* 52(3): 223.

Shimizu, K. 2012. Risks of corporate entrepreneurship: Autonomy and agency issues. *Organization Science*, *23*(1), 194-206.

Sousa-Poza, A., Sousa-Poza, A.A. 2000. Well-being at work: A cross-national analysis of the levels and determinants of job satisfaction. *Journal of Socio-economics* 29(6): 517-538.

Spenner, K.I. 1990. Skill: Meanings, methods and measures. *Work and Occupations*, 17(4), 399-421.

Stern, S. 2004. Do scientists pay to be scientists?. *Management Science,* 50(6), 835-853.

Venkatraman, N. 1989. The concept of fit in strategy research: Toward verbal and statistical correspondence. *Academy of Management Review*, 14(3), 423-444.

Vroom, V.H. & Jago, A.G. 1988. *The new leadership: Managing participation in organizations*. Prentice-Hall, Inc.

Vroom, V.H. & Yetton, P.W. 1973. *Leadership and decision-making*. University of Pittsburgh Press.

Werbel, J.D. & DeMarie, S.M. 2005. Aligning strategic human resource management and person–environment fit. *Human Resource Management Review*, *15*(4), 247-262.

Wright, P.M. & Snell, S.A. 1998. Toward a unifying framework for exploring fit and flexibility in strategic human resource management. *Academy of Management Review*, 23(4), 756-772.

Youndt, M.A., Snell, S.A., Dean, Jr. J.W., & Lepak, D.P. 1996. Human resource management, manufacturing strategy, and firm performance. *Academy of Management Journal*: 836-866.

Yukl, G. & Fu, P.P. 1999. Determinants of delegation and consultation by managers. *Journal of Organizational Behavior*, 20(2), 219-232.

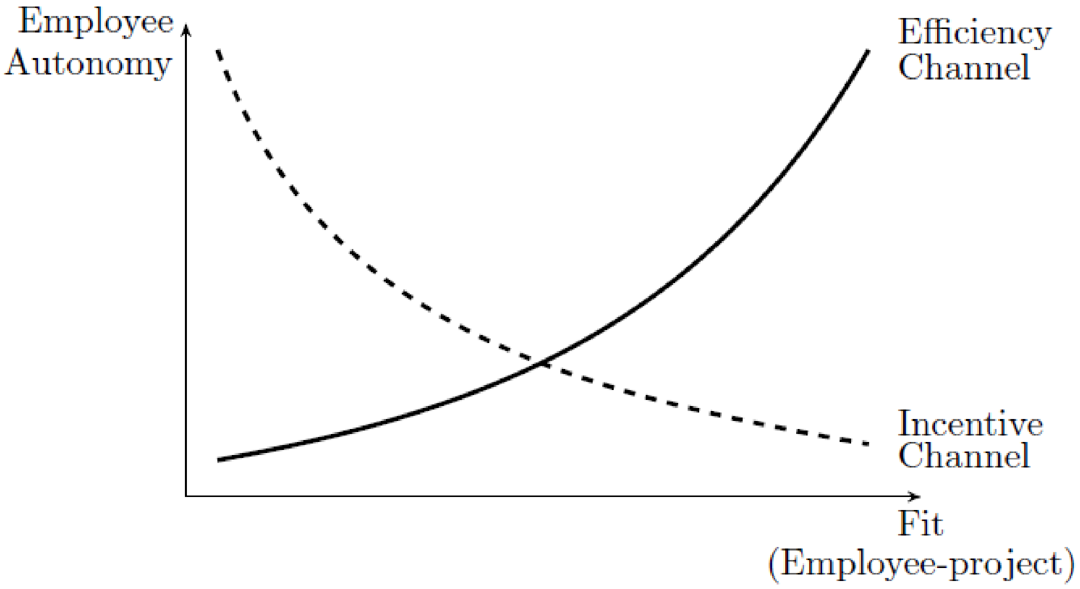

Figure 1 Efficiency and incentive channels of autonomy with respect to the EP fit

Table 1. Variable Definitions

Variable		Definition
Autonomy Measures	*autonomy in the selection of tasks* (AUT1)	respondent's score regarding the question on her autonomy level in *selection of tasks or projects* (b/w 1-6)
	autonomy in time allocation among tasks(AUT2)	respondent's score regarding the question on her autonomy level in *allocation of working time among different tasks* (b/w 1-6)
	autonomy in determining working time (AUT3)	respondent's score regarding the question on her autonomy level in *Flexibility of working hours* (b/w 1-6)
	broad autonomy measure (AUTONOMY)	Sum of the variables: AUT1, AUT2 & AUT3 (b/w 3-18)
EP Fit	*employee-side* (FIT)	respondent's agreement score (b/w 1-5) to the statement: "*... the combination of your previous experience with the knowledge of your new employer was instrumental in enhancing the inventive activity at the new organization.*"
	*Technical Instruments (*FIT_ASSET1)	respondent's agreement score (b/w 1-5) to the statement:: *'The organization had all the right instruments and technical equipment for this invention'.*
	*Complementary Resources (*FIT_ASSET2)	respondent's agreement score (b/w 1-5) to the statement:: *'The organization had all the complementary resources to make the invention a technical success'.*
	*Commercializing Resources (*FIT_ASSET3)	respondent's agreement score (b/w 1-5) to the statement:: *'The organization had all the resources to turn the invention into something economically valuable'*
Intellectual motive towards project (MOTIVE)		respondent's score regarding the question on the importance of *intellectual challenge as the motivation* for making particular invention (b/w 1-5)

GENDER	Dummy = 1 if the individual is female.
AGE	Age of the respondent
Employee's education (EDU)	Educational degree of the individual: 1= Secondary School or lower; 2= High School Diploma or equivalent; 3= Bachelor or equivalent; 4= Master or equivalent; 5= PhD or equivalent; 6= Post-doctoral degree.
Employee's gross annual income (INCOME)	Individual's approximate annual gross income in the year of the patent application: 1= Below 10,000 Euro; 2= 10,000-29,999 Euro; 3= 30,000-49,999 Euro; 4= 50,000-69,999 Euro; 5= 70,000-99,999 Euro; 6= 100,000 and more Euro
Firm size (SIZE)	Size of the employer firm: 1= 1-9 employees; 2= 10-19 employees; 3= 20-49 employees; 4= 50-99 employees; 5= 100-249 employees; 6= 250-499 employees; 7= 500-999 employees; 8= 1000-4999 employees; 9= 5000 and more employees.
Project man-month (PROJ_SIZE)	Individual's response to the question: "*How many man-months did the invention process require in total?*" 1= No research needed; 2= less than 1 man-month; 3=1-3 man-months; 4= 4-6 man-months; 5=7-12 man-months; 6=13-24 man-months; 7=25-48 man-months; 8=49-72 man-months; 9=more than 72 man-months
RANK	Individual's rank in the firm's hierarchy, based on the number of people reported to the individual at the time of invention: zero= 0 people; 1= 1-5 people; 2= 6-20; 3= 21 people and more.
MOBILITY	=1 if the respondent has moved once during her career.
Targeted project	=1 if the respondent reported the invention project as "*the targeted achievement of a research or development project*".
Individual-work project	=1 if the respondent reported the organization of the inventive activities leading to the Invention as "*individual work*".
Commercial Company	=1 if the respondent was working at a *private firm* at the time of invention.
Technological Class	ISI-INPI-OST Technology Classes

Table 2a Descriptive statistics for the sample of analysis

	Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
1	*AUT*	13.50	3.18	3	18
2	*AUT1*	4.12	1.51	1	6
3	*AUT2*	4.60	1.25	1	6
4	*AUT3*	4.80	1.33	1	6
5	*MOTIVE*	3.89	1.16	1	5
6	*FIT (employee)*	3.88	1.21	1	5
7	*FIT_SQ (employee)*	16.51	8.15	1	25
8	*FIT_ASSET1*	3.93	1.15	1	5
9	*FIT_ASSET1_SQ*	16.79	7.98	1	25
10	*FIT_ASSET2*	3.69	1.18	1	5
11	*FIT_ASSET2_SQ*	15.03	8.02	1	25
12	*FIT_ASSET3*	3.59	1.25	1	5
13	*FIT_ASSET3_SQ*	14.46	8.39	1	25
14	*GENDER*	0.05	0.22	0	1
15	*AGE*	49.15	10.26	5	91
16	*EDU*	3.84	1.14	1	7
17	*INCOME*	4.00	1.18	1	6
18	*RANK*	0.91	0.87	0	3
19	*SIZE*	7.22	2.40	1	10
20	*PROJ_SIZE*	4.77	1.98	1	9

Table 2b Correlation matrix for the sample of analysis

	Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	*AUT*	1									
2	*AUT1*	0.81	1								
3	*AUT2*	0.82	0.57	1							
4	*AUT3*	0.69	0.27	0.37	1						
5	*MOTIVE*	0.15	0.15	0.13	0.05	1					
6	*FIT (employee)*	0.12	0.11	0.09	0.09	0.13	1				
7	*FIT_SQ*	0.14	0.12	0.10	0.10	0.14	0.98	1			
8	*FIT_ASSET1*	0.04	-0.04	0.01	0.13	0.02	0.04	0.04	1		
9	*FIT_ASSET1_SQ*	0.05	-0.03	0.02	0.14	0.02	0.04	0.04	0.98	1	
10	*FIT_ASSET2*	0.02	-0.04	0.03	0.07	0.01	0.04	0.04	0.63	0.62	1
11	*FIT_ASSET2_SQ*	0.03	-0.03	0.03	0.08	0.02	0.04	0.04	0.62	0.63	0.98
12	*FIT_ASSET3*	-0.01	-0.07	0.01	0.04	-0.02	0.04	0.04	0.43	0.42	0.63
13	*FIT_ASSET3_SQ*	0.00	-0.06	0.02	0.04	-0.01	0.03	0.03	0.42	0.43	0.63
14	*GENDER*	0.01	0.01	0.03	-0.03	0.01	-0.03	-0.03	0.03	0.03	0.02
15	*AGE*	0.21	0.25	0.14	0.08	0.09	0.10	0.12	-0.05	-0.05	-0.01
16	*EDU*	0.12	0.10	0.11	0.08	0.04	0.04	0.04	0.04	0.04	-0.02
17	*INCOME*	0.21	0.19	0.15	0.16	0.03	0.09	0.11	0.09	0.08	0.12
18	*RANK*	0.14	0.18	0.11	0.02	0.00	0.08	0.09	0.04	0.04	0.01
19	*SIZE*	-0.22	-0.23	-0.19	-0.09	-0.06	-0.05	-0.06	0.19	0.19	0.17
20	*PROJ_SIZE*	0.12	0.14	0.07	0.06	0.13	0.04	0.05	-0.04	-0.05	-0.06

	Variable	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
12	*FIT_ASSET3*	0.62	1							
13	*FIT_ASSET3_SQ*	0.64	0.98	1						
14	*GENDER*	0.01	-0.03	-0.03	1					
15	*AGE*	0.00	-0.02	0.00	-0.11	1				
16	*EDU*	-0.03	-0.13	-0.12	0.07	0.05	1			
17	*INCOME*	0.12	0.14	0.13	-0.13	0.42	0.22	1		
18	*RANK*	0.01	0.01	0.00	-0.06	0.26	0.13	0.37	1	
19	*SIZE*	0.17	0.20	0.20	0.01	-0.20	-0.01	0.01	-0.07	1
20	*PROJ_SIZE*	-0.06	-0.08	-0.07	0.07	0.06	0.14	0.00	0.12	-0.08

Table 3 Ordered logit and OLS estimation of the determinants of autonomy with employee-side fit measure (main sample)

Dep. variable: ***Autonomy in...***	**AUT1** *selection of projects & tasks*		**AUT2** *time allocation among tasks*	
	(1) *OLogit*	(2) *OLS*	(3) *OLogit*	(4) *OLS*
GENDER	0.267	0.218	0.231	0.134
	(0.175)	(0.142)	(0.180)	(0.111)
AGE	0.027***	0.020***	0.006	0.003
	(0.004)	(0.003)	(0.004)	(0.002)
EDU	0.022	0.016	0.075**	0.051**
	(0.033)	(0.027)	(0.033)	(0.021)
INCOME	0.180***	0.150***	0.194***	0.124***
	(0.035)	(0.027)	(0.033)	(0.021)
RANK	0.123***	0.119***	0.081**	0.053**
	(0.040)	(0.034)	(0.040)	(0.026)
SIZE	-0.165***	-0.126***	-0.136***	-0.083***
	(0.014)	(0.011)	(0.013)	(0.008)
PROJ_SIZE	0.071***	0.061***	0.047**	0.030***
	(0.018)	(0.015)	(0.018)	(0.011)
FIT	-0.639***	-0.515***	-0.515***	-0.359***
	(0.159)	(0.125)	(0.154)	(0.096)
FIT_SQ	0.110***	0.089***	0.097***	0.066***
	(0.024)	(0.019)	(0.023)	(0.014)
Constant	.	3.578***	.	4.694***
	.	(0.292)	.	(0.225)
Technological Class	YES	YES	YES	YES
Observations	2,861	2,861	3,094	3,094
R-squared[1]	0.053	0.158	0.035	0.095
log likelihood	-4567.821	.	-4444.342	.

Robust standard errors in parentheses.

[1] Mc Fadden's pseudo R-squared is reported for ordered logit estimations. *** p<0.01, ** p<0.05, * p<0.1

Table 3 (*Continued*)

Dep. variable: ***Autonomy in...***	**AUT3** ***determining working time***		**Autonomy** **(*broad*)**	
	(5) *OLogit*	(6) *OLS*	(7) *OLogit*	(8) *OLS*
GENDER	-0.239	-0.161	0.119	0.175
	(0.175)	(0.112)	(0.180)	(0.289)
AGE	0.006	0.004*	0.014***	0.021***
	(0.004)	(0.002)	(0.004)	(0.006)
EDU	0.024	0.011	0.054	0.089
	(0.032)	(0.021)	(0.033)	(0.055)
INCOME	0.218***	0.135***	0.269***	0.460***
	(0.032)	(0.021)	(0.036)	(0.055)
RANK	-0.100**	-0.063**	0.052	0.105
	(0.040)	(0.026)	(0.040)	(0.068)
SIZE	-0.099***	-0.058***	-0.174***	-0.277***
	(0.013)	(0.008)	(0.014)	(0.021)
PROJ_SIZE	0.017	0.009	0.068***	0.117***
	(0.018)	(0.011)	(0.018)	(0.030)
FIT	-0.416***	-0.276***	-0.572***	-0.978***
	(0.159)	(0.096)	(0.160)	(0.253)
FIT_SQ	0.080***	0.051***	0.107***	0.181***
	(0.023)	(0.014)	(0.024)	(0.038)
Constant	.	4.944***	.	12.836***
	.	(0.224)	.	(0.592)
Technological Class	YES	YES	YES	YES
Observations	3,125	3,125	2,797	2,797
R-squared[1]	0.022	0.055	0.037	0.159
log likelihood	-4450.863	.	-6535.751	.

Robust standard errors in parentheses.

[1] Mc Fadden's pseudo R-squared is reported for ordered logit estimations. *** p<0.01, ** p<0.05, * p<0.1

Table 4 Ordered logit estimation of the determinants of autonomy with company-side fit measure (main sample)

Ordered Logit Estimates *Dep. Var.:* AUTONOMY		AUTONOMY (broad) (1)	AUTONOMY (broad) (2)	AUTONOMY (broad) (3)
GENDER		0.094	0.074	0.091
		(0.099)	(0.100)	(0.100)
AGE		0.016***	0.015***	0.015***
		(0.002)	(0.002)	(0.002)
EDU		0.062***	0.067***	0.071***
		(0.018)	(0.018)	(0.018)
INCOME		0.281***	0.280***	0.278***
		(0.019)	(0.019)	(0.019)
RANK		0.106***	0.102***	0.106***
		(0.022)	(0.022)	(0.022)
SIZE		-0.183***	-0.185***	-0.183***
		(0.008)	(0.008)	(0.008)
PROJ_SIZE		0.049***	0.052***	0.047***
		(0.010)	(0.010)	(0.010)
Technical Instruments	FIT_ASSET1	-0.317***		
		(0.090)		
	FIT_ASSET1_SQ	0.071***		
		(0.013)		
Complementary Resources	FIT_ASSET2		-0.304***	
			(0.089)	
	FIT_ASSET2_SQ		0.075***	
			(0.013)	
Commercializing Resources	FIT_ASSET3			-0.275***
				(0.085)
	FIT_ASSET3_SQ			0.062***
				(0.013)
Technological Class		YES	YES	YES
Observations		9,342	9,242	9,273
log likelihood		-22246.967	-21967.379	-22089.204
chi-square		1447.857	1495.677	1408.651

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5 Ordered logit estimation of the determinants of intellectual motive (main sample)

Ordered Logit estimates *Dep. Var.*: **MOTIVE**	(1)	(2)	(3)	(4)
GENDER	0.309*	0.305	0.339*	0.348*
	(0.186)	(0.186)	(0.180)	(0.180)
AGE	0.007*	0.008*	0.010***	0.011***
	(0.004)	(0.004)	(0.004)	(0.004)
EDU	0.017	0.017	0.016	0.016
	(0.033)	(0.033)	(0.032)	(0.032)
SIZE	-0.006	-0.006	-0.010	-0.011
	(0.014)	(0.014)	(0.013)	(0.013)
PROJ_SIZE	0.065***	0.065***	0.070***	0.071***
	(0.019)	(0.019)	(0.018)	(0.018)
INCOME	0.016	0.015	0.000	0.003
	(0.034)	(0.034)	(0.033)	(0.033)
RANK	-0.134***	-0.134***	-0.118***	-0.117***
	(0.042)	(0.042)	(0.041)	(0.041)
FIT (employee)	0.159***	0.332***	0.161***	0.434***
	(0.029)	(0.085)	(0.028)	(0.109)
AUT1	0.111***	0.268***		
	(0.025)	(0.077)		
AUT1*FIT (employee)		-0.041**		
		(0.019)		
AUT2			0.152***	0.371***
			(0.029)	(0.089)
AUT2*FIT (employee)				-0.058***
				(0.022)
AUT3				
AUT3*FIT (employee)				
AUTONOMY				
AUTONOMY*FIT (employee)				
Observations	2,793	2,793	3,022	3,022
log likelihood	-3580.335	-3577.993	-3848.550	-3845.194
chi-square	94.324	99.009	116.070	122.782

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5 (*continued*)

Ordered Logit estimates *Dep. Var.*: **MOTIVE**	(5)	(6)	(7)	(8)
GENDER	0.330*	0.330*	0.342*	0.337*
	(0.180)	(0.180)	(0.188)	(0.188)
AGE	0.011***	0.011***	0.008*	0.008*
	(0.004)	(0.004)	(0.004)	(0.004)
EDU	0.016	0.016	0.011	0.010
	(0.032)	(0.032)	(0.034)	(0.034)
SIZE	-0.018	-0.019	-0.005	-0.006
	(0.013)	(0.013)	(0.014)	(0.014)
PROJ_SIZE	0.073***	0.073***	0.067***	0.068***
	(0.018)	(0.018)	(0.019)	(0.019)
INCOME	0.006	0.006	0.003	0.004
	(0.033)	(0.033)	(0.035)	(0.035)
RANK	-0.108***	-0.108***	-0.132***	-0.132***
	(0.040)	(0.040)	(0.043)	(0.042)
FIT (employee)	0.158***	0.177*	0.157***	0.456***
	(0.028)	(0.097)	(0.030)	(0.127)
AUT1				
AUT1*FIT (employee)				
AUT2				
AUT2*FIT (employee)				
AUT3	0.081***	0.096		
	(0.027)	(0.078)		
AUT3*FIT (employee)		-0.004		
		(0.020)		
AUTONOMY			0.067***	0.150***
			(0.012)	(0.037)
AUTONOMY*FIT (employee)				-0.022**
				(0.009)
Observations	3,048	3,048	2,736	2,736
log likelihood	-3894.796	-3894.774	-3497.223	-3494.290
chi-square	93.919	93.964	108.060	113.925

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

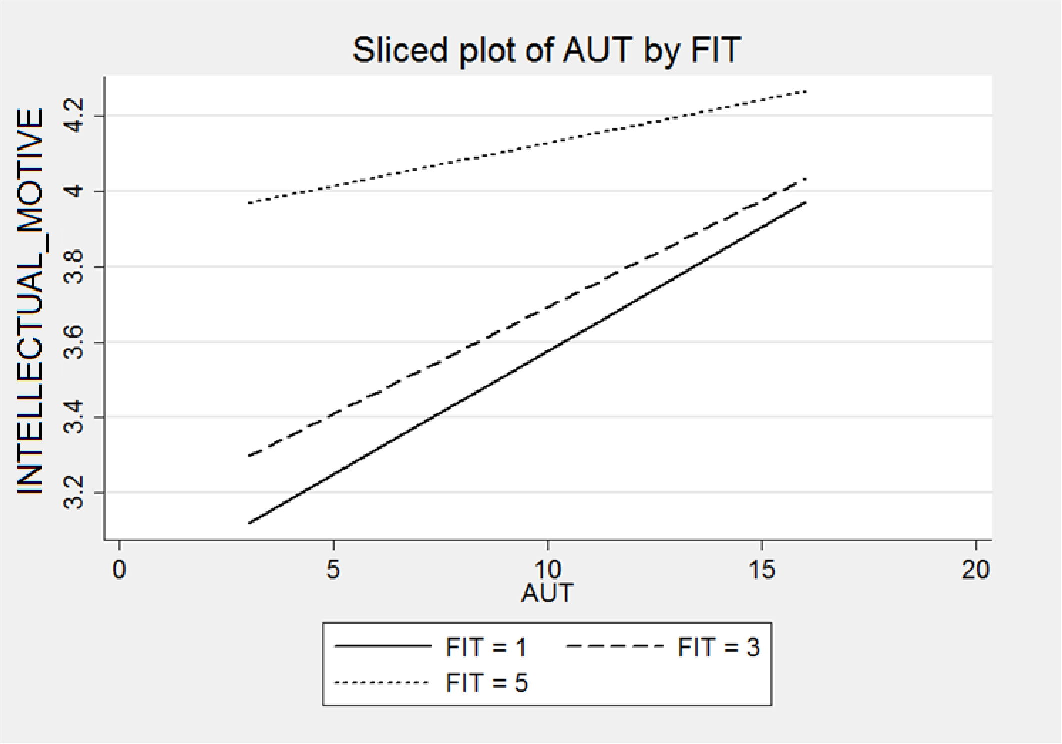

Figure 2. Sliced plot of INTELLECTUAL_MOTIVE and AUTONOMY by FIT (employee)

Table 6 Ordered logit estimations of determinants of autonomy based on different subsamples

	Targeted and planned projects		
Dep. var: **Autonomy in...**	**Selection of tasks** (1)	**Time allocation among tasks** (2)	**Determining working time** (3)
GENDER	0.198	0.486*	-0.406
	(0.255)	(0.253)	(0.288)
AGE	0.030***	0.010*	0.004
	(0.006)	(0.005)	(0.005)
EDU	0.014	0.112**	0.038
	(0.046)	(0.048)	(0.045)
INCOME	0.158***	0.184***	0.268***
	(0.049)	(0.046)	(0.045)
RANK	0.143**	0.072	-0.107*
	(0.058)	(0.057)	(0.057)
SIZE	-0.148***	-0.134***	-0.099***
	(0.018)	(0.018)	(0.018)
PROJ_SIZE	0.063**	0.003	0.016
	(0.026)	(0.026)	(0.025)
FIT (employee)	-0.613***	-0.871***	-0.674***
	(0.238)	(0.219)	(0.228)
FIT_SQ (employee)	0.108***	0.146***	0.117***
	(0.035)	(0.032)	(0.033)
Technological Class	YES	YES	YES
Observations	1,489	1,613	1,634
Log likelihood	-2392.281	-2281.830	-2303.829

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6 (*continued*)

Dep. var: **Autonomy in...**	**Individual-work projects** **Selection of tasks** (4)	 **Time allocation among tasks** (5)	 **Determining working time** (6)
GENDER	-0.139	0.154	-0.329
	(0.389)	(0.427)	(0.400)
AGE	0.025***	0.004	0.012**
	(0.006)	(0.006)	(0.006)
EDU	-0.007	0.056	0.020
	(0.054)	(0.053)	(0.051)
INCOME	0.159***	0.230***	0.128**
	(0.055)	(0.053)	(0.051)
RANK	0.102	0.084	-0.085
	(0.071)	(0.070)	(0.070)
SIZE	-0.207***	-0.174***	-0.122***
	(0.022)	(0.021)	(0.021)
PROJ_SIZE	0.096***	0.080**	-0.024
	(0.034)	(0.033)	(0.032)
FIT (employee)	-0.661***	-0.464*	-0.095
	(0.245)	(0.237)	(0.238)
FIT_SQ (employee)	0.117***	0.086**	0.034
	(0.037)	(0.036)	(0.036)
Technological Class	YES	YES	YES
Observations	1,037	1,106	1,123
Log likelihood	-1594.730	-1578.825	-1617.934

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7 Estimation based on the whole sample to check for potential sampling bias

Dep. var: **Autonomy in...**	**Commercial Companies (Main Sample)**		
	Selection of tasks (1)	**Time allocation among tasks** (2)	**Determining working time** (3)
GENDER	-0.035	0.196*	0.089
	(0.104)	(0.103)	(0.100)
AGE	0.025***	0.006***	0.007***
	(0.002)	(0.002)	(0.002)
EDU	0.049***	0.065***	0.009
	(0.017)	(0.018)	(0.017)
INCOME	0.167***	0.198***	0.256***
	(0.019)	(0.019)	(0.019)
RANK	0.152***	0.107***	-0.029
	(0.022)	(0.021)	(0.022)
SIZE	-0.179***	-0.138***	-0.087***
	(0.009)	(0.008)	(0.008)
PROJ_SIZE	0.048***	0.035***	0.021**
	(0.010)	(0.010)	(0.009)
MOBILITY	0.592**	0.539**	0.264
	(0.246)	(0.241)	(0.248)
FIT (employee)	-0.637***	-0.518***	-0.378**
	(0.156)	(0.153)	(0.154)
FIT_SQ (employee)	0.110***	0.097***	0.073***
	(0.023)	(0.023)	(0.023)
Technological Class	YES	YES	YES
Observations	9,981	10,523	10,658
log likelihood	-16269.475	-15771.247	-15633.945
chi-square	1349.443	810.908	503.064

Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7 (*continued*)

Dep. var: **Autonomy in...**	**Non-commercial institutions** **Selection of tasks** (4)	 **Time allocation among tasks** (5)	 **Determining working time** (6)
GENDER	0.001	-0.019	-0.166
	(0.242)	(0.215)	(0.215)
AGE	0.012	0.001	0.003
	(0.008)	(0.007)	(0.008)
EDU	0.270***	0.185**	0.190**
	(0.077)	(0.075)	(0.078)
INCOME	0.190***	-0.018	-0.104
	(0.073)	(0.070)	(0.071)
RANK	0.374***	0.234**	0.223**
	(0.102)	(0.099)	(0.104)
SIZE	-0.015	-0.010	0.071**
	(0.032)	(0.029)	(0.029)
PROJ_SIZE	0.115***	0.052	0.060
	(0.036)	(0.035)	(0.037)
MOBILITY	0.378	0.019	0.329
	(0.733)	(0.864)	(0.801)
FIT (employee)	-0.694	-0.234	-0.304
	(0.490)	(0.542)	(0.518)
FIT_SQ (employee)	0.128*	0.055	0.050
	(0.076)	(0.080)	(0.077)
Technological Class	YES	YES	YES
Observations	788	821	827
log likelihood	-1071.149	-1153.811	-1087.463
chi-square	92.080	31.580	29.611

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Chapter 2

Micro-organization of Innovative Projects:

Delegation and the Direction of Innovative Output[5]

Abstract

Delegation of autonomy to employees is an important job dimension for knowledge-intensive activities where the tasks are less routine and is scheduled and there is much room for creativity. Yet, it is not clear how delegation impacts the characteristics of innovative output especially at the project-level. In this study, we focus on innovative projects and discuss two main mechanisms that autonomy impacts the innovative output through them; the effort mechanism and the control mechanism. Using a novel dataset based on a survey of inventors, we test our theory and find that delegation of autonomy increases the scientific value of the project, however its effect on the commercial value is insignificant and sometimes negative. Discussing the reasons why companies decide to bear this cost for delegation, we show that the impact of autonomy on commercial value also depends on the fit between the employee and the assigned project.

Introduction

Knowledge and innovation are considered key drivers of firms' competitive advantage especially in knowledge-intensive contexts. The role of human capital in this process is found to be crucial (Castanias & Helfat, 1991, 2001; Gittelman & Kogut 2003) to the extent that the

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[5] Co-authored with Alfonso Gambardella and Claudio Panico.

effective management of key employees has been introduced as the ultimate determinant of performance (Youndt, Snell, Dean Jr. & Lepak, 1996). Thus, finding the optimal organization of innovative activities is critical for companies. In this paper, we focus on an important dimension in micro-organization of innovation, which is knowledge workers' level of autonomy in projects. More specifically, we investigates how delegation of autonomy to knowledge workers impacts the output in innovative projects and how the impact is related to individual and environmental characteristics. Since prior research has shown substantial variations in autonomy levels across projects in a company (Khashabi, Gambardella, & Panico, 2014), we focus our analysis at the level of projects and study the effect of project-level autonomy on the project's output, namely on its direction and value.

Knowledge-intensive projects- unlike ordinary ones- are typically less routine and scheduled, and more based on creativity. Thus, employee autonomy within the project is an important dimension of knowledge-intensive contexts. Prior studies have highlighted that delegating to employees is associated with undeniable costs for companies, e.g. losing control over the project (Aghion & Tirole, 1997; Gambardella, Panico, & Valentini, 2015) and giving rise to agency issues (Christie, Joye & Watts, 2003; Jensen & Meckling 1976; Shimizu, 2012). In spite of this, knowledge workers in practice exercise a considerable degree of autonomy (Sauermann & Stephan, 2013; Vallas & Kleinman, 2008) due to two main of reasons: firstly because delegation improves decision efficiency (Grant, 1996; Jensen & Meckling, 1992), especially in innovative projects where employees often have higher levels of expertise over the project technicalities than the managers (Sauermann & Cohen, 2010). Secondly because autonomy is delegated as an incentivizer to knowledge workers (Gambardella et al., 2015) especially in environments where employee motivation is a matter of concern (Khashabi et al., 2014). Accordingly, the amount of delegation is an important and strategic decision for companies. Understanding about how this decision impacts the output of the projects, contingent on individual and environmental factors, would be important for both practitioners and scholars; an issue which to the best of our knowledge has not been investigated deeply.

In this article, we discuss two main mechanisms that autonomy impacts the output through them: the effort mechanism, and the control mechanism; since delegation is known to satisfy motivational needs (Horngren, et al. 2013; Gagne & Deci, 2005), boost creativity (Amabile, 1996) and support intrinsic motivations (Hackman & Oldham, 1980), it improves the *level* and *character* of innovative effort (Sauermann & Cohen, 2010); what we label as the *effect of autonomy via effort mechanism*. Also, since autonomy allows employees to practice their decision rights over the project, it enables them to shift the project direction to towards goals that hold greater benefits for them (e.g. scientific direction) instead of goals that company favors (e.g. commercial direction). We term this as the *effect of autonomy via control mechanism* and discuss how the interplay of these two mechanisms impact the scientific and commercial value of the innovative output.

To test the implication of the theoretical framework, we use a novel dataset which is based on a specifically designed survey of inventors of the European Patent Office (EPO). The survey collects a wide range of data related to the inventor and the inventive process of EPO patents with priority dates between 2003–2005 in twenty European countries, U.S., Japan, and Israel. We have matched this information with other complementary sources such as PATSTAT, Amadeus, Orbis and Compustat to build our sample. Based on this sample, the empirical results show that delegation of autonomy to knowledge workers, increases the scientific value of the output. However, the impact on the commercial value is insignificant and sometimes negative. Moreover, we find that the negative impact of autonomy on commercial value is typically associated with the cases where there is a poor employee-project fit, which are cases where autonomy is reported to be used as an instrument to strategically motivate employees (Khashabi et al., 2014).

We believe this study contributes to the literature in several ways: first, we address an important issue in strategy research- i.e. performance of innovative projects- by employing a novel and unique dataset. The use of the specifically designed survey allows us to analyze our question, at the project level; to the best of our knowledge, there is no other study which has investigated the impact of autonomy on output at this level. Second, we link strategic management of key employees to the innovative output; while it is straight forward to assume that management of knowledge workers influences their innovative output, there is little integration and dialogue among the literatures of Innovation and Strategic Human Capital. This study is an attempt to bridge between these two lines of research. Third, this study contributes to the literature studying the determinants of value of inventions, by introducing a micro-project level variable that impacts the organization of innovative activities. Fourth, we shed light on one of the dimensions regarding how firms organize their R&D *inside* the company; although there is a wide and established literature studying organization of R&D, its focus is almost always at *inter-firm* organization.[6] As Argyres and Silverman (2004) highlight, "*... academic research has focused on the inter-firm organization of R&D activities...almost to the exclusion of intra-firm organization*". Our study contributes to the emerging studies of *intra-firm* organization of R&D at the individual and project- level.

The remainder of this article is organized as follows. Section 2 discusses the theoretical background, whereas the empirical setting, data, and the sample are described in section 3. Section 4 reports and discusses the main results, and section 5 concludes.

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[6] Few exceptions include Arora, Belenzon,& Rios (2014) and Argyres & Silverman (2004).

Theory

Employee autonomy and output.

As pointed in the introduction, autonomy is a crucial dimension in innovative and knowledge-intensive contexts. Therefore, the level of delegation is among the first decisions that managers make about the organization of innovative activities. Recent studies highlight that knowledge workers' autonomy level varies across R&D projects within the same company and is a project-level variable (Khashabi et al., 2014). Most R&D projects are composed of several discrete activities; for each activity, company should decide who is in charge, the external partners to engage, how to tackle a specific problem, what to do with the prospective outcome of the activity, and so on (Cassiman, Di Guardo & Valentini, 2010). This is an important issue since the distribution of decision rights in a project can impact the R&D process and consequently the output of the project (Gambardella et al., 2015). In this section, we discuss two main mechanisms that this impact happens through them: *the effort mechanism* and *the control mechanism*. Below, we present each mechanism and their impact on the innovative output.

The Effort Mechanism. Individuals have a fundamental need for autonomy. Hackman & Oldham (1976) introduce autonomy as one of the five core job characteristics in their job design model that is crucial for employees. Autonomy is also mentioned among prominent factors contributing to employees' job satisfaction (Benz & Frey,2008a & 2008b; Nguyen, Taylor & Bradley, 2003; Sousa-Poza & Sousa-Poza, 2000) which leads to higher effort and efficiency. For the case of knowledge workers, autonomy is even a more significant factor (Baylin, 1985). Empirical evidence supports the positive effect of autonomy on creativity and innovative behavior (Shalley, Zhou & Oldham, 2004). Also, Psychology literature has highlighted the importance of intrinsic motivations for employees (Amabile 1996, Ryan & Deci, 2000) which is supported by autonomy; it is discussed that employees with higher levels of knowledge enjoy the sense of independence which allows them to take credit for their decisions and assign achievements to their own (Gagne & Deci 2005, Sauermann & Cohen, 2010) which is an intrinsic motive for them.

Accordingly, it is straight forward to expect that more autonomous knowledge workers to be more motivated for their tasks. As higher motivation for a particular tasks leads to lower marginal disutility of effort, this should increase the optimal *level* of exerted effort by the knowledge worker.

In addition to this, motives may also shape the *character* of a certain quantity of effort - i.e. "*... the allocation of [...] effort to different activities or [...] the intensity or quality of cognitive effort*" (Sauermann & Cohen, 2010). The character of effort can positively impact the extent of creativity and productivity for a given unity of effort. All in all, we expect that delegation of autonomy in the projects, increases the level of effort *and* the positive effect of effort on the output of the project. This is what we label as the impact of autonomy via effort mechanism

The Control Mechanism. As discussed above, through motivational effect of delegation, and via effort, autonomy impacts innovative output of the project. However, the effect of autonomy is not bounded to the effort channel. Autonomy in projects enables knowledge workers to select tasks, approaches, challenges and directions that are of particular interest to them (see e.g. Frey & Stutzer, 2004, Gagne & Deci 2005, Hackman & Oldham 1976). Therefore, delegating decision rights to knowledge workers can impact the project direction and consequently the project output. Below, we analyze the impact of this mechanism based on two arguments: firstly we discuss that that autonomy, when delegated will be practiced by knowledge workers to increase their utility. Secondly, we argue that knowledge workers have a "*taste for science*" and gain utility from working in projects more aligned with scientific directions.

It is quite established in the literature that creative individuals have peculiar motives in their job (Ederer & Manso, 2013; Stern, 2004) and non-monetary motives play a key role for them (Shalley et al., 2004). Prior studies on knowledge workers (e.g. scientists, inventors, R&D personnel) have shown that these individuals are mostly driven by motives such as scientific curiosity, intellectual challenge and visibility (Cohen & Sauermann 2007, Giuri et al. 2007, Katz, 2004). This is what Stern (2004) names as "*taste for science"* in his seminal work. The taste for science shapes the preference, approaches, and decisions of knowledge workers in their tasks. For example, it has been reported that PhD scientists and engineers tend to be engaged much in upstream research (Roach & Sauermann, 2010) and keep close ties with the broader scientific community (Cockburn & Henderson 1998; Sauermann & Stephan, 2013). Also, survey results from industrial inventors show that motives such as intellectual challenge or satisfying scientific curiosity- rather than monetary rewards - are the main personal drivers of making inventions. Figure 1, based on a survey of industrial inventors, shows a comparison between two motives of invention: monetary rewards vs. intellectual challenge. As it is shown, the respondents clearly have reported intellectual challenge a more important motive for their innovative activity. This is the essence of what we refer as scientific direction and assume that projects being aligned more with this direction would generate higher private benefits for knowledge workers. It is reasonable to assume that knowledge workers use their decision rights to shift the project more towards the scientific direction.

[Insert Figure 1 here]

As it is established that knowledge workers favor a scientific direction, it is also taken for granted that companies follow other goals from their activities. It is a standard assumption in Economics that increasing the profit is companies' main objective. For an innovative project, this can be achieved through directing the project towards a commercial scope, e.g. having a more market-driven target, or faster commercializing of the output. Therefore, from the company-side, commercial value is always the main goal of the project and the scientific value will be important only if it increases the commercial value of the output. Therefore, in many instances, the objectives of the company may not be perfectly aligned with the preferences of the knowledge worker. Basic research in the industry is a classic example: both the company and the researcher may benefit from it, but the researcher may prefer to further explore to gain a better understanding of a scientific phenomenon, whereas the company may want to move on faster to develop and commercialize the innovation; Smith and Hounshell (1985) report the case of Wallace Carothers, a science "purist" who discovered *nylon* while working for DuPont. After the invention, he was interested to do further research and explore the fundamental properties of nylon, while DuPont was only interested in faster developments of the fiber and moving to the commercialization phase. This divergence of interests eventually led Wallace Carothers to leave the company. As seen from the example, there are conflict of interest between the knowledge worker preferences and the company. Therefore, delegation of autonomy can create a loss, due to the reduction of control over the project by company (Aghion & Tirole, 1997), which we refer as the cost of delegation.

Value of Innovative Output

Scientific value of the output. From the discussion above, delegating autonomy will increase the level of effort exerted by knowledge worker through leveraging her intrinsic motivation. Also, this positively shapes the character of the effort. And finally the role of autonomy in boosting the creativity is another positive factor. Accordingly in projects with higher levels of autonomy delegated to the employee, we expect knowledge worker to exert higher levels of effort, and achieve more productivity for a given unit of effort. Also, we expect that the creativeness to be higher for the same unit of effort. Although innovative projects are uncertain and not perfectly related to effort, however, we expect that higher autonomy on average, increases the scientific value of the project output via the effort mechanism,.

Also as explained, the innovative projects typically do not have a routine and perfectly predefined arrangement. Therefore, they can be directed toward goals that hold greater interest for the company(e.g., profits) or for the employee (e.g., scientific curiosity, intellectual challenge, visibility). Thus, when more control and decision rights are delegated to the knowledge worker - as opposed to the company- we expect her to shift the direction of the project towards the scientific direction (Figure 2). When the project is more targeted towards a scientific direction, it is more likely that the output entails a higher scientific value. Accordingly, we expect higher autonomy, via the control mechanism, also to positively impact the scientific value of the project output.

Since both mechanisms predict a positive impact of delegation on the scientific value, their overall effect will enforce each other, and we hypothesize:

H1. Higher the knowledge worker's autonomy level in a project, higher the scientific value of the project output.

[Insert Figure 2 here]

Commercial value of the output. Via the effort mechanism, we have argued that higher autonomy level will improve knowledge workers' initiative and creativity. Therefore, and regardless of the project direction, we expect the output to entail higher novelty and innovativeness. Also, since with higher autonomy the employee has exerted higher levels of effort, it is natural to expect higher quality for the project output on average. Higher quality outputs are typically of higher commercial value (easier to commercialize, higher market success), thus via the effort channel we expect higher autonomy to generate higher commercial value (figure 2). The effect of autonomy via the effort mechanism is similar on the scientific and commercial value. Via this channel, the preferences of the employee aligns with the objective of the company. This is the reason why companies use delegation as an incentive instrument: leveraging intrinsic motivations to benefit from employee's desired setup to achieve higher quality output. However, there is another mechanism that moves in the opposite direction and the tradeoff defines the optimal level of employee's autonomy in the project. We discuss this mechanism below.

Output's commercial value is also impacted by the direction of the project. As our assumption with respect to autonomy is that the knowledge worker will use control to support her intrinsic motivations and preferences, we expect her to shift the direction of the project towards her preferred path (i.e. scientific direction). And since scientific direction does not necessarily coincide with the commercial direction, this on average reduces the commercial value of the output. Similar to the case of Carothers, one might think of many examples where pursuing a scientific approach may negatively impact the commercial value of the output; e.g. it is widely accepted that reputation and scientific visibility is highly valued by knowledge workers. Therefore, if they receive autonomy in release of information outside the organization, they are very likely to show off their achievements in activities such as publishing or presenting in scientific conferences. However, this might hurt the commercial scope of their achievements through leak of information to competitors. Parallel to the case in our example, we expect that via control mechanism, higher autonomy leads to lower commercial value (Figure 2).

In the case of commercial value, delegation of autonomy creates two forces on opposite directions: from one side, delegating more to knowledge workers creates a loss for company due to lack of control (the control mechanism) which reduces the commercial value. From the other side, autonomy creates private benefits for the worker, and leveraging their intrinsic motivations helps the company to increase the performance and creativity (the effort mechanism). Therefore, the overall effect will depend on which mechanism to be stronger and prevail over the other. The direction of the effect in reality is an empirical issue which we intend to investigate in our data, therefore we formulate two competing hypotheses:

H2a. Higher the knowledge worker's autonomy level in a project, higher the commercial value of the project output.

H2b. Higher the knowledge worker's autonomy level in a project, lower the scientific value of the project output.

Hypothesis 2a in our analysis stands for the case where the effort mechanism overcomes the control mechanism while hypothesis 2b is for the opposite case.

The Moderating Role of Employee-Project Fit

Recent studies have demonstrated that the congruence between the characteristics of employees and their project, job, team, and organization, matters for a wide variety of outcomes in companies (Kristof, 1996). Employee-project (EP) fit is related to the congruence between an employee's skills, knowledge, abilities and preferences with her project-related tasks. B*oth* companies and employees benefit from this congruence (Werbel & DeMarie, 2005). Companies benefit as they gain higher productivity inside the projects, the employees also benefit from enjoying higher job satisfaction and motivation in good fit jobs (Holland, 1985).

[Insert Figure 3 here]

Recent studies have found that EP fit is a key determinant of delegation to knowledge workers (Khashabi et al., 2014). Based on the EP fit quality, two categories of knowledge workers receive relatively higher levels of autonomy in projects: very high and very low EP fit cases (see figure 3). When the EP fit is high, companies delegate higher levels of autonomy to employees in order to achieve higher efficiency (Chen, Chang & Yeh, 2004; Igbaria, Greenhaus & Parasuraman, 1991). This is because in high EP fit case, employee's knowledge and experience becomes more instrumental for the project, so she can make better decisions regarding the project issue. Therefore, companies delegate more to higher fit cases for performance reasons (i.e. commercial value). However, when the EP fit is extremely low, the employee is neither productive nor motivated to work in the project. This gives rise to agency concerns especially since the output of the project is not verifiable in short-term. In these cases, companies may also delegate higher autonomy levels to a low EP fit employee to motivate her and correct the agency costs by leveraging intrinsic motivation (Gambardella, et al. 2015; Khashabi et al. , 2014). As a result, the employee will shift the project towards her preferred direction, be more motivated to work and consequently, generate *an* output; this output would not probably be the output that company favors. However, if a poor EP fit case does not receive autonomy, it is very likely that she even cannot reach an output in an innovative project, since she is neither motivated nor productive. Therefore, companies delegate to these cases to motivate them to generate *something*, which is not what exactly company wants, but it is better than *nothing*.

In this framework, good EP fit employees when receiving autonomy, can make better decisions for the goals of the project (i.e. increase the commercial value), while poor EP fit employees only receive autonomy for motivational purposes, even outside the commercial scope of the project. Accordingly, we expect that the commercial value of projects increase when autonomy is given to a high EP fit cases- as opposed to a low EP fit cases. This implies a moderating relation of fit between autonomy and the commercial value. Therefore we hypothesis:

H3. The relation between commercial value and autonomy is positively moderated by EP fit.

Note that the theory of delegation based on EP fit is only concerned with the commercial value of output. We do not expect the same moderating relation for the scientific value, since EP fit is defined for the congruence between the employee with the *commercial* aspects of her project; this is because the project is defined by company. For scientific value, employee shifts the project towards her own preferred direction, so she departs from the defined project of the company and the notion of EP fit becomes almost meaningless and ineffective. Therefore H3 only highlights the moderating effect for the commercial value and we do not expect the same moderating role for the scientific value.

Method

Data and Sample

We use a restricted use, extensive data drawn from the PatVal-2 survey. This dataset is based on a survey of inventors for the European Patent Office (EPO) granted patents with priority dates between 2003 –2005 in twenty European countries, the U.S., Japan, and Israel. More details about the project is described in Gambardella et al. (2014). The key advantage of the survey is that it collects data about the "*the process leading to invention*", so we access the project-level information. The survey also includes a wide range of questions at the level of individual, project, company, region and technology. In the sample of our study, the survey data is merged with other data sources including Amadeus, Orbis and Compustat datasets to access complementary information about the companies. Also to access some of the measures related to the scientific value of invention, the survey data is merged with PATSTAT databases by matching the inventor in the survey to its unique PATSTAT identifier. This enables the use of information in patent examiner's search report (such as number of non-patent literature references).

To address our research question, we select our sample of analysis from the inventors in PatVal-2 survey working in commercial companies at the time of invention and exclude inventions originating from universities and academic research centers. This subsample includes more than 7770 observations. However, for the majority of cases, there are numerous missing values regarding our key dependent and explanatory variables which reduce the sample size in different specifications.

Dependent Variables

Scientific value of output. We use two measures as a proxy for scientific value of the innovative output (patents): the number of references made to the non-patent literature (typically to scientific journals) and the inventive step of the patent. The two measures are explained as follows.

a. *Number of references made to the non-patent literature* (NPL Refs) is the number of relevant scientific documents that patent examiners have listed when evaluating the patent application. The logic behind this measure is that scientific publications document the state of the art, and so, they can be used against the claims in patent application during its evaluation (Harhoff, Scherer & Vopel, 2003). For this reason, patent examiners search in the scientific literature for relevant publications and list them against the application. Accordingly, a relatively high number of references to the scientific literature may indicate strength of a patent's scientific linkage and novelty. This measure has been used in the literature as a proxy for scientific quality of patents (see e.g. Harhoff et al., 2003; Meyer, 1999). Notice that our sample is composed of successful patent applications, so while the reference has made against the application, the patent has been finally granted to the applicant. So in our case, higher number of reference to non-patent literature, shows proximity to knowledge frontier of the granted patent.

We use this measure as one of our dependent variables in testing for H1.

b. *Inventive step* is based on a question from the survey asking respondents to rate the degree inventive step for their invention according to the legal definition in the European Patent Convention. According to the European Patent Convention, an inventive step means that "*...the invention, having regard to the state of the art, must not be obvious to a person skilled in the art*" (Article 56, European Patent Convention). This measure captures mostly the degree of innovativeness of the output. The respondents could answer to this question based on a Likert scale from one ('very low') to five ('extremely high'). Although inventors may overestimate the degree of inventive step for their invention, we believe this can be considered a common bias among the individuals and will not impact the direction of the effect which we are studying. We use this construct as another dependent variable in testing for H1.

Commercial value. For this variable, we are interested to capture the extent to which the project output is valuable for the company. Having inventions as the output makes it extremely difficult to calculate the output value (Arora, Fosfuri & Gambardella, 2001). In this paper, as a proxy for the commercial value, we use information on whether the company has used the *patented invention commercially*, (i.e., in a product, service or in a manufacturing process) or not. We believe that this measure is able to distinguish between outputs that are in line with the objectives of the company, as opposed to the outputs which are only favored by the inventor (pure scientific patents).[7]

We build this measure based on information extracted from the survey. To make the best of the richness in data, we distinguish between three cases. First, cases where the patented output is already commercialized, second, cases where the patent is not commercialized but there is still ongoing process/ plans of commercialization, and third patented outputs which are neither commercialized nor there is any plan of commercialization associated with them. On this basis, we build a proxy for the commercial value of the output as:

zero= non-commercialized patented inventions, *one*= inventions still in the process of commercialization, and *two*= commercialized patent inventions. We use this constructs to check H2 and H3.

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[7] The literature also widely uses patent citations as a proxy to calculate the financial value of the output (e.g. Gambardella, Giuri, & Luzzi, 2007; Harhoff et al., 2003). However, there this measure is also highly correlated with scientific value of patents. Therefore, we prefer to use commercial use of patents in this paper. However, the results of analysis with patent citation is available upon request.

Independent Variables

Autonomy. By the autonomy in the project, we intend to capture the degree to which the employee is empowered with decision rights in defining her tasks. Our constructs are based on a question from the survey asking respondents to rate their autonomy level, on a Likert scale from one ('no autonomy') to six ('very high autonomy') on the items:

(a) *'selection of your tasks or projects'*, (b) '*allocation of your working time among different tasks or projects'*, (c) '*flexibility of your working hours*'

To build our measure of employee's autonomy (AUTONOMY), we simply sum up the responses over the items above.

Employer-project fit. The quality of fit between the employee's background, experience, and preferences with the employer's inventive project is the key dimension for our third hypothesis. To capture this concept, we need a reference point for the employee's background with respect to the inventive project. Thus we employ a question from survey, asking the inventors to consider their knowledge and experience from their prior organization and to indicate whether their experience matched the specific inventive activity leading to invention. We build this measure using a question from the survey asking inventors to which extent they agree or disagree with the following statements:

'... the combination of your previous experience with the knowledge of your new employer was instrumental in enhancing the inventive activity at the new organization.'

The responses were collected on a Likert scale from one ('fully disagree ') to six ('fully agree'). The statement captures a broad concept of PE fit. We make use of this item to build the variable FIT.

Controls

We control for a wide range of variables at the level of individual, project, company, region and technological area. At the individual level, we control for the gender, age and gross income of the employee. Moreover, we control for the inventor's level of education and rank in the project's structure. At the project and firm level, we control for the project size (project man-month), and firm size (measured by number of employees). Also, thanks to the information from the survey, we control for the project-level complementary assets and resources (e.g. technical instruments, complementary resources for technical success, resources for making the invention economically valuable and etc.) which improves the fit quality from the company side. These variables helps us to isolate the effects that we study from other channels impacting the value of output. Finally, due to potential role of technology-specific and geographical factors, we control for the location of the employee and technological areas.

A brief variable definition and summary of their statistics and correlations are presented in Tables 1 and 2.

[Insert Table 1 and Table 2 here]

Results

As the first step to test our theory, we focus on the determinants of scientific value of patents. According to H1, we expect autonomy to positively impact scientific value of the patent. Therefore, we estimate the equation below:

$$\textit{Scientific value}_i = \beta_0 + \beta_1 AUTONOMY_i + \mathbf{X}'_i\boldsymbol{\gamma} + \varepsilon_i \qquad (1)$$

We estimate the equation above for the scientific value of the project, generated by the employee *i*, where **X** in equation (1) is a vector of controls with a vector of coefficients as $\boldsymbol{\gamma}$. The proper econometric model to estimate the equation (1) would depend on the dependent variable. We consider a count model when using the number of references made to the non-patent literature as the proxy for scientific value. Also in the specifications where the inventive step is the dependent variable, we use an ordered response model to estimate the coefficients in equation (1).

Table 3, presents the results of the estimates for equations (1) where the dependent variables are the measures scientific value. As in equation (1) we include employee's autonomy and EP fit as independent variables. Also, we include a wide set of controls at the employee level (such as gender, age, education, and income) and the work/ project level (including firm and project size, resources). All specifications include geographical, technological, and firm fixed effect controls.

In columns (1) and (2) in table 3, we use number references to non patent literature as the dependent variable. Since this variable is a non-negative count, we estimate equation (1) by a negative binomial regression. Since our dependent variable is over-dispersed (mean=2.43, variance=6), the negative binomial model would be more proper than a Poisson model for our regression. The post-estimation results also report a significant dispersion factor, supporting our choice in using a negative binomial model. After excluding the missing values, we perform our test on 404 employee-project observations.

[Insert Table 3 here]

Also, as a alternative proxy, we use the inventive step of output as our dependent variable in columns (3) and (4). Since inventive step is reported in levels, we posit an ordered logit estimation of equation (1) and report the estimates in columns (3) and (4). For this measure, we perform our test on 2,120 employee-project observations.

The key variables of interest in table 3 are the measures of autonomy and fit. As shown in column (1), autonomy positively impacts the number of references to non-patent literature associated to the output. This implies that in projects where autonomy is higher, the output is typically closer to the knowledge boundaries and has higher scientific value. Also in column (3), AUTONOMY enters the regression with a positive and very significant coefficient. We interpret this as the positive effect of autonomy on the output's innovativeness which is another element of scientific value for patents. All in all, the results in columns (1) and (3) in table-3 support H1, implying that delegation increases the scientific value of innovative output. This in inline with the arguments of both mechanisms of control and effort.

To compare the moderating effect of FIT with its effect on the commercial value, we also include an interaction term between AUTONOMY and FIT and estimate the equation below:

$$Scientific\ value_{i} = \beta_0 + \beta_1 AUTONOMY_i + \beta_2 FIT_i + \beta_3 AUTONOMY*FIT + \mathbf{X}'_{i}\boldsymbol{\gamma} + \varepsilon_{i} \tag{2}$$

The results of the estimation for equation (2) are reported in columns (2) and (4). We will discuss these results together with the results in table 4, when testing for H3.

To test our arguments in the theory section on the commercial aspect, this time we estimate the determinants of commercial value of the projects as equation below:

$$Commercial\ value_{i} = \beta_0 + \beta_1 AUTONOMY_i + \mathbf{X}'_{i}\boldsymbol{\gamma} + \varepsilon_{i} \tag{3}$$

Equation (3) is similar to equation (1), with the difference of having commercial value as the dependent variable. Since our measure of commercial value is reported in levels, we estimate equation (3) with an ordered logit model and report the results in table 4. The coefficients in table 4 can be reported as logs of odd ratios.

[Insert table 4 here]

In the column(1), we estimate equation (2) without including the FIT variable. In this specification, AUTONOMY while having a negative coefficient, does not exert a significant impact. Also when we include the variable FIT in column (2), still both AUTONOMY and FIT show insignificance in impacting the commercial value. However, the distinction in the impact of autonomy on the scientific versus commercial value is still intuitive for our theory. The insignificance of autonomy in columns (1) and (2) of table 4 might be due to coexistence of two mechanism moving in the opposite directions and canceling-out each other; where as these two mechanisms are aligned in the case of scientific value. Nevertheless, we cannot confirm any of the competing hypotheses H2a and H2b based on the results in columns (1) and (2).

To test for hypothesis 3, we include the interaction term and regress the specification in equation (4).

$$\textit{Commercial value}_i = \beta_0 + \beta_1 AUTONOMY_i + \beta_2 FIT_i + \beta_3 AUTONOMY{*}FIT + \mathbf{X}'_i\gamma + \varepsilon_i \qquad (4)$$

As seen from column (3) of table 4, when having the interaction term included, both direct effects and the interaction of autonomy and fit gain significance. As H3 predicts, EP fit positively moderates the effect of autonomy on commercial value. This implies that the commercial value of the project is lower in cases where autonomy is delegated to a poor EP fits case. Also, autonomy in this specification enters with a negative and significant impact on the commercial value- which is in support of the control mechanism explanation; but when

EP fit improves, delegating autonomy results in higher efficiency and wipes off this negative impact. Therefore, the results in column (3) confirm H3.

As said above, the main effect of autonomy only becomes significant when we include the interaction. This may have occurred since our moderator variable (FIT) produces a large differences in the slope of AUTONOMY around zero. In other words, the sign and slope of AUTONOMY changes a lot at different levels of the moderating variable (i.e. FIT). Therefore, when the interaction term is absent, the coefficient of autonomy shows the average impact, which is close to zero and insignificant; when the interaction term is included, it can disentangle the effects based on the levels of moderating variable and make the direct effects significant. We interpret this as an evidence for existence of two opposite forces through delegation on the commercial value of output.

Also notice that as explained in the theory section, EP fit is a relevant moderator for commercial value, since it is defined for the congruence of employee with company defined project. For the scientific value, employee departs from the company-defined project. Therefore, this notion becomes less meaningful. Accordingly, we do not expect to see the moderating effect for the case of scientific value of output. We check this in columns (2) and (4) of table 3. For both proxies of scientific value of output, the interaction term between AUTONOMY and FIT is insignificant confirming our arguments. Also when the interaction term being included, the direct effects also lose significant which could be due to multicollinearity.

Conclusion and Future Direction

The purpose of this study is to theoretically and empirically examine the questions of how does delegation of autonomy impact the innovative output? We believe that due to special characteristics of innovative tasks, the question should be addressed at the project-level. Our work develops new theoretical framework and presents empirical evidence to address this question and improve our understanding about the effects of autonomy delegation in knowledge intensive activities.

Based on our finding, delegating more in a project to a knowledge worker typically increases the scientific value of the project's output through better effort and shifting the project direction towards a more scientific direction. The result on commercial direction is mixed and sometime negative but this impact is better when it is delegated to employees who fit the project better.

Our findings have important implications for micro-organization of innovation, contingent on the project and employee-related factors. Besides managerial implications, our results highlights the role of micro-foundations in understanding the value of innovaative output and bridges between the literatures of strategic human capital and innovation.

As the next step, we are planning to address the issue of counterfactuals to enrich our analysis. To support our theory we are interested to study cases such as the output of a the same project/ employee with different delegation levels. To make this analysis, we have been carefully designing a *survey experiment* for the inventors in our sample. In the survey experiment we design relevant hypothetical scenarios of an inventive project and each time, manipulate one of the key factors relevant for our theory (e.g. high/low level of autonomy, fit, etc.). By sending the scenarios to inventors, we plan to collect their responses about their attitudes (e.g. motivation) and behaviors (e.g. their effort, choice of project direction and etc.) when they face different situations in a hypothetical situation. The survey experiment is currently at the pilot stage and we believe that matching its final results with our analysis will add to the quality and contribution of our study.

References

Aghion, P. & Tirole, J. 1997. Formal and real authority in organizations. *Journal of Political Economy*, 1-29.

Amabile, T. 1996. *Creativity in Context*. Westview Press, Boulder, CO.

Argyres, N. S., & Silverman, B. S. 2004. R&D, organization structure, and the development of corporate technological knowledge. *Strategic Management Journal*, *25*(8-9), 929-958.

Arora, A., Belenzon, S., & Rios, L. A. 2014. Make, buy, organize: The interplay between research, external knowledge, and firm structure. *Strategic Management Journal*, *35*(3), 317-337.

Arora, A., Fosfuri, A., & Gambardella, A. 2001. *Markets for technology: The economics of innovation and corporate strategy*. MIT press.

Bailyn, L. 1985. Autonomy in the industrial R&D lab. *Human Resource Management*. 24: 129-146.

Benz, M., & Frey, B.S., 2008a. Being independent is a great thing: subjective evaluations of self-employment and hierarchy. *Economica*, 75: 362–383.

Benz, M. & Frey, B.S., 2008b. The value of doing what you like: Evidence from the self-employed in 23 countries. *Journal of Economic Behavior & Organization*, 68(3): 445-455.

Cassiman, B., Di Guardo C. & Valentini, G. 2010. Organizing links with science: Cooperate or contract? A project-level analysis. *Research Policy*, 39: 882-892.

Castanias, R.P. & Helfat, C.E. 1991. Managerial resources and rents. *Journal of Management*, 17: 155-171.

Castanias, R.P. & Helfat, C.E. 2001. The managerial rents model: Theory and empirical analysis. *Journal of Management*, 27: 661-678.kk

Chen, T., Chang, P. & Yeh, C.A. 2004. Study of career needs, career development programs, job satisfaction and the turnover intentions of R&D personnel. *Career Development International*, *9*, 424–37

Christie, A.A., Joye, M.P. & Watts, R.L., 2003. Decentralization of the firm: theory and evidence. *Journal of Corporate Finance*, 9(1), pages 3-36

Cockburn, I. M., & Henderson, R. M. 1998. Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. *The Journal of Industrial Economics*, *46*(2), 157-182.

Cohen, W. M. & Sauermann, H. 2007. Schumpeter's prophecy and individual incentives as a driver of innovation. F. Malerba, S. Brusoni, eds. *Perspectives on Innovation*. Cambridge University Press, Cambridge, UK, 73–104.

Ederer, F. & Manso, G., 2013. Is Pay for Performance Detrimental to Innovation? *Management Science*, *59*(7), 1496-1513.

Frey, B. & Stutzer A., 2004. Introducing procedural utility: Not only what, but also how matters. *Journal of Institutional Theoretical Economy*. 160(3) 377–401

Gagne, M. & Deci, E.L., 2005. Self-determination theory and work motivation. *Journal of Organizational Behavior* 26(4): 331-362.

Gambardella, A., Giuri, P., Harhoff, D., Hoisl, K., Mariani, M. & Torrisi, S. 2014. Inventive Process and Economic Use of EPO Patents: Summary Evidence from the PatVal Surveys, *Working Paper*

Gambardella, A., Giuri, P., & Luzzi, A. 2007. The market for patents in Europe. *Research Policy*, *36*(8), 1163-1183.

Gambardella, A., Panico, C., & Valentini, G. 2015. Strategic incentives to human capital. *Strategic Management Journal*, 36(1): 37-52.

Giuri, P., Brusoni, S., Crespi, G., Francoz, D., Gambardella, A., Garcia-Fontes, W., Geuna, A., Gonzales, R., Harhoff, D., Hoisl, K., Lebas, C., Luzzi, A., Magazzini, L., Mariani, M., Nesta, L., Nomaler, O., Palomeras, N., Patel, P., Romanelli, M., & Verspagen, B. 2007. Inventors and invention processes in Europe. Results from the PatVal-EU survey. *Research Policy*, 36(8): 1107-1127.

Gittelman, M., & Kogut, B. 2003. Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns. *Management Science*, *49*(4), 366-382.

Grant, R. 1996. Toward a knowledge-based theory of the firm. *Strategic Management Journal*, 17: 109–122

Hackman J.R., & Oldham G.R. 1976. Motivation through the design of work: Test of a theory. *Organizational Behavior and Human Performance*, 16(2), 250-279.

Hackman, J.R., & Oldham, G.R. 1980. *Work redesign*. Reading, MA: Addison-Wesley.

Harhoff, D., Scherer, F. M., & Vopel, K. 2003. Citations, family size, opposition and the value of patent rights. *Research Policy*, *32*(8), 1343-1363.

Holland, J.L. 1985. *Making vocational choices***.** *Englewood Cliffs*, NJ7 Prentice Hall.

Horngren, C.T., Datar, S.K., Foster, G., Rajan, M. & Ittner, C. 2013. *Cost Accounting: A Managerial Perspective*. (Upper Saddle River, NJ: Prentice Hall)

Igbaria, M., Greenhaus, J.H. & Parasuraman, S. 1991. Career orientations of MIS employees: An empirical analysis. *MIS Quarterly*, *15*, 151–69

Jensen M. C & Meckling W.H. 1976. Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4), 305-360.

Jensen, M.C. & Meckling W.H. 1992. Specific and general knowledge and organizational structure. *Knowledge Management & Organizational Design*, 17-18.

Katz, R. 2004. Motivating professionals in organizations. R. Katz, ed. *The Human Side of Managing Technological Innovation*. Oxford University Press, New York, 3–20

Khashabi, P., Gambardella, A. & Panico, C. 2014. Autonomy in Knowledge-intensive Activities; Efficiency or Incentives. *Working paper*.

Kristof, A.L. 1996. Person-organization fit: An integrative review of its conceptualizations, measurement, and implications. *Personnel Psychology*, 49, 1-49

Meyer, M., 1999. Does science push technology? Patents citing scientific literature. *Research Policy* 29 (3) 409– 434.

Nguyen, A. N., Taylor, J., & Bradley, S. 2003. *Job autonomy and job satisfaction: New evidence.* Lancaster University Management School Working Paper

Roach, M., & Sauermann, H. 2010. A taste for science? PhD scientists' academic orientation and self-selection into research careers in industry. *Research Policy*, 39(3), 422-434.

Ryan, R. M. & Deci, E. L. 2000. Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, 25(1) 54–67

Sauermann, H. & Cohen, W.M. 2010. What makes them tick? Employee motives and firm innovation. *Management Science*, 52(3): 223

Sauermann, H., & Stephan, P. 2013. Conflicting logics? A multidimensional view of industrial and academic science. *Organization Science*, *24*(3), 889-909.

Shalley, C.E., Zhou, J. & Oldham, G.R. 2004. The effects of personal and contextual characteristics on creativity: Where should we go from here?. *Journal of management*, 30(6), 933-958.

Shimizu, K. 2012. Risks of corporate entrepreneurship: Autonomy and agency issues. *Organization Science*, *23*(1), 194-206.

Smith, J. & Hounshell, D. 1985. Wallace Carothers and fundamental research at DuPont. *Science*, 229: 436-442.

Sousa-Poza, A. & Sousa-Poza, A. A. 2000. Well-being at work: a cross-national analysis of the levels and determinants of job satisfaction**.** *Journal of Socio-economics*, 29(6), 517-538.

Stern, S. 2004. Do scientists pay to be scientists?. *Management Science*,*50*(6), 835-853.

Vallas, S. P. & Kleinman, D. L. 2008. Contradiction, convergence and the knowledge economy: The confluence of academic and commercial biotechnology. *Socio-Economic Review*, *6*(2), 283-311.

Werbel, J.D. & DeMarie, S.M. 2005. Aligning strategic human resource management and person–environment fit. *Human Resource Management Review*, *15*(4), 247-262.

Youndt, M.A., Snell, S.A., Dean, Jr. J.W., & Lepak, D.P. 1996. Human resource management, manufacturing strategy, and firm performance. *Academy of Management Journal*: 836-866.

Figure 1 Monetary rewards versus intellectual challenge as the main motivation for invention (data source: PatVAl-2)

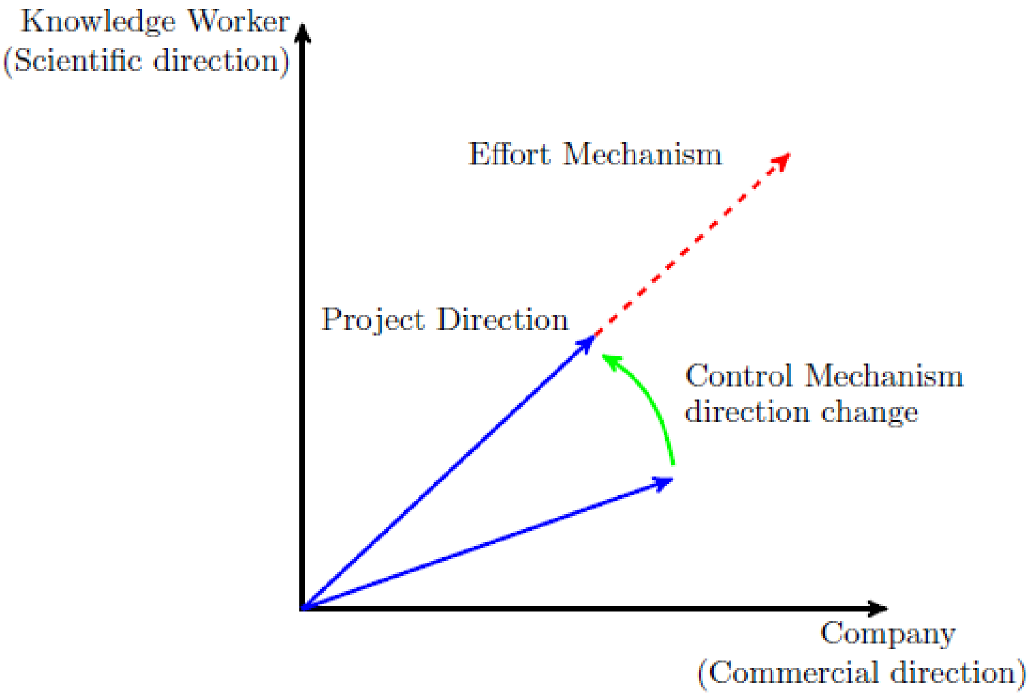

Figure 2 Innovative project and the effort and control mechanisms of autonomy

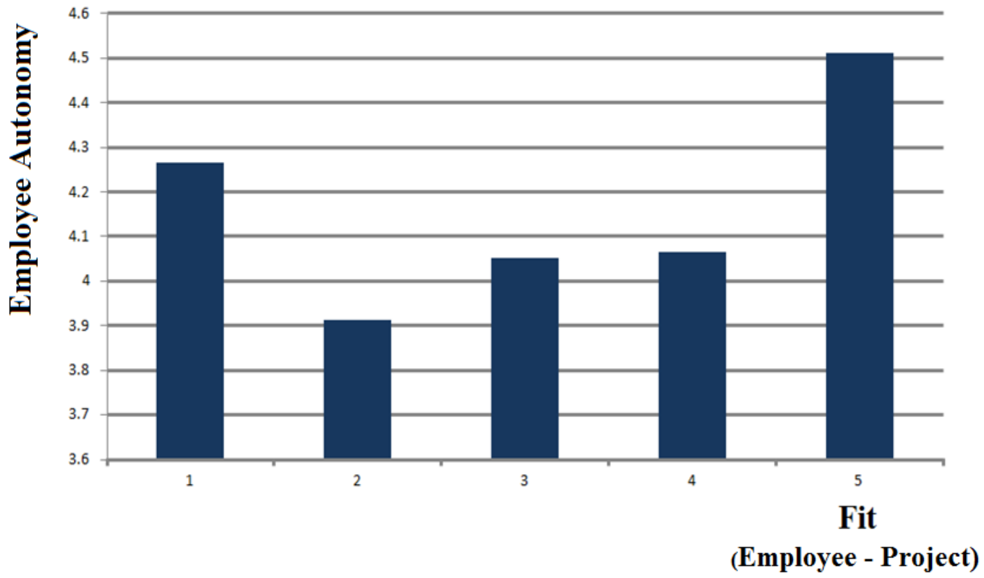

Figure 3 Mean of autonomy levels for the categories of employee-project fit in innovative projects (data source: PatVAl-2)

Table 1 Variable Definition

Variable		Definition
Commercial Value		0 for non commercialized patented inventions, 1 for inventions still in the process of commercialization, and 2 for commercialized patent inventions.
Scientific Value	NPL Refs	Number of references to non-patent literature (scientific publications)
	Inventive step	respondent's score (b/w 1-5) regarding the question on the patent's inventive step (EPC definition) in the European Patent Office application.
Autonomy	*autonomy in the selection of tasks* (AUT1)	respondent's score regarding the question on her autonomy level in *selection of tasks* (b/w 1-6)
	autonomy in time allocation among tasks (AUT2)	respondent's score regarding the question on her autonomy level in *allocation of working time among different tasks or projects* (b/w 1-6)
	autonomy in determining working time (AUT3)	respondent's score regarding the question on her autonomy level in *Flexibility of working hours* (b/w 1-6)
	broad autonomy measure (AUTONOMY)	Sum of the variables: AUT1, AUT2 & AUT3 (b/w 3-18)

Project-Employee fit (FIT)	respondent's agreement score (b/w 1-5) to the statement: "*... the combination of your previous experience with the knowledge of your new employer was instrumental in enhancing the inventive activity at the new organization.*"
GENDER	Dummy = 1 if the individual is female.
AGE	Age of the individual.
Employee's education (EDU)	Educational degree of the individual: 1= Secondary School or lower; 2= High School Diploma or equivalent; 3= Bachelor or equivalent; 4= Master or equivalent; 5= PhD or equivalent; 6= Post-doctoral degree.
Employee's gross annual income (INCOME)	Individual's approximate annual gross income in the year of the patent application: 1= Below 10,000 Euro; 2= 10,000-29,999 Euro; 3= 30,000-49,999 Euro; 4= 50,000-69,999 Euro; 5= 70,000-99,999 Euro; 6= 100,000 and more Euro
Firm size (SIZE)	Size of the employer firm: 1= 1-9 employees; 2= 10-19 employees; 3= 20-49 employees; 4= 50-99 employees; 5= 100-249 employees; 6= 250-499 employees; 7= 500-999 employees; 8= 1000-4999 employees; 9= 5000 and more employees.
Project man-month (PROJ_SIZE)	Individual's response to the question: "*How many man-months did the invention process require in total?*" 1= No research needed; 2= less than 1 man-month; 3=1-3 man-months; 4= 4-6 man-months; 5=7-12 man-months; 6=13-24 man-months; 7=25-48 man-months; 8=49-72 man-months; 9=more than 72 man-months
RANK	Individual's rank in the firm's hierarchy, based on the number of people reported to the individual at the time of invention: zero= 0 people; 1= 1-5 people; 2= 6-20; 3= 21 people and more.
Commercial Company	=1 if the respondent was working at a *private firm* at the time of invention.
Technological Class	ISI-INPI-OST Technology Classes

Project Resources (Equipment)	respondent's agreement score (b/w 1-5) to the statement: " *The organization had all the right instruments and technical equipment for this invention*"
Project Resources (Technical)	respondent's agreement score (b/w 1-5) to the statement: *"The organization had all the complementary resources to make the invention a technical success"*
Project Resources (Budget)	respondent's agreement score (b/w 1-5) to the statement: " *I was satisfied with the available budget for this invention*"
Project Resources (Commercial)	respondent's agreement score (b/w 1-5) to the statement:*"The organization had all the resources to turn the invention into something economically valuable"*

Table 2 Descriptive statistics and correlation matrix for the sample of analysis

	Variables	Mean	Std Dev.	Min	Max	1	2	3	4	5	6
1	**NPL Refs**	2.43	2.45	1	59	**1**					
2	**Inventive step**	3.31	0.9	1	5	0.11	**1**				
3	**COMM. Value**	1.34	0.81	0	2	-0.10	0.01	**1**			
4	**AUTONOMY**	13.47	3.28	3	18	0.13	0.14	0.01	**1**		
5	**FIT**	3.83	1.24	1	5	0.16	0.09	0.03	0.01	**1**	
6	**GENDER**	0.04	0.2	0	1	0.14	0.01	-0.10	-0.05	0.01	**1**
7	**AGE**	49.95	10.24	5	91	0.07	0.18	0.08	0.04	0.10	-0.16
8	**EDU**	3.59	1.16	1	7	0.10	0.16	-0.13	0.11	0.11	-0.09
9	**INCOME**	4.03	1.19	1	6	0.04	0.08	0.08	0.15	0.08	-0.17
10	**RANK**	0.88	0.9	0	3	0.07	0.02	0.08	0.09	0.09	-0.12
11	**SIZE**	7.01	2.56	1	10	-0.08	-0.08	-0.10	-0.23	-0.13	0.00
12	**PROJ_SIZE**	4.29	2.01	1	9	0.12	0.06	0.02	0.08	0.02	0.05
13	**Proj. Res. (Equipment)**	3.87	1.2	1	5	-0.01	-0.02	-0.03	0.06	0.00	0.06
14	**Proj. Res. (Technical)**	3.64	1.2	1	5	0.01	0.01	0.01	0.05	0.03	0.03
15	**Proj. Res. (Budget)**	3.68	1.21	1	5	-0.03	-0.02	0.04	-0.03	0.03	0.02
16	**Proj. Res. (Commercial)**	3.64	1.25	1	5	-0.08	0.00	0.14	-0.04	0.02	-0.04

	Variable	7	8	9	10	11	12	13	14	15
8	**EDU**	0.12	**1**							
9	**INCOME**	0.31	0.23	**1**						
10	**RANK**	0.16	0.12	0.28	**1**					
11	**SIZE**	-0.18	-0.04	0.01	-0.13	**1**				
12	**PROJ_SIZE**	-0.07	0.00	-0.12	0.11	-0.1	**1**			
13	**Proj. Res. (Equipment)**	-0.06	0.08	0.05	0.03	0.22	0.05	**1**		
14	**Proj. Res. (Technical)**	-0.01	0.01	0.14	0.02	0.18	0.11	0.65	**1**	
15	**Proj. Res. (Budget)**	-0.03	-0.01	0.04	-0.03	0.30	0.03	0.62	0.65	**1**
16	**Proj. Res. (Commercial)**	-0.04	-0.04	0.02	-0.03	0.25	0.04	0.44	0.48	0.60

Table 3 Estimations of determinants of scientific value of output

Dep var:	Negative Binomial		Ordered Logit	
Scientific Value	***NPL Refs***	***NPL Refs***	***Inventive Step***	***Inventive Step***
	(1)	(2)	(3)	(4)
GENDER	0.012	0.014	-0.086	-0.087
	(0.140)	(0.140)	(0.197)	(0.197)
AGE	-0.005	-0.005	0.028***	0.028***
	(0.005)	(0.005)	(0.005)	(0.005)
EDU	0.048	0.048	0.105**	0.105**
	(0.049)	(0.049)	(0.042)	(0.042)
INCOME	0.018	0.019	-0.008	-0.008
	(0.038)	(0.038)	(0.046)	(0.046)
RANK	0.030	0.029	-0.103**	-0.102**
	(0.045)	(0.045)	(0.050)	(0.050)
SIZE	-0.016	-0.016	-0.065***	-0.066***
	(0.015)	(0.016)	(0.017)	(0.017)
PROJ_SIZE	0.010	0.010	0.122***	0.122***
	(0.022)	(0.022)	(0.023)	(0.023)
Project Resources				
EQUIPMENT	-0.013	0.022	-0.024	-0.024
	(0.031)	(0.038)	(0.052)	(0.052)
TECHNICAL	-0.045*	-0.015	-0.063	-0.062
	(0.024)	(0.036)	(0.050)	(0.050)
BUDGET	0.066*	0.013	-0.065	-0.066
	(0.037)	(0.046)	(0.054)	(0.054)
COMMERCIAL	-0.037	-0.042	0.061	0.061
	(0.028)	(0.042)	(0.046)	(0.046)
AUTONOMY	0.031**	0.046	0.048***	0.070
	(0.014)	(0.036)	(0.015)	(0.048)
FIT	0.077**	0.131	0.082**	0.161
	(0.033)	(0.139)	(0.038)	(0.169)
AUTONOMY*FIT	--	-0.003	--	-0.006
		(0.008)		(0.011)
Technological class	YES	YES	YES	YES
Firm fixed effects	YES	YES	YES	YES
Observations	404	404	2,120	2,120
log likelihood	-750.038	-749.984	-2649.493	-2649.352
chi-square	160.274	164.161	186.834	186.813

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 4 Ordered logit estimations of determinants of Commercial value of output

Ordered Logit Estimations	***Commercial Value* (1)**	***Commercial Value* (2)**	***Commercial Value* (3)**
GENDER	-0.545***	-0.593***	-0.585***
	(0.118)	(0.215)	(0.215)
AGE	-0.003	0.008	0.009*
	(0.003)	(0.005)	(0.005)
EDU	-0.202***	-0.225***	-0.224***
	(0.022)	(0.044)	(0.044)
INCOME	-0.015	-0.045	-0.048
	(0.024)	(0.044)	(0.044)
RANK	0.126***	0.162***	0.166***
	(0.028)	(0.053)	(0.053)
SIZE	-0.099***	-0.086***	-0.085***
	(0.010)	(0.018)	(0.018)
PROJ_SIZE	0.107***	0.124***	0.122***
	(0.012)	(0.024)	(0.024)
Project Resources:			
EQUIPMENT	-0.119***	-0.090*	-0.089*
	(0.026)	(0.048)	(0.048)
TECHNICAL	-0.017	-0.032	-0.036
	(0.025)	(0.047)	(0.048)
BUDGET	-0.009	-0.034	-0.032
	(0.030)	(0.055)	(0.055)
COMMERCIAL	0.460***	0.502***	0.507***
	(0.025)	(0.046)	(0.046)
AUTONOMY	-0.007	-0.007	-0.103**
	(0.008)	(0.015)	(0.045)
FIT		0.035	-0.316**
		(0.036)	(0.161)
AUTONOMY*FIT			0.025**
			(0.011)
Technological class	YES	YES	YES
Firm fixed effects	YES	YES	YES
Observations	7,770	2,205	2,205
log likelihood	-7236.164	-1990.975	-1988.409
chi-square	925.416	323.835	328.968

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Chapter 3

Inefficiencies in Essential Patent Pool Formation: Are Pool Administrators also involved?

Abstract

Technology standards are becoming increasingly important in economic extent. Facilitating and building patent pools for technology standards is a crucial part for their success, which is done by *pool administrators*. Practitioners believe that political economy of pool formation has lead to inefficiencies such as failures in launching new pools and inclusion of non-essential patents (pool inflation). However, the potential role of expert pool administering party on the efficiencies has not been studied yet. This paper develops a simple model of pool formation which determines the optimal strategies of a rent seeking "pool administrator". The results show that pool forming strategies by the pool administrator may contribute to failures in patent pool formation process. Also, in the environments where the essentiality claims are difficult to assess or in industries with higher pace of technology, the pool administrator may find it optimal to include the patents in the pool regardless of the essentially evaluation (pool inflation) and launch the patent pool faster.

Introduction

In the last decade, technology standards have grown rapidly in policy importance and economics impact. The growth is aggressive in industries where the pace of technology is fast and there is higher demand for building a common platform and guarantee interoperability among the new products.[8] In industries such as telecommunication, IT, computing and etc., technology standards have played a crucial role in successfully presenting new products to the market (Shapiro, 2001). The market size associated with technology standards is huge and vastly growing. Estimates in 2004 report the US sales of devices based on technology standards to be at least $100 billion annually (Clarkson, 2004). These altogether illustrate technology standards an important and attractive topic to study.

Since nearly all the advanced technologies are patented, building standards involves complex interactions with IP holders. Therefore, parties seeking to commercialize products based on the standard would need to acquire license from relevant patentees. Considering the huge- and growing- number of *essential patents*[9] in hi-tech industries, obtaining licenses independently can act as a big obstacle in commercializing new products.

Patent pools have emerged as a solution to reduce the costs of navigating through the *patent thicket*. Pooling patents refers to a joint licensing program in which patent holders decide to transfer their IP rights to a third party in order to bundle the rights and license them as a package. By bundling the IP rights and creating the opportunity of one-stop shopping, patent pools have alleviated the problem of multiple marginalization and reduced the royalty rates (Gallini, 2010). These organizational forms are considered among successful solutions for the inefficiencies involved with markets for technologies.

Almost all modern pools have been built around the standardization purposes (Layne-Farrar & Lerner, 2011). However, these pools have not been formed by the IP holders themselves. Due to the complexities involved with identifying the essential patents, gathering the IP

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[8] As most famous examples of technology standards, one can think of *DVD, USB, MPEG, 4G* and etc.

[9] From the legal perspective, an essential patent for a particular standard is a patent which the standard adopters should either "*license or infringe it*". Therefore, acquiring the license is "essential' to use the standard.

holders, marketing the standard and licensing procedures, all the recent standards have been formed by professional patent *pool administrators*. Patent pool administrators are third-party agents that facilitate pool formation and oversee its operations. They are expected to smooth the pool formation procedure and the standard adoption, by reducing the negotiation and waiting cost for the IP holders and the search and licensing cost for the licensees.

Nevertheless, some stakeholders believe the pool formation process is "becoming increasingly politicized" and "less capable of producing timely standards" (Simcoe, 2012; see also Lamely, 2007). Discussions on some recent failed pool formation attempts have made this standpoint a hot topic among practitioners. Besides pool formation failures, some licensees have also accused the patent pools to include patents which are not essential in reality (Baron & Delcamp, 2011).[10] This is in line with the recent observed trend in dramatic increase of the pool sizes, a phenomenon which is known as *pool inflation.* As an example, "*MPEG-4 Visual part 2"* patent pool started in 2004 with 77 patents but it currently includes 1225 patents claimed to be essential.

A common premise links all these inefficiencies to the patent holder sides, which try to lobby and increase their patents' share inside the pool to increase their royalty rate. This causes pool inflations when the pool formation is successful and pool failures when the conflicts cannot be resolved. In this article, I try to study the potential role of pool administrators in the inefficiencies involved with pool formation process, which is -to the best of my knowledge-absent in the related literature. I believe that this is an important issue given the market power which pool administrators have gained. Although there are more number of pool facilitating

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[10] Baron & Delcamp (2011) report this as a patent misuse defense in many patent infringement cases, e.g. the defense by disc replicator ODS in its litigation MPEGLA over the MPEG2 patent pool.

and administering companies emerging, however most renowned pool standards are formed by few prominent companies.[11] Therefore, it reasonable to assume that given their central role, their strategies may contribute to these inefficiencies.

To study the potential role of pool administrators, I develop a simple model of pool formation where there is information asymmetry between the pool administrator and patent holders on the essentiality of the patents for the standard. By determining the optimal strategies of the pool administrator, I try to show how the environmental conditions, may affect the pool formation strategies of the pool administrator. In particular, I focus on the conditions where the pool forming strategies may cause inefficiencies in the standardization process. The results show that pool forming strategies by the pool administrator may contribute to failures in standard setting process. Also, the pool administrator may find it optimal to announce more patents as essential and act lax in evaluating the patents in the industries where the pace of technology is faster or in the environments where essentiality assessments are less accurate. The results can be interesting from policy point of view; they suggest that the role of pool administration could have been underestimated in the technology adoption process. Thus, employing proper regulations on the administrating party may result in a more efficient technology selection/adoption both for patent holders and licensees.

The rest of this paper is organized as follows: in the next section, I briefly discuss the pool forming process for technology standards. Third section describes related literature. The fourth section presents a model of pool formation, where the results of the model are discussed in section five. Section six concludes.

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[11] The major pool administering companies are considered MPEG LA, Via Licensing Corporation, SISVEL, the Open Patent Alliance, 3G Licensing and ULDAGE.

How Essential Patent Pools are Created?

The start of standard setting efforts is initiated in standard developing organizations (SDOs) where the basic dimensions of a technical standard are being discussed, developed and announced to address the needs of potential technology adopters. Generally, SDOs will consider multiple (substitute) technologies that may fulfill the objectives of the standard and settle on a choice. The final decision of the SDO will be announced as the definition of the new technology standard. Afterwards, a professional pool facilitator/ administrator will be in charge of detecting and packaging the essential patents for implementing the standard. Usually the pool administrator announces a call for essential patents and those patent holders claiming to posses essential patents approach the specialized pool administrator. Since having essential patents in the standard's patent pool will generally generate rents for the patent holder, firms -as expected- over-claim their patents' essentiality. The pool admin will be responsible to run the essentiality evaluation procedure and then, facilitate the negotiations among the essential patent holders. Members in the committees will discuss and set other arrangements of the pool including royalty rate, revenue sharing rule, licensing policies and etc. After launching the standard, pool administrator will be in charge to market the packaged patents, detect the potential licensees, collect the licensing fees and distribute it among the members. In reality, however, things may be much more complicated.

Assessing the patent essentiality may be very complicated. With the "legal" definition, an essential patent for a particular standard is a patent that will be necessarily infringed by the implementation of the standard (so the patent is either being licensed or infringed by the users of the standard). However, the concept of essentiality can also be dependent on other factors such as the rules of the institutions developing the standard. For example, some standard pools consider a "commercial essentiality" definition. A commercially essential patent may not be necessarily essential for the standard from legal perspective, but is crucial for successful commercialization of the standard.[12] In most cases the essentiality is assessed by an evaluator appointed by the pool admin. This evaluator -based on the criteria defined by the pool- will announce whether a patent is essential to the standard and may be included to the corresponding pool, or not.

In practice, regardless of which essentiality definition being adopted, evaluating the patent essentiality can be very difficult. First of all, essentiality in reality is not a zero/one concept and may be considered as a range (Carlson, 1999). Also, in practice, when an essentially claimed patentee litigates an infringement case, courts' decisions on the patent essentiality may be dependent on various considerations. Legal environmental factors such as the rules of the standard setting organization and antitrust considerations may affect the courts' decision (Allekotte & Blumenröde, 2010).

In some countries with stricter IP protection, to prove an infringement over an essential patent, the IP holders only need to demonstrate that a certain commercialized device is "in compliance with a given standard" and, further, that their patent covers an essential feature of that standard. The advantage of this approach for the owners of essential patents is that they are not required to show how technically a device is infringing their patent-which can be very difficult for complex hi-tech applications.

The [accused] infringer may raise antitrust defense claiming that patentee is misusing its market-dominant position. If a patentee refuses to grant its patents -to licensees or to a pool-

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[12] Patents related to fast forward function in DVD standard are examples for commercially essential patents. This function was not a part of DVD standard, but no manufacturer could make a DVD player without fast forward function. So, the relevant patents were added as commercially essential.

the accused infringer may argue that the patent was needed to enter the market and the patentee has prevented the competition.

The courts' decision on these arguments may very well depend on the antitrust regulations of the environment. Besides these, as any ordinary litigation case, the strength of the IPR regime can also affect the essentiality in practice. So, in the real process, the patent evaluators consider these factors when deciding if a patent should be included in a pool or not.

Another issue adding to the complexity is strategic actions of the players in the pool formation. Some studies have shown that the founding members of a pool manage to include their patents easier than new comers (e.g. Baron & Delcamp, 2011, Layne-Farrar & Lerner, 2011). Also, in some cases, licensees have accused pools to have "overly lax" evaluation procedure and include patents that are not truly essentially (Baron & Delcamp, 2011).

As the final issue, the pool administrators may enjoy a market power. When a pool administrator has managed a first version of the pool for a standard (i.e. has formed he pool and licensing program), it is more likely that the next version of the standard, or other standards in the similar field be also given to the same pool administrator. This may be due to the knowledge and proficiency that these firms gain in dealing with network of patent holders, important licensee's and other industry level factors in that field.

What seems obvious from the above is the complex nature of the essential patent pool formation. However, there has been interesting studies trying to improve our understanding from this complex process which I discuss in the next section.

Literature Review

The literature on patent pools and technology standards had not attracted much attention from economists until recently. However, after the rise of technical standards as a crucial element in high-tech industries, patent pools- as the basis for standard setting process- have emerged as an important topic for economic analysis (Chaio et. al., 2007: Layne-Farrar and Lerner, 2011).

Literature has already discussed the role of patent pools on consumers and licensees, mostly highlighting the effect of pools on reducing the overall royalty rates (Gallini, 2010: Gilbert & Katz, 2006). These studies underline the role of patent pools in reducing the problem of marginalization by bundling the IP rights and creating the opportunity of one-stop shopping for the potential licensees.

On the interaction of the standards and firms, the literature has mostly attacked the subject from the patentee's point of view. There are various patentee-side issues already studied by the scholars, among them are patentees' joining rule (outsider's dilemma), firms' choice of SSO, patenting behavior and disclosure policies.

Aoki and Nagaoka (2004), model pool participation and show that manufacturing firms can be better off by opting to stay out of the pool. Layne-Farrar and Lerner (2011) study the determinants of joining rule for standards' patent pools and empirically confirm the results of Aoki and Nagaoka (2004).

The impact of standards on the patenting behavior of firms is also a well established topic in the literature. Baron and Pohlmann (2010) report that the existence of a patent pool increases the patenting activity even after the pool's formation. Also the characteristics of the declared patents are different for the insider firms comparing the new entrants (Baron and Declamp, 2011). Bekkers et al. (2011) show that firms with higher voting weight and involvement in a SDO, are also more likely to declare essential patents.

Lerner and Tirole (2006) model the choice of patent holders among SSOs which suit them the most. Their work is supported empirically by Chaio et al. (2007) which links SDO's orientation towards technology with their disclosure policies and test it based on a data of SDOs.

Another patentee side issue addressed by the literature is patents' value when they are associated with patent pools and standards (endorsement effect). Studies show that market value of patents which are included in the standard's pool is higher comparing their similar twins outside the pool (Declamp, 2010; Rysman and Simcoe, 2008)

Inefficiencies of standard setting process are also a small part of the patentee side analysis in the literature. However, most relevant studies focus on the role of patentee-side factors as the cause of inefficiency in this procedure. Köhler et al. (2011) find evidence of strategic patent filing delays for essential patents. The study shows that when a standard is in its drafting phase, [potentially] essential patents are pending significantly longer than similar patents in the control group. Authors interpret this as a time buying strategy to achieve maximum conformity with standards' specifications. Baron and Pohlmann (2010) suggest that existence of informal consortia prior to standard formation can reduce inefficient coordination problems. Simcoe (2012) highlights the concern that SDOs are "increasingly politicized" and " incapable of producing timely standards". By building a model of standard setting, Simcoe (2012) tests the predictions of model using a data on an internet standard setting and finds evidence that the conflicts inside the pool caused by the rapid commercialization of internet, has slowed down standardizations process.

Although the literature has shed light on many aspects of paten pools, the role of pool administrating side seems to be still missing in the literature. This paper adds to the literature by including pool administrating party in the picture and studying its implications on the potential inefficiencies associated with pool formation.

Model

I propose a model of pool formation for a specific standard with asymmetry of information among the pool administrator (hereafter the PA) and the patentees. The information asymmetry is on the level of patents' essentiality for the corresponding standard. In the first stage, the PA can form the pool with lower profit or take the game to the second stage where higher profits are attainable but with uncertainty. I start with determining the agents.

Agents

There are three risk-neutral agents in the game; two patentees and one pool administrator (PA). Each patentee owns a single patent. Patents differ only in their level of *true essentiality* for the corresponding standard. True essentiality level -denoted by e- is a continuous variable indicating the essentiality of the patent for the standard. So, patents with higher values of e are more essential for implementing the standard. True essentiality of patents (e) is assumed to be uniformly distributed between [0,1]. In the beginning of the game, the patents' true essentiality is only known by patent holders.

Since essentiality in practice is a dichotomous concept, I assume that there is a threshold on the true essentiality level which patents above that will be considered *essential* by the courts. I show this threshold by $e^* \in (0,1)$, which is commonly known by the agents from the beginning of the game. Based on this assumption, I define:

Definition 1 *A patent is essential to the standard if it's true essentiality level is equal or greater than* e^*.

In the other words, if a patent with a true essentiality level below this threshold (i.e. $e < e^*$), is not included in the standard's patent pool, standard adopters would not face the risk of litigation by the patent holder simply because the courts will not consider the case as an infringement case.

On this basis, I define the patentee's *types* as below:

Definition 2 *There are two possible types for a patent* $\theta \in \{\underline{\theta}, \overline{\theta}\}$. *The types are defined as:* $\left\{\begin{matrix} \overline{\theta} & if\ e \geq e^* \\ \underline{\theta} & if\ e < e^* \end{matrix}\right\}$. *Type of the patentees are considered the same as the type of patent they hold.*

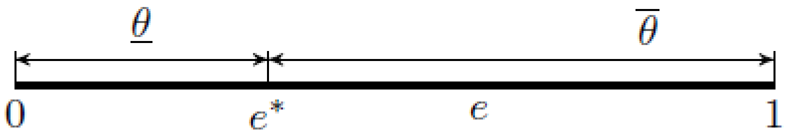

Figure 1 True essentiality levels and the patentee types

The type of patents $\theta \in \{\underline{\theta}, \overline{\theta}\}$ also represents patentees' outside options out of this particular pool forming effort$(0 < \underline{\theta} < \overline{\theta})$. Note that here, the only dimension that the patents differ is their essentiality level for the standard. Therefore, outside this game, *essential* patents may enjoy the opportunity to be included in a pool formed by another pool administrator -besides the non-standard licensing- where the non-essential patents only have non-standard licensing opportunity. This distinction is the cause for the difference in the outside options. The outside option of the pool administrator is set to zero. I also assume that only PA can form the pool.

Patent Pool's Profit

I assume that in case of infringement for an essential patents $(\overline{\theta})$, litigation happens and succeeds with probability one. Therefore, technology adopters will have to license *all* the essential patents in order to be able use the standard. So the pool will be attractive for the technology users if it provides them with the "one-stop shopping" opportunity (i.e. the pool contains all the essential patents).

Definition 3 *A pool formation is successful if it contains all the essential patents* $(\overline{\theta})$ *of the game.*

According to above, for a successful implementation of the standard, no $\overline{\theta}$ type patents should be missing in the standard's patent pool, because then the essential outsider would successfully litigate the standard users.[13] As defined above, PA will have to include all the $\overline{\theta}$ patents of the game in order to form the pool successfully. When there is no $\overline{\theta}$ patents in the

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[13] Essential patents outside the pool have been introduced as a source of failure in implementation of technical standards (Aoki and Nagaoka, 2004). In line with many works in the literature, I only consider complete patent pools in this model.

game (i.e. both patentees are $\underline{\theta}$) PA can form the pool successfully with only one of the non-essential patents, since in this case, there is no $\overline{\theta}$ patents left out of the pool.[14]

The pool's profit is attainable only when the pool formation is successful. I define the pool's profit as follows.

$$\pi^t(\theta^1, \theta^2) = \begin{Bmatrix} \delta^t \pi > 0 & successful\ poor\ formation \\ zero & otherwise \end{Bmatrix} \quad (1)$$

π is a fixed value standing for the maximum amount of achievable profit, δ^t is the discount rate which represents the waiting costs and losses in the patent pool's profit due to delays in implementing the standard. In the first stage (t= 0), there is no waiting cost since zero δ^0 =1, but increases to $\delta \in (0,1)$ in t = 1.

Since the model considers the legal definition of essentiality, in this analysis, I neglect non-essential patents which may cause quality improvements or cost reductions. I assume that when the pool formation is successful, the generated profit is fixed, common knowledge and positive. I also assume that:

$$\delta^t \pi > 2\overline{\theta} \qquad (2)$$

This implies that the PA can always receive positive payoff for building the pool. This assumption guarantees pool creation to be always profitable for the PA, regardless of the type of patentees and stage of the game.

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[14] The intuition to build the pool with one patent in the model is that the PA has already some critical mass of relevant patents (e.g. from the previous generation of the standard) and is searching for the essential patents for the new generation. Therefore, it can build the pool even with one patent adding to the previous stock of patents. The crucial issue would be not to miss any essential patents.

Timing of the Game

In the beginning of t = 0, two patentees enter the pool formation game and approach the pool administrator claiming essentiality. Each patentee holds a single patent with a randomly drawn essentiality level- i.e. $e \in [0,1]$. In the beginning of the game, there is complete information asymmetry on the type (essentiality) of the patents. I denote the true types of the patentees with (θ_1, θ_2) in this model.

The PA has two choices two build the pool. It can either *act lax* in checking the essentiality and include both patentees without paying the waiting cost and going to through the essentiality evaluation (i.e. form the pool in t = 0) or take the process to the essentiality assessment in t = 1. If PA decides to form the pool without evaluating the essentiality, it should offer both patentees at least equal to their (over)claimed outside option $(\overline{\theta}, \overline{\theta})$ to join the pool. If not, the game goes to the essentiality assessment process in t = 1.

If PA chooses to go to essentiality evaluation, it imperfectly learns the types in the beginning of t = 1, and the information asymmetry reduces. In order to build the pool based on this learning, PA offers each patentee a compensation to join the patent pool. I denote PA's offers for the first and second patentee with the notation (θ_1', θ_2').[15]

If the pool formation is successful, PA will take the generated profit paying each patentee with offered payoff. If not, the game ends with each agent receiving their outside option. I assume that the asymmetry totally dies at the end of the game.

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[15] If PA decides to exclude a patentee *i* from the pool, it can just fix the offer at $\theta_i^{'} = 0$

Due to the equation (2), PA is always able to guarantee a successful pool formation by providing both firms with $\theta_i' = \overline{\theta}$. With this strategy, the pool will contain all the essential patents of the game - in case they exist- with certainty. This is implicitly like treating both patents as essential regardless of essentiality evaluation results. However with this offer, a non-essential patentee -if present in the game- will take the information rent, which could have been attainable for the PA. The tree of the game is presented in figure 2.

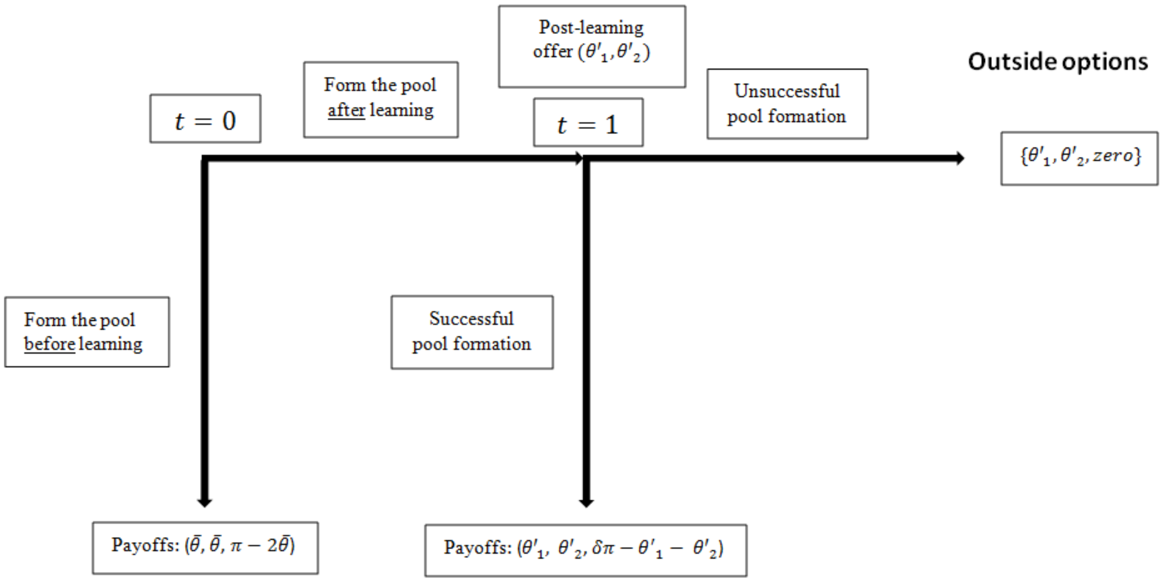

Figure 2 Timing of the game

Payoffs

As mentioned above, agents can take their share from the pool profit, only if the pool formation is successful. If pool formation in *t* is successful, the patentees will take their compensation (θ_i') and the PA will receive $R_t = \delta^t \pi - \theta_1' - \theta_2'$. If pool administrator does not manage to form a successful essential patent pool in *t* = 1, the game ends with all agents receiving their outside option. Table 1 summarizes the payoffs in each stage.

	Success in t = 0	Success in t = 1	t=2 & outside
Pool Administrator	$R_{t=0}^{\overline{\theta}\overline{\theta}} = \pi - 2\overline{\theta}$	$R_{t=1}^{\theta'_1\theta'_2} = \delta\pi - \theta'_1 - \theta'_2$	*zero*
Patentee 1	$\overline{\theta}$	θ'_1	θ_1
Patentee 2	$\overline{\theta}$	θ'_2	θ_2

Essentiality evaluation

Assessing the essentiality takes place in the second stage (t=1), if PA decides to learn the patentees' type before making them the offer in t=0. Starting the *t* = 1, pool administrator -and patentees- imperfectly learn the true essentiality level of the patents (e). In the learning process, for a patent with a true essentiality level of $e_i = \tilde{e}$, the administrator realizes an essentiality level in the interval of $\hat{e}_i \in [\tilde{e} - \Delta, \tilde{e} + \Delta]$. The *realized essentiality* by PA is denoted $\hat{e}_i$ and uniformly distributed over the interval $[\tilde{e} - \Delta, \tilde{e} + \Delta]$. Here, Δ is the parameter of error, which determines the quality of learning. Higher values of Δ represent bigger error in the essentiality evaluation. I assume that there is no cost of learning for the patentees and PA. However, the learning process takes the time from *t* = 0 to *t* = 1 which induces the waiting cost. Figure 3 gives an overview on the learning procedure and realized essentiality interval.

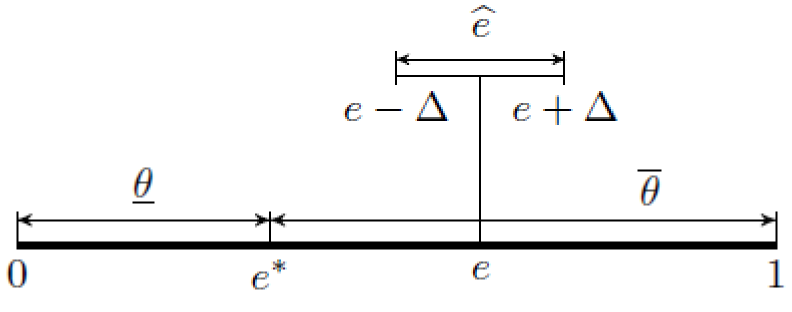

Figure 3 The realized essentiality interval in the learning procedure

Model Results

I offer a backwards solution for the game from the viewpoint of PA. Since the last node where PA can take a decision is in t = 1, I start with PA's optimal strategy in this node.

Optimal strategy for PA in t =1.

At the end of *t* = 1, PA will try to create the pool based on the updated beliefs (due to learning). The crucial point is that if the PA mistakenly excludes a $\overline{\theta}$ from the pool, the pool will not be implemented. Since the learning occurs in the beginning of the *t* = 1, PA has already the posterior beliefs - resulted from the essentiality evaluation- on the type of the patentees. I show these beliefs with $p_i^t \in [0,1]$ which stand for PA's belief that patentee *i* is non-essential (i.e. the type is $\underline{\theta}$).

In the beginning of the game in *t* = 0, due to the symmetry among patentees, PA has identical beliefs about them. So the prior belief (probability of the patentee *i* to be $\underline{\theta}$) is:

$$p_i^{t=0} = prob(e < e^*) = \mathrm{F}(e^*) = e^* \qquad (3)$$

Where F is the cumulative distribution function. In the *t* = 1 and after the learning, the beliefs will depend on the realization of $\hat{e}$. Since the error of learning is Δ, for any realized value of $\hat{e} < e^* - \Delta$, the patentee's true essentiality level lies in the interval of $[0, e^*)$ which means the patent is non-essential ($\underline{\theta}$) with certainty. That is to say:

$$prob(e < e^* | \hat{e} < e^* - \Delta) = 1 \qquad (4)$$

With a similar argument, we get:

$$prob(e < e^* | \hat{e} \geq e^* + \Delta) = 0 \qquad (5)$$

Accordingly, the detection is perfect in the above cases. However, when the realized essentiality is in the interval of $\hat{e} \in [e^* - \Delta, e^* + \Delta)$, there is no perfect detection. This is the grey interval for which the corresponding beliefs are calculated as below:

$$prob(e < e^* | \hat{e} \in [e^* - \Delta, e^* + \Delta)) = \int_0^{e^*} f(e| \hat{e} \in [e^* - \Delta, e^* + \Delta)) f(e) de = \frac{e^* - \hat{e} + \Delta}{2\Delta} \quad (6)$$

Thus, the posterior beliefs in the three intervals can be summarized as follows:

$$P_i^{t=1}: \begin{cases} 1 & if\ \hat{e} \in [0, e^* - \Delta] \\ \frac{\Delta + e^* - \hat{e}}{2\Delta} & if\ \hat{e} \in [\, e^* - \Delta, e^* + \Delta\,] \\ 0 & if\ \hat{e} \in [\, e^* + \Delta, 1\,] \end{cases} \quad (7)$$

Figure 4, shows the posterior beliefs in t = 1 with respect to the realized essentiality level.

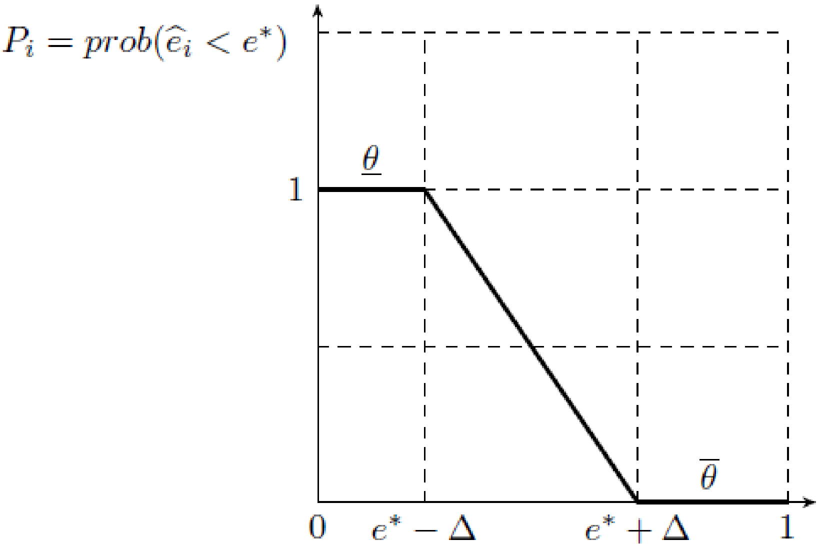

Figure 4 Posterior beliefs with respect to realized essentiality level

Accordingly and based on the definition of successful pool formation, I define "lax evaluation" and "failure" for a pool formation process as follows:

Definition 4 *For the pool formation by the PA I define:*

(i) Lax evaluation: when PA builds the pool in t=0 with no essentiality evaluation.

(ii) Failure: when PA dose not successfully build the pool in the game.

For the sake of simplicity and without loss of generality, I assume that $P_1^{t=1} \geq P_2^{t=1}$ in rest of the game solution. At *t* = 1, PA may successfully build the pool with either one or both patentees. Considering that $P_1^{t=1} \geq P_2^{t=1}$, PA has five decisions ($D_i \in \{0,1\}$) to potentially form the pool. I have summarized the decisions in the table below.

PA's decision in *t* = 1	**PA's payoff if pool is formed**
$D_1 = 1$ → PA offers $(\overline{\theta},\overline{\theta})$	$R^{\overline{\theta}\overline{\theta}} = \delta\pi - 2\overline{\theta}$
$D_2 = 1$ → PA offers $(\underline{\theta},\overline{\theta})$	$R^{\underline{\theta}\overline{\theta}} = \delta\pi - \underline{\theta} - \overline{\theta}$
$D_3 = 1$ → PA offers $(\underline{\theta},\underline{\theta})$	$R^{\underline{\theta}\underline{\theta}} = \delta\pi - 2\underline{\theta}$
$D_4 = 1$ → PA offers $(0,\overline{\theta})$	$R^{0\overline{\theta}} = \delta\pi - \overline{\theta}$
$D_5 = 1$ → PA offers $(0,\underline{\theta})$	$R^{0\underline{\theta}} = \delta\pi - \underline{\theta}$

Accordingly, in *t* = 1, PA maximizes its expected payoff by choosing one of the decisions above. To make the optimal decision, PA solves the following optimization problem:

Pool administrator's problem in t=1

$$\max_{D_1, D_2, D_3, D_4, D_5} \; D_1\left(R^{\overline{\theta}\overline{\theta}}\right) + D_2\left(R^{\underline{\theta}\overline{\theta}}\right)p_1 + D_3\left(R^{\underline{\theta}\underline{\theta}}\right)p_1p_2 + D_4\left(R^{0\overline{\theta}}\right)p_1 + D_5\left(R^{0\underline{\theta}}\right)p_1p_2$$

$$s.t.: D_1 + D_2 + D_3 + D_4 + D_5 = 1 \tag{8}$$

To solve the pool administrator's problem in *t* = 1, I start with two lemmas.

Lemma 1. *In t = 1, it is never optimal for the pool administrator to offer* $(\underline{\theta},\overline{\theta})$ *or* $(\underline{\theta},\underline{\theta})$.

Proof: PA will offer $(\underline{\theta},\overline{\theta})$ *or* $(\underline{\theta},\underline{\theta})$ if and only if the expected payoffs in these strategies exceed the others.

PA will play $(\underline{\theta},\overline{\theta})$ if and only if $(\delta\pi - \overline{\theta} - \underline{\theta})\, p_1 \geq \delta\pi - 2\overline{\theta}$ and $(\delta\pi - \overline{\theta} - \underline{\theta})\, p_1 \geq (\delta\pi - 2\underline{\theta})\, p_1 p_2$ and $\left(\delta\pi - \overline{\theta} - \underline{\theta}\right)p_1 \geq (\delta\pi - \underline{\theta})p_1 p_2$ and $\left(\delta\pi - \overline{\theta} - \underline{\theta}\right)p_1 \geq (\delta\pi - \overline{\theta})\, p_1$. The latter equation requires $\underline{\theta} < 0$ which is a contradiction.

Also, PA will play $(\underline{\theta},\underline{\theta})$ if and only if the payoff for this strategy is higher than others. This requires $\left(\delta\pi - 2\underline{\theta}\right)p_1 p_2 > (\delta\pi - \underline{\theta})p_1 p_2$, which again requires $\underline{\theta} < 0$, a contradiction.

For sake of ease in use of notation, I label the profit ratios as $A = \frac{R^{0\overline{\theta}}}{R^{0\underline{\theta}}}$ and $B = \frac{R^{\overline{\theta\theta}}}{R^{0\overline{\theta}}}$. The optimal decision regime is dependent to the relation between A & B. To clarify this relation, I formulate another lemma as follows.

Lemma 2. *When the pool formation is profitable* $(i.e.\, \delta^t\pi > 2\overline{\theta})$*, A is always greater than B.*

Proof. The proof is straight forward and comes directly from subtracting the terms a.

$$A - B = \frac{\delta\pi - \overline{\theta}}{\delta\pi - \underline{\theta}} - \frac{\delta\pi - 2\overline{\theta}}{\delta\pi - \overline{\theta}} = \frac{\overline{\theta}^2}{\left(\delta\pi - \underline{\theta}\right)(\delta\pi - \overline{\theta})} + \frac{\underline{\theta}(\delta\pi - 2\overline{\theta})}{\left(\delta\pi - \underline{\theta}\right)(\delta\pi - \overline{\theta})} > 0$$

For the sake of simplicity - and without loss of generality, I assume A>0.5>B. The optimal decision regimes can be depicted as follows.

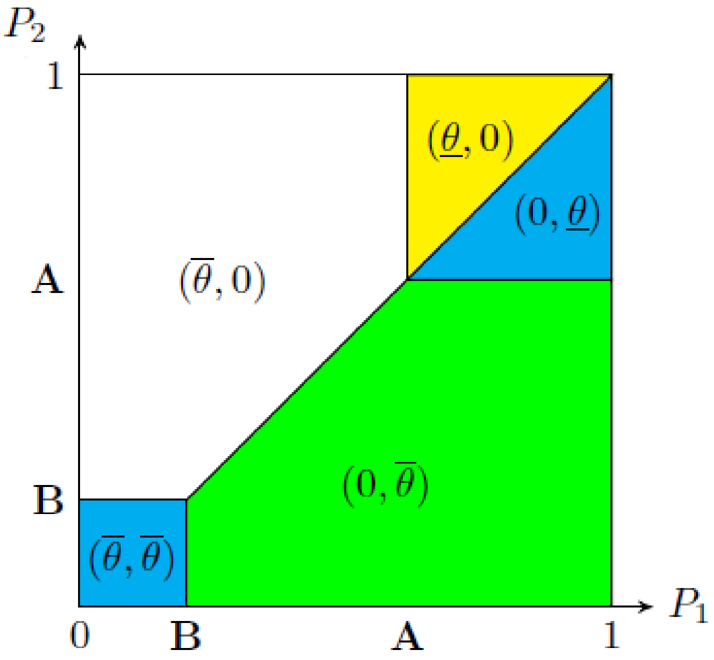

Figure 5 PA's optimal decision regime after learning

Proposition 1. *When PA decides to form the pool after learning (in t = 1), the probability of failure is always positive.*

Proof. Failure happens when an essential patentee is not included to the pool. This may only happen in the interval where the essentiality is not assessed with certainty. According to (7) PA faces the risk of wrong type detection in the interval of $[e^* - \Delta, e^* + \Delta]$. However, if the true essentiality is below e^*, a wrong detection will not result in a *failure* since in this case, a non-essential ($\underline{\theta}$) patentee is mistakenly added to the pool (this may only reduce the PA's payoff). Thus, the PA faces the risk of failure only in the interval $[e^*, e^* + \Delta]$. In this interval, PA may mistakenly detect an essential patent as non-essential and exclude it from the pool. Accordingly, the probability of failure for different intervals can be shown as follows:

$$prob(failure|e) = \begin{cases} zero & 0 < e < e^* \\ failure(e) & e^* \leq e < e^* + \Delta \\ zero & e^* + \Delta \leq \ e \ < \ 1 \end{cases} \tag{9}$$

When $e \in [e^*, e^* + \Delta)$, PA will fail to successfully form the pool only if mistakenly detects the patent as $\underline{\theta}$. As depicted in the figure (5), when $p_i \geq B$, pool admin considers the patentee as $\underline{\theta}$ (recall that p_i is the PA's belief on the patentee *i* to be $\underline{\theta}$) and offers her zero or $\underline{\theta}$. So the failure happens when the belief on an essential patentee ($e^* \leq \hat{e} < e^* + \Delta$) is mistakenly $p_i^{t=1}(\hat{e}) > B$. Plugging for the posterior belief from (7) we can calculate the $prob(p_i^{t=1}(\hat{e}) > B)$ as:

$$prob(p_i^{t=1}(\hat{e}) > B) = prob\ (\hat{e} < e^* + \Delta - 2\Delta B) = prob(\hat{e} < e^* + \Delta(1 - 2B)) \tag{10}$$

This means that the PA considers a patent as $\underline{\theta}$ when its realized essentiality ($\hat{e}$) is below $e^* + \Delta(1 - 2B)$. I denote this threshold with $\hat{e}^*$ ($\hat{e}^* = e^* + \Delta(1 - 2B)$). Accordingly, the probability of failure caused by learning error on a single patent evaluation is:

$$failure(e) = prob(\hat{e} < \hat{e}^*, e \geq e^*) \tag{11}$$

$$failure(e) = prob(\hat{e} < \hat{e}^* | e \geq e^*).prob(e \geq e^*) \tag{12}$$

According to the distribution of $\hat{e}$, the probability of failure for a single firm can be written (see appendix for the calculations regarding the distribution of $\hat{e}$ and equation 13):

$$failure\ (e) = \frac{\Delta(3-4B)(1-e^*)}{2(1-e^*-\Delta)} \tag{13}$$

which is always greater than zero. Therefore, PA's strategy to take the game to t=1 can contribute to a failure in the pool formation.

Proposition 2. *The probability of failure in t=1*

(i) increases with the error of learning.

(ii) increases with essential patents' outside option.

(iii) decreases with e^**- i.e. the legal strictness on essentiality.*

Proof. The first and third results directly come from equation (13). The second result can be achieved also by equation (13) and considering that $\frac{\partial B}{\partial \theta} < 0$.

Solving the pool formation backwards, the pool administrator, will be able to calculate only the *expected* payoff in the second stage. This will depend on the updated beliefs, waiting cost and the size of error among other variables. However, the payoff for the first stage of the game is known by the PA with certainty. Therefore, in the first stage PA will need to compare the expected payoff of the second stage with the certain payoff of the first stage and choose about its strategy:

Pool administrator's problem in t=0

$$\max_{z\in\{0,1\}}[E_{t=1}(R_{t=1}), R^{\overline{\theta\theta}}\ ]$$

Where $z \in \{0,1\}$ is PA's decision on whether to take the game to the second stage or not.

Proposition 3. *Under proper conditions (waiting cost and learning error sufficiently high), PA's optimal decision is to include all the patents to the pool, regardless of their essentiality.*

Proof. See the appendix.

Discussion and Conclusion

According to proposition 1, when PA goes through the essentiality evaluation, there is a non-negative probability of failure. Obviously, this comes from the nature of imperfect learning. So even in the cases where pool administrators outsource the essentiality evaluation to independent examiners, the effect stays. This reason of failure is different from the common reason in the literature which assumes patentee-side issues to be the drivers of failures. Also, proposition 2 summarizes factors which increase the probability of failure. The first factor -i.e. the error of learning- is straight forward. The second factor -i.e. value of patents- assigns higher failure rates when essential patents have higher outside options. These are relevant for recent failed pool formation cases in advanced ICT industries, where due to technological complexities, it is extremely difficult to assess the essentiality (higher learning error). Also in these contexts patents typically have higher commercial values outside the pool. The results can explain some degrees of contribution from pool administrators' side to these failures. Moreover, proposition 3 states the conditions where the pool administrator is better off by acting lax and including non-essential patents to the pool. In reality, pool administrators have already been alleged of being "overly lax" in the essentiality evaluation procedures. Proposition 3 may be able to explain the reasons that this concern exists among stakeholders; with high pace of technology in hi-tech industries, waiting and delays almost translate into losing the market to competitors (very high waiting cost). When this combines with higher errors in essentiality evaluation (again the cases for hi-tech context), the pool administrator finds it optimal to skip both the waiting cost and the risk of failure and include non-essential patents to the pool to lunch it faster. A trend which is already observable in some areas of hi-tech industries, known as the patent pool inflation. Figure 6 summarizes the discussion based on environmental factors. From the findings, I expect factors such as value of essential patents, strictness of IP law and pace of technology to explain - and predict -some of the inefficiencies in pool formation attempts. For example, I expect pool inflation to be a more serious issue in those areas of ICT industry (which typically has high waiting cost and learning error) that patents entail lower outside options.

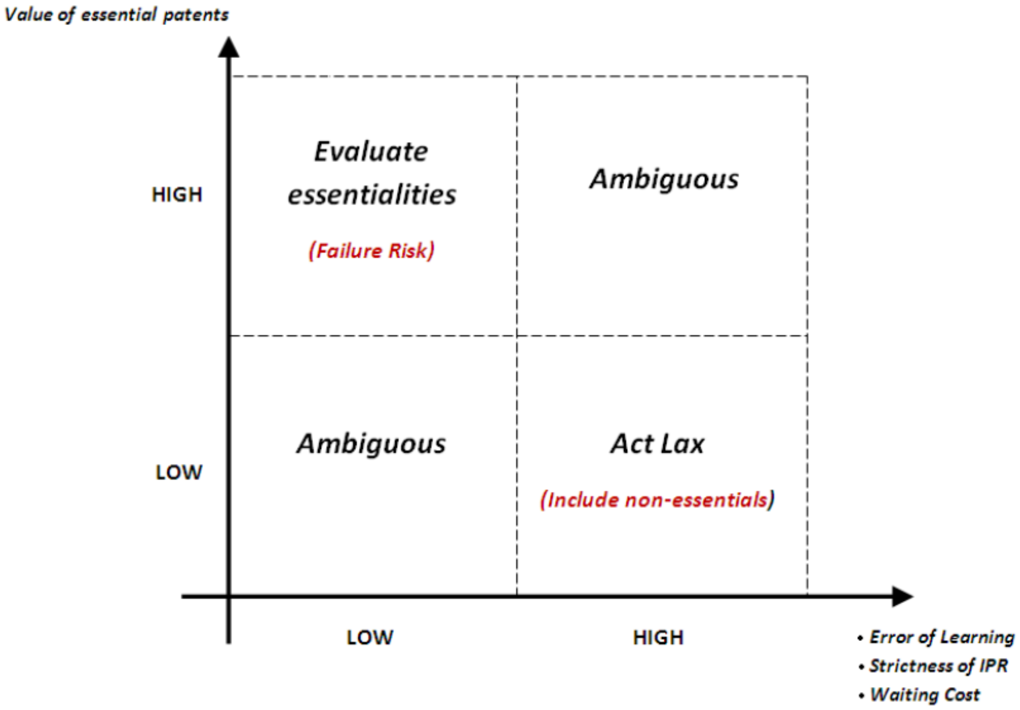

Figure 6 Inefficiencies rising from pool administrator side based on environmental factors

I do not intend to exaggerate the potential role of the pool administrating party on inefficiencies. Obviously, IP holders have a significant role in the inefficiencies caused in pool formation. However, it is very difficult to measure the magnitude of the effects potentially caused by the administrator and moreover, to compare it with the role of other sources of inefficiencies in the literature (e.g. distributional conflicts among firms).

Finally, there are some shortcomings in the model that I am aware of them. The model assumes a very powerful pool administrator whom can include or exclude the patentees without further constraints. The administrator's market power caused by the experience of pool formation in specific areas of the industry and the body of knowledge that it posses, plays a key role in this assumption. Also, the model assumes that the patentees are eager to be included in the pool and does not considering the outsider strategy. This is an assumption which is realistic for the case of many important patent pools but may not be always the case.

To conclude, I believe the next step of the study should focus on validating the findings of the model. Besides potential empirical analysis, this may be achievable by designing proper experiments to investigate the behaviors of practitioners and the stakeholders including pool administrators.

References

Allekotte, B. & Blumenröde, U. 2010. *Building and enforcing intellectual property value*, 37-39

Aoki, R., Nagaoka, S. 2004. *The consortium standard and patent pools*. Hitotsubashi University Research Unit for Statistical Analysis in Social Sciences (Hi-Stat) Working Paper No.32.

Baron, J., Delcamp, H. 2010. Strategic inputs into patent pools, *Cerna working paper*.

Baron, J., Pohlmann, T. 201. Essential Patents and Coordination Mechanisms, *CERNA working paper series.*

Bekkers, R., Bongard, R., Nuvolari, A. 2011. An empirical study on the determinants of essential patent claims in compatibility standards, *Research Policy*, Volume 40, Issue 7, 1001-1015.

Blind, K., Thumm, N. 2004. Interrelation between patenting and standardization strategies: empirical evidence and policy implications, *Research Policy* 33 (2004) 1583--1598.

Brenner, S. 2006. Optimal Formation Rules for Patent Pools, *mimeo.*, Humboldt University, Berlin.

Clarkson, G. 2004. "Objective Identification of Patent Thickets: A Network Analytic Approach for Measuring the Density of Patent Space", *Ph.D. thesis*, Harvard University

Delcamp, H. 2010. Essential patents in pools: Is value intrinsic or induced?, *Cerna working paper*.

Gallini N. 2010. Private agreements for coordinating patent rights: the case of patent pools, UBC Departmental Archives, UBC Department of Economics

Gilbert, R. 2004. Antitrust for patent pools: a century of policy evolution". *Stanford Technology Law Review* 3.

Gilbert, R. and Katz, M. 2006. Should good patents come in small packages? A welfare analysis of intellectual property bundling, *International Journal of Industrial Organization,* Vol. 24, Issue 5, pp. 931-952

Berger, F., Blind, K., & Thumm, N. 2012. Filing behaviour regarding essential patents in industry standards. *Research Policy*, 41(1), 216-225.

Lampe, R., & Moser, P. 2010. Do patent pools encourage innovation? Evidence from the nineteenth-century sewing machine industry. *Journal of Economic History*, 70(4), 898.

Layne-Farrar, A., & Lerner, J. 2011. To join or not to join: Examining patent pool participation and rent sharing rules. *International Journal of Industrial Organization*, 29(2), 294-303.

Lemley, M.A. 2002. "Intellectual property rights and standard-setting organizations". *California Law Review* 90, 1889--1980.

Lerner, J., Strojwas M., Tirole J. 2007. The design of patent pools: the determinants of licensing rules, *The Rand Journal of Economics* 38, 610--625.

Lerner, J. and Tirole, J. 2004. Efficient Patent Pools, *American Economic Review*, vol. 94(3).

Simcoe, T. 2012. Consensus Governance for Shared Technology Platforms, *American Economic Review*, 102(1)

Appendix

A. Distribution of $\hat{e}$

For the proposition 1, the failure probability is:

$$failure(e) = prob(\hat{e} < \hat{e}^* | e \geq e^*) prob(e \geq e^*) \quad (14)$$

To calculate the $prob(\hat{e} < \hat{e}^* | e \geq e^*)$, I use the distribution of $\hat{e}$ for the interval of $e \in [e^*, 1]$. Figure 7 shows the distribution function. The height of the trapezoid is calculated as:

$$F(\hat{e} | e \in [e^*, 1]) = \int_{e^*-\Delta}^{1+\Delta} f(\hat{e} | e \in [e^*, 1]) d\hat{e} = 1 \rightarrow h = \frac{1}{1+\Delta-e^*} \qquad (15)$$

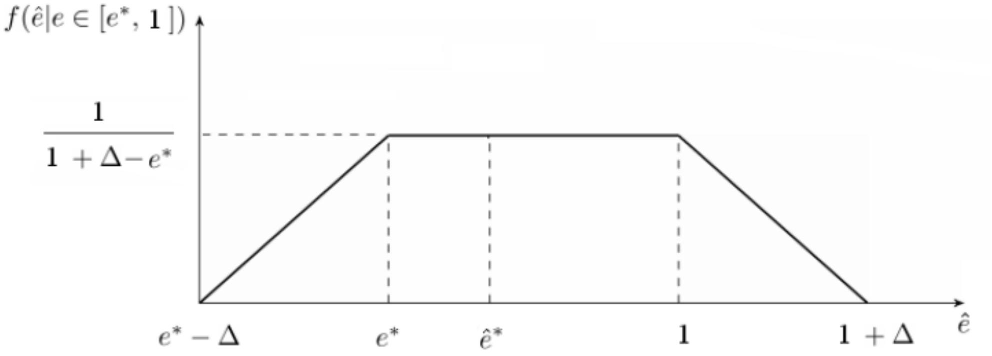

Figure 7 The distribution of $\hat{\boldsymbol{e}}$ for $e \in [e^*, 1]$

The distribution for the intervals on $\hat{e}$ are as follows:

$$f(\hat{e}) = \begin{cases} \frac{\hat{e}-(e^*-\Delta)}{\Delta(1+\Delta-e^*)} & if\ \hat{e} \in [e^* - \Delta, e^*] \\ \frac{1}{(1+\Delta-e^*)} & if\ \hat{e} \in [e^*, 1] \\ \frac{(1+\Delta)-\hat{e}}{\Delta(1+\Delta-e^*)} & if\ \hat{e} \in [1, 1+\Delta] \end{cases} \qquad (16)$$

Considering the above, $prob(\hat{e} < \hat{e}^* | e \geq e^*) = \frac{\Delta(3-4B)}{2(1-e^*-\Delta)}$ and we are done.

B. Proof of proposition 3.

The administrator can always guarantee a certainty payoff by forming the pool successfully in the first stage. PA's payoff with pre-learning offer ($\overline{\theta}$,$\overline{\theta}$) at t = 1 is

$$R_{t=1} = \pi\text{-}2\overline{\theta} \qquad (17)$$

However, if PA takes the game to t = 1, the payoff does not come with certainty and would depend on the real essentiality level of the patents. Below, I calculate PA's *expected* payoff at t = 1.

As we have from equation (10), there is a threshold on the axis of observed essentiality signal ($\hat{e}$) that PA treats the patentees below that as non-essential ($\underline{\theta}$). I have shown this threshold by $\widehat{e^*}$. From equation (10) this threshold is equal to:

$$\widehat{e^*} \ = e^* + \Delta(1 - 2B) \qquad (18)$$

To calculate PA's expected payoff in t=1, I divide the $\hat{e}$ axis into two separate intervals, I_1: $[0, e^*)$ and I_2: $[e^*$,1]. (Figure 8)

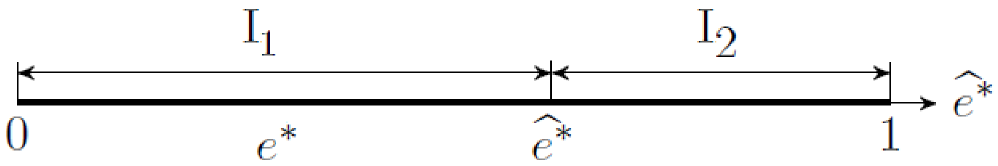

Figure 8

PA will treat all the patentees with $\hat{e} \in I_2$ as $\overline{\theta}$ and the rest as $\underline{\theta}$. I also define $\tilde{p}$ as the probability of wrong detection when the patentee is $\overline{\theta}$. As previously mentioned, $\tilde{p}$ is the probability that the pool will not be created successfully in t = 1 due to the error of learning. This can be formulated as:

$$\tilde{p} = prob(e > e^* | \hat{e} < \widehat{e^*}) \qquad (19)$$

So, one can imagine four conditions with this setup, about the location of $\widehat{e_1}, \widehat{e_2}$ inside the two intervals:

Case	$prob(success)$	Payoff if success
$\widehat{e_1}, \widehat{e_2} \in I_1$	$(1-\tilde{p})^2$	$\delta\ (\pi - \underline{\theta})$
$\widehat{e_1} \in I_1, \widehat{e_2} \in I_2$	$(1-\tilde{p})$	$\delta\ (\pi - \overline{\theta})$
$\widehat{e_1} \in I_2, \widehat{e_2} \in I_1$	$(1-\tilde{p})$	$\delta\ (\pi - \overline{\theta})$
$\widehat{e_1}, \widehat{e_2} \in I_2$	1	$\delta\ (\pi - 2\overline{\theta})$

Considering the four cases above, PA's expected payoff for t=1 can be formulated as:

$$\begin{aligned} E_{t=1}(R_{t=1}) = {} & prob(\widehat{e_1}, \widehat{e_2} \in I_1\ ).(1-\tilde{p})^2.\delta\ (\pi - \underline{\theta}) \\ & + prob(\widehat{e_1} \in I_1). prob(\widehat{e_2} \in I_2).(1-\tilde{p}).\ \delta\ (\pi - \overline{\theta}) \\ & + prob(\widehat{e_1} \in I_2).\ \text{prob}(\widehat{e_2} \in I_1).(1-\tilde{p}).\ \delta\ (\pi - \overline{\theta}) \\ & +\ prob(\widehat{e_1}, \widehat{e_2} \in I_2\ ).\ \delta\ (\pi - 2\overline{\theta}) \end{aligned} \qquad (20)$$

And PA will find it optimal to take the game to t=1 if and only if:

$$E_{t=1}(R_{t=1}) \geq R_{t=1}^{\overline{\theta}\overline{\theta}} \qquad (21)$$

From $\underline{\theta}<\overline{\theta}$ it follows that $\pi - \underline{\theta} > \pi - \overline{\theta} > \pi - 2\overline{\theta}$. Also, from (7) and (16) we get that if learning error converges to zero ($\Delta \rightarrow 0$), then $\hat{e} \rightarrow e$ and $\widehat{e^*} \rightarrow e^*$. Consequently, the probability of failure ($\tilde{p}$) will converge to zero $\tilde{p} \rightarrow 0$. Considering equation (20), with sufficiently low waiting cost (i.e. sufficiently high δ), PA's expected payoff in t=1 will exceed its payoff in t=0 (equation 21). So in this case, the expected payoff for going to the learning phase will exceed the certain payoff of forming the pool in t=0. On the contrary, with sufficiently high waiting cost and learning error, PA's optimal decision would be to include all the patents without going to the learning phase and build the pool in t=0.