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Employed inventors, inter-firm mobility, bonus pay with multi-stage R&D processes, and optimal innovation policy

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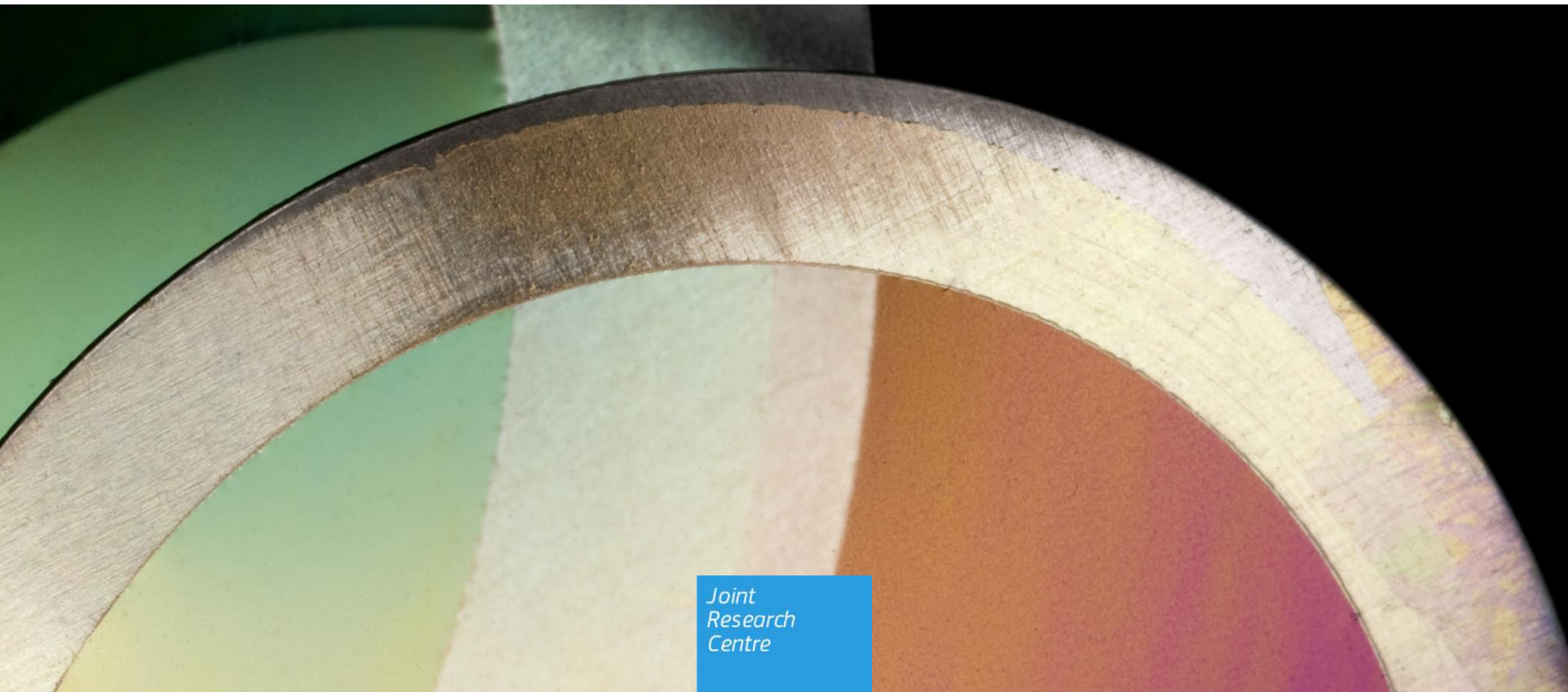

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Abstract

A temporary change in pay to employed inventors around the time of patent application has been observed in a number of countries. A theoretical model is here developed to provide an explanation to said findings based on the idea that inventors may be able to use the knowledge previously generated while working in a firm, in a rival company. The model features firms who hire workers in R&D functions to make product innovations. The innovation process consists of distinct phases separated by a patent application. Firms compete to attract workers, and workers can transfer part of the generated new knowledge to a new employer. Results suggest that the capital intensity of R&D investments, and the type and size of knowledge spillovers, may affect the probability to observe bonus pay at the time of a patent application.

Different tax incentives and subsidies are then studied as a means to correct for possible under-investment of capital. We study the effect of a patent box, a subsidy to R&D capital investments, and a subsidy to bonus pay. When market rivalry prevails over positive knowledge externalities, a bonus pay incentive was found to obtain the social first-best while a patent box or a subsidy to capital investment would cause overinvestment. When positive knowledge externalities prevail, either a patent box or a subsidy to capital investment obtain the social optimal level of capital investments.

1. Introduction

Tax incentives and subsidies for R&D activities conducted by private companies are widely used in many developed countries. Our understanding of the structure of incentives that employed inventors face is however limited, regardless of the fact that labor costs account for a large part of private R&D expenses (about 70% according to Harhoff et al. 2003). Both monetary and non-monetary incentives (Cohen & Sauermann 2007, Sauermann & Cohen 2010, Stern 2004) appear to be important drivers for inventors' decisions about where to work (Akcigit et al. 2015, Roach & Sauermann 2010) and, possibly, about the allocation of time and effort among multiple job tasks (Hellmann & Thiele 2011, Manso 2011).

That R&D workers mobility between firms is a potential conduit for knowledge transfers is a recognized fact. Such transfers can produce positive knowledge spillovers (Møen 2005), but also make competing firms steal market shares from previous employers through partial imitation of product innovations (Bloom et al. 2013). In Kim & Marschke (2005) the authors report that the latter form of rivalry can be so intense at times that "*a number of Silicon Valley firms, such as Adobe Systems, Apple, Google, Intel Corporation, Intuit, and Pixar, agreed in 2009 not to approach each other's employees, even at the risk of violating the U.S. competition law.*"

The model presented in this study contributes to the literature in two ways. First, it explores the market conditions under which some observed regularities in employed inventors' pay (an average rise in pay around the time of a patent application) are compatible with rational expectations, inventors mobility, capital investments in R&D, and the existence of knowledge externalities that are transmitted between companies through labor mobility. Second, it derives implications for policymakers with regard to the optimal tax and subsidy scheme to use in order to reach the social optimal capital investment in R&D activities under different types of knowledge transfer regimes. We study the effect of a patent box, a subsidy to R&D capital investments, and a new form of subsidy to bonus pay.

The model assumes costless mobility of workers across firms and, as in the superstars literature stemming from Rosen (1981), workers in the model extract all the surplus from firms thanks to a competitive bidding over pay in which multiple firms participate. The model is particularly suited to address conditions that could potentially arise in a market for star scientists employed in private companies. Star scientists and technologists are known for being particularly mobile across firms and countries, so the full mobility assumption taken here fits well to them. The model can also provide insight for specific markets and situations where R&D workers ability to move is large, their supply is rationed in the short run while demand is increasing fast. Such a description reminds of the New Economy boom in Silicon Valley during the second half of the 1990s, when skill shortage was a common issue for firms with a high propensity to invest in innovative projects.

The structure of the paper is as follows. Section 2. reviews the relevant literature and discusses some recent empirical results about changes in inventors' pay around the time a patentable innovation is produced. Section 3. presents the general framework and then, in section 4., we solve the model to obtain equilibrium pay and capital investment. Section 5. derives the relevant policy implications, while in section 6. the model is changed to accomodate for additional assumptions. Section 7. concludes.

2. Previous literature

A traditional rationale for public intervention in private R&D productions is the existence of positive externalities in the form of knowledge spillovers (Arrow 1962). Positive externalities motivate the use of subsidies and tax incentives, in line with standard arguments supporting Pigouvian taxes and subsidies in presence of externalities and large coordination costs preventing to reach first-best equilibria by decentralized contracting alone. The exact nature of such transfers of knowledge between firms is however subject to debate as they could operate through distinct channels (Griliches 1992). In the following sections our focus is on employed inventors and on the transmission of knowledge caused by their mobility.

Several studies (see as examples: Almeida & Kogut 1999, Miguélez & Moreno 2013, Saxenian 1996, Scarpetta & Tressel 2004) have documented that a larger inter-firm mobility of technical workers is associated with more intense innovation at regional level. The channel identified by researchers through which mobility can enhance innovation is the transfer of knowledge caused by highly skilled workers moving between companies. This finding may explain why a region where mobility is particularly high (like Silicon Valley, where as shown in Fallick et al. (2006) the practice of "job-hopping" is common) features more intense production of innovations in comparison to lower-mobility regions. The evidence also suggests that the benefit of knowledge transfers through mobility may dissipate over time (Hoisl 2006), and that firms may anticipate the possibility of a leaving inventor by reducing their R&D investments and by increasing their propensity to patent (Kim & Marschke 2005). The benefits a firm obtains from knowledge contributed by newly hired workers also depend on the firm's absorptive capacity which is determined by past investments as well as by organizational characteristics (Cohen & Levinthal 1990).

The mobility of R&D workers is strictly related to the structure of their pay, because the labor market can internalize the possibility of knowledge transmission. The equilibrium pay offered to inventors can be reduced to anticipate for the possibility of leaving, or variable pay can be employed to retain the worker after an innovation is produced (Franco & Filson 2006, Møen 2005, Pakes & Nitzan 1983). With regard to the pay structure, Balkin & Gomez-Mejia (1984) empirically show that firms with a faster job turnover are more likely to offer forms of variable compensation to R&D workers. The PatVal survey documented that a large share of employed inventors in the E.U. receives a temporary bonus pay when an innovation is produced (Giuri et al. 2007). Subsequent empirical research has shown that around the time of a patent grant (Toivanen & Väänänen 2012) or patent application (Depalo & Di Addario 2014) employed inventors in Finland and Italy, respectively, experience a rise in pay. Part of this bonus pay is permanent, while part is temporary and last just some years after the time of patent application or grant. Results similar to the ones reported in Depalo & Di Addario (2014) are obtained in a replication study using U.S. data (Bell et al. 2015), even though some differences arise between the U.S. and the E.U., maybe due to the fact that in the U.S. it is more common to employ stock-based compensation.

The study by Depalo & Di Addario (2014) is particularly relevant for the sake of the present research: the dataset they exploit links uncensored income data from social security registries with patent data. In Italy, contrary to other countries like Germany or Finland, employed inventors are not entitled by law to gain some parametrized or predefined pay when a patent is produced. Therefore any observed variation in pay is only due to market forces. The authors report that the part of the increased pay which is permanent positively correlates with the stock of patents the inventor produced in the past, and argue it might be related to the fact that patents also signal an inventor's ability to produce valuable innovations.

However the reason why firms might want to grant a temporary increase in pay around the time a patent is applied for, is not fully clear. As a first hypothesis, it might be that work contracts include *ex ante* profit sharing schemes, as we know that these payment forms are common in R&D-intensive firms (refer to d'Andria (2016) and the literature cited therein). The temporary rise in pay at the time of patent application could then just reflect the automatic effect of profit sharing schemes. But it is unlikely that, already at the time of patent application, the value (profits, sales, stock value) upon which profit sharing schemes are computed upon is known to the parties. Moreover the evidence in Toivanen & Väänänen (2012) and Depalo & Di Addario (2014) that pay also rises several years before a patent application can hardly be explained by the existence of *ex ante* contracts, and points instead to a bargaining process over pay after a patentable innovation has been observed by firms and employees. Note however that even if such pay is determined *ex post* (by *ex post* here we mean that the bonus pay is established only after the firm realizes that a patentable innovation is generated and identified), rational workers will anticipate its existence and base their decisions in earlier stages also on such rational expectations.

A second hypothesis is related to the informational content of patents. A patent application launches signals to other agents in the market (Anton & Yao 2004, Hsu & Ziedonis 2008). Technical details have to be disclosed to patent offices at the time of a patent application, thus making such knowledge (which could otherwise remain secret) observable by competing firms. This means that a patent application might provide information about an innovation value and trigger either imitation by competing firms or competitive bidding over this innovation by potential investors. Imitation can use as input the knowledge possessed by technical workers previously employed in the patenting firm, therefore the competitive bidding could take the form of a bid over pay in order to acquire such workers. A rise in pay offered by current employers could then have the purpose to impede a transfer of internally generated knowledge to competitors who could benefit from it and perform faster, or better, in imitating the innovation or generating a better technical solution for similar needs. As an additional reason for bonus pay, the innovation process may not be fully completed at the time of patenting. Maybe an invention has yet to be transformed into a working prototype, or a pilot prototype must be developed into a blueprint for large scale industrial production. A firm might then use *ex post* bonus compensation. This would fulfill the purpose to keep a fundamental resource (the inventor) needed in order to complete the full innovation process up to the final phase of commercialization.

Survey-based evidence from the U.S. (Ittner et al. 2003) and from the E.U. (d'Andria 2016) support the attraction and retention motive as one of the most important for providing profit sharing compensation to employees. In Andersson et al. (2009) the software industry is studied. The authors find that "*firms that choose to operate in sectors that have high risk payoffs will choose human resource practices that help them attract and retain higher quality workers and pay more for performance.*" It would seem therefore that the structure of the pay, and not only its level, plays a role in the competition over talent.

The model presented here considers the effects of inventors mobility and knowledge transfers on the structure of inventors compensation. We will study a very specific kind of mobility that can happen at the time when a patent application is filed and published, and we will consider also cases where a moving inventor does not generate an increase in aggregate production of innovation value from the point of view of society. These cases under study are interesting for several reasons. First, our aim is to provide an explanation for the finding that inventors' pay temporarily rises before and after a patent application. Second, the theory here developed complements empirical findings from regional economics by explaining under what exact conditions observed mobility should be positively associated with larger aggregate innovation. Third, rises in pay of the kind studied here are observable by a policy maker and therefore they can be in principle exploited for the sake of innovation policy design.

We build on Pakes & Nitzan (1983) moving the focus of the analysis on a specific event (a patent application) that makes information about the innovation value public. Differently from Pakes & Nitzan (1983) we do not consider heterogeneous skills levels for inventors, and also contrary to them we include capital investments in R&D which introduce more realism and an additional constraint for the employer. Also differently we introduce competition over talent in all stages of the game, so that profits from innovation are entirely extracted by workers rather than by entrepreneurs.

As a further addition in comparison to Pakes & Nitzan (1983) we also study the implications for optimal innovation policy. Standard modeling of incentives for R&D usually frames the investment problem solved by firms by considering R&D workers as a resource the firm can simply acquire on some job market at some equilibrium price (see for instance the approach exemplified by Griliches 1979) and that remains with the firm until the R&D investment is concluded. The consequence of such a line of thinking is that subsidies and tax incentives for R&D are studied and applied in countries almost exclusively on corporate investments and taxable income, respectively. The evidence discussed so far in this section strongly supports the idea that R&D workers and employers bargain over pay at the time an innovation is produced. Because R&D costs are for a majority spent for labor services, these variations in pay can have important effects on the overall level of R&D expenditures and thus affect the relative efficacy of different policy tools. The possibility that a worker leaves the employer before the completion of a R&D process can also modify traditional policy prescriptions and require new strategies to deal with underinvestment.

A recent strand of the literature considered forms of tax incentives for R&D applied on *ex ante* bonus pay earned by employed innovators. It was shown that in a multi-task job setting where an innovative worker can allocate effort among competing job tasks a bonus pay incentive can be a complementary policy to traditional incentives on corporate income taxation (d'Andria 2016). The relative efficiency of a so-called patent box incentive and of a bonus pay incentive has been explored by considering a large set of scenarios in a simulation study (d'Andria & Savin 2015), which found workers mobility to be an important determinant. Our present model is related to these studies as we also jointly consider a bonus pay incentive and incentives for R&D in the form of a subsidy to capital investments or a patent box. However we rule out effort intensity and multiple job tasks in order to focus the analysis on mobility and competition for talent alone.

3. The model

As a basis for the model and following labor laws most commonly found in developed countries, we will assume that workers are given by law the right to leave an employer at no cost. Consequently any agreement made about future pay can be broken by a worker if observed conditions make it more favorable to do so. To simplify the discussion we assume a symmetric option for the employer (following previous works that assume non-binding labor contracts for those employees who are not easily replaceable, like top managers and key technologists: Stole & Zwiebel 1996*a*,*b*), so that pay has to be recontracted in each period.[1] We therefore consider a two-phase innovation and firms offering two separate wages in each phase. Workers and firms form expectations about the second phase, so the way pay is formed at the equilibrium in the first phase also depends upon said expectations. The two phases are divided by a patent application event that makes the value of the innovation under development known to all parties.

Employers are assumed to have full ownership of an innovation protected by some intellectual property right system, while workers cannot claim ownership on an innovation they produced. Property rights are however incomplete and therefore, some newly produced value can be lost to the advantage of competing firms regardless of legal rights. The model is able to highlight under what market conditions inventors pay is expected to rise after the first phase of the innovation process.

We impose an additional assumption (again following Stole & Zwiebel 1996*a*) in order to add realism to the model: wages are restricted to non-negative offers. This may be interpreted as a situation where employees do not own enough wealth to invest as capital and they are restricted from accessing the credit market to finance R&D investments themselves.

There exists a large fixed number of identical firms and a fixed number of identical inventors who can be hired by firms. Firms and inventors are assumed to be risk neutral. Each firm can hire zero or more inventors, and each hired inventor is put to work on a single R&D project related to a product innovation. We assume that R&D projects are financed through internal funds and cannot be cross-subsidized, therefore projects are financially independent even when belonging to the same firm. This assumption means that firms enforce internal rules that forbid to use revenues from one internal department to finance other internal departments.

Workers are assumed identical *ex ante* before an invention is generated. All workers invest the same amount of time and effort in the R&D process, therefore the model can be thought of as one where the invention process is only driven by creativity, and monetary incentives cannot affect the outcome of such process as per experimental evidence on purely creative tasks (see for example Eckartz et al. 2012). In other words inventors can choose for which firm to work, but not how much to work. These assumptions rule out possible moral hazard during contract execution, or adverse selection at the time of hiring.

Each firm can both act as an original innovating firm or as a competing firm. Original innovating firms set up one or more R&D projects in stage 1 and compete to attract workers by offering them a pay w_I. When considered in the role of competing firms, firms in stage 2 try to attract workers from R&D projects started in stage 1. In stage 2 we therefore have both original innovating firms and competing firms. Again these are just roles, and because of the homogeneity of firms, all firms in the market can act at the same time as original innovating firms (for the projects they funded in stage 1) and as competing firms (for all projects in the market).

Each period is divided into two stages. In the first stage (invention and early development phase), original innovating firms invest capital K in each of their projects and offer a pay w_I to each worker they hire. Capital has an opportunity cost equal to r which captures the expected return from alternative uses of the internally generated funds. Firms competitively bid on the pay offered to inventors, consequently the equilibrium pay w_I is homogeneous across firms and projects, and all projects are financed with the same amount of capital. At the end of stage 1, each worker produces an invention of value v, drawn from a distribution of values $V = f(K)$

[1] As an alternative setting contracts might be fully specified *ex ante*, for example by allowing firms to offer profit sharing schemes in stage 1 that provide a share of the value that will be produced in stage 2 to the worker if he remains with the employer. However we do not explore this setting because in case of a produced innovation value larger than the expected value, the monetary compensation specified in the *ex ante* contract could be insufficient to retain the worker against bids from competitors, therefore some degree of bargaining would still be required in stage 2 of the game. Also because of the arguments provided in previous section we believe that the referenced empirical evidence demonstrates that some *ex post* bargaining over pay happens around the time of a patent application, and therefore a fully recontracted pay in stage 2 allows us to better focus on such bargaining. Finally, because of the assumed full extraction of rents by workers an *ex ante* contract would simply shift part of the pay from stage 1 to stage 2, without affecting the main arguments and results presented in the following sections.

with expected value $E(V|K)$. Function $f(.)$ is a probabilistic production function, and its expected value function $E(V|K)$ is assumed continuous, twice differentiable, increasing in K and with $\frac{\partial^2 E(V|K)}{\partial K^2} < 0$. Each generated value v is perfectly known at the end of stage 1 to all firms and workers in the market. The assumption is that at the end of stage 1 a patent application is immediately filed and published, and as such the technical details of the innovation are made public, so that everyone in the market can assess at no cost its monetary value. Contrary to the findings in Kim & Marschke (2005), for simplicity we assume that firms always patent their innovations.

In the second stage (development and commercialization phase), each worker is offered a pay w_{II} from his current employer, and a pay w_c by competing firms. If a competing firm manages to attract a worker, he is employed to produce a derived product innovation which entails partial imitation of the product innovation developed at the previous employer. Again, firms competitively bid on the pay w_c offered to inventors. The worker chooses whether to remain with the former employer if $w_{II} \geq w_c$ (in case of equality the worker is assumed to stay with the current firm, which can be thought of as a weak form of *status quo* bias). At the end of stage 2, each worker knows his final payoff which is either $w_I + w_{II}$ or $w_I + w_c$.

At the end of stage 2 an original innovating firm obtains revenues equal to v if the worker stayed, or equal to $v(1-l)$ (with $0 \leq l \leq 1$) if the worker left. A competing firm hiring the worker in stage 2 would earn revenues equal to va (with $0 \leq a \leq 1$) if the worker left the previous employer and was hired by this firm, and zero otherwise. Therefore, l measures the loss a firm suffers if the worker leaves in stage 2, while a measures the benefit a hiring company in stage 2 obtains. The values for a and l are assumed project-specific and known to the firm at the beginning of stage 1. The value of $a - l$ will also be interpreted in the next sections as a measure of knowledge spillovers from the original innovating firm to a competing firm if $a > l$, meaning that positive knowledge externalities prevail over the loss in value generated by a worker switching employer. When $a = l$ we will talk of a "transfer" of knowledge rather than of a "spillover". The reason is that welfare-wise having a mere transfer of value between firms does not *per se* affect social well-being (it only affects welfare because capital investments can possibly be below optimum). Finally when $a < l$ we will talk of a "product market rivalry" effect as discussed in Bloom et al. (2013), meaning that part of the value generated is stolen by the competing firm, either by subtracting market shares from it, or by impairing the latter stages of the innovation process of the original innovating firm causing a loss in value that is larger than the effect of positive externalities.

For each hired worker, an original innovating firm chooses K in stage 1 by solving the constrained-maximization problem represented in the following problem (1), given the pay w_I offered in stage 1 and the expected pay w_{II} which is going to be offered in stage 2. Second-stage pay w_{II} enters as expected value because it depends upon the value of the innovation v observed at the end of stage 1, which as stated is stochastic. To make the text and equations more readable we will use a slight abuse of notation and write $E(w_{II}) = E(w_{II}|E(V|K))$.

Hereafter notation $W = \{w_I, E(w_{II})\}$ represents together first-stage pay w_I which is contractually binding for the parties, plus the expected second-stage pay w_{II} that firms and workers are assumed to be unable to define contractually *ex ante* in stage 1. Note that without competition over talent the reservation wage of a worker would be zero and therefore, the equilibrium pay would be $W = \{0, 0\}$. The existence of competing firms trying to hire workers and bidding over pay in both stages of the game rises the equilibrium pay up to the point where all surplus is extracted by employees, as per standard assumptions in superstars models (refer as examples of this modeling strategy to Acharya et al. 2013, Baranchuk et al. 2011). Consequently, firms do not really set pay variables in W but rather they behave as price-takers. The derivation of the exact values at the equilibrium for pay w_I, w_{II} and w_c depends upon the specific values of parameters l and a and will be the object of sections 4. and 6..

The problem in stage 1 for an original innovating firm is therefore to choose a value for capital K that solves:

$$\max_{K} \mathit{\Pi} = E(V|K)1(.) + E(V|K)(1-l)(1-1(.)) - (1+r)K \tag{1a}$$

$$\text{s.t.} \quad \mathit{\Pi} \geq w_I + E(w_{II})1(.) \tag{1b}$$

Function $1(.) = 1(E(w_{II}) \geq E(w_c))$ is an indicator function equal to 1 if its argument is true, and zero if it is false. In the context of the present model it is assigned value 1 if the worker chooses to remain with the current employer, and zero if he switches to a competing firm in stage 2. A worker is expected to stay with the current employer in stage 2 if the condition $E(w_{II}) \geq w_c$ is satisfied, that is, if the worker is expected to obtain at least the same pay as offered by competing firms.

The logic behind the problem expressed by (1) is as follows. Firms attempt to maximize profits over stages 1-2 subject to the constraint that they must be at least able, in expected terms, to cover the initial investment

K plus the opportunity cost of capital r (this is implicitly stated by the definition of profit in eq. (1a) and by eq. (1b) as we assumed pay cannot be negative in any of the two stages, so eq. (1b) implies that it must be $\Pi \geq 0$). If no solution obtains a non-negative profit, the firm will choose $K = 0$ and consequently no bidding over pay will take place, so at the equilibrium pay will just be $W = \{0, 0\}$.

Because the supply of funds is assumed unconstrained and firms compete to attract workers, the bidding process over pay is such that workers extract all the surplus from firms (at the equilibrium, therefore, the inequality in eq. (1b) becomes an equality) so that, in equilibrium with non-negative investments, it must be verified in stage 1 that $w_I + E(w_{II}) + (1+r)K = E(V|K)$ if the worker is expected to stay with the firm in stage 2 (any lower w_I, given the expect value of w_{II}, would make some other firm offer a larger pay in stage 1 thus hiring the worker in lieu of the current firm), or it must be such that $w_I + (1+r)K = E(V|K)(1-l)$ if the worker is expected to switch employer in stage 2 (any lower w_I would again make some other firm offer a larger pay in stage 1, thus hiring the worker in lieu of the current firm). Whether the worker is expected to stay or to switch employer is determined by the combined effect of expected second-stage pay $E(w_{II})$ and the offer $E(w_c)$ expected at the market equilibrium by competing firms.

In a similar way, competing firms in stage 2 will compete to attract workers by bidding over pay w_c. At the equilibrium workers extract all profits Π_c from competing firms, so pay w_c is determined in stage 2 as:

$$\Pi_c = va = w_c \tag{2}$$

We assume an Utilitarian policymaker who is not concerned with how wealth is distributed among firms and workers. The social welfare associated with each invention is thus equal to $S = v(1-l+a) - (1+r)K$ if the worker chooses to switch employer, and to $S = v - (1+r)K$ otherwise.

4. Comparative statics

In this section we change the values a and l exogenously, and study the behavior of the agents at the market equilibrium. In order to make the discussion easier and without loss of generality we introduce the possibility that the values of a and l can diverge by a constant factor x which can either be positive or negative, so that:

$$x = a - l \tag{3}$$

within the interval of values such that $0 \leq a, l \leq 1$.

Generally whenever $x \leq 0$, knowledge complementarity is low or firms benefit from low levels of absorptive capacity. Therefore, a leaving worker produces harm to the current employer which is larger than the benefit he can bring to a new employer. A special case is $x = 0$ or equivalently $a = l$. This equates to assume that there are no knowledge spillovers and workers switching to a different employer in stage 2 transfer value between firms so that no destruction or creation of new value occurs, once the capital investment is set. In the following we refer to the case with $x = 0$ also as "pure knowledge transfers".

Whenever $x > 0$, the benefit received by a competing firm is always larger than the damage suffered by the original innovating firm when a worker switches employer. This can be interpreted as a scenario where knowledge is complementary to firm-specific characteristics so that knowledge generated in another firm is more productive than knowledge generated within the same firm. In the following we refer to the values of $x > 0$ also as "knowledge spillovers".

As a preliminary step we analyze the case where $l = 0$ and $a = 0$, which means competing firms enjoy no benefit from hiring workers from other firms in stage 2 (so they always offer $w_c = 0$). Because of the assumed full extraction of surplus by workers, total pay set in stage 1 must be such that $w_I + w_{II} = E(V|K) - (1+r)K$. The worker has no incentive to leave the firm in stage 2 regardless of the value produced, and leaving the firm would do no harm to the firm's profits as $l = 0$. Consequently, a rational worker realizes that in stage 2 the firm could offer him any $w_{II} < w_I$ and that he would be forced to accept it as the alternative payoff is zero. The competing bidding assumption demands that, in equilibrium, $w_I = E(V|K) - (1+r)K$ and $w_{II} = 0$. It is trivial to see that social welfare S is maximized without any policy intervention, as firms will invest capital to the amount K^* which maximizes $E(S) = E(V|K) - (1+r)K$ (as a side note: any other value of K would not allow to pay the worker as much, and as such in stage 1 the worker would be hired by another firm investing K^*).

Another boundary case is when $l = 1$ and $a = 0$. This means the worker can fully destroy the value generated by leaving the current employer, but competitors will always offer him $w_c = 0$. There are two polar situations to analyze (which are closely related to the perfect equilibrium concept discussed in Rubinstein (1982), assuming fixed bargaining costs such that agreement is reached after the first offer, and where the strong contractual part acts as first mover with lower bargaining costs). The first situation gives more contractual power to the firm. Interpreting this bargaining process as an equivalent Ultimatum game (Güth et al. 1982) where the firm acts as proponent and the worker as respondent, the worker faces the choice in stage 2 to accept any pay the firm offers him, or to obtain a payoff of zero. The Nash (sub-game perfect) equilibrium pay will be equal (or just above) $w_{II} = 0$. Therefore, the equilibrium in stage 1 will be $w_I = E(V|K) - (1+r)K$ and capital investment will be socially optimal.

The alternative polar situation when $l = 1$ and $a = 0$ gives the worker more contractual power than the firm. Using again the Ultimatum game representation but this time assigning the role of the proponent to the worker, the general solution obtains a second-stage pay equal to $w_{II} = vl$ (as any request for compensation larger than vl will always be rejected by the firm who could then obtain a payoff of $v(1-l)$). However, in the specific case we are analyzing, expecting $w_{II} = vl$ (and because $l = 1$, this obtains $w_{II} = v$) would mean the firm always expects negative profits for any $K > 0$ if w_I is bound to be non-negative, therefore firms anticipate this outcome and invest $K = 0$. In the following sections and unless stated otherwise we assume the first situation so that full contractual power is given to firms. We keep this assumption because we are only interested here in contractual power obtained by workers thanks to external employment options, while we are not interested in the possible effects of intrinsic contractual power (due to institutional factors like stronger labor unionization).

As a raises above zero, competing firms in stage 2 will offer a positive pay $w_c = av$ to the worker. Thus the employee receives a positive payoff from leaving the current employer in stage 2, and during stage 1 this positive payoff is expected to be equal to $aE(V|K)$.

At some value of a, the appropriability by competitors could be so large that no investment at all is done. If $(1-a+x)E(V|K) < (1+r)K$ or, equivalently if $a > 1+x-\frac{(1+r)K}{E(V|K)}$, the investment will be unfeasible, meaning that in expected terms the capital investment in case of switching will never be recovered. We label this feasibility threshold a^{**}:

$$a^{**}|_{x>0} = 1 + x - \frac{(1+r)K}{E(V|K)} \tag{4}$$

If $a > a^{**}$, a firm would need to offer a negative pay in stage 1 (a possibility we ruled out by assumption) to expect to retain the worker in stage 2. If the worker switches in stage 2 and $a > a^{**}$, the residual revenues $E(V|K)(1-a)$ are insufficient to cover the capital investment. Note that here capital intensity is relevant because a larger share $\frac{(1+r)K}{E(V|K)}$ of capital over produced value lowers a^{**} and makes more R&D projects unfeasible.

As the sections that follow will discuss, when $x \leq 0$ workers are expected to never switch employer. In such cases the expression for the feasibility threshold reduces to:

$$a^{**}|_{x\leq 0} = 1 - \frac{(1+r)K}{E(V|K)} \tag{5}$$

The intuition behind eq. (5) is that for some large enough second-stage pay $w_{II} = aE(V|K)$ that makes the worker stay, the initial investment would never be recovered. And if the worker is allowed to switch employer by offering him w_{II}, the loss in value $lE(V|K)$ would be not smaller than this pay w_{II} as $x \leq 0$ means that $a \leq l$.

As a generalization to eq. (4) and (5) we can then write the feasibility threshold as:

$$a^{**} = 1 + 1(x>0)x - \frac{(1+r)K}{E(V|K)} \tag{6}$$

which makes the addendum x disappear if the worker is expected to switch employee, therefore when $x > 0$.

We can think of the values of a (assumed, as already stated, to be project-specific) as following some probabilistic distribution that is industry-specific. Some projects for which $a > a^{**}$ would be anticipated to be unfeasible and therefore not funded at all. This is the reason why it could be socially desirable to undertake a policy action with the aim to increase the threshold value a^{**}, even if the general level of capital investments for funded projects is already optimal.

An original innovating firm will invest capital in a feasible investment up to (from problem (1)):

$$\frac{\partial E(V|K)}{\partial K}|_{x\leq 0} = 1 + r \tag{7}$$

if it expects the worker to stay, and up to:

$$\frac{\partial E(V|K)}{\partial K}|_{x>0} = \frac{1+r}{1-a+x} \tag{8}$$

if it expects the worker to switch. As done before for the feasibility threshold we can generalize eq. (7) and (8) and write them as:

$$\frac{\partial E(V|K)}{\partial K} = \frac{1+r}{1+1(x>0)(x-a)} \tag{9}$$

4.1 Case with $x \leq 0$

If $x \leq 0$, a worker will never switch employer. The payoff for the original firm in case of switching is indeed always smaller or equal to the payoff obtained with a worker staying because the inequality $E(V|K)(1-a) \geq E(V|K)(1-l)$ is always true (also refer to Pakes & Nitzan (1983) who obtain a similar conclusion). Consequently, workers will always stay with the current employer if $x \leq 0$. The minimum wage which makes a worker stay in stage 2 is $E(V|K)a$. Pay in stage 2 for a feasible investment with worker staying is therefore:

$$E(w_{II}) = E(V|K)a \tag{10}$$

and the equilibrium wage in stage 1 for a feasible investment with a worker staying is:

$$w_I = E(V|K)(1-a) - (1+r)K \tag{11}$$

Note that the level of capital investment for a feasible investment is given by eq. (7) and is equal to the socially optimal level obtained by maximizing eq. (15).

After the specific innovation value v is known to agents at the end of stage 1, pay offered in stage 2 will change accordingly. Competing firms will offer $w_c = av$ and as such the original innovating firm will have to offer $w_{II} = av$ to retain the worker. The model therefore predicts a pay w_{II} which monotonically increases with the value of the innovation. This is coherent with the empirical evidence discussed in section 2..

In order to obtain bonus pay in stage 2, or equivalently to obtain that $w_{II} > w_I$ on average (as per empirical evidence discussed in section 2.), several conditions have to be fulfilled. The only case that can produce the empirical regularity according to which $E(w_{II}) > w_I$ is the case where $x \leq 0$ and $a < a^{**}$, which means the investment is feasible and the worker is expected not to switch. Pay in stage 2 will be larger than in stage 1 if the inequality $E(V|K)a > E(V|K)(1-a+x) - (1+r)K$ holds (this inequality is simply obtained by substituting eq. (10) and (11) into $E(w_{II}) > w_I$), or equivalently after rearranging:

$$a > a^{bonus} = \frac{1+x}{2} - \frac{(1+r)K}{2E(V|K)} \tag{12}$$

We obtain therefore the result that the level of capital intensity in the generation of innovations is an important parameter in defining how pay is structured. Eq. (12) tells that, other things the same, for less capital-intensive R&D productions a lower amount of positive knowledge spillovers is needed to obtain $E(w_{II}) > w_I$, consequently it is more likely to observe such pay structure in high-capital R&D industries with low absorptive capacity. Put in a slightly different perspective, this result can be rephrased by stating that more capital-intensive innovations (and maybe more radical innovations, for which competing firms hardly possess the right kind of absorptive capacity) are more likely to generate the empirical regularity which suggests an increase in pay around the time of patent application.

The last result adds an additional interpretation to the findings of previous literature pointing to the more intense use of bonus pay in the IT industry: it might be that the particular combination of moderate capital intensity in R&D, potentially highly mobile workforce and low absorptive capacity (not large enough to compensate for the losses caused in the original innovating firms) makes it optimal to provide a two-stage pay structure, where bonuses offered at the time an innovation is produced serve the purpose of capturing the worker and retain him within the firm.

4.2 Case with $x > 0$

When $x > 0$, the payoff for the original innovating firm in case of switching is always larger than the payoff obtained with a worker staying because the inequality $E(V|K)(1-a) < E(V|K)(1-l)$ is always true. Consequently, the pay structure will be such that workers will always switch employer if $x > 0$. For a feasible investment with switching worker the equilibrium pay in stage 1 will be equal to:

$$w_I = E(V|K)(1-a+x) - (1+r)K \tag{13}$$

and pay in stage 2 will be such that $w_{II} = 0$ and $w_c = va$.

As a side note, this case would make any *ex ante* contract with clawback clauses inapplicable. Because workers anticipate that they will switch and so $E(w_{II}) = 0$, any contract offered with a larger pay in stage 1 and lower promised pay in stage 2 will be preferred. The equilibrium *ex ante* contract would therefore be $W = \{w_I = E(V|K)(1-a+x) - (1+r)K, w_{II} = 0\}$ exactly as per eq. (13).

5. Policy implications

How should a policymaker intervene in this market? As previously stated we assume an Utilitarian policy maker so the optimal investment maximizing welfare S is set regardless of how value is split between firms and workers, or between the original innovating firm and competing firms. The socially optimal capital investment, in case of workers switching employers, is such that it maximizes:

$$S = E(V|K)(1+x) - (1+r)K \tag{14}$$

If workers stay with the current employer, the socially optimal capital investment is such that it maximizes:

$$S = E(V|K) - (1+r)K \tag{15}$$

Three policy tools are identified here:

1. A patent box tax incentive p, that is a reduced tax rate on profits earned from a patented invention, can increase profits obtained by firms from innovative projects. This means that all firms receive an increased payoff in stage 2. The patent box analyzed here is modeled as a subsidy and assumed to apply a multiplier $(1+p)$ to revenues (gross of R&D costs) generated by any patented innovation.
2. A subsidy τ to the cost of capital invested in R&D can reduce the value of r so that, *ceteris paribus*, more capital is invested and also (by rising a^{**}) more projects get funded.
3. A tax incentive t on bonus pay in stage 2 is introduced, so that for each monetary unit of w_{II} paid to the worker, an additional $w_{II}t$ is paid to him as a subsidy.

The combined effect of patent box and R&D subsidy policies on capital investments in stage 1 is summarized by the following modified first-order condition to be compared with eq. (9):

$$\frac{\partial E(V|K)}{\partial K} = \frac{1 + r(1-\tau)}{[1 + 1(x>0)(x-a)](1+p)} \tag{16}$$

while their combined effect on the feasibility threshold, to be compared with eq. (6), is:

$$a^{**} = 1 + 1(x \leq 0)x - \frac{w_I + (1+r)K}{(1+p)E(V|K)} \tag{17}$$

We will discuss each policy tool in turn.

1) First, note that a patent box might be somewhat ineffective in this context. A patent box acts on both the original innovating firm and on competing firms, assuming the latter also patent their derived innovations. Therefore, as all revenues are increased by multiplying them by $(1+p)$, $E(w_{II})$ is raised to $E(w_{II}) = E(V|K)a(1+p)$, which in turn makes pay in stage 1 with $x \leq 0$ equal to $w_I = E(V|K)(1-a)(1+p) - (1+r)K$. A consequence of this shift of pay from stage 1 to stage 2 is that the threshold a^{**} could become smaller and consequently less projects get funded. We can prove that this worry is not founded, however, as the threshold for R&D funding with a patent box policy in the general case is given by eq. (17) and therefore, $\frac{\partial a^{**}}{\partial p} > 0$.

From eq. (16) we see that a patent box induces more investment in stage 1. However because from eq. (15) we obtain that with $x \leq 0$ the socially optimal investment is given by $\frac{\partial E(V|K)}{\partial K} = 1 + r$, the patent box results in in overinvestment when $x \leq 0$. When $x > 0$ and without policy intervention the original innovating firms invests by solving the FOC given by eq. (8), but this level of investment is lower than the socially optimal investment given by eq. (14). Hence a patent box is able in the latter case to induce larger (and thus socially preferable) investment.

2) A subsidy (or tax incentive) to R&D allows to reduce the opportunity cost of capital r by $(1-\tau)$. Similarly to a patent box it can increase the threshold a^{**} (refer again to eq. (17)) thus making more projects funded. But again as the patent box, it produces overinvestment when $x \leq 0$, while it can correct for underinvestment when $x > 0$.

3) Let us now analyze the third policy tool. First, notice that by definition it only applies to the cases when $w_{II} > 0$, thus to cases where the worker does not switch. By increasing the pay received by the worker in stage

2 without directly affecting the cost for the employer, this policy is equivalent to introducing a tax wedge $(1+t)$ so that, in equilibrium (in order not to make the worker switch) firms expect that $E(w_{II})(1+t) \geq E(w_c)$ or equivalently:

$$E(w_{II}) \geq \frac{E(V|K)a}{(1+t)} \tag{18}$$

If the investment is feasible, K will now be chosen to satisfy:

$$\frac{\partial E(V|K)}{\partial K} = 1 + r \tag{19}$$

therefore obtaining the socially optimal level. The participation threshold will be:

$$a^{**} = \left[1 - \frac{(1+r)K}{E(V|K)}\right](1+t) \tag{20}$$

thus the feasibility threshold is affected by t.

On the contrary when $x > 0$ a bonus pay subsidy t does not work well. Either a bonus pay subsidy is too small to affect a^{**} because there is no pay w_{II} which is such to keep the worker from switching and at the same time make expected profits non-negative, or the subsidy is large enough to make the worker decide not to switch employer anymore which would make society lose produced value equal to $E(V|K)x$.

The previous considerations are summarized in the following two Propositions.

Proposition 1: When $x > 0$ the optimal innovation policy is made of a combination of $p \geq 0$, $\tau \geq 0$ and $t = 0$.

Proposition 2: When $x \leq 0$ the optimal innovation policy is made of a combination of $p = 0$, $\tau = 0$ and $t \geq 0$.

6. Some further considerations

In this section we modify some assumptions, first introducing capital investments also by competing firms, then modifying the structure of the game so that information about the innovation value is first known to the original firm and inventor only (thus introducing information asymmetry in the first stage of the game), and finally we consider overlapping stages where the worker can also be hired in stage 2 to commence an entirely new R&D project.

6.1 Capital investments from competing firms

In previous sections we assumed that competing firms can reap the benefits from a new hire without investing any capital. Regardless of how we interpret their doing (as imitation or as production of a new innovation) it is reasonable to believe that they will also need to engage in an investment and that such investment will be not larger than the capital investment made by the original innovating firm. If we further postulate that such investment is perfectly proportional to the original investment by a factor $0 \leq i \leq 1$ such that the cost of capital for the competing firm is $(1+r)iK$, then following exactly the same procedure as per section 4. the expected wage in stage 2 will be:

$$E(w_{II}) = E(V|K)a - (1+r)iK \tag{21}$$

and the equilibrium wage in stage 1 for a feasible investment with a worker staying is:

$$w_I = E(V|K)(1-a) - (1+r)(1+i)K \tag{22}$$

while the equilibrium pay in stage 1 for the case with switching worker remains the same as in section 4..

Two aspects are worth noting. First, the condition for which $E(W_{II}) > w_I$ is exactly the same as the one expressed in eq. (12). Second, also the feasibility threshold a^{**} is still expressed as in eq. (6) and the investment from the original innovator will be still chosen to satisfy eq. (9). Even though the levels of pay change when we introduce investments from competing firms, the qualitative implications for optimal policy are not modified.

6.2 The original innovating firm knows about the innovation value before competing firms

Throughout previous versions of the model we assumed that at the end of stage 1, all parties in the market (the original innovating firm, competing firms, and workers) know the exact value v of the produced innovation. However it could be argued that before a patent application, the original innovating firm and inventor enjoy an informational advantage over anyone who is not within the boundaries of the original innovators' organization.

To study how this kind of advantage might shape inventors pay we now modify the model presented in sections 3. and 4. by splitting the first stage into two sub-stages, which we label 1A and 1B. In stage 1A the value of the innovation is still unknown to anyone in the market, but the amount of capital invested by each firm is public information (this seems realistic enough, as companies are bound to produce public accounting reports at least once per year). At the end of stage 1A, both the inventor and the original innovating firm know the exact value v, but all other firms and workers do not know it yet. Only at the end of stage 1B it will be verified that all other firms and workers will also perfectly know v. If a worker leaves the firm in stage 1B, the payoff for the original firm will be $v(1-2l)$; if the worker leaves in stage 2 the payoff will be $v(1-l)$. A switching worker can bring expected benefit $E(V|K)a$ to a competing firm either in stage 1B, or in stage 2, or in both.

We follow the procedure applied before. Pay in stage 1B is the outcome of a bargaining process between the original employer and the worker, and they both perfectly observe v. But, as competing firms know that such worker has produced an expected value of $E(V|K)$ (because the production function $f(.)$ is the same for every firm and because investments K are also known by assumption) they will offer him a pay $w_{cIB} = E(V|K)a$ in stage 1B, and $w_cII = va$ in stage 2 when they can observe v. The pay structure at the equilibrium therefore, in expected terms and with the original innovating firm expecting the worker to stay, must be such that $w_{IA} = E(V|K)(1-2a) - (1+r)K$, $w_{IB} = E(V|K)a$, $w_{II} = E(V|K)a$.

Ex post at the beginning of stage 1B when the value v is known by the original innovating firm, this firm has no reason to deviate from $w_{IB} = E(V|K)a$ as long as $v(1-2l) < v(1-a) - E(V|K)a$, or equivalently as long as the innovation value is large enough to satisfy:

$$v \geq v^* = \frac{a}{a-2x}E(V|K) \tag{23}$$

With pure knowledge transfers ($x = 0$) any innovation of value not smaller than $E(V|K)$ makes the pay w_{IB} equal to $E(V|K)a$ in stage 1B, provided the original innovating firm has enough room to make the worker not to switch and still cover capital costs. Values of v smaller than v^* make the original firm offer a pay $w_{IB} < E(V|K)a$ so the worker will switch in stage 1B and therefore $w_{II} = 0$. As x increases it needs a progressively smaller value v to make pay decrease and workers switch in stage 1B.

If v is larger than v^*, in stage 2 the original innovating firm is capable to offer the worker up to $(1+a)v - aE(V|K)$, because of the fact that in stage 1B the firm did not have to raise pay above expected values predicted in stage 1. This kind of information asymmetry therefore gives original innovating firms more room for retaining their workers in case the innovation produced has large value.

These results bring additional insight. Under the kind of asymmetric information discussed here, the larger the actual value produced $v > v^*$ and the larger net spillovers x are, the more likely is to observe a rise in pay around patent application. Note however that the last result goes in the opposite direction in comparison to what we got from eq. (12). Consequently we cannot make a general prediction about the sign of the relationship between spillover intensity and bonus pay use, without first assessing the exact nature of the timing of information and its availability to agents not belonging to the original innovating firm.

6.3 Overlapping stages

So far we considered each game in isolation, meaning that under some conditions it was acceptable that a worker received a pay of zero in the second stage. We here amend the model and consider the possibility that in stage 2, a worker can be hired by another firm (or by the same current employer) to enter into an entirely new R&D project. In this way, each stage 2 can become the stage 1 of another project.

The consequence of this new assumption is that in each stage the pay w_{II} or w_c cannot be lower than the equilibrium w_I, because otherwise a worker would always switch to a new employer to start a new project. If in stage 2 it is true that $aE(V|K) > w_I$ then this has no consequences as the worker would nevertheless either stay with the original innovator receiving a bonus pay of $w_{II} = aE(V|K)$, or switch to a competing firm paying $w_c = aE(V|K)$. For $x > 0$ and $a < a^{**}$ this new version of the model changes nothing, except for the fact that if the innovation value is low enough so that $va < w_I$, the worker in stage 2 is rehired by the original innovating firm in a new project with pay w_I instead of switching to another employer. The original innovating firm's payoff is still $v(1-l)$ and the social payoff is also $v(1-l)$, which is lower than the socially optimal value $v(1+x)$ obtained when a worker switches. Again, for $x > 0$ the optimal policy would employ R&D incentives or a patent box to increase capital investments.

If $x \leq 0$ and $a < a^{**}$ the investment is feasible and the worker stays with the firm. However, notice that in stage 2 any value of the innovation such that $aE(V|K) < w_I$ makes the employer offer w_I, allocate the worker to a new project and earn a payoff of $v(1-l)$. Two consequences stem from these considerations.

First, in expectancy when $a < a^{bonus}$ the firm always expects that $w_{II} < w_I$, so the firm has to anticipate that the payoff will always be $E(V|K)(1-l)$ as the worker will always be reallocated. This causes underinvestment and requires, as per the case with $x > 0$ (and differently from the base model we discussed in sections 3. and 4.), to use R&D incentives or a patent box to increase capital investments. After setting p and τ so that investment is equal to the social optimum level, a positive t can be employed to further increase the number of funded projects. The previous considerations are summarized in the following two Propositions.

Proposition 3: When $x > 0$ and with overlapping stages, the optimal innovation policy is made of a combination of $p \geq 0$, $\tau \geq 0$ and $t = 0$.

Proposition 4: When $x \leq 0$ and with overlapping stages, the optimal innovation policy is made of a combination of $p \geq 0$, $\tau \geq 0$ and $t \geq 0$.

Second, because the actual value v will sometimes be so low that the worker is reallocated and paid w_I this assumption would produce a more stable pay structure. A worker would on average stay with the original employer and earn w_I, while occasionally receiving a bonus $w_{II} > w_I$ when the value of a produced innovation is large enough. This stability in pay over time is very likely when the distribution of innovation is highly skewed (and the real distribution appears indeed to resemble a Log-Normal or Pareto distribution, see Giuri et al. 2007, Harhoff et al. 2003) so that the majority of innovations have low value but a minority can produce large upswings.

In conclusion, overlapping stages as discussed in the present section produce a more stable pay structure, but do not affect the qualitative results derived in the previous versions of the model. One exception which provides a different policy implication is that also in the case with $x \leq 0$ a policymaker should employ R&D incentives or a patent box in order to increase investments in R&D, together with a bonus pay incentive.

7. Conclusions

The model presented in this study combines employed inventors mobility under competition for talent with a multi-stage innovation process, capital investments in R&D and knowledge externalities. The model assumes full (potential) mobility of workers and provides general conditions under which we can expect pay to be increasing at the time of a patent application. It was shown that these conditions are function of the level of knowledge spillovers caused by labor mobility, of absorptive capacity possessed by competing firms, and of capital intensity. The model provides some testable assertions: it should be more common to use bonus pay at the time of a patent application in industries or firms where the R&D process features larger capital intensity and when innovations are highly profitable.

As per the intensity of knowledge spillovers, results are mixed and the exact sign of the relation was found to depend upon how information about the value of an innovation is made available to all parties involved before the time of a patent application. When the original innovating firm and employed inventor enjoy an informational advantage and can assess the value of the produced innovation some time before patent application, larger spillovers make it more likely to observe bonus pay. When the harm caused to the original innovating firm due to an inventor switching employer is larger than the benefit produced for the new employer, bonus pay becomes less likely as the gap between the harm and the benefit reduces. The latter situation may represent a market with weak IPR protection and low absorptive capacity.

We then compared different policies designed to foster R&D investments. On the intensive margin, R&D subsidies or a patent box can be employed to increase the amount of capital investments. However, if knowledge is simply transferred between firms without causing any aggregate increase or decrease in productivity or if the benefit obtained by competing hiring firms is smaller (maybe because of low absorptive capacity, or because of intrinsic characteristics of the new technology) in comparison to the market rivalry effect suffered by original innovating firms loosing their inventors, it was shown that such policies can cause overinvestment in R&D projects that would anyway be funded. A policy based on a bonus pay subsidy can instead increase the feasibility and therefore the number of funded R&D projects characterized by high inappropriability without affecting capital investment decisions. The model therefore supports, under given circumstances, the use of tax incentives for R&D on the bonus pay of employed inventors as a first-choice means to increase the aggregate amount of R&D done and correct for a specific form of market failure attributable to potential inventors' mobility across firms.

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