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Why are researchers paid bonuses? On technology spillovers and market rivalry

Diego d'Andria[1]

European Commission, Joint Research Centre – Unit B.2 Fiscal Policy Analysis, Seville, Spain

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ABSTRACT

A temporary change in pay to employed inventors around the time of patent application has been documented. 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 each with different access to information about the innovation value for firms. 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 underinvestment 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.

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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 (Stern, 2004; Cohen and Sauermann, 2007; Sauermann and Cohen, 2010) appear to be important drivers for inventors' decisions about where to work (Roach and Sauermann, 2010; Akcigit et al., 2015) and, possibly, about the allocation of time and effort among multiple job tasks (Manso, 2011; Hellmann and Thiele, 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 and 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 *à la* Rosen (1981), workers in the model extract all the surplus from firms thanks to a competitive

E-mail address: diego.dandria@gmail.com

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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. Some of the key assumption of our model are also discussed. Sections 3 and 4 present the general framework and solve the model to obtain equilibrium pay and capital investment. Section 5 derives the relevant policy implications from a reduced model based on expected values. Section 6 concludes.

2. Previous literature

2.1. *The mobility of workers, knowledge spillovers, and innovation*

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: Saxenian, 1996; Almeida and Kogut, 1999; Scarpetta and Tressel, 2004; Miguélez and Moreno, 2013) 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 and 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 and 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 (Pakes and Nitzan, 1983; Møen, 2005; Franco and Filson, 2006).

2.2. *Profit sharing pay, innovation, and mobility*

With regard to the pay structure, Balkin and 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 and Väänänen, 2012) or patent application (Depalo and 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 and Di Addario (2014) are obtained in a 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 and 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 and Uebelmesser, 2014 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 and Väänänen (2012) and Depalo and 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 and Yao, 2004; Hsu and 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 and Uebelmesser, 2014) 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.

2.3. Main assumptions of the model

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.

For simplicity we assume that firms always patent their innovations. This is not in line with the empirical evidence (in Cohen et al., 1997; Arundel, 2001; Kim and Marschke, 2005) which shows that many innovations are not subject to intellectual property, or not stemming from (formal) R&D activities. As the patent application event is assumed to signal to all competing firms the value of the produced innovation, the model cannot apply to innovations that are protected by secrecy, nor it applies to innovations that are protected by forms of property rights (i.e. copyrights and trademarks) that do not require to file an application disclosing detailed information on the innovation itself before it is commercialized. Therefore, the model describes forms of technological innovations, valuable enough to surpass the costs associated with patent application, and with imitation having characteristics such that secrecy is not as viable as property rights to protect the company interests.

We build on Pakes and Nitzan (1983) but moving the focus of the analysis on a specific event (a patent application) that makes information about the innovation value public. Differently from Pakes and Nitzan (1983) we do not consider heterogeneous skills levels for inventors, and 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 and Nitzan (1983) we 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 and 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 and Zwiebel, 1996a,b), so that pay has to be recontracted in each period.[2] We consider a three-phase innovation and firms offering three separate wages in each phase. Workers and firms form expectations about the second and third phases, so the way pay is formed at the equilibrium in the first phase also depends upon said expectations. The second and third phases are divided by a patent application event that makes the value of the innovation under development known to all parties. During the second phase, the value of the produced innovation is not known

[2] As an alternative setting contracts might be fully specified *ex ante*, for example by allowing firms to offer profit sharing schemes that provide a share of the value that will be produced in later stages 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 the later stage 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 later stages 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 the initial stage to later stages, without affecting the main arguments and results presented in the following sections.

to competing firms, but is perfectly observed by the original innovating firm and its employees.

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 and Zwiebel, 1996a) 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.

From now on we will employ the following notation:

- superscript O indicates the Original Innovating Firm, while superscript C is for (any of the) Competing Firm(s);
- the 3 stages of the game are labeled I, II, III;
- wages offered by O are w_I, w_{II}, w_{III}, respectively for stages I, II, III;
- wages offered by C are w_{II}^C, w_{III}^C, respectively for stages II, III;
- function $1(\cdot)$ is Boolean: it returns 1 if the expression within brackets is true, and zero otherwise;
- we write 1_X to indicate that $1_X = 1$ if the worker leaves O in period X, with X taking values "stay" (meaning the worker never leaves), II or III. Therefore, $1_{stay} = 1$ iff $1_{II} = 0$ and $1_{III} = 0$;
- a competing firm C needs to invest a share $i_X K$ of capital in stage X to benefit from the 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 I and compete to attract workers by offering them a pay w_I. When considered in the role of competing firms, firms in stages II and III try to attract workers from R&D projects started in stage I. In stages II–III 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 I) and as competing firms (for all other projects in the market).

As already stated, each period is divided into three 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. The wage w_I can be also though of as the wage that equalizes to the average marginal product of labour in this market. At the end of stage I, each worker produces an invention of value v, drawn from a distribution of values $V = f(K)$ with expected value $E(V|K)$. Function $f(\cdot)$ 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 known only to the firm and employee that produced it at the end of stage I.[3] At the end of stage II, the value v is perfectly known to all firms and workers in the market. The assumption is that at the end of stage II 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.

In stage II each worker is offered a pay w_{II} from his current employer, and a pay w_{II}^C by competing firms. Similarly in stage III each worker is offered a pay w_{III} from his current employer (if he is still employed at the same firm hiring him in stage I), and a pay w_{III}^C by competing firms. Moreover a worker can be hired by another firm (or by the same current employer) to enter into an entirely new R&D project, paid w_I. In this way, each stage II or III can become the stage I of another project and the wage w_I is always the minimum level of earnings a worker can get. If a competing firm manages to attract a worker in stage II or III, 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_X^C offered to inventors in stage X. The worker chooses whether to remain with the former employer if $w_X \geq w_X^C$ (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 III, each worker knows his final payoff which is either: $w_I + w_{II} + w_{III}$ if he stayed all stages with the same employer, or $w_I + w_{II} + w_{III}^C$ if he left the employer in stage III for an imitating firm, or $w_I + w_{II}^C + w_I$ if he left the employer in stage II for an imitating firm and was hired for a new project in stage III, or $w_I + w_{II} + w_I$ if he leaves the initial employee in stage III for a new project, or finally $w_I + w_I + w_I$ if he is hired for new projects in each stage.

The logic behind the problem expressed in the model is as follows. Firms in stage I attempt to maximize expected profits over stages I–II–III 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. If no solution obtains a non-negative profit, the firm will choose $K = 0$, no worker is hired and consequently no bidding over pay will take place.

Firm O sets K in stage I, given the exogenous wage w_I and the expectations the firm has w.r.t. wages in stages II and III, to solve the following maximization problem:

$$\max_K \Pi_O = E(V|K)(1_{stay} + 1_{II}(1 - l_{II}) + 1_{III}(1 - l_{III})) - (1 + r)K \qquad (1)$$

$$\text{s.t.} \quad \Pi_O \geq w_I + E(w_{II})(1 - 1_{II}) + E(w_{III})(1 - 1_{III}) \qquad (2)$$

$$\text{s.t.} \quad E(w_{II}) \geq w_I \qquad (3)$$

$$\text{s.t.} \quad E(w_{III}) \geq w_I \qquad (4)$$

Condition (2) requires expected profits in stage I to be non-negative. Conditions (3) and (4) impose that expected wages

[3] Alternatively also the original innovating firm and its worker might be uncertain about the value of the innovation in stage II. This different assumption does not affect any relevant part of the model, except for the fact that it may increase wage in stage II and reduce wage in stage III. This will be further clarified in the following sections.

offered by O in stages II–III cannot be below the exogenous wage w_I.

Firm C in stage II expects to obtain:

$$\Pi_C = E(V|K)a_{II} - (1+r)i_{II}K \quad (5)$$

$$\text{s.t.} \quad \Pi_C \geq w_{II}^C \quad (6)$$

$$\text{s.t.} \quad w_{II}^C \geq w_I \quad (7)$$

while in stage III it expects to obtain:

$$\Pi_C = va_{III} - (1+r)i_{II}K \quad (8)$$

$$\text{s.t.} \quad \Pi_C \geq w_{III}^C \quad (9)$$

$$\text{s.t.} \quad w_{III}^C \geq w_I \quad (10)$$

Again the constraints require C to obtain non-negative profits and to offer wages that are never below w_I. We now solve the game by backward induction.

3.1. Stage III

In order to attract the worker, C offers him a wage $w_{III}^C = va_{III} - (1+r)i_{III}K$ if, and only if, $w_{III}^C \geq w_I \geq 0$.

Firm O offers the worker $w_{III} = w_{III}^C$, if and only if $v(1 - l_{III}) - w_I - w_{II} - (1+r)K \leq v - w_I - w_{II} - (1+r)K - w_{III}$, or equivalently, iff $w_{III} \leq vl_{III}$ (that is, if keeping the worker is better than let him go). Otherwise if C offers zero (because no wage $w_{III}^C \leq w_I$ exists that generates non-negative profits for C), O will offer $w_{III} = w_I$.

The worker leaves O (and consequently 1_{III} is true) if $vl_{III} < \max(va_{III} - (1+r)i_{III}K, w_I)$. Note that, given the initial values for $(1+r)K$ and w_I, 1_{III} only depends upon the vector $[v, l_{III}, a_{III}, i_{III}]$.

3.2. Stage II

C offers now a wage $w_{II}^C = E(V|K)a_{II} - (1+r)i_{II}K$ iff $w_{II}^C \geq w_I \geq 0$.

O will offer $w_{II} = w_{II}^C$ iff $v(1 - l_{II}) - w_I - (1+r)K \leq (v - E(w_{III}))1_{stay} + v(1 - l_{III})1_{III} - w_{II} - w_I - (1+r)K$, or equivalently, iff $w_{II} \leq (v - E(w_{III}))1_{stay} + v(1 - l_{III})1_{III} - v(1 - l_{II})$. Otherwise, it will offer $w_{II} = w_I$ if $w_{II}^C = 0$.

Note that in stage II, $E(w_{III}) = [va_{III} - (1+r)i_{III}K]$ in the case that the worker stays for all three stages.

The worker leaves O in stage II (and thus 1_{II} is true) if $(v - E(w_{III}))1_{stay} + v(1 - l_{III})1_{III} - v(1 - l_{II}) < \max(E(V|K)a_{II} - (1+r)i_{II}K, w_I)$. Given the initial values for $(1+r)K$ and w_I and the expectations $E(V|K)$ of the competing firms, and also given that in previous section we derived that the value of 1_{III} only depends upon the vector $[v, l_{III}, a_{III}, i_{III}]$, then 1_{II} only depends upon the vector $[v, l_{II}, a_{II}, i_{II}, l_{III}, a_{III}, i_{III}]$.

3.3. Stage I

Firm O offers the following wage in stage I:

$$w_I = E(V|K)[1_{stay} + 1_{II}(1 - l_{II}) + 1_{III}(1 - l_{III})]$$
$$- (1+r)K - E(w_{II})(1 - 1_{III}) - [E(w_{II}) + E(w_{III})]1_{stay} \quad (11)$$

Eq. (11) means that, if the worker is expected to leave in II, O will expect both wages in II and III to be zero and thus w_I will be equal to the full net value of the innovation (reduced by $(1 - l_{II})$). If the worker is expected to leave in III, then $E(w_{II})$ is positive and so w_I reduces accordingly, while innovation value is reduced by $(1 - l_{III})$. Finally, if no leave is expected, then w_I will be equal to the full net innovation value, less the expected wages to be paid in II and III.

The expected wage values at stage I are:

$$E(w_{II}) = E(V|K)a_{II} - (1+r)i_{II}K \quad (12)$$

and

$$E(w_{III}) = E(V|K)a_{III} - (1+r)i_{III}K \quad (13)$$

respectively in case the worker does not leave in II, or does not leave at all.

Given that we already derived the conditions for having 1_{II} or 1_{III} (and therefore also for having 1_{stay}), we determined the expected values for wages in stages II and III (see Eqs. (12) and (13)), and the expectation are assumed homogeneous across firms, the value of the market wage w_I is uniquely determined by Eq. (11).

4. Wage setting and initial investment

The model is such that wages offered by O are function of O's expected losses (l_{II} and l_{III}) and C's expected gains (a_{II} and a_{III}), given an innovation $[E(V|K), v]$ and the investment structure for C, represented by $[i_{II}, i_{III}]$. When the values in $[E(V|K), v]$ are low enough the worker simply stays with O and earns w_I in each stage. In the following discussion we focus on the more interesting case where both $[E(V|K), v]$ are large enough to trigger competition between O and C.

In stage I, firm O also needs to decide about the level of its investment K. From the optimization problem in (1) we obtain the first order condition:

$$\frac{\partial E(V|K)}{\partial K} = \frac{(1+r)}{1_{stay} + (1 - l_{II})1_{II} + (1 - l_{III})1_{III}} \quad (14)$$

We assumed (see Eq. (2)) that all and only investment with non-negative expected profit will be started. As the values $E(w_X)$ are increasing function of a_X, there can be some large enough value a_X^{**} in either stage II or III that makes expected profits negative in case the worker remains with O in stage II and (or) stage III. In the latter case because of the assumption that $E(V|K)$ is marginally decreasing in K (while the quantities $-(1+r)i_XK$ are linear in K), the optimization process leads O to lower K until either positive expected profit is obtained (satisfying condition (14)), or if no positive profit is found for any K the investment is not started at all.

In this section we assume that $a_{II} < a_{II}^{**}$ and $a_{III} < a_{III}^{**}$, so the investment always produces positive profits in expectancy and thus the amount of capital K is always positive. This is done as we are here interested in how the parameters may shape the structure of wages over time. In Section 5 we will amend the assumption that $a_{II} < a_{II}^{**}$ and $a_{III} < a_{III}^{**}$ and we will discuss the extensive margin of investment from a policy perspective.

4.1. Cases with worker staying

As a first step we start from the case where the innovation value is fully rival and losses and benefits are symmetrical, so that $l_{II} = a_{II}$ and $l_{III} = a_{III}$. Because competing firms should make an investment $(1+r)i_XK$ to benefit from the new hire, O is always at an advantage and will always keep the worker offering him $w_{II} = E(V|K)l_{II} - (1+r)i_{II}K$ and $w_{III} = vl_{III} - (1+r)i_{III}K$. This is rather intuitive: the larger the investment C has to make, the lower the wage offered by O in stages II and III; the larger the realized value v, the larger the wage that O offers in stage III (when C also observes v). On average, when therefore $v = E(V|K)$, the structure of wages $[w_I, w_{II}, w_{III}]$ is uniquely determined by $[a_{II}, a_{III}]$ (equivalently by $[l_{II}, l_{III}]$) and by $[i_{II}, i_{III}]$.

In order to obtain an evolution of wages around patent application time that resemble the empirical evidence discussed in previous sections (that is: first increasing, peaking at the application time, and then decreasing), one needs that $E(V|K)a_{II} - (1+r)i_{II}K > w_I$ and that $a_{II} \gg a_{III}$ or $i_{II} \ll i_{III}$. The condition $l_{II} = a_{II} \gg l_{III} = a_{III}$ makes sense from the point of view of realism: it is likely that the harm suffered by O is larger if the worker leaves at earlier stages of the innovation process. The condition $i_{II} \ll i_{III}$ means that C has to invest more in III than in II to get the same result. The latter condition is questionable, as it may well be that earlier phases of the innovation process require larger investments than development phases (this really depends upon the specific kind of innovation under scrutiny).

More generally it can be that $l_{II} \geq a_{II}$ and $l_{III} \geq a_{III}$. In these cases the very same consideration done for the symmetric case apply: O will offer $w_{II} = E(V|K)a_{II} - (1+r)i_{II}K$ and $w_{III} = va_{III} - (1+r)i_{III}K$ in stages II and III and will retain the worker. Note that what sets the levels of wages is not the expected harm l, but the expected benefit a from competitors.

In this case as the worker never leaves O, $1_{stay} = 1$ and the f.o.c. for capital investment in Eq. (14) reduces to $\frac{\partial E(V|K)}{\partial k} = (1+r)$. This means that the capital investment is determined solely by its rate of return and cost of capital r, regardless of the levels of the wages across the three stages. The latter result will be relevant in the next section dedicated to policy.

4.2. Cases with worker moving to competitors

We derived before that the worker leaves O in III if $vl_{III} < \max(va_{III} - (1+r)i_{III}K, w_I)$, and leaves O in II if $(v - E(w_{III}))1_{stay} + v(1 - l_{III})1_{III} - v(1 - l_{II}) < \max(E(V|K)a_{II} - (1+r)i_{II}K, w_I)$. This happens if the differences $l_{III} < a_{III}$ and $l_{II} < a_{II}$ are sufficiently large. In this case, as the worker changes employer, the empirical finding of a rise in wages around patent applications cannot hold true within the same firm, but it holds true if one accounts for the new wage the innovator earns in C.

For innovations where $v > E(V|K)$ the difference $v - E(V|K)$ can be large enough that O offers a larger wage than C and manages to retain the worker in stage II, but not in III when also C observes v. For such highly valuable innovations, therefore, the model predicts on average an increase in w_{II} and then the worker moves to C in stage III, where he will be offered a wage still larger than w_I. For the more generic or low-value innovation (v close to, or lower than, $E(V|K)$) the worker leaves O already in stage II.[4]

In stage I, expecting that the worker will likely leave in either stage II or III firm O invests capital satisfying Eq. (14). This means that a lower amount of capital, as compared to the case with $1_{stay} = 1$, will be invested by O.

4.3. Taking stock: some testable predictions

The model described so far provides some clear predictions that are, in principle, empirically testable. In cases where workers tend to stay with the original innovating firm, so that observed mobility is low (but the potential for high mobility is still large), the rise of pay around patent applications will be larger as the ability for competing firms to gain from attracting the worker is also larger. This is more likely to happen when imitation costs are low and competing firms enjoy greater absorptive capacity. The shape of the changes in pay around patent applications will be determined by the relative size of the benefit for competing firms, and of the capital investments required to imitate, before and after the application event.

Generally speaking the model predicts that the lower capital intensity in the R&D functions prevalent in the industry, the larger the rise in wages in stages II and III. Therefore in markets or industries where the capital intensity is low in R&D functions, like those for software and Web-based services, one should expect to find bigger jumps in pay around patent applications. On the contrary in markets or industries where R&D activities are capital-intensive, like in many manufacturing sectors, the observed change in pay should be, *ceteris paribus*, smaller.

In markets where workers tend to leave the original innovating firm for competitors, their wage (from former and from new employers) will rise around patent applications by a larger extend when the advantage to the new hirer is larger. However if for any reason there is a systematic mistake in the expectations formed by firms such that under-valuation occurs, wages will on average rise before patent applications, and lower in the stage after patent application (as compared to the case without under-valuation). Given this sensitivity of wages to expected values, they might be as well sensitive to market conditions and business cycles.

5. Policy implications

How should a policy maker 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. Social welfare, in expected terms in stage I, is then obtained as the algebraic sum of the total value produced, net of O's and C's investments:

$$S = E(V|K)[1_{stay} + 1_{II}(1 - l_{II} + a_{II}) + 1_{III}(1 - l_{III} + a_{III})] - (1+r)K(1 + 1_{II}i_{II} + 1_{III}i_{III}) \quad (15)$$

From the point of view of the social planner, whose target is to maximize S, it is better that workers stay with O if the differences $l_X - a_X$ are positive (or negative but small in comparison to investments i_{II} and i_{III}), and it is better that workers change employer if the a_X are larger enough than the l_X.

In order to simplify the following discussion and without loss of generality (given that we study the planner problem in expected terms, that is, only in the first stage of the game), we here assume a reduced game with two stages only, so we will drop the stage indexes where the meaning of the symbol is unambiguous and just write l, a and i. Stages II and III can be collapsed into one single stage (in this section we will label the two newly-formed stages as A and B not to confound them with the 3-stage model: A is equivalent to stage I, while stage B now is equivalent to stage III as all parties are informed about v at that time). In stage A the original firm offers a wage w_A, and in stage B the two firms can offer wages w_B and w_B^C. The "market" wage (previously w_I) is w_A. We also introduce the new notation $z = a - l$: from previous section we now that without taxes, in case $z < 0$ the worker will never leave O for a competing firm.

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 B. 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 B is introduced, so that for each monetary unit of w_B paid to the worker, an additional w_Bt is paid to him as a subsidy.

[4] If, instead, a different assumption is taken so that the original innovating employer and the worker are also unable to observe v in stage II, the ability for O to retain the employee in stage II is lowered in the case where $v > E(V|K)$ is large.

The combined effect of patent box and R&D subsidy policies on capital investments in stage A is summarized by the following modified first-order condition (compare with Eq. (14)):

$$\frac{\partial E(V|K)}{\partial K} = \frac{1+r(1-\tau)}{[1+1_B(z-a)](1+p)} \quad (16)$$

where 1_B is equal to 1 if the worker leaves O in stage B.

The combined effect of patent box and R&D subsidy policies on the feasibility threshold is:

$$a^* = 1 - 1_B z - \frac{w_A + (1+r)(1-1_{stay} i)K}{(1+p)E(V|K)} \quad (17)$$

The threshold expressed by (17) is the maximum value for a that makes O invest some positive amount of capital in the project (refer again to Section 4).

We will now 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 $(1+p)$, $E(w_B)$ is raised to $E(w_B) = E(V|K)a(1+p) - i(1+r)K$, which in turn makes pay in stage 1 with $z \le 0$ equal to $w_A = E(V|K)(1-a)(1+p) - (1+r)(1-i)K$. A consequence of this shift of pay from stage A to stage B 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 A. However because we obtained that with $z \le 0$ the socially optimal investment is given by $\frac{\partial E(V|K)}{\partial K} = 1+r$, the patent box causes overinvestment when $z \le 0$. When $z > 0$ and without policy intervention the original innovating firms invests by solving the FOC given by Eq. (16), but this level of investment is lower than the socially optimal investment. 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 $z \le 0$, while it can correct for underinvestment when $z > 0$.

3) Let us now analyze the third policy tool. First, notice that by definition it only applies to the cases when $w_B > 0$, 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 $E(w_B)(1+t) \ge E(w_B{}^C)$ or equivalently:

$$E(w_B) \ge \frac{E(V|K)a - i(1+r)K}{(1+t)} \quad (18)$$

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

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

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

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

thus the feasibility threshold is affected by t.

On the contrary when $z > 0$ 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_B 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 $E(V|K)z$.

The previous considerations are summarized in the following two Propositions.

Proposition 1. *When $z > 0$ the optimal innovation policy is made of a combination of $p \ge 0$, $\tau \ge 0$ and $t = 0$.*

Proposition 2. *When $z \le 0$ the optimal innovation policy is made of a combination of $p = 0$, $\tau = 0$ and $t \ge 0$.*

Even if the model does not explicitly account for unobservability issues on the side of the policymaker, it is worth stressing that all the three policy instruments studied here face some degree of moral hazard. A classical problem with tax credits and allowances for R&D expenditures is a possible reclassification of expenditures that the beneficiary might mask as R&D-related. Patent boxes (or more generally, IP boxes) have also been found (Alstadsæter et al., 2015) to be used by multinational company groups for tax planning reasons, with little relation to actual R&D activities, as (absent any reliable arm's length price to compare with) it is hard to fully disentangle transfer pricing from true pricing in transactions involving intangible assets. The third, hypothetical policy which is based on personal taxation brings a trade-off between being more restrictive (as, for example, the solution proposed in d'Andria, 2016 where the tax benefit only applies to changes in pay from the same employer, and only in the years after a patent application), or being able to capture a wider set of innovations (those not related to R&D) by focusing on a broader definition of profit shifting schemes. A less restrictive policy, however, might allow firms to reclassify compensation and would present problems similar to the ones observed for the other two policies.

6. 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 joint effect of knowledge spillovers caused by labor mobility and of absorptive capacity possessed by competing firms, and of capital intensity in R&D functions. 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 lower capital intensity in R&D and when innovations are highly profitable. Larger spillovers, more absorptive capacity and low investment costs for imitation make it more likely to observe bonus pay. When market rivalry (and thus 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 protection for intellectual property.

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, with similar results, to increase the amount of capital investments. However, if knowledge is simply transferred between firms without causing any aggregate change 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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