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Evolutionary efficacy of a Pay for Performance scheme with motivated agents

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Evolutionary efficacy of a Pay for Performance scheme with motivated agents.

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Abstract

The paper studies the short run and long run effects of the introduction of a Pay-for-Performance, P4P, payment scheme. Providers of a public service are assumed to employ more than one agent. If agents have different attitude to the job (for example only a portion of the agents has some form of vocation/motivation) and providers are rewarded for the aggregate effort of all agents employed, we show that the definition of the scheme needs to take into consideration the effects produced on the evolution of the attitude to work of new generations. Suppose that new potential employees were able to assess the expected pay-offs of current workers. Then they may modify their attitude to work in order to follow the employee type that earned the highest expected pay-off. The analysis is in part motivated by the introduction in UK in 2004 of a P4P scheme for family practitioners in the UK (Quality and Outcomes Framework, QOF) and of a new system of assessing the quality of academic research that will be completed in 2014 (Research Excellence Framework, REF).

1 Introduction

The use of incentive schemes and in particular Pay for Performance (P4P) has been growing worldwide in the last two decades. Even more so recently due to the global economic downturn and the increased financial pressure created by austerity programmes. Understanding the effects of the introduction of such a type of payment schemes is particularly important in light of the recent trend in

public administrations[1], universities worldwide[2] and health case sectors[3] to hire new employees on *temporary contracts* (or directly outsource some production processes). This tendency is creating a change in the way new generations of workers are hired and financially treated within the same organization compared to colleagues in previous generations. Nonetheless the economic literature has still to find a general consensus over the efficacy, the applicability and optimal implementation of such schemes. The recent and growing literature[4] that studies the effects and desirability of the introduction of a P4P payment scheme on sectors that provide public services offers the following lessons (i) the introduction of a quality/performance-dependent payment scheme in general tends to have positive effects on the provision of quality; (ii) there is still room to improve the current P4P schemes (that in some cases might even produce negative effects in terms of quality provision[5], financial costs for the society[6] and increase in geographic disparities[7]); (iii) more detailed theoretical and empirical studies of P4P schemes are still required.
When considering the effects of the introduction of a payment scheme, the literature in general focuses on static analysis. Most contributions describe how the contract defined by a Principal (the payer) may affect the behavior of an Agent (the provider of the service), usually in an environment of asymmetric information. We believe that to improve our understanding of the effects of the introduction of a P4P scheme, it is essential to consider also the dynamic effects that such a scheme may have on the different attitudes that agents may have towards their job. It is also critical to take into consideration how the effects may propagate within an organization given different contractual forms.

The market for health care and higher education may be good examples to make our point. In UK primary care is provided in General Practices usually

[1] The uncertain and *precarious* condition of the jobs of younger generations is a recurring topic of spirited debate in Italy.
http://www.ansa.it/web/notizie/collection/rubriche_english/10/18/Letta-vows-govt-give-hope-young-generations_9482975.html

[2] In describing the temporary (and sometimes financial disadvantageous) nature of some academic contracts, the media have forged the term "disposable academic". See http://www.economist.com/node/17723223
http://www.theguardian.com/education/2013/sep/16/zero-hours-contracts-at-universities
http://www.aaup.org/report/heres-news-annual-report-economic-status-profession-2012-13

[3] For example a General Practice in UK can be operated by salaried doctors and partners. See http://careers.bmj.com/careers/advice/view-article.html?id=20001005

[4] The American experience is studied, among others, in Dudley (2004), Rosenthal et al. (2005), Rosenthal and Dudley (2007). The UK recent introduction of a pay-for-performance system for General Practices is described in Shekelle (2003), Roland (2004), Doran et al. (2006) and (2008), Maynard (2012).

[5] See for example Siciliani (2009). If a P4P scheme introduced some form a reputational stigma, i.e. the improvement in medical quality were explained by the society only by the introduction of the financial incentives and not by any form of altruistic behaviour or motivation from the doctors, then it might induce some physicians to reduce their efforts.

[6] In particular when providers may find ways to *game* the system. See for example Doran et al. (2006) and (2008), Gravelle and Sutton (2010), Kontopantelis et al. (2012).

[7] This may be the case when P4P schemes reward only the top performers and not the quality improvements of providers operating in more deprived areas.

operated by more than one doctor. In 2004 a P4P scheme for family practitioners (Quality and Outcomes Framework, QOF[8]) has been introduced. The performance (and consequently the QOF payment) of a *practice* depends on the aggregate effort invested by *all* doctors employed in the practice. Similarly Higher Education Departments in UK are evaluated (and funded) according to the research output of *all* their members[9]. The agents that belong to such organizations may have different vocation[10], i.e. attitude towards their job, different concern towards the quality of the service that they provide or even different sensitivity towards the reputational effects produced by the organization's performance. For example, from the same population of doctors (i.e. same degree and ability), there might be doctors with a concern for the quality of the service provided (i.e. they may gain additional utility increasing in the quality their practice) and others who are in the market only for the financial pay. If agents who belonged to the two different types where randomly matched to work in the same practice, for example, it should be expected that they would employ different levels of effort in visiting patients and obtain in equilibrium different levels of utility for a given payment scheme that rewards organizations and not individuals. The difference in utility achieved by the two doctors would be common knowledge for young doctors who just graduated and are entering the market. Possibly their preferences (i.e. their vocational approach to the job) may be updated according to the indirect experience of their predecessors via, for example, some process of social/professional learning. Think alternatively of a Ph.D. student who has observed for 3/4 years the utility obtained by the members of staff in her academic department. If the non-vocational professors had consistently obtained higher payoffs than the altruistic colleagues, should the newly graduated student pursue a vocational approach in that department? If the introduction of a P4P scheme affected the payoffs and behavior of agents in one generation, it may also indirectly affect the approach to work of the future generations. Consequently we believe that to correctly assess and design an effective scheme it may be essential to consider also the dynamic effects that the introduction of payment scheme may produce. In other words a scheme may produce positive effects in the short run (when for example the quality of the service provided by a generation of workers could increase due to performance-dependent financial incentives), but negative effects in the long run (when new generations have re-assessed their approach to the job based on the payoffs obtained by the colleagues of the previous generations).

The economic literature offers already a few contributions that consider the

[8] http://www.hscic.gov.uk/qof.

[9] http://www.ref.ac.uk/

[10] We are not giving a precise definition of "vocation" on purpose in our setting. In the rest of the paper an agent with vocation will be concerned about the quality of the organisation where she is employed. It may be for altruistic reasons (she enjoys to contribute to the welfare of consumers); it may be for motivational reasons (she is committed to the mission of the organisation) and enjoys just doing her job; it may be for reputational reasons (she enjoys to work in an organisation that it is recognised to performe well) and indirectly related financial reasons (she may obtain a better job in the future if being currently employed in a good organisation).

vocational nature of some jobs related to the provision of public services such as health care and education[11]. These contributions study how incentives may affect the provision of quality for a given distribution of vocational agents. We contribute to this literature providing a novel (to the best of our knowledge) approach. Abstracting from the specific Principal-Agent relationship and issues related to asymmetric information, the paper introduces the (very realistic) possibility that the payment may be related to the aggregate performance of multiple agents that interact within the same organization that provides the public service.

Studying the way the proportion of vocational and non-vocational agents may evolve after the introduction of an incentive scheme, the model tries to answer the following questions. May the introduction of a P4P scheme have long term negative effects in terms of workers' motivation and provision of effort? May such negative effect more than offset the possibly positive initial effect in terms of effort provision? How do the static and dynamic effects of a P4P scheme depend on the power of the performance-dependent incentive? How does the internal organization of providers affect the effectiveness of P4P schemes?

To answer these questions the model considers an evolutionary game, where pairs of agents are randomly selected from the same population and matched to work in an organization that provides a public service. A portion r, $r \in [0, 1]$, of agents in the population is *programmed* to be of type v (i.e. *with vocation:* they have a concern for the quality of the service that they will provide) and the remaining $(1 - r)$ are *programmed* to be of type n (i.e. *without vocation*: they are only concerned about the financial pay that may be earned from the future job). In each generation r will evolve with time according to a replicator dynamics that will assess the expected payoffs of belonging to either group of agents. If for a generation the expected pay-off of type v agents is lower than the expected pay-off of type n agents, then the number of agents of the next generation who will be *programmed* to be of type v will decrease. We assume that r does not affect only the expected matching between workers, but also it may affect the expected level of the costs of quality. In other words, we consider the possibility that type v agents may be more efficient in performing a task compared to type n colleagues. In addition we assume that the efficiency in providing quality of type n agents may increase in r. In a given population the agents with no concern for quality may tend to be more efficient if more vocational agents belonged to the same population. Vocational and non-vocational players are able to assess the type of the agent they are matched with and so they play optimally against the matched type. With this respect, we may define players as 'Nash' agents, in the sense defined by Droste et al. (2002). Of course, vocational agents will maximize a 'subjective' utility that depend also on non-monetary assessment, namely the overall quality of their practice. However, evolutionary pressure of the two strategy is determined by the accrued payoff of each strategy, i.e. by an 'objective' measure of fitness of a strategy. This is in line with the methodology studied in Algier and Weibull (2013), for studying

[11] See for example Glazer (2003), Canton (2005) and Heyes (2005).

the evolutionary dynamics of behaviors (rather than strategies).

We show that the adoption of a performance-dependent financial incentive may have positive effects on the provision of quality both in the short run (i.e. for given r) and in the long run (i.e. when we allow r to evolve). If the individual in an organization were able to perceive the effects of the financial incentives, then effort and motivation would increase in the market.

However the short run and long run effects of the introduction of a P4P may dramatically change depending on the internal organization of providers. If financial incentives are paid to the organizations and not directly to the individuals, then the way the payments are allocated internally may play a critical role in defining the efforts of agents. For a realistic form of organization internal sharing of the payment (i.e. when the allocation of financial incentive to an agent depends on the effort invested by the individual and her bargaining power within the organization), we show that the short run positive effect of the introduction of a P4P may gradually disappear if the financial incentive is not sufficiently powerful, the cost of providing quality is sufficiently high and in particular if the *initial* level of r when the scheme is introduced is relatively small. In other words, it may happen that when the initial level of r is sufficiently small agents with no concern for quality will obtain higher expected payoffs than those earned by concerned colleagues. In a population where the number of type n agents and the costs of quality are sufficiently high, a low powered incentive payment may not be enough to invert an evolutionary process that will make r shrink to zero. In this sense our results based on an evolutionary analysis offer a policy recommendation that goes in the opposite direction of Heyes (2005). The author discussed the possibility that the probability to hire vocational nurses may decrease with their pay[12]. Our approach instead looks at the effects that a payment scheme may have on the distribution of vocation in future generations of agents. Taking into account the evolutionary effects created by financial incentives and the way such incentives are distributed internally, in some cases providers of public services may need to be paid more to ensure the efficacy of a scheme in the long run.

Our findings are closely related to three of the five key design elements of a P4F scheme as described in a static setting by Rosenthal and Dudley (2007). In particular, in line with their analysis our model shows that the way the scheme rewards the groups and the individuals in an organization may be critical. In our setting the finding is produced by the possibility that r may be updated according to the desirability (in terms of expected payoffs) of choosing a particular attitude to work. In addition the power of the incentive should be increased if individual agents were only partially able to receive the performance-dependent payments. Another design element described by Rosenthal and Dudley (2007) is the prioritization of the quality provided to underserved populations in order to reduce inequalities. We provide a similar implication based on the evolutionary behavior of r. A deprived population may imply higher costs of quality provi-

[12] For a given distribution of vocational and non-vocational nurses, increasing the salary will have the somewhat perverse effect to incentivise the participation to the job market of non-vocational/financially concerned nurses.

sion. For a given r, a P4P scheme to be desirable in a long term perspective (i.e. in order to achieve a long run equilibrium with a strictly positive r) will need to reward performance significantly more, otherwise with time all agents will end up having a non-vocational attitude to work (making the incentive scheme practically ineffective). Finally, similar to Rosenthal and Dudley (2007), we stress the importance of correctly choosing the right power of incentives. However, while their indication is based on standard economic theory prescribing the incentives should be proportional to the incremental cost of quality, we introduce a new perspective to the study of the problem with the study of the evolutionary development of r. If financial incentives can affect the evolution of the professional attitude of workers (and consequently the efficacy of the scheme for future generations) then they should not only be defined to cover for increments in short run costs, but also to incentivize a positive switch in agents' attitude to work. Such incentive, as we discussed above, will have to be more powerful for those agents who belong to a population with low professional attitude and/or operate in an area (for example a deprived one) where costs of quality might be relatively high.

The paper is organised as follows. Section 2 describes the model. Section 3 studies the equilibrium and Section 4 provides the evolutionary analysis. Section 5 concludes.

2 The model

Consider a population of agents ready to enter the job market. If selected, they will work in an organization that employs two agents[13] and provides a public service to a representative consumer. The organization receives a payment from a third party payer (e.g. an insurer, a Government Department) and the payment may be dependent on the performance (e.g. quality of the service) of the organization (P4P). The payment may be shared between the workers in proportion to the level of effort invested by each agent.

Suppose that the level of effort chosen by agent i, $i = 1, 2$, is m_i and the level of quality of the organization is equal to[14] $Q = m_1 + m_2$.

[13] The results described in the evolutionary analysis will be qualitative the same if more than two agents were hired by the organization. For expositional reasons, we describe the model in the simplest case.

[14] The linearity and additivity of the production function of quality obviously are simplifications. Nonetheless this specification captures interesting and realistic interaction in workplaces such as a General Practice or an Academic Department. About the additivity assumption, it is reasonable to assume that doctors visit patients in different times and rooms, meaning that the effort of one doctor may not directly affect the marginal productivity of the other doctor in the practice. Similarly the way a researcher's output contributes to define the quality of department is not related to the research outputs of other colleagues. About the linearity assumption, Q could be interpreted as the benefit of quality experienced by students/patients. It is often assumed by the literature on vertical and horizontal product differentiation that consumers' indirect utility increases linearly with quality. See Gravelle (1999), Barros and Martinez-Giralt (2002), Brekke et al. (2006).

Suppose that the organization that provides quality Q receives a (linear[15]) payment equal to

$$P = A + bQ$$

where $A \geq 0$ is a fixed capitation payment and $b \geq 0$ is the quality-dependent financial incentive of a P4P scheme. Let us assume that each agent receives a portion $\zeta_i = m_i L$ of the payment, where L is the portion of payment allocated to agent i per unit of effort[16]. When accepting the employment contract, L is known to the agents and it can not be renegotiated after effort has been provided. L represents the way the organization distributes internally the quality-dependent financial incentives.

There are two types of agents, with vocation (v) and without vocation (n). An agent with vocation will be directly concerned about the quality provided by the organization where she is employed and her utility will be directly increasing in quality. An agent without vocation instead will be concerned about quality only if it were connected to a payment system. Suppose that at each point in time[17] the proportion of agents with vocation in the population is given by $r \in [0, 1]$.

For both types of agents effort comes at a cost. Suppose that the vocational agents face the cost of effort $c_v = \gamma \frac{m_i^2}{2}$, where $\gamma > 0$ is the parameter that describes the inefficiency of vocational agents. For the agents without vocation, we allow for the possibility of a positive externality arising from vocational agents. More precisely, we assume a cost function of the form

$$c_n = [\gamma + \beta (1 - r)] \frac{m_i^2}{2} \tag{1}$$

where we assume that $\beta \in \{0, 1\}$.[18] Obviously, when $\beta = 0$ the inefficiency parameter of vocational and non-vocational workers coincides. When $\beta = 1$, the cost of the effort of the agent without vocation is realistically negatively related to the number of vocational agents in the population. The presence of vocational agents in the population produces a positive externality that, thanks to some form of social/professional learning, allows a non-vocational agent to increase her efficiency. Notice that when $\beta = 1$, if $r \to 1$, then $c_n \to c_v$. For values of $0 < r < 1$, $c_n > c_v$ and in particular for $r = 0$ $c_n = (1 + \gamma) \frac{m_i^2}{2}$.

[15] The linearity of the payment scheme simplifies the analysis, but it is a good aproximation of reality. Indeed many incentive schemes (such as QOF in UK) are linear. See Holmstrom and Milgrom (1987), (1991) and Zweifel et al. (2009).

[16] Obviously $L \geq 0$. Moreover, a constraint on the upper bound of L must be imposed to ensure that $\zeta_1 + \zeta_2 = (m_1 + m_2) L \leq 1$. Since agents' efforts are bounded, as shown below, one can always assume that $L \leq \overline{L}$, where $\overline{L}$ is the reciprocal of the maximum level of quality Q provided by the organization. When $L < \overline{L}$, part of the payment is left with the organization's management although agents exert the maximum effort possible.

[17] To simplify the notation, in what follows we will not report the time variable t unless necessary to explain the evolutionary behaviour of r.

[18] Although in principle β can assume any real value in the interval $[0, 1]$, the behavior of the model with $\beta \in (0, 1)$ provides qualitatively the same behavior of the model with $\beta = 1$.

The utility of a type v agent is:

$$\Pi_{iv} = a + \zeta_i \; b \; (m_{iv} + m_j) - c_v + \alpha \; (m_{iv} + m_j) \tag{2}$$

where $a \equiv \frac{A}{2}$ (we are assuming that the agents share equally the capitation fee and receive a portion ζ_i of the quality-dependent incentive); $\alpha > 0$ represents the degree of concern for quality of the vocational agent. Type n agent obtains:

$$\Pi_{in} = a + \zeta_i \; b \; (m_{in} + m_j) - c_n \tag{3}$$

In each period two agents are randomly chosen from the population and matched to work in the same organization. The two selected agents will choose effort to maximise their respective payoffs. An agent with vocation is programmed to maximise function (1) and an agent without vocation is programmed to maximise function (2). It follows that the organization may employ with probability r^2 two agents with vocation, with probability $(1-r)^2$ to agents without vocation and with probability $r\,(1-r)$ one agent with vocation and one agent without vocation. Section 3 studies the (static) equilibria in these three cases.

3 Equilibrium and comparative statics

In this section we study the equilibrium provision of effort (and the corresponding payoffs of the agents) in a given period (i.e. for given r).

Assume that

$$b < \frac{\gamma}{3L} \tag{4}$$

Assumption (4) ensures strict concavity of the payoffs functions and non-negativity of the levels of effort selected in every equilibrium considered.

We assume that the organization that hires the worker can not observe their type. However, once selected, workers are able to observe the type of their matched agent and best reply accordingly.

Suppose that two agents with vocation are selected. They will simultaneously maximise (2) with respect to their effort. In equilibrium

$$m_{1vv} = m_{2vv} = m_{vv} \equiv \frac{\alpha}{\gamma - 3bL}$$

Not surprisingly, effort (and aggregate quality) is increasing in the degree of vocation α and in the quality-dependent financial incentive b (scaled by the portion effectively paid allocated to the individual agent). A larger degree of inefficiency, γ, implies lower effort and quality in equilibrium.

If two agents without vocation are matched, then maximizing both (3) they will choose in equilibrium:

$$m_{1nn} = m_{2nn} = m_{nn} \equiv 0$$

In this scenario the effort defined by each agent's best response function is represented by a linear function passing through the origin. If the colleague provided a strictly positive level of effort, then it would be optimal for an agent to provide a positive level of effort. However the intersection of the best response functions happens when $m_1 = m_2 = 0$ (in equilibrium neither agent invests in effort) and $Q = 0$.

Suppose now that agent 1 has vocation and agent 2 does not. Both agents experience linear and increasing best response functions. In particular

$$\begin{aligned} BR_1 &\quad : \quad m_1 = \frac{bLm_2 + \alpha}{\gamma - 2bL} \\ (BR_2)^{-1} &\quad : \quad m_1 = \frac{m_2}{bL}\left[\gamma - 2bL + \beta\left(1 - r\right)\right] \end{aligned}$$

Notice that due to assumption (4), $(BR_2)^{-1}$, the inverse of agent's 2 best response function, is steeper than BR_1 ensuring positive equilibrium levels of effort. In addition in this scenario effort and quality depend also on r. A larger r implies that agents without vocation are more efficient. An increases in r translates into a flatter BR_2 and higher effort in equilibrium. An increase in the quality-dependent financial incentive or the portion that is attributed to the worker, i.e. respectively b and L, has a positive effects on efforts. An increase in γ not surprisingly reduces effort.

In equilibrium:

$$\begin{aligned} m_{1vn} &= m_{vn} \equiv \frac{\alpha\left[\beta\left(1-r\right) + \gamma - 2bL\right]}{3b^2L^2 - 2bL\beta + 2bLr\beta - 4bL\gamma + \beta\gamma - r\beta\gamma + \gamma^2} \\ m_{2nv} &= m_{nv} \equiv \frac{bL\alpha}{3b^2L^2 - 2bL\beta + 2bLr\beta - 4bL\gamma + \beta\gamma - r\beta\gamma + \gamma^2} \end{aligned}$$

For a given r, payoffs are represented in the following table.

	v	n
v	(Π_{vv}, Π_{vv})	(Π_{vn}, Π_{nv})
n	(Π_{nv}, Π_{vn})	(Π_{nn}, Π_{nn})

where, for $\beta = 0$ it is

$$\begin{aligned} \Pi_{vv} &\equiv a + \ 2b\ m_{vv}^2 - c_v + 2\alpha\ m_{vv} = a + \frac{\alpha^2\left(4b - \gamma\right)}{2\left(\gamma - 3b\right)^2} \\ \Pi_{nn} &\equiv a + b\ m_{nn}^2 - c_n = a \\ \Pi_{vn} &\equiv a + m_{vn}\ b\ \left(m_{vn} + m_{nv}\right) - c_v + \alpha\ \left(m_{vn} + m_{nv}\right) = \\ &= a + \frac{\alpha^2(2bL - \gamma)\left(2b^2L^2 - 4bL\gamma + \gamma^2\right)}{2(-3bL + \gamma)^2(-bL + \gamma)^2} \\ \Pi_{nv} &\equiv a + m_{nv}\ b\ \left(m_{nv} + m_{vn}\right) - c_n = \\ &= a + \frac{1}{8}bL\alpha^2\left(\frac{1}{(\gamma - 3bL)^2} - \frac{1}{(\gamma - bL)^2}\right) \end{aligned}$$

whereas for $\beta = 1$, Π_{vv} and Π_{nn} are as above and

$$\begin{aligned}
\Pi_{vn} &= a + \frac{\alpha^2 \left(2bL + r - 1 - \gamma\right) \left(2bL \left(bL + r - 1\right) - \gamma \left(4bL + r\right) + \gamma^2\right)}{2 \left[bL \left(-2 + 3bL + 2r\right) + \gamma - \gamma \left(4bL + r\right) + \gamma^2\right]^2} \\
\Pi_{nv} &= a + \frac{b^2 L^2 \alpha^2 \left(-2bL - r + 1 + \gamma\right)}{2 \left[bL \left(-2 + 3bL + 2r\right) + \gamma - \gamma \left(4bL + r\right) + \gamma^2\right]^2}
\end{aligned}$$

We assume that a is always sufficiently large to ensure non-negative profits in equilibrium. Notice that if γ is not too large (i.e. $\gamma < 6bL$) then all payoffs (obviously except Π_{nn}) are increasing in b and L, otherwise for $\gamma > 6bL$ the payoffs of vocational agents (Π_{vv} and Π_{vn}) will decrease with the financial incentives. The financial incentives induce the vocational agents to provide more effort, but they would be incurring high costs and obtain lower payoffs. Moreover notice that, when cost externalities are present ($\beta = 1$), increasing r has positive effect on both Π_{vn} and Π_{nv}.

4 Evolutionary analysis

When hired, an agent does not know whether the colleague will be of type v or n. Nonetheless, after the matching has taken place, agents observe the type of their colleague and engage in the game described in the previous section by selecting the proper Nash equilibrium outcome. In this section, we endogenize the fraction of agents playing v or n at time t by considering the average payoff obtained by each strategy. We denote by $r(t)$ the fraction of vocational agents at time t to emphasize the dependence on time.

Notice that, although vocational agents care also about the quality of their organization, in the evolutionary model their fitness is based on realized payoff only. This is coherent with the indirect evolutionary approach, postulating that individual behavior is driven by subjective utility maximization, whereas evolutionary success depends on objective accrued payoff (see Algier and Weibull (2013) for details).

The average payoffs at time t of an agent of type v and one of type n are, respectively,

$$\mathbb{E}\left[\Pi_v \left(r(t)\right)\right] = r(t) \left[\Pi_{vv} - 2\alpha \left(m_{vv}\right)\right] + \left(1 - r(t)\right) \left[\Pi_{vn} - \alpha \left(m_{vn} + m_{nv}\right)\right] \quad (5)$$

and

$$\mathbb{E}\left[\Pi_n \left(r(t)\right)\right] = r(t)\Pi_{nv} + \left(1 - r(t)\right) \Pi_{nn} \quad (6)$$

Suppose that the agents who belong to the population of potential workers can observe the payoffs experienced by the workers effectively employed in the previous generation. For example, medical students can observe the payoffs of doctors with and without vocation. Similarly Ph.D. students can observe the payoffs of supervisors and other academic staff, with and without vocation. It is reasonable to assume that at each time period $t = 0, 1, 2, ...$ the probability $r(t)$ is updated according to *monotone selection dynamics* (see Cressman (2003)) through a map

$$r(t+1) = G(r(t), \phi(r(t))) \tag{7}$$

where the "gain" function $\phi(r(t)) = \mathbb{E}[\Pi_v(r(t))] - [\Pi_n(r(t))]$ is defined as the payoffs difference (see (5) and (6)) and $G(r, \phi(r)) : [0,1] \to [0,1]$, is such that $\frac{\partial G}{\partial \phi} > 0$ and $G(r^*, \phi(r^*)) = r^*$ whenever $\phi(r^*) = 0$. A well-behaved evolutionary model that have these properties is, among others, the *exponential replicator* dynamics (see Cabrales and Sobel (1992) and Hofbauer and Weibull (1996)):

$$r(t+1) = G(r(t), \phi(r(t))) = \frac{r(t)}{r(t) + (1 - r(t)) \exp(-\theta\ \phi(r(t)))} \tag{8}$$

where the parameter $\theta \geq 0$ models agents' intensity of choice, i.e. the propensity to switch to the more rewarding behavior as a consequence of payoffs differences. Monotone selection ensures that strategies with higher expected payoffs increase in relative frequency according, i.e. $r(t+1) > r(t)$ whenever $\phi(r(t)) > 0$. In other words, if in expected payoffs terms it is desirable to have vocation, r will increase over time; otherwise, a smaller portion of agents with vocation enters the market.

If no P4P payment is distributed to agents, i.e. $L = 0$, only vocational agents will provide effort and bear a cost, but all agents will obtain the same payment, regardless of their type. Consequently, vocational agents are always worst off financially, so that vocational behavior will disappear under indirect evolutionary dynamics (7). Notice that the payoff difference in this case is $\phi = -\frac{\alpha^2}{2\gamma}$.

4.1 No cost externalities

Let us begin the analysis by setting $\beta = 0$ in (1), i.e. no cost externalities arise from vocational agents to non-vocational ones. In other words all agents have the same cost of effort. Without loss of generality, we set $L = 1$. In this case it is easy to obtain an equilibrium of the evolutionary model, given by

$$r^* = \frac{(\gamma - 2b)\left(2b^2 - 4b\gamma + \gamma^2\right)}{2b^3} \tag{9}$$

When the fraction of vocational agents is exactly r^* then no evolutionary dynamics occur. The following proposition clarifies that r^* is always an unstable equilibrium for a monotone selection dynamics (7), i.e. when the system is out-of-equilibrium either all agents are vocational or all are non-vocational (coordination game). In particular, this proposition applies to map (8) as well as other possible evolutionary selection models.

Proposition

Consider a monotone selection dynamics (7) for the vocational Vs. non-vocational agents, where their expected payoffs in terms of the current fraction *of vocational agents $r(t)$ are given, respectively, in (5) and (6), r^* is in (9), $\widetilde{b} = \gamma\left(1 - \frac{1}{\sqrt{2}}\right)$ and $\widehat{b}$ solves the equation $6b^3 - 10\gamma b^2 + 6\gamma^2 b - \gamma^3 = 0$. Assume that it is $\frac{\partial G(r^*,\phi(r^*))}{\partial r} = 1$ for (7).*

Depending on the level of quality-dependent financial incentive $b \in \left[0, \frac{\gamma}{3}\right)$, the following three cases arise:

- *if $b \in \left[0, \widehat{b}\right)$ then $\phi(r) < 0$ for all $r \in [0,1]$, i.e. the generic trajectory converges to the equilibrium r_0=0 where all agents are non-vocational;*
- *if $b \in \left(\widehat{b}, \widetilde{b}\right)$ then $\phi(r) < 0$ for all $r \in [0, r^*)$ and $\phi(r) > 0$ for all $r \in (r^*, 1]$, i.e. a trajectory with initial condition $r \in [0, r^*)$ converges to the equilibrium r_0=0 (all non-vocational agents), whereas a trajectory with initial condition $r \in (r^*, 1]$ converges to the equilibrium r_1=1 (all vocational agents).*
- *if $b \in \left(\widetilde{b}, \frac{\gamma}{3}\right)$ then $\phi(r) > 0$ for all $r \in [0,1]$, i.e. the generic trajectory converges to the equilibrium r_1=1 where all agents are vocational.*

Proof

The proof is very simple, as the "gain" function

$$\phi(r) = \frac{\alpha^2\left(2b^3(2+r) - 10b^2\gamma + 6b\gamma^2 - \gamma^3\right)}{2\left(3b^2 - 4b\gamma + \gamma^2\right)^2}$$

is linear in r and has positive slope. Therefore, the conditions for having all non-vocational or all vocational agents can be simply obtained by letting $\phi(1) < 0$ or $\phi(0) > 0$ respectively. Similarly, condition $\phi(1) > 0 > \phi(0)$ grants that it is $r^* \in (0,1)$ [see (9)]. At the equilibrium $r^* \in (0,1)$, it is $\frac{dr(t+1)}{dr(t)} > 1$ by $\phi'(r^*) > 0$ and assumption $\frac{\partial G(r^*,\phi(r^*))}{\partial r} = 1$, so that r^* is locally asymptotically unstable and the game is of anti-coordination type. From a technical point of view, r^* is created (more precisely r^* enters the unit interval $(0,1)$) at $\widehat{b}$ through a transcritical bifurcation, at which r^* and r_1 exchange their stability properties. A similar bifurcation occurs at $\widetilde{b}$, in which r^* and r_0 collide and r^* leaves the unit interval. QED

Some comments are in order here. The previous proposition is pretty intuitive. It shows that, without cost externalities, only one type will eventually be present in the population, either v or n. More precisely, if the quality-dependent financial incentives b is too low (below $\widehat{b}$), in the long-run only non-vocational agents will be present: in this scenario, the extra effort exerted by vocational agents is not repaid by the low incentive provided and so the evolutionary dynamics, which is based on accrued payoffs only, rule out vocational agents from the system. More precisely, when the quality-dependent incentive b is above the threshold level $\widetilde{b}$, then all agents will eventually switch to a vocational behavior, no matter what the initial share vocational agents is. Similar results are obtained when the incentive level is below the threshold $\widehat{b}$, so that all agents

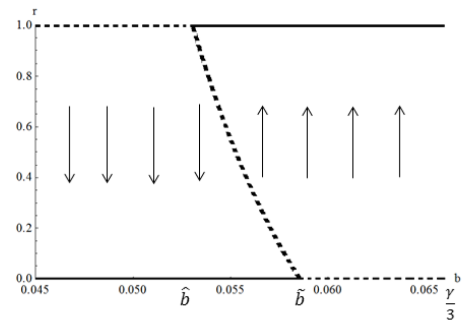

Figure 1

Figure 1: *Bifurcation diagram without cost externalities showing in the vertical axis the asymptotic values of the fraction of vocational agents. Parameters are* $\alpha = 0$; $\gamma = 0.2$; $\beta = 0$ *and* $\theta = 0.25$ *and with* $b \in \left[0.045, \frac{\gamma}{3}\right)$.

will eventually be of non-vocational type. For intermediate level of incentive, i.e. $b \in \left(\widehat{b}, \widetilde{b}\right)$, then the long-run level of vocational agents depends on the *initial share* of vocational agents in the population. This is important. A the introduction of the same P4P scheme may produce very different long run effects depending on the initial motivation of workers. In an international environment, a scheme successful in one country may have catastrophic effects in another. In fact, suppose that at a given time (for instance at the beginning of the game) there is a small but positive incremental payoff for v agents. Then, being $\phi(r)$ strictly increasing in r, through (7) at the next period a greater number of agents will choose to be vocational. Exactly the opposite occurs with small but negative payoff differences for playing n, so that at each period some agents will switch to non-vocational behavior.

For illustrative purposes and to better compare this benchmark case with the more complicated one obtained when positive cost externalities are introduced, we depict the long-run equilibria for the share of vocational agents r as the quality-dependent incentive b is increased. The following bifurcation diagram[19] shows such equilibria in the (b, r) plane, where a solid line denotes a stable equilibrium whereas a dotted line represents an unstable one. The arrows illustrate qualitatively the direction of the dynamics for the fraction $r(t)$ for a given value of b. The figure is generated through the exponential replicator dynamics (8) with parameters $\alpha = 0$; $\gamma = 0.2$; $\beta = 0$ and $\theta = 0.25$ and with $b \in \left[0.045, \frac{\gamma}{3}\right)$. For this set of parameters, it is $\widehat{b} \approx 0.0530604$ and $\widetilde{b} \approx 0.0585786$.

[19]The bifurcation diagram shows the possible long-term values (equilibria/fixed points, periodic or chaotic orbits) of the system as a function of a bifurcation parameter.

4.2 Positive cost externalities

In this section we explore, mainly through a leading numerical example, how the long run behavior of the system changes when positive cost externalities are taken into account, i.e. when $\beta = 1$ in (1). Although this is a single example of behavior of the model (the parameters are fixed as in Figure 1), it is paradigmatic of what happens, in general, in the model for some set of parameters.

Recall that a positive cost externality entails that the higher the fraction of vocational agents is, the lower the inefficiency of non-vocational agent is and vice-versa. The idea is that the effort of vocational agents is fundamental to reduce average effort costs, thus non-vocational, in general, benefits indirectly from the presence of an high share of vocational agents.

When cost externalities are present and the quality-dependent financial incentives b is sufficiently low, the long-run behavior of the system is the same as observed without externalities. In particular, when $r = 1$, the models with and without cost externalities coincide. Therefore, the threshold level such that the equilibrium point $r_1 = 1$ becomes locally asymptotically stable is the same $\widehat{b}$ specified in the previous proposition. Differently from the previous case, here there exists another incentive level $\overline{b} < \widehat{b}$ such that also a branch of locally asymptotically stable equilibrium $r^{**} \in (0, 1)$ exists, i.e. with long-run coexistence of both types of players in the system[20]. This equilibrium is created when b is increased beyond the point $\overline{b}$ by means of a fold bifurcation of the map (8) at which also an unstable equilibrium $\overline{r}$ is created. Equilibria of type r^{**} disappear at $b = \widehat{b}$ through a transcritical bifurcation of the map, which causes a stability exchange between r^{**} and r_1, with r^{**} leaving the interval $[0, 1]$. On the other hand, equilibria of the type $\overline{r}$ remain unstable for all subsequent increment of b, and delimits the basins of attraction of trajectories converging to r_0 and to r^{**} or r_1, following a qualitative similar behavior of the system without cost externalities when $b \in \left(\widehat{b}, \widetilde{b}\right)$ (see again the previous proposition). However, and interestingly, with cost externalities an unstable equilibrium such as $\overline{r}$ remains so for all values of $b \in \left(\overline{b}, \frac{\gamma}{3}\right)$, i.e. all values from the fold bifurcation point to the upper bound level of b, see (4). See Figure 2(a).

From the point of view of a policy maker, this kind of mechanism can provide interesting insights.

First of all, and differently from the previous case, the model with cost externalities admits equilibria with coexistence in the population of both types of agents (vocational and non-vocational). Moreover, if the policy maker introduces a 'small' reduction in the quality-dependent financial incentives, e.g. from

[20] For an evolutionary model such as (8), an equilibrium r^* with $\phi'(r^*) < 0$ is always locally asymptotically stable provided that the intensity of choice θ is sufficiently low. Otherwise, it can bifurcate through period-doubling and lead to chaotic motion (see Kopel et al. (2014) for more details).

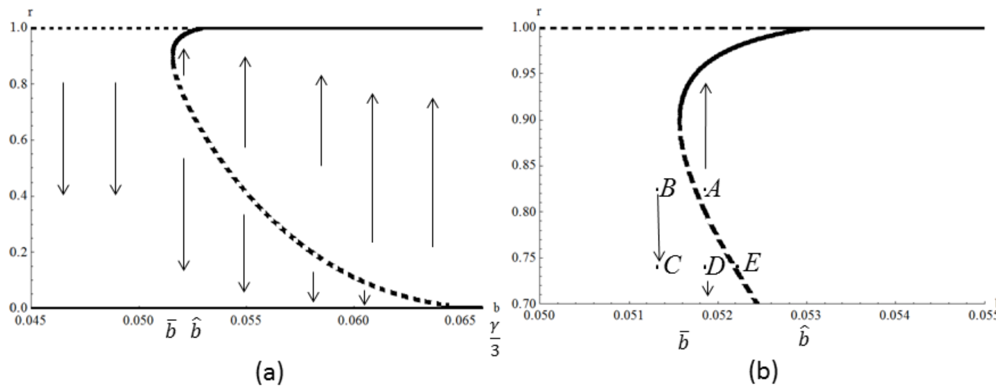

Figure 2

Figure 2: *Bifurcation diagram with cost externalities. (a) shows asymptotic values of the share r of vocational agents in the whole interval* $[0, 1]$*; (b) shows a zoom of (a) with* $b \in [0.05, 0.055]$ *and* $r \in [0.7, 1]$*. Parameters are as in Figure 1 with* $\beta = 1$*.*

$\widehat{b}$ to another level $b > \overline{b}$, then a 'small' reduction in the number of vocational agents will be detected (which is pretty intuitive), with the majority of agents preferring to remain vocational. However, when the reduction in b is pushed below the threshold value $\overline{b}$, then a rapid decreasing of vocational agents will be triggered, as all vocational agents would be willing to switch to non-vocational attitude. Notice that if the policy maker tried to convert again agents to vocational behavior, a financial incentive slightly above $\overline{b}$ could be insufficient to convince the population to reverse the trend, but a bigger level of incentive would be needed.

This point can be better understood through an example. Imagine that the current share of vocational agents and the level of incentive is as in point A in Figure 2(b), which is just a zooming-in of Figure 2(a). In such a point in the long run, over 90% of the agents will be vocational, with the current incentive scheme, as convergence to r^{**} is achieved. Now suppose that the policy maker reduces the incentive below the level $\overline{b} \approx 0.05156$ so that the system is moved to point B through this policy change. The policy maker could consider the observed reduction in the share of vocational agents as a natural consequence of the reduction in the incentive and decide to leave it unchanged for a while. This will bring a massive switching of the population to non-vocational behavior, for instance to some point as the one labeled C in Figure 2(b). Now if the policy maker intends to restore an high level of vocational agents by setting the same initial financial incentive of point A, he/she will continue to observe a decrement in the number of vocational agents over time. In fact, the system in a point as D is trapped in the basin of attraction of the (bad) equilibrium $r_0 = 0$ and will tend to converge towards it. In order to have again a big number of vocational agents, the level of incentive must be increased to a greater extent (i.e. over the point E). Only this policy guarantees that the generic trajectory belongs again to the basin of attraction of a 'good' equilibrium, such as r^{**} or r_1. Thus, from a point of view of the global dynamics, the system can exhibit the presence of *hysteresis* effects, see Arnold (1992) for a mathematical treatment and Ball (2009) for an overview of these concepts in well-known economic models.

This last point highlights another relevant difference between the cases without and with cost externalities. Without cost externalities, if the quality-dependent financial incentives b is above the level $\widetilde{b}$ then all agent will eventually be vocational. However, when cost externalities are present, then even a very high incentive to quality provision could be insufficient to push the system to a level where the majority of agents are vocational. This is due to the fact that if a critical mass of vocational agents is not present, then on average agents have low efficiency (see again (1)); in such states, their cost for exerting effort would be so high that they would decide to remain non-vocational. In other words, with these cost externalities, the quality-dependent incentive could be insufficient to make agents switch to vocational behavior. In any case, an higher b increases the likelihood of having more vocational agents in the population, but also a critical mass of vocational agents must be present in the system. For comparing the two leading example, it is useful to see Figure 3, which depicts together the bifurcation diagrams with $\beta = 0$ (gray line) and $\beta = 1$ (black line).

5 Conclusions

We have shown that while the introduction of a P4P may have positive quality-enhancing effects in the short run, i.e. when workers' motivation is given, in the long run evolutionary dynamics may reduce motivation and consequently affect the efficacy of the payment scheme. The long term effects of the evolutionary dynamics on workers' motivation depend on (i) the initial level of motivation in the market, (ii) the power of the quality-dependent financial incentive defined in the scheme and (iii) the possibility that motivated workers may produce a positive externality in the production of the quality of the service. In particular the policy implications of our analysis are as follows.

1. It is essential to consider the interaction among agents within organizations that provide a public service and vocational/reputational issues may play an important role in the definition of quality. An incentive scheme may be more effective for only a portion of the agents and the effectiveness of the scheme itself maybe depends on the type distribution of workers.

2. The short run effects of the introduction of a P4P scheme have to be evaluated together with the long run effects. If the scheme tips the balance between the payoffs of different types of workers, it may be that new

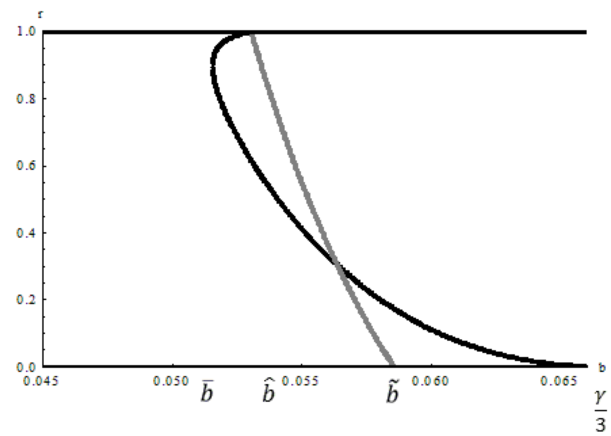

Figure 3

Figure 3: *Comparison of inner equilibria (stable and unstable) without cost externalities ($\beta = 0$; gray curve) and with cost externalities ($\beta = 1$; black curve). Other parameters are as in Figure 1 and 2.*

generations of agents entering the job market might adjust their vocation and motivation to work.

3. The power of a financial incentive should not be defined only by a static assessment of the increment in the costs of quality provision. A financial incentive that targets quality may have positive effects both in the short and in the long run. However, it is essential that the incentive is sufficiently high to ensure the existence of a long run equilibrium where a strictly positive portion of agents remain vocational. The incentive will have to be higher the more expensive it is to provide quality. Thus agents operating in more deprived areas should be financially rewarded more for their effort.

4. In order to ensure that a long run equilibrium with vocation exists, the incentive will have to be higher the lower is the portion of vocational agents when the scheme is introduced. Otherwise over time it will be preferred by new generations to act in a non-vocational manner and obtain higher (in expected terms) payoffs.

5. It is very important to take into consideration the way financial incentives are shared within an organization. A careful design of a P4P scheme requires to understand how the effect of the incentives on individual actions may be diluted by the internal organization of a provider. If, for example due to tighter financial budgets, providers and public administrations

were more inclined to hire (or even outsource) temporary/salaried agents, then the power of financial incentives should be increased accordingly in order to ensure the effectiveness of a P4P scheme in the long run.

6. A reduction in quality incentive must be carefully evaluated by the regulator, since restoring it at the previous level is unlikely to bring back the previous level of vocational agents in the society. Moreover, coexistence of both types of agents in the population can arise in our stylized model when non-vocational agents benefit from cost externalities from vocational agents.

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