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# WITHHOLDING OF KNOWLEDGE IN ORGANIZATIONS**


## ABSTRACT

This paper examines a principal's trade-off when he decides whether to transfer knowledge to other members of the organization. Although knowledge makes an agent more productive (productivity effect), knowledge transfer could cause the agent to become self-employed. The agent would then become a strong competitor of the principal (competition effect). I show that there is also an effort effect, which determines the principal's optimal knowledge transfer and his preference for either a principal-agent relationship or a duopolistic competition with the agent. The principal's decision depends crucially on whether knowledge transfer leads only to a relative competitive advantage for the agent, or additionally to an absolute advantage when the agent becomes self-employed. I also show that teamwork makes a principal-agent relationship more attractive for the principal and that such effort sharing leads to lower costs.

JEL-Classification: L2, M2.


## 1 INTRODUCTION

Organizational relationships can be often described by a principal-agent model. The principal (e.g., the employer) decides on the tasks he wants to delegate to an agent (e.g., the employee). The principal then offers the agent a contractual arrangement that specifies a certain compensation rule. The agent must then decide whether to accept or to reject the principal's contract. If he rejects the offer, he will receive an exogenously given reservation value. But if the agent accepts the contract, then, given the principal's compensation rule, he will choose an effort level that maximizes his expected utility.

In practice, the principal must also solve several decision problems during the principal-agent relationship. For example, the principal must decide how much knowledge he should transfer to his agent to make the agent more productive. The principal can transfer knowledge about customers, about technology, or about competitors. If this transfer of knowledge is not very costly[1] we might

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1 Hence, the problem discussed in this paper abstracts from investing in human capital which is discussed by *Becker* (1962) and others.

expect that from the employer's viewpoint, a maximal transfer would be optimal. However, the principal faces a fundamental trade-off when deciding about knowledge transfer: The more knowledge he gives to the agent, the more productive the agent will be. But on the other hand, the more knowledge he transfers to the agent the higher is the probability that the agent will use this knowledge to become self-employed and a strong competitor of the principal.

There are many examples in practice for just such a separation of the principal and his agent: Employees of consulting and law firms become self-employed and compete in the same (local) market as their former employers. The same can also happen in the medical profession, in craft firms or between physiotherapists. *Rajan/Zingales* (2001) p. 806 mention the concrete example of Intel (Integrated Electronics) which was founded by *Robert Noyce* and *Gordon Moore*, both of whom previously worked for Fairchild Semiconductor. *Moore*'s R&D department at Fairchild developed the so-called silicon-gate technique. This technique became a key part of Intel's product line. Furthermore, *Rajan* and *Zingales* report – referring to *Bhide* (2000) p. 94 – that 71 per cent of the Inc 500[2] firms were founded by people who used promising ideas from their former employers. Thus, when we look at the principal-agent framework, a general implication will be that the agent no longer has an exogenous reservation value: Now, depending on the amount of knowledge received, the agent will have an endogenous outside option.

In this paper, I discuss the principal's trade-off in his decision on knowledge transfer in more detail and under different situations. My aim is to analyze the major factors that determine the principal's trade-off. For example, I can show that the transfer of knowledge depends on the risk of the production technology (although both principal and agent are risk neutral), on the market size, the costs of production, the type of principal-agent relationship (*division of labor* or *teamwork*), and on whether the knowledge the agent receives leads only to a comparative advantage for the agent when competing with the principal (= *relatively profitable knowledge*) or also to an absolute advantage for the agent when he maximizes his profits (= *absolutely profitable knowledge*). For example, relatively profitable knowledge can be knowledge about the strong and weak points of the principal's management style. Or it can be a technological innovation, as in the Intel example above, or knowledge about customers (e.g., clients or patients) that will be captured by the agent when he becomes self-employed. In all these examples, knowledge transfer – directly or indirectly – leads to a higher market share of the agent at the expense of the principal's market share. In addition to this relative advantage, knowledge transfer may also generate an absolute advantage for the agent that has no influence on the principal's profits. For example, the agent might also decide to invest in other markets where he does not compete with the principal. These markets may be locally different from the principal's market, or they may be markets for different products that require the same technology (e.g., microelectronics)[3]. Therefore, in what follows I examine two situations – knowledge

2 "Inc 500" denotes a collection of young firms with large growth rates.

3 The second point becomes obvious when we look at the literature on related diversification that builds on the resource-based view. See, for example, *Prahalad/Hamel* (1990), *Farjoun* (1994) and *Markides/Williamson* (1994).

transfer yields a relative advantage for the agent when competing with the principal, or a relative and an absolute advantage.

The problem considered in this paper is loosely related to the literature on information gathering by an agent discussed by *Crémer/Khalil* (1992) and *Crémer/Khalil/Rochet* (1998a, 1998b). *Crémer/Khalil* (1992) consider the case in which an agent can observe the true state of nature at a cost before the contract is signed. They show that the optimal contract makes information gathering unattractive for the agent, and thus reduces the agent's information rent. In *Crémer/Khalil/Rochet* (1998a) the principal does or does not prefer information gathering by the agent depending on the magnitude of the information costs. *Crémer/Khalil/Rochet* (1998b) introduce the possibility of an agent who may be informed (i.e., an agent who chooses a mixed strategy to acquire information).

Other papers examine the case in which the principal retains control whether an agent becomes informed or not. *Lewis/Sappington* (1991) discuss the principal's trade-off that making the agent be informed enhances his productivity, but also shifts rents from the principal to the agent. *Sobel* (1993) shows that the principal always prefers the agent to acquire information after he has signed a contract to pre-contract information. Moreover, whether the principal prefers an informed agent to an uninformed one or vice versa depends on the number of possible outcomes in the principal-agent relationship. *Rajan/Zingales* (2001) discuss the connection between the hierarchical structure of a firm and the agent's incentive to use the firm's information for becoming self-employed. Their results show that physical-capital-intensive industries consist of large and steep hierarchies, but flat hierarchies will predominate in human-capital-intensive industries. This paper is also related to the *Schnedler/Sunde* (2002) study. These authors also discuss an agent's endogenous outside option. When creating work incentives, the principal must trade off higher outcomes against an agent's better position in future renegotiation due to the agent's higher effort. The paper is most closely related to an article by *Barcena-Ruiz/Rubio* (2000). They discuss the problem that giving information to an agent makes a high outcome more likely, but giving information also opens the opportunity for the agent to become self-employed. In such a case, the principal is replaced by the agent (i.e., the principal must shut down his business since the market is a natural monopoly). *Barcena-Ruiz/Rubio* show that depending on the agent's set-up costs for a new firm, the principal may or may not find it profitable to withhold information.

My paper differs in several respects from the studies mentioned above. For example, in this paper, if the agent becomes self-employed the resulting market will be a duopoly in which the principal and the agent compete for market shares, instead of a monopoly, as in *Barcena-Ruiz/Rubio* (2000). I model the duopolistic competition concretely as a non-cooperative game. However, in the *Rajan/Zingales* (2001) paper, an extreme form of competition is assumed in which only the strongest competitor survives and wins the whole market. Furthermore, in this paper knowledge (or information) transfer to the agent can be continuously chosen by the principal, but in *Barcena-Ruiz/Rubio* (2000) and *Rajan/Zingales* (2001), the agent's access to information either is or is not allowed by the principal. Intermediate outcomes between these two polar cases are not possible. However, in *Rajan/Zingales* (2001) the only variation in the amount of transfered knowledge comes from the fact that the hierarchical position of an agent determines his degree of access.

The paper is organized as follows. Since there is no standard model for discussing the withholding of knowledge in organization, I discuss three model variants. Doing so allows me to identify the major determinants of a knowledge transfer. Section 2 focuses on relatively profitable knowledge and a strict division of labor between the agent (who performs the operational tasks) and the principal (who is responsible for the administration, for example). Section 3 again discusses the case of relatively profitable knowledge but now focuses on teamwork between principal and agent. Section 4 considers the case in which transfered knowledge leads to a comparative advantage for the agent when he becomes self-employed and competes against the principal, but also yields an absolute advantage for the self-employed agent. Section 5 concludes.

## 2 Relatively Profitable Knowledge and Division of Labor

In this section, I assume that the agent can only acquire relatively profitable knowledge. I also assume that there is a strict division of labor between principal and agent, as in the standard principal-agent model: The agent manages the firm and performs all the operations. The principal acts as residual claimant who does no operational work[4]. The section falls into two parts. Subsection 2.1 considers the general case without restriction on the probability distribution. Subsection 2.2 discusses the special case of uniformly distributed noise.

### 2.1 General Case

The timing of the game is as follows: In the *first stage*, we have a training or probationary period during which the agent $A$ receives the amount of knowledge $\gamma$ by the principal $P$. At that time, $A$ gets a market wage that compensates him for his disutility of work and his job alternatives. I assume that due to limited liability, $A$ cannot pay for the anticipated benefits from receiving knowledge $\gamma$. Furthermore, $P$ cannot offer a binding long-term contract to prevent A from quitting after he receives knowledge $\gamma$. In the *second stage*, $P$ offers $A$ a principal-agent contract $(\alpha, \beta)$ described below (see Eq. (2)). In the *third stage*, $A$ decides whether to accept or reject the contract offer. If $A$ accepts, then in the *fourth stage* we will have a simple principal-agent relationship. However, if $A$ rejects the contract, then there will be a duopolistic competition between $A$ and $P$.

4 For example, the principal might be in charge of the general administration of the firm, or he might be the senior partner of a law firm that uses his reputation to serve as a so-called rainmaker whose major task is the acquisition of new clients. In these cases, there is an additional advantage from work sharing that will be lost if the agent becomes self-employed. By explicitly modeling this effect, a principal-agent relationship would become more attractive compared to the model discussed here. Alternatively, we can assume that strict disadvantages restrain the principal from providing operational effort (e.g., cannibalization effects on the customers or clients).

Before solving the game backwards more details of the game must be described. I assume that both $P$ and $A$ are risk neutral[5]. If $A$ accepts the contract offered by $P$, his production function will be given by

$$q = \gamma + e + \varepsilon + m. \tag{1}$$

$e$ denotes the agent's effort and $\varepsilon$ a random variable with mean zero. $m$ stands for the market size. In case of a principal-agent relationship there is a (local) monopoly, i.e., $A$ serves the whole market and $m$ denotes the monopoly gain. Since market revenues are already given by $m$, the effort variable $e$ characterizes effciency gains that can be realized by improving the firm's technology, for example. $\gamma$ describes the knowledge that is transfered to $A$ by $P$ with $\gamma \in [0, \bar{\gamma}]$. $\gamma$ also leads to effciency gains, analogous to $e$[6]. Knowledge transfer is costless. $P$ cannot observe $A$'s choice of $e$ and the realization of $\varepsilon$. Hence, we have a standard moral hazard problem. The parameter $m$ is exogenously given, but $\gamma$ is endogenously chosen by $P$. Effort entails costs on $A$ that are described by $c(e) = \frac{c}{2}e^2$ with $c > 0$. $P$ offers a linear compensation scheme[7]

$$p = \alpha + \beta q \tag{2}$$

to $A$ with $\beta \in [0, 1]$. If $A$ accepts, his expected utility will be[8]

$$EU_A^{pa}(e) = E[p] - c(e) = \alpha + \beta(\gamma + e + m) - \frac{c}{2}e^2 \tag{3}$$

and that of the principal

$$EU_P^{pa}(\gamma) = E[q - p] = (1 - \beta)(\gamma + e + m) - \alpha. \tag{4}$$

If $A$ does not accept $P$'s contract offer, he will become self-employed. Further, $P$ and $A$ become duopolists who compete for market shares, which sum up to the initial market size $m$. To make this situation comparable to the principal-agent relationship, I assume that each player $i$ ($i = A,P$) at the same time can realize effciency gains $e_i$ at costs $c_i(e_i) = \frac{c}{2}e_i^2$. The player $i$'s expected utility is given by[9]

$$EU_i^{co}(e_i) = e_i + m \cdot s_i(e_i, e_j; \tau\gamma) - \frac{c}{2}e_i^2 \tag{5}$$

5 In other words, this paper does not consider the well-known trade-off between incentives and risk-sharing. Furthermore, risk neutrality of both parties allows a better comparison of the principal-agent relationship and the case of a self-employed agent. Perhaps, if the agent is risk averse, a principal-agent relationship may be always dominant solely because of insurance reasons.

6 Hence, $\gamma$ and $e$ are substitutes. For example, $P$ can either tell $A$ a promising idea that is effciency enhancing ($\gamma$), or he can withhold his knowledge but $A$ can develop the same idea at effort costs $c(e)$ (see below).

7 For tractability reasons, I restrict the set of possible contracts to those that are linear. This assumption is not restrictive in the case of division of labor. However, it may be restrictive for the teamwork case in Section 3, where first-best effort cannot be implemented.

8 Here, "*pa*" denotes the case of a principal-agent relationship.

9 "*co*" stands for competition.

($i,j = A,P;\; i \neq j$) where $s_i(e_i,e_j;\tau\gamma)$ denotes $i$'s market share in $m$ with $s_A + s_P = 1$. According to Eq. (5), the market share depends on both players' efforts and on the agent's relatively profitable knowledge $\tau\gamma$ with $\tau \in [0,1]$. Here, $\tau$ measures the comparative advantage of $A$ – *relative* to $P$ – having received the amount of knowledge $\gamma$ from $P$. $\tau$ is exogenously given. $\tau = 1$ indicates a large comparative advantage from knowledge transfer, i.e., $A$'s received knowledge depends on $A$'s specific characteristics that $P$ lacks. For example, $A$ – contrary to $P$ – has certain professional skills, so that he can profitably use the knowledge $\gamma$. In this case, $P$ has a promising idea $\gamma$ but only limited skills to profitably make use of it[10]. On the other hand, $\tau \to 0$ indicates that $P$ and $A$ nearly have the same professional skills, so they can profit equally from the knowledge $\gamma$. In other words, there is no comparative advantage in $A$ having received knowledge $\gamma$ when competing with $P$ for the market $m$.

To derive explicit solutions, $s_i(e_i,e_j;\tau\gamma)$ is determined by the relative performance $q_i - q_j$ of both players with $q_i = e_i + \varepsilon_i$ and $q_j = e_j + \varepsilon_j$ ($i,j = A,P;\; i \neq j$), in which the two random variables $\varepsilon_i$ and $\varepsilon_j$ are identically and independently distributed with mean zero. To be more precise, I assume that

$$s_A(e_A,e_P;\tau\gamma) = F(\tau\gamma + e_A - e_P) \quad \text{and} \quad s_P(e_A,e_P;\tau\gamma) = 1 - F(\tau\gamma + e_A - e_P) \qquad (6)$$

with $F(\cdot)$ as the cumulative distribution function of the composed random variable $\varepsilon_P - \varepsilon_A$[11]. $f(\cdot)$ is the corresponding density with a unique mode at zero[12]. For the existence of pure-strategy equilibria $f(\cdot)$ is assumed to be suffciently flat and $c$ to be suffciently large[13]. According to Eq. (6) $A$'s ($P$'s) market share increases in his relative performance $e_A - e_P$ ($e_P - e_A$) and increases (decreases) in the amount of relatively profitable knowledge $\tau\gamma$. Using Eqs. (5) and (6), the expected utilities of the two players in case of a self-employed agent can be written as

$$EU_A^{co}(e_A) = e_A + mF(\tau\gamma + e_A - e_P) - \frac{c}{2}e_A^2 \qquad (7)$$

$$EU_P^{co}(e_P) = e_P + m[1 - F(\tau\gamma + e_A - e_P)] - \frac{c}{2}e_P^2. \qquad (8)$$

10 For this argumentation see also *Barcena-Ruiz/Rubio* (2000), p. 187; *Rajan/Zingales* (2001), p. 805.

11 Hence, the duopolistic competition between $P$ and $A$ is characterized by a probit-form contest (*Dixit* (1987)) or a rank-order tournament (*Lazear/Rosen* (1981), *Nalebuff/Stiglitz* (1983)) instead of Cournot or Bertrand competition. This characterization makes the duopoly case comparable to the principal-agent relationship. In addition, it is not unusual to model oligopolistic competition as a contest or a tournament (see, e.g., *Schmalensee* (1976, 1992)).

12 The last assumption is not unusual for tournament models (see, e.g., *Drago/Garvey/Turnbull* (1996)). For example, if $\varepsilon_i$ and $\varepsilon_j$ are normally distributed, $\varepsilon_j - \varepsilon_i$ will also be normally distributed with mean zero.

13 For the existence of pure-strategy equilibria see also *Lazear/Rosen* (1981), p. 845, fn. 2; *Nalebuff/Stiglitz* (1983).

Solving the game backwards, we can first look at the fourth stage of a principal-agent relationship. Maximizing Eq. (3) for a given contract ($\alpha,\beta$) and a given knowledge transfer $\gamma$ yields

$$e^* = \frac{\beta}{c}. \tag{9}$$

Inserting into (3) and (4) gives

$$EU_A^{pa}(e^*) = \alpha + \beta(\gamma + m) + \frac{\beta^2}{2c} \tag{10}$$

$$EU_P^{pa}(\gamma) = (1-\beta)\left(\gamma + \frac{\beta}{c} + m\right) - \alpha. \tag{11}$$

In case of duopolistic competition between $A$ and $P$, we obtain from the first-order conditions using Eqs. (7) and (8):

$$1 + mf(\tau\gamma + e_A - e_P) = ce_A = ce_P.$$

Hence, we have a symmetric equilibrium in which both players choose identical efforts:

$$e_A^* = e_P^* = \frac{1 + mf(\tau\gamma)}{c}. \tag{12}$$

According to Eq. (12) the equilibrium effort increases in the market volume $m$, and decreases in the cost parameter $c$ and the relative knowledge advantage $\tau\gamma$ of the agent. The intuition for the last point comes from the fact that the higher the "lead" $\tau\gamma$ of $A$ the smaller is $P$'s relative market share for given effort levels $e_A$ and $e_P$[14]. In other words, $P$ becomes more discouraged with rising $\tau\gamma$ and, thus chooses lower effort. But then $A$'s best response will also be to exert less effort. Substituting (12) into Eqs. (7) and (8) leads to

$$EU_A^{co}(e_A^*) = \frac{1 - m^2 f^2(\tau\gamma)}{2c} + mF(\tau\gamma) \tag{13}$$

$$EU_P^{co}(e_P^*) = \frac{1 - m^2 f^2(\tau\gamma)}{2c} + m(1 - F(\tau\gamma)). \tag{14}$$

14 Technically, as $f(\cdot)$ has a unique mode at zero $f(\cdot)$ becomes flatter at the tails, i.e., $f(\cdot)$ is monotonically decreasing for positive values.

In the third stage of the game, $A$ accepts the contract $(\alpha,\beta)$ as long as

$$\alpha+\beta(\gamma+m)+\frac{\beta^2}{2c}\geq\frac{1-m^2f^2(\tau\gamma)}{2c}+mF(\tau\gamma). \tag{15}$$

The first and the second stage can be considered together because only $P$ has to make a decision. If $P$ prefers a principal-agent relationship, he will choose $\alpha$, $\beta$ and $\gamma$ to maximize (11) subject to $A$'s participation constraint (15) and his own participation constraint $EU_P^{pa}(\gamma)\geq EU_P^{co}(e_P^*)$. In this case, $P$ will choose $\alpha$ so that (15) holds with equality, because otherwise he could save labor costs by reducing $\alpha$ without influencing $A$'s incentives characterized by (9). Substituting this $\alpha^*$ in $P$'s objective function (11) and his participation constraint $EU_P^{pa}(\gamma)\geq EU_P^{co}(e_P^*)$ yields:

$$EU_P^{pa}(\gamma)=\gamma+\frac{\beta}{c}+m(1-F(\tau\gamma))-\frac{1-m^2f^2(\tau\gamma)}{2c}-\frac{\beta^2}{2c} \tag{16}$$

$$\gamma+\frac{\beta}{c}\left(1-\frac{\beta}{2}\right)\geq\frac{1-m^2f^2(\tau\gamma)}{c}. \tag{17}$$

The optimal $\beta$ that maximizes (16) (and the left-hand side of (17)) is $\beta^*=1$[15]. Inserting into (16) and (17) gives the following results:

**Proposition 1** *The principal will prefer a principal-agent relationship to a duopolistic competition, if*

$$\gamma\geq\frac{1-2m^2f^2(\tau\gamma)}{2c}. \tag{18}$$

*In that case, he will choose*

$$\gamma^*=\arg\max_{\gamma}\left\{\gamma+m(1-F(\tau\gamma))+\frac{m^2f^2(\tau\gamma)}{2c}\right\} \tag{19}$$

*subject to (18) and $\gamma\in[0,\bar{\gamma}]$. If $\bar{\gamma}\rightarrow\infty$, he will always prefer a principal-agent relationship to a duopolistic competition and will therefore choose $\gamma^*=\bar{\gamma}$.*

**Proof.** To prove the last part of the proposition, I begin with the case of duopolistic competition. In this case, $P$ chooses $(\alpha,\beta)$ so that $A$ rejects $P$'s contract offer and $\gamma$ so that (14) is maximized. Eq. (14) shows that $P$ faces a strict trade-off when choosing $\gamma$. He can maximize his market share $(1-F(\tau\gamma))m$ by choosing $\gamma=0$ which leads to a share $m/2$. Or he can minimize the symmetric equilibrium effort and, therefore, effort costs with $\gamma\rightarrow\infty$ so that the first term in (14) simplifies to $1/(2c)$ – the first-best payoff in a standard principal-agent model[16]. If it were possi-

15 Substituting into (9) shows that if there is a principal-agent relationship, the agent will choose first-best effort $e^*=1/c$, since there is no trade-off between incentives and risk sharing.

16 Since $f(\cdot)$ has a unique mode at zero, $f(\tau\gamma)\rightarrow 0$ for $\gamma\rightarrow\infty$.

ble to combine both effects – which is not –, $P$ would receive $EU_P^{co}(e_P^*) = 1/(2c)+ m/2$. However, in the case of a principal-agent relationship, $P$ can maximize $EU_P^{pa}(\gamma)$ according to (19) subject to (18) by choosing $\gamma = \bar{\gamma} \rightarrow \infty$ so that (18) simplifies to $\bar{\gamma} \geq 1/(2c)$ and $EU_P^{pa}(\bar{\gamma}) \approx \bar{\gamma} \rightarrow \infty$. ■

Proposition 1 shows that $P$ must consider three effects when choosing $\gamma$ given that this relatively profitable knowledge is limited. This result can be clearly seen from the right-hand side of Eq. (19), which describes $P$'s expected utility of a principal-agent relationship, $EU_P^{pa}(\gamma)$. The right-hand side of Eq. (19) consists of three terms. The first term ($\gamma$) is strictly increasing in $\gamma$, but the second and the third one are strictly decreasing in $\gamma$. The **first** term denotes the absolute advantage of using the transfered knowledge inside the principal-agent relationship. I can label this effect as *productivity effect*, since the agent's performance is directly raised by $\gamma$. The **second** term describes the monopoly gain $m$ minus $A$'s forgone market share $mF(\tau\gamma)$ in case of duopolistic competition. Hence, the higher $\gamma$ the higher the forgone market share for which $A$ must be compensated to make him accept the principal-agent contract. I call this effect the *competition effect*, as the principal's initial monopoly gain is decreased by the threat of duopolistic competition. The **third** term corresponds to the *effort effect* described in the discussion subsequent to Eq. (12): The higher $\gamma$ the lower is $A$'s (and $P$'s) equilibrium effort in the duopoly case and, therefore, his effort costs. $A$ must also be compensated for this forgone advantage when he signs a principal-agent contract.

Eq. (13) also shows the competition and the effort effect. This equation describes $A$'s expected utility for the duopoly case, which is strictly increasing in $\gamma$: The last term denotes $A$'s market share, and the first term consists of $A$'s effort minus effort costs. Since $A$ must be completely compensated for his forgone $EU_A^{co}(e_A^*)$ according to (13) when there is a principal-agent relationship, such a contract becomes very costly for high values of $\gamma$. In addition, $P$ would also profit from the effort effect because of the high $\gamma$ in the duopoly case, since equilibrium efforts are symmetric[17].

Clearly, when choosing a principal-agent relationship $P$ has to trade off between the productivity effect on the one hand, and the competition and the effort effect on the other. In general, this trade-off makes it unclear whether $P$ is better off choosing a principal-agent relationship or a duopolistic competition[18]. However, if $\gamma$ is unlimited (i.e., $\bar{\gamma} \rightarrow \infty$), $P$ will always prefer a principal-agent contract because the productivity effect will dominate the other two effects. The intuition for this result comes from the fact that the players can only realize an absolute advantage from $\gamma$ when signing a principal-agent contract. For $\bar{\gamma} \rightarrow \infty$, this advantage becomes arbitrarily large and can be shared among $A$ and $P$. However, if there is a duopolistic competition, profits are limited because of the limited market size $m$ and the convex cost function.

17 Looking at Eq. (14) shows that $P$ profits from the effort effect in the same way as $A$.

18 Here and in the following, “choosing duopolistic competition” means choosing a contract offer $(\alpha,\beta) = (-\infty, 0)$ which will always be rejected by $A$.

Before discussing a special form of $F(\cdot)$ and two variants of the general model, we can do some comparative statics. According to (18), if $m$ increases, $P$'s preference for a principal-agent relationship will become stronger. If $m$ is suffciently large, the right-hand side of (18) becomes negative and $P$ will always make $A$ sign the principal-agent contract to realize the complete monopoly gain $m$. Furthermore, if the right-hand side of (18) is positive and the cost parameter $c$ becomes large, the effort effect will become less important, and the principal-agent relationship will become more profitable. If $c$ approaches infinity, $P$ will always prefer a principal-agent relationship to duopolistic competition, since $EU_P^{pa} = \gamma + m(1 - F(\tau\gamma)) > m(1 - F(\tau\gamma)) = EU_P^{co}$. If $A$ has only a very small comparative advantage from having received knowledge $\gamma$ (i.e., if $\tau \to 0$), then the impact of $\gamma$ on the competition and the effort effect discussed above will disappear. Hence, there will no longer be a trade-off on the choice of $\gamma$, and if $\bar{\gamma}$ is sufficiently large, $P$ will always prefer a principal-agent contract because of the productivity effect.

### *2.2 A Special Case: Uniformly Distributed Noise*

Here, I use a special form of the distribution function $F(\cdot)$ to derive an explicit solution of the game. I let $\varepsilon_A$ and $\varepsilon_P$ be independently and uniformly distributed over the interval $[-\bar{\varepsilon},\bar{\varepsilon}]$ so that $f(\varepsilon_P - \varepsilon_A)$ and $F(\varepsilon_P - \varepsilon_A)$ describe a triangular distribution over $[-2\bar{\varepsilon},2\bar{\varepsilon}]$. For this case, we need three additional assumptions:

$$m < 4c\bar{\varepsilon}^2 \tag{20}$$

to guarantee concavity of the players' objective functions in a duopolistic competition[19],

$$\tau\gamma \leq 2\bar{\varepsilon} \Leftrightarrow \gamma \leq \bar{\gamma} = \frac{2\bar{\varepsilon}}{\tau} \tag{21}$$

to ensure that the symmetric equilibrium solution for the duopoly case falls into the interval $[-2\bar{\varepsilon},2\bar{\varepsilon}]$, and

$$\tau \leq \frac{4c\bar{\varepsilon}^3}{m(4c\bar{\varepsilon}^2 + m)}$$

to guarantee real-valued roots of $P$'s objective function if there is a principal-agent relationship. The results are:

**Proposition 2** *(i) If $\tau > 4\bar{\varepsilon}c$ and $m^2 < 2\bar{\varepsilon}^2$, the principal will always prefer duopolistic competition to a principal-agent relationship. He chooses $\gamma^* = 0$, and his expected utility is*

19 The second-order condition requires $mf'(\tau\gamma + e_A - e_P) - c < 0$. Substituting the triangular form from the Appendix for $f(\cdot)$ leads to (20).

$$EU_P^{co}(e_P^*) = \frac{4\bar{\varepsilon}^2 - m^2 + 4mc\bar{\varepsilon}^2}{8c\bar{\varepsilon}^2}. \tag{22}$$

*(ii) If $m^2 > 2\bar{\varepsilon}^2$, the principal will always prefer a principal-agent relationship. He chooses $\gamma^* = \bar{\gamma}$, and his expected utility is*

$$EU_P^{pa}(\gamma^*) = \frac{2\bar{\varepsilon}}{\tau}. \tag{23}$$

*(iii) If $\tau < 4\bar{\varepsilon}c$ and $m^2 < 2\bar{\varepsilon}^2$, there will be a cut-off value $\hat{\gamma} \in [0, \bar{\gamma}]$ so that the principal prefers a principal-agent relationship (duopolistic competition) for $\gamma > (<)\, \hat{\gamma}$. He will choose $\gamma > (<) \hat{\gamma}$, if (23) is larger (smaller) than (22)*[20].

**Proof.** See the Appendix. ■

The findings of Proposition 2 confirm the comparative static results for the general model above. If the monopoly gain (or market size) $m$ is sufficiently large, $P$ will always prefer a principal-agent relationship (case (ii) compared to (i)). The same is true for suffciently large values of the cost parameter $c$ (case (ii) compared to (i))[21].

If knowledge transfer leads to only a small comparative advantage for $A$ when competing with $P$ (i.e., $\tau \to 0$), then a principal-agent relationship becomes more attractive for $P$ than a duopoly: For $\tau \to 0$, case (ii) becomes relevant[22] but the condition $\tau > 4\bar{\varepsilon}c$ for case (i) does not hold. In case (iii), both a principal-agent relationship and a duopoly may be preferable to $P$, depending on his choice of $\gamma$. However, since $\tau \to 0$ $P$'s expected utility $EU_P^{pa}(\gamma^*)$ becomes arbitrarily large according to (23). Hence, he will choose a principal-agent contract.

At last, we have the parameter $\bar{\varepsilon}$ which does not appear in the general model considered above. $\bar{\varepsilon}$ describes the risk of the two players' production technology: If $\bar{\varepsilon}$ is large, the used technology is very risky, and the realized market shares in the duopoly case are determined more by luck than by effort. The results of Proposition 2 show that the influence of $\bar{\varepsilon}$ is ambivalent, which has a simple explanation: For large values of $\bar{\varepsilon}$ symmetric equilibrium efforts, and therefore effort costs, become small in the duopoly case, which would lead to large expected utilities for $A$ and $P$ (note, for example, that $\partial EU_P^{co}(e_P^*)/\partial\bar{\varepsilon} > 0$ according to (22)). Hence, in a principal-agent contract paying $A$ his forgone duopoly profits will be very costly for $P$, and the duopoly case will also be attractive to $P$ because of the small effort costs. These two points are reflected by the restriction $m^2 < 2\bar{\varepsilon}^2$ (or $m^2 > 2\bar{\varepsilon}^2$) of case (i) (case (ii)) in Proposition 2. According to these points, a higher production technology risk $\bar{\varepsilon}$ makes duopolistic competition very attractive to $P$. In practice, this effect would imply an implicit cartel between $A$ and $P$ in the duopoly: For $\bar{\varepsilon} \to \infty$, pure luck determines the players' market shares (e.g., whether a customer

20 The calculation for the concrete value of the cut-off, $\hat{\gamma} = \gamma_R$, is shown in the Appendix.

21 Note that case (ii) implies $\tau < 4\bar{\varepsilon}c$.

22 Again, note that condition $\tau < 4\bar{\varepsilon}c$ holds in case (ii).

will buy at $A$ or at $P$ would be purely random). Hence, for both $A$ and $P$, it would not pay to exert any effort, resulting in zero effort costs.

On the other hand, for simplicity I have combined the upper limit for knowledge transfer, $\bar{\gamma}$, with the upper limit of the triangular distribution, $2\bar{\varepsilon}$ (see condition (21)). By this, as $\bar{\varepsilon}$ becomes large $\bar{\gamma} = 2\bar{\varepsilon}/\tau$ will become large, too. But from Proposition 1 and Eq. (23) we know that because of the productivity effect a principal-agent relationship will be more attractive if $\bar{\gamma}$ is large. (The Appendix shows that this effect does indeed drive the results for the restrictions $\tau > 4\bar{\varepsilon}c$ and $\tau < 4\bar{\varepsilon}c$ in Proposition 2)[23]. Since the second implication of an increasing $\bar{\varepsilon}$ is somewhat artificial, we can conclude that a high risk of the production technology will make $P$ prefer duopolistic competition to a principal-agent relationship.

## 3 Relatively Profitable Knowledge and Teamwork

Often – especially in partnerships – $P$ and $A$ have identical skills and perform identical tasks. For example, in a law firm in which $P$ is the senior partner and $A$ is either a junior partner or an employed lawyer, both players may perform similar tasks. Thus, the firm's collective output or performance can be better described by

$$q = \gamma + e_A + e_P + \varepsilon + m \tag{24}$$

instead of Eq. (1), where $e_i$ (i = $A,P$) denotes $i$'s unobservable effort. In this case, the organization of work can be roughly characterized as teamwork, since both players directly contribute to the performance $q$[24]. Now, both $P$ and $A$ must bear a disutility of effort that is described by the cost function $c_i(e_i) = \frac{c}{2}e_i^2$ ($i = A,P$). Therefore, the two players' expected utilities in a principal-agent contract are given by

$$EU_A^{pa}(e_A) = \alpha + \beta(\gamma + e_A + e_P + m) - \frac{c}{2}e_A^2 \tag{25}$$

$$EU_P^{pa}(e_P) = (1-\beta)(\gamma + e_A + e_P + m) - \frac{c}{2}e_P^2 - \alpha. \tag{26}$$

Since the optimal efforts are

$$e_A^* = \frac{\beta}{c} \quad \text{and} \quad e_P^* = \frac{1-\beta}{c}, \tag{27}$$

Eqs. (25) and (26) can be rewritten as

23 The assumption $\bar{\gamma} = 2\bar{\varepsilon}/\tau$ also directly determines the magnitude of $EU_P^{pa}$ in Eq. (23), which is also shown in the Appendix.

24 Eq. (24) does not meet the non-separability condition for team production defined by *Alchian/ Demsetz* (1972). However, there is a similar team problem (namely, free-riding) since we have only a collective performance measure and individual efforts are not contractible.

$$EU_A^{pa}(e_A^*) = \alpha + \beta\left(\gamma + \frac{1}{c} + m\right) - \frac{\beta^2}{2c} \tag{28}$$

$$EU_P^{pa}(e_P^*) = (1-\beta)\left(\gamma + \frac{1}{c} + m\right) - \frac{(1-\beta)^2}{2c} - \alpha. \tag{29}$$

The optimal efforts described by (27) emphasize the additional incentive problem in this modified version of the initial model: *P* can enhance *A*'s incentives by raising $\beta$, but only at the expense of lowering his own incentives.

In the case of duopolistic competition, the expected utilities from *A* and *P* choosing optimal efforts are again described by (13) and (14). Hence, if there is such a competition I assume that *P* cannot profitably hire a new agent to form a team again[25].

In the first and the second stage of the game, *P* must decide about $\alpha$, $\beta$, and $\gamma$, and therefore between a principal-agent relationship and a duopolistic competition. If he prefers a principal-agent contract, *P* will choose $\alpha^*$ to make *A*'s participation constraint $EU_A^{pa}(e_A^*) \geq EU_A^{co}(e_A^*)$ binding. From (25) and (13) we get

$$\alpha^* = \frac{1 - m^2 f^2(\tau\gamma)}{2c} + mF(\tau\gamma) + \frac{\beta^2}{2c} - \beta\left(\gamma + \frac{1}{c} + m\right). \tag{30}$$

Substituting (30) into *P*'s participation constraint $EU_P^{pa}(e_P^*) \geq EU_P^{co}(e_P^*)$ and his objective function (29) yields that, in the case of a principal-agent contract, *P* will maximize

$$EU_P^{pa}(e_P^*) = \gamma + m(1 - F(\tau\gamma)) + \frac{m^2 f^2(\tau\gamma)}{2c} + \beta\frac{1-\beta}{c} \tag{31}$$

subject to

$$\gamma + \frac{\beta}{c}(1-\beta) \geq \frac{1 - 2m^2 f^2(\tau\gamma)}{2c}. \tag{32}$$

In this situation, *P* chooses $\beta^* = \frac{1}{2}$ to maximize (31) (and the left-hand side of (32)), and we obtain the following results:

**Proposition 3** *The principal will prefer a principal-agent relationship to a duopolistic competition, if*

$$\gamma \geq \frac{1 - 4m^2 f^2(\tau\gamma)}{4c}. \tag{33}$$

25 This assumption might be motivated by the fact that a new agent would lack the knowledge his predecessor has received during the probationary period.

*In that case, he will choose*

$$\gamma^* = \arg\max_{\gamma} \left\{ \gamma + m(1 - F(\tau\gamma)) + \frac{m^2 f^2(\tau\gamma)}{2c} + \frac{1}{4c} \right\} \tag{34}$$

*subject to (33) and* $\gamma \in [0, \bar{\gamma}]$. *If* $\bar{\gamma} \to \infty$, *he will always prefer a principal-agent contract to a duopolistic competition and choose* $\gamma^* = \bar{\gamma}$.

Comparing Propositions 3 and 1 shows that a principal-agent relationship is more likely to occur (i.e., condition (33) is less strong than (18)) and more profitable with teamwork than under a division of labor. These findings are not surprising, although teamwork is accompanied by an additional type of incentive problem characterized by (27): Under division of labor, optimal incentives are induced by $\beta^* = 1$ which leads to effort $e^* = 1/c$. Under teamwork, $P$ chooses $\beta^* = \frac{1}{2}$. By this, the team $(A,P)$ exerts effort $e_A^* + e_P^* \overset{(27)}{=} 1/c$. Hence, the same effort is achieved in either situation. But under teamwork, the collective effort $1/c$ is shared among $A$ and $P$ and since effort costs are convex, realizing the same effort under teamwork is less costly than if there is a division of labor.

More importantly, comparing Propositions 3 and 1 shows that again, the trade-off between the productivity effect on one side and the competition and the effort effect on the other side determines whether $P$ prefers a principal-agent relationship or a duopolistic competition. Therefore, the general findings of Section 2 can be called robust to the type of work organization.

## 4 Relatively and Absolutely Profitable Knowledge

The previous sections have focused on the case of relatively profitable knowledge. In other words, when $A$ becomes self-employed, his acquired knowledge only leads to a relative advantage for him when he is competing with $P$ in a duopoly. The knowledge itself does not generate an absolute advantage for $A$ (e.g., in markets other than the local duopoly with $P$). On the other hand, transfered knowledge $\gamma$ yields an absolute advantage in a principal-agent relationship, as can be seen from Eq. (1). In Section 2, I called this effect the "productivity effect". Moreover, the discussion of Propositions 1 and 3 shows that $P$'s preference for a principal-agent relationship depends on whether the productivity effect dominates the competition and the effort effect.

Therefore, as in Section 2, in this section I again consider the division of labor, but now I assume that knowledge $\gamma$ is not only relatively profitable (as in Section 2), but also absolutely profitable to $A$: Transfered knowledge $\gamma$ leads to an identical absolute advantage for $A$ in both a principal-agent relationship and a duopolistic competition. Hence, I replace expected utilities (7) and (8) by

$$EU_A^{co}(e_A) = \gamma + e_A + mF(\tau\gamma + e_A - e_P) - \frac{c}{2} e_A^2 \tag{35}$$

and

$$EU_P^{co}(e_P) = \delta\gamma + e_P + m[1 - F(\tau\gamma + e_A - e_P)] - \frac{c}{2}e_P^2 \tag{36}$$

with $\delta \in (0, 1]$ indicating that $A$ is at least as competent as $P$ when he is using the knowledge to gain an absolute advantage. This assumption reflects the key assumption of all principal-agent models: that $A$ is employed by $P$ because he is a professional agent with special professional skills or abilities. Otherwise, $P$ himself could manage the firm without any agency problem[26]. Solving this model backwards, the optimal efforts in the principal-agent relationship and the duopoly are again described by (9) and (12), respectively. But now, $A$'s and $P$'s participation constraints in the principal-agent contract must be modified. Again, $A$'s constraint will be binding in optimum as argued before, but now we have

$$\alpha^* = \gamma + \frac{1 - m^2 f^2(\tau\gamma)}{2c} + mF(\tau\gamma) + \frac{\beta^2}{2c} - \beta\left(\gamma + \frac{\beta}{c} + m\right). \tag{37}$$

Substituting (37) into (11) and $P$'s participation constraint $EU_P^{pa}(\gamma) \geq EU_P^{co}(e_P^*)$ shows that if $P$ prefers a principal-agent relationship he will maximize

$$EU_P^{pa}(\gamma) = \frac{\beta}{c} + m(1 - F(\tau\gamma)) - \frac{1 - m^2 f^2(\tau\gamma)}{2c} - \frac{\beta^2}{2c} \tag{38}$$

subject to

$$\frac{\beta}{c}\left(1 - \frac{\beta}{2}\right) \geq \delta\gamma + \frac{1 - m^2 f^2(\tau\gamma)}{c}. \tag{39}$$

Again, $\beta^* = 1$ will maximize $P$'s objective function (38) and the left-hand side of (39). Hence, I obtain the following results:

**Proposition 4** *The principal will prefer a principal-agent relationship to a duopolistic competition, if*

$$\delta\gamma + \frac{1 - 2m^2 f^2(\tau\gamma)}{2c} \leq 0. \tag{40}$$

*In that case, he will choose $\gamma^* = 0$. If $\bar{\gamma} \to \infty$, he will always prefer duopolistic competition to a principal-agent relationship and choose $\gamma^* = \bar{\gamma}$.*

26 See analogous arguments for $\tau \in (0,1]$ in Section 2.

**Proof.** Inserting $\beta^* = 1$ into (39) and rearranging gives (40). Substituting $\beta^* = 1$ into (38) yields

$$EU_P^{pa}(\gamma) = m(1 - F(\tau\gamma)) + \frac{m^2 f^2(\tau\gamma)}{2c} \tag{41}$$

which is maximized at $\gamma^* = 0$. This $\gamma^*$ will also minimize the left-hand side of (40). In the case of a duopolistic competition, according to (36) and (12) we have

$$EU_P^{co}(e_P^*) = \delta\gamma + \frac{1 - m^2 f^2(\tau\gamma)}{2c} + m(1 - F(\tau\gamma)).$$

Hence, in analogy to the proof of Proposition 1 $P$ will choose duopolistic competition in combination with $\gamma^* = \bar{\gamma}$ if $\bar{\gamma} \to \infty$ so that $EU_P^{co}(e_P^*) \approx \delta\bar{\gamma} + \frac{1}{2c} \to \infty$. ■

Comparing the results of Proposition 1 and Proposition 4 (especially (18) and (40)) shows that a principal-agent relationship will become less attractive for $P$ if knowledge is also absolutely profitable. If knowledge transfer is unlimited (i.e., $\bar{\gamma} \to \infty$), then $P$ will always prefer duopolistic competition.

The intuition for the impact of absolute profitableness of knowledge can be seen most clearly from (11) and (37). According to (37), the fixed payment $\alpha$ now contains the full absolute advantage from knowledge transfer, because $A$ must be compensated for this forgone advantage when agreeing to a principal-agent contract. Hence, the term $\gamma$ is cancelled out when substituting (37) into (11). In other words, $P$'s absolute advantage from using $\gamma$ inside the principal-agent relationship is completely offset by compensating $A$ for this forgone advantage that he would have realized if he became self-employed. This effect completely eliminates the productivity effect. Moreover, if $P$ is also able to use the knowledge $\gamma$ outside the principal-agent relationship (up to the degree $\delta$), then duopolistic competition will be very attractive for $P$, given that $\bar{\gamma}$ is suffciently large. In addition, a large value of $\gamma$ will optimize the effort effect mentioned in Section 2: $\gamma = \bar{\gamma} \to \infty$ leads to zero effort costs in the duopoly case.

However, if $\bar{\gamma}$ is too low, $P$ will prefer a principal-agent contract, but now chooses $\gamma^* = 0$ instead of $\gamma^* = \bar{\gamma}$. Comparing Eqs. (19) and (41) shows that the trade-off described by (19) is now resolved because the productivity effect has been cancelled out. The competition effect and the effort effect remain. Both can be best exploited by choosing $\gamma^* = 0$.

In Section 3, I show that the qualitative results of Section 2 carry over to another way of organizing work (namely, teamwork). However, in this section, I have checked the robustness of Proposition 1 according to the type of knowledge, i.e., relative profitableness and absolute profitableness. The findings of Proposition 4 demonstrate that the principal's decision on knowledge transfer is very sensitive to the type of knowledge.

## 5 Conclusion

When a principal must decide about transfering knowledge to his agent he faces a serious trade-off. On the one hand, knowledge transfer will make the agent more productive, which will be advantageous from the principal's viewpoint. On the other hand, if the agent obtains knowledge from the principal, he may be able to become self-employed and might then compete with the principal in the same market. This trade-off has also been identified in the paper, because there is a strict conflict between the productivity and the competition effect.

However, my analysis shows that there is a third effect that may be as important as the other two. I call this effect the "effort effect". This effect makes a principal-agent relationship less attractive for the principal when he transfers knowledge to his agent. According to the effort effect, knowledge transfer leads to low incentives when the agent becomes self-employed, and therefore, to low effort costs for both competitors. The intuition is that the more knowledge the agent has, the more uneven competition will become. Thus, it does not pay for the players to exert effort for large values of knowledge transfer and as a result we have a kind of implicit cartel. This effort effect makes competition more attractive for the principal relative to a principal-agent relationship for two reasons: In the case of a principal-agent relationship, the principal must compensate the agent for his forgone profits from competition. Thus, if the effort effect is strong due to a large knowledge transfer, this compensation will be very high and, therefore, a principal-agent relationship becomes very costly for the principal. Furthermore, the principal himself will directly profit from the effort effect (and the resulting implicit cartel) when he is separated from the agent. My analysis has also shown that the effort effect will be strong if luck (rather than effort) primarily determines the outcome of the competition between principal and agent (e.g., if customers' preferences can hardly be influenced by the competitors).

## Appendix

*Proof of Proposition 2:*

Since $\varepsilon_A$ and $\varepsilon_P$ are identically and uniformly distributed over $[-\bar{\varepsilon},\bar{\varepsilon}]$, the composed random variable $y = \varepsilon_P - \varepsilon_A$ is triangularly distributed with density $f(y)$ and cumulative distribution function $F(y)$:

$$f(y) = \begin{cases} \frac{1}{2\bar{\varepsilon}} + \frac{y}{4\bar{\varepsilon}^2} & \text{if } -2\bar{\varepsilon} \le y \le 0 \\ \frac{1}{2\bar{\varepsilon}} - \frac{y}{4\bar{\varepsilon}^2} & \text{if } 0 < y \le 2\bar{\varepsilon} \\ 0 & \text{otherwise.} \end{cases} \quad \text{and}$$

$$F(y) = \begin{cases} 0 & \text{if } y < -2\bar{\varepsilon} \\ \frac{y}{2\bar{\varepsilon}} + \frac{y^2}{8\bar{\varepsilon}^2} + \frac{1}{2} & \text{if } -2\bar{\varepsilon} \le y \le 0 \\ \frac{y}{2\bar{\varepsilon}} - \frac{y^2}{8\bar{\varepsilon}^2} + \frac{1}{2} & \text{if } 0 < y \le 2\bar{\varepsilon} \\ 1 & \text{if } y > 2\bar{\varepsilon}. \end{cases}$$

Since $\tau\gamma > 0$, the positive tail of the triangular distribution must describe $f(\tau\gamma)$ and $F(\tau\gamma)$. Substituting for $f(\tau\gamma)$ and $F(\tau\gamma)$ in (18) and (19) yields:

$$\gamma \ge \frac{1 - 2m^2 f^2(\tau\gamma)}{2c} \Leftrightarrow$$
$$\Psi(\gamma) := m^2\tau^2\gamma^2 + (16c\bar{\varepsilon}^4 - 4m^2\bar{\varepsilon}\tau)\gamma - 8\bar{\varepsilon}^4 + 4\bar{\varepsilon}^2 m^2 \ge 0$$

and

$$\begin{aligned} EU_P^{pa}(\gamma) &= \gamma + m(1 - F(\tau\gamma)) + \frac{m^2 f^2(\tau\gamma)}{2c} \\ &= \frac{m\tau^2(4c\bar{\varepsilon}^2 + m)\gamma^2 + 4\bar{\varepsilon}(8c\bar{\varepsilon}^3 - 4m\tau c\bar{\varepsilon}^2 - \tau m^2)\gamma + 4\bar{\varepsilon}^2 m(4c\bar{\varepsilon}^2 + m)}{32c\bar{\varepsilon}^4} \\ &=: \Omega(\gamma). \end{aligned}$$

The graphs for $\Psi(\gamma)$ and $\Omega(\gamma)$ are both parabolas open at the top.

First, I consider the parabola $\Omega(\gamma)$ which describes $P$'s objective function in a principal-agent relationship. This parabola has the two roots

$$\gamma_r = \frac{\left(2m\tau(4c\bar{\varepsilon}^2 + m) - 16c\bar{\varepsilon}^3 + 8\sqrt{c\bar{\varepsilon}^3(4c\bar{\varepsilon}^3 - 4m\tau c\bar{\varepsilon}^2 - \tau m^2)}\right)\bar{\varepsilon}}{m\tau^2(4c\bar{\varepsilon}^2 + m)}$$

$$\gamma_l = \frac{\left(2m\tau(4c\bar{\varepsilon}^2 + m) - 16c\bar{\varepsilon}^3 - 8\sqrt{c\bar{\varepsilon}^3(4c\bar{\varepsilon}^3 - 4m\tau c\bar{\varepsilon}^2 - \tau m^2)}\right)\bar{\varepsilon}}{m\tau^2(4c\bar{\varepsilon}^2 + m)},$$

which are real values due to the above assumption

$$\tau \leq \frac{4c\bar{\varepsilon}^3}{m(4c\bar{\varepsilon}^2 + m)}. \qquad (*)$$

I can show that the right root $\gamma_r$ is negative. This claim will be true, if

$$\frac{\left(2m\tau(4c\bar{\varepsilon}^2 + m) - 16c\bar{\varepsilon}^3 + 8\sqrt{c\bar{\varepsilon}^3(4c\bar{\varepsilon}^3 - 4m\tau c\bar{\varepsilon}^2 - \tau m^2)}\right)\bar{\varepsilon}}{m\tau^2(4c\bar{\varepsilon}^2 + m)} < 0 \Leftrightarrow$$

$$4\sqrt{c\bar{\varepsilon}^3(4c\bar{\varepsilon}^3 - 4m\tau c\bar{\varepsilon}^2 - \tau m^2)} < 8c\bar{\varepsilon}^3 - m\tau(4c\bar{\varepsilon}^2 + m).$$

Note that the right-hand side of this inequality is positive because of (*). Squaring both sides leads to

$$-\tau^2 m^2 (4c\bar{\varepsilon}^2 + m)^2 < 0$$

which is obviously true. Since $\gamma_r < 0$ the objective function $\Omega(\gamma)$ is increasing monotonically in the relevant range $\gamma \epsilon [0,\bar{\gamma}]$.

Next, I consider *P*'s participation constraint $\Psi(\gamma) \geq 0$. The two roots of this parabola are given by

$$\gamma_R = \frac{\left(2\tau m^2 - 8c\bar{\varepsilon}^3 + 2\sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)}\right)\bar{\varepsilon}}{m^2\tau^2}$$

$$\gamma_L = \frac{\left(2\tau m^2 - 8c\bar{\varepsilon}^3 - 2\sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)}\right)\bar{\varepsilon}}{m^2\tau^2}.$$

These roots are real values:

$$8\bar{\varepsilon}^4 c^2 - 4\bar{\varepsilon} c\tau m^2 + m^2\tau^2 > 0$$

holds, since according to (*), in the worst case we have

$$8c^2\bar{\varepsilon}^4 \frac{4c\bar{\varepsilon}^2 - m}{4c\bar{\varepsilon}^2 + m} + m^2\tau^2 > 0$$

which is true because of the concavity condition (20).

I can show that the left root $\gamma_L$ is negative. This claim will be true, if

$$\frac{\left(2\tau m^2 - 8c\bar{\varepsilon}^3 - 2\sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)}\right)\bar{\varepsilon}}{m^2\tau^2} < 0 \Leftrightarrow$$

$$\tau m^2 - 4c\bar{\varepsilon}^3 < \sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)}$$

which always holds as the left-hand side is negative because of (*).

Now, I look at the right root $\gamma_R$. This root will be positive (negative) if

$$\frac{\left(2\tau m^2 - 8c\bar{\varepsilon}^3 + 2\sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)}\right)\bar{\varepsilon}}{m^2\tau^2} > (<) 0 \Leftrightarrow$$

$$\sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)} > (<) 4c\bar{\varepsilon}^3 - \tau m^2.$$

Note that the right-hand side of the inequality is positive because of (*). Squaring both sides and simplifying yields:

$2\bar{\varepsilon}^2 > (<) m^2.$

At last, it will be interesting to see whether $\gamma_R$ is smaller or larger than the upper bound $\bar{\gamma} = \frac{2\bar{\varepsilon}}{\tau}$ given by condition (21). I obtain

$$\begin{aligned} \gamma_R &\lesseqgtr \bar{\gamma} \Leftrightarrow \\ \frac{\left(2\tau m^2 - 8c\bar{\varepsilon}^3 + 2\sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)}\right)\bar{\varepsilon}}{m^2\tau^2} &\lesseqgtr \frac{2\bar{\varepsilon}}{\tau} \Leftrightarrow \\ \sqrt{2\bar{\varepsilon}^2(8c^2\bar{\varepsilon}^4 - 4c\bar{\varepsilon}\tau m^2 + m^2\tau^2)} &\lesseqgtr 4c\bar{\varepsilon}^3. \end{aligned}$$

Squaring both sides and simplifying gives

$\tau \lesseqgtr 4\bar{\varepsilon}c.$

I can now use the earlier discussion of the parabolas $\Omega(\gamma)$ and $\Psi(\gamma)$ to prove the results (i)–(iii) of Proposition 2. Under the conditions of result (i), the right root of $\Psi(\gamma)$ is larger than the upper bound $\bar{\gamma}$. Therefore, *P*'s participation constraint for a principal-agent relationship can never be met and *P* will prefer duopolistic competition. I can calculate $P$'s optimal choice of $\gamma$ for this case. Substituting for $f(\tau\gamma)$ and $F(\tau\gamma)$ in Eq. (14) leads to

$$EU_P^{co}(\gamma) = \frac{(4c\bar{\varepsilon}^2 - m)m\tau^2\gamma^2 + (m - 4c\bar{\varepsilon}^2)4m\bar{\varepsilon}\tau\gamma + 4\bar{\varepsilon}^2(4\bar{\varepsilon}^2 - m^2 + 4mc\bar{\varepsilon}^2)}{32c\bar{\varepsilon}^4}.$$

Because of (20) the function $EU_P^{co}(\gamma)$ describes a parabola open at the top with roots

$$\frac{\bar{\varepsilon}}{2m(4c\bar{\varepsilon}^2 - m)}\left(4m(4c\bar{\varepsilon}^2 - m) \pm 8\sqrt{\bar{\varepsilon}^2 m(m - 4c\bar{\varepsilon}^2)}\right).$$

According to (20) both roots are not real values, hence the parabola lies above the abscissa. In addition, the parabola has its minimum at $\gamma = 2\bar{\varepsilon}/\tau = \bar{\gamma}$. This result implies that $EU_P^{co}(\gamma)$ is maximized at $\gamma = 0$. Inserting into $EU_P^{co}(\gamma)$ gives Eq. (22).

Under the condition of result (ii), the right root of $\Psi(\gamma)$ is negative. Therefore, $P$'s participation constraint is always satisfied and he will prefer a principal-agent relationship. Since his objective function $\Omega(\gamma)$ is increasing monotonically, he will optimally choose $\gamma = \bar{\gamma}$. Inserting into $\Omega(\gamma)$ yields Eq. (23).

Under the conditions of result (iii), the right root $\gamma_R$ of $\Psi(\gamma)$ lies between zero and $\bar{\gamma}$. Thus, I have a cut-off value $\hat{\gamma} = \gamma_R$ so that for $\gamma > (<)\ \hat{\gamma}$ the principal prefers a principal-agent relationship (duopolistic competition). Given the conditions of result (iii), $P$ can select the alternative that gives him the highest expected utility. He chooses a principal-agent relationship or a duopolistic competition, depending on whether (23) is greater than (22) or less than.

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