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BIDDING THE INVENTIONS AS INCENTIVE SCHEMES AND THE OWNERSHIP STRUCTURE

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Tiivistelmä

Tässä tutkimuksessa tarkastelemme sitä, miten keksintö tulisi myydä, kun kaupan muodolla voidaan vaikuttaa kannustimiin. Keksijäyritys myy keksinnön tuotemarkkinayrityksille. Analysoimme tilannetta, jossa epätäydellinen informaatio ei anna sijaa keksinnön lisenssoinnille ja muulle sopimuksenvaraiselle yhteistyölle. Keksinnön kaupallisen arvon oletetaan olevan ostajien yksityistä tietoa. Keksijäyrityksen kannattaa myydä keksintö huutokaupassa eniten tarjoavalle. Kiinteähintaisen huutokaupan ohella on mahdollista käyttää maksuvälineenä ostajayrityksen osakkeita. Tämä niin sanottu kannustinhuutokauppa vaikuttaisi myyjäyrityksen kaupan jälkeisiin kannustimiin olla mukana keksinnön kaupallistamisessa ja viemisessä markkinoille. Tässä tutkimuksessa mallinnetaan kannustinhuutokauppamekanismi ja osoitetaan, että mitä suurempi merkitys keksijäyrityksen kaupallistamista edistävillä ponnisteluilla on, sitä hanakammin keksijäyritys pyrkii järjestelyyn, jossa siitä tulee ostajayrityksen osakas. Tutkimuksessa osoitetaan myös, että keksijäyrityksen edun mukaista on painottaa omia kannustimia ostajayrityksen kannustimien kustannuksella, jotta keksinnön hinta saataisiin mahdollisimman lähelle sen todellista arvoa ja siten ostajalle maksettava korvaus tai vero sen hallussa olleen yksityisen tiedon paljastamisesta mahdollisimman pieneksi.

Bidding the inventions as incentive schemes and the ownership structure

Eero Lehto

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Abstract

In this study we consider the selling of an invention as an incentive scheme. The innovating firm sells the invention to other firms who are established in the product market. We consider a situation in which imperfect monitoring rules out the contractual mechanisms, and also royalty agreements. It is still possible to sell the invention through an auction mechanism. Actually the auction is used, because it maximizes the auctioneer's (inventor's) income. In situation considered it is required that the inventor also exerts some effort in the commercialization phase after the invention is sold. Owing to this post-trade effort, it may turn out to be beneficial to use the stocks of the product market firm in payment of the invention. This is implemented most easily through merger or acquisition. We show that the more effective the inventor's own effort is in the commercialization phase, the more beneficial for the inventor is that alternative which includes ownership arrangements, too. This alternative is attractive especially when the inventor acts as an auctioneer.Then the producer's (informational) rents can be effectively decreased by limiting the producer's own incentices to exert post-trade effort.

1 Introduction[1]

In this study we consider how product innovations can lead to mergers or ownership changes. The firm which innovates is assumed to be rather small and young. The innovating firm sells an invention to other firms who are established in the product market. The sale is not based on bilateral contract, because the inventor does not know in advance which of the producers will pay the highest price. To maximize income, the inventor sells the invention at an auction. Suppose that the producer wishes that the inventor also exerts some effort in the commercialization phase after the invention is sold. Owing to the post-trade effort, the fixed price auction is necessarily no longer the most beneficial way to sell the invention. It may turn out to be more attractive for the inventor to demand, in payment of an invention, the shares of the buyer or of such a firm that is born as a result of a merger of the innovating and buying firms.

Because the post-trade effort is not observed it cannot be contracted directly. In addition, we assume that the income stream which is generated by the invention is not a contractible variable either, and so the possibility of a royalty agreement is excluded. More specifically, we focus on the case in which the following conditions apply:

(i) One firm, an inventor, is specialized in the innovation activity by investing in human capital which decreases the costs of inventing. The inventor is not present in the production market.

(ii) The producer, the potential buyer of an invention, has redeemed the presence in the product market through investments which involve sunk costs.

(iii) The commercialization phase may require both the producer's and the inventor's effort.

(iv) Because it is neither possible to monitor the inventor's efforts associated with commercialization nor the volume of production which arises from the invention in question, the sale of an invention through a royalty license or any other type of bilateral contract is excluded.

(v) The invention is sold at an auction either at the fixed fee or as an ownership arrangement which has an effect on the incentives to exert effort in the commercialization phase.

[1]This paper is a part of a larger project which is ordered and funded by Tekes, the National Technology Agency.

In our approach we stress the relationship between the product innovator and the product market firms. We abstract from technology transfers motivated by a difference of costs between two incumbent firms that are analysed by Gallini and Winter (1985) and Katz and Shapiro (1985). In our setting the technology transfer does not affect the product market competition, which in the related literature, is regarded as one of the main factors which govern R&D investments and the sharing of high tech information (see Brander and Spencer (1984), Spence (1984), Katz (1986), Katz and Ordover (1990), d'Asperemont and Jacquemin (1988) and Kamien et al. (1992)). The possibility that one firm is specialized in producing inventions is discussed in Tirole (1989), Aghion and Tirole (1994) and Choi (2001). Our approach is tangent to Aghion and Tirole's analysis in some other respects, too. In our study the complete contract is excluded as in Aghion and Tirole (1994). But those authors focus on the arrangement of innovative activity, whereas we focus on the commercialization phase which leads to new arrangements in the ownership structure. Aghion and Tirole (1994) analyse a bilateral relationship, whereas we consider an auction in which the ex-ante bargaining power of bidders (producers) is determined by their number. In our approach we do not need to make assumptions about the players' ex-ante bargaining power as in Aghion and Tirole (1994). The assumption by which an invention is sold out at an auction rather than in bilateral bargaining is justified by the fact that for the inventor the auction is a more profitable way to sell the invention than negotiations are.[2]

In focusing on the commercialization phase our approach is similar to Choi's study (2001), who analyses how to resolve the moral hazard problem related by the effort setting of both the inventor and the producer in commercializing the invention. Unlike us, Choi considers the bilateral licensing contract in which the product volume generated by an invention is a verifiable variable.

Basically, our approach belongs to the tradition initiated by Hart and Moore (1990) and Hart (1995) which explains property rights. These authors have shown that by the appropriate ownership structure of physical assets the incentives to invest in relation specific human capital (in post-trade

[2]Klemperer (1996) showed that auction with no reserve price is (under reasonable assumptions) preferable to negotiations with one less bidder when the bidders' signals are independent.

commercialization efforts in our model) can be affected in the cases where the non-verifiability of crucial variables excludes the contractual mechanism. Hart (1995) argues that residual control rights concerning firms' physical asset (the property right of innovation in our model) finally affects the total surplus which is divided between the firms in Nash bargaining.[3]. Ownership is finally formed in a way which maximizes the outcome of the firms which are involved in the trade.

We next consider the bidding of an invention as an incentive scheme. The idea is to sell an invention which has to be commercilized by the help of an inventing firm itself and a firm which is established in the product market. If there are no post-trade efforts involved, the innovation can be sold through a fixed price auction. The efforts associated with commercialization complicate the situation. The bidding of incentive contracts has previously been considered in McAfee and McMillan (1987) and in Laffont and Tirole (1987). In considering the bidding of incentive systems, our approach relies on McAfee and McMillan (1987). Like them, the principal (the inventor) is assumed to auction the input (an invention) in the form which encourages the agent (the producer) to exert an optimal amount of effort which is required to complete the production process. We, however, extend the analysis to cover the principal's (inventor's) own effort, too. In addition to that, we consider the bidding model in which the outcome of actions is not verifiably observable. Therefore the actual device to implement the post-trade efforts on appropriate levels is the arrangements in the ownership structure.

2 Traditional auction

Suppose that there are n product market firms (producers) and one inventing firm. The price for the invention is determined through the auction mechanism. Let h_i be the innovations value for producer i. We assume that

[3]Hart's analysis (1995) can be applied in the analysis of ownership structures in an innovation setting as well. We feel uncomfortable, however, with some aspects of Hart's model. This model assumes that the fit of input produced by firm A to the needs of firm B in production of output is resolved after the relation-specific investments are made. In the R&D context it would be more convenient to assume that the inventor makes sure that the stochasticity related to the input-output fit is realized before the firms decide on closer cooperation in the commercilization of the invention. This already pushes the inventor to the auction market and not to bilateral bargaining.

(i) the reservation values h_i lie on the range $[0, 1]$ and they are independent;
(ii) these values are drawn from continuous probability distribution $F(h_i)$;
(iii) h_i is private information for producer i.

In the beginning of the auction the value of the invention is private information for each producer. So each producer knows how much he values the invention for sale, but does not know the valuations of other producers. These values are determined independently and they are identically distributed. The bidders and the seller are risk-neutral and they trade on a single indivisible invention.

We consider the descending (Dutch) auction, which is strategically equivalent to the the first-price sealed-bid auction. [4]

The producer with h_i bids in first-price auction according to

$$b_i = h_i - \frac{\int_{\underline{h}}^{h_i} F(x_i)^{n-1} dx}{F(h_i)^{n-1}}. \tag{1}$$

The bidder whose value is h_i then obtains

$$\frac{\int_{\underline{h}}^{h_i} F(x_i)^{n-1} dx_i}{F(h_i)^{n-1}}.$$

Here $F(h_i)^{n-1}$ describes the probability that producer i wins the auction. The expected pre-trade gain or rent for bidder h_i is then

$$\int_{\underline{h}}^{h_i} F(x_i)^{n-1} dx_i. \tag{2}$$

The seller's expected gain is, respectively,

$$\int_{\underline{v}}^{\overline{v}} n(F(h_i))^{n-1} f(h_i)(h_i - \frac{\int_{\underline{h}}^{h_i} (F(x_i))^{n-1} dx_i}{(F(h_i))^{n-1}}) dh_i. \tag{3}$$

[4]According to the revenue equivalence theorem the seller's and the buyers' expected incomes are, however, the same in any auction in which the traded item goes to that bidder whose reservation value is highest and in which the bidder with the lowest reservation value expects zero profits. Thus the first-price auction generates the same expected incomes as the ascending-bid (English) auction - which is equivalent to the second-price sealed-bid auction.

In ascending auctions the sellers bid according to the reservation values. The expected gains do not, however, differ from (2) and (3).

Let us assume, for simplicity, that $F(h_i)$ is uniform distribution. Then the producer $i's$ expected gain is

$$\frac{h_i^n}{n}$$

Before h_i realizes, the producer's expected gain is of size $\frac{1}{n(n+1)}$. The producers' aggregate gain is thus only $\frac{1}{n+1}$. Respectively, the seller's expected gain is then $\frac{n-1}{n+1}$ when h_i follows uniform distribution. This shows how sharply the bidders' rent decreases when their number becomes larger.

Abstracting from the informational problems associated with effort setting or with investment behaviour, it is difficult to see why the inventor and the producer would involve themselves in closer cooperation including mergers and acquisitions. The simple and effective way to sell the invention is the fixed price auction. Before we go to a case in which the unobservable efforts (or investments) play a central role, we briefly discuss the case in which the merger would, however, bring some cost savings.

Suppose that the invention can be sold either with or without a merger. In the case of a merger the inventing firm could participate in the commercialization of the invention. Assume that there is no moral hazard involved, but that, owing to duplicative and high administration costs under two separate organizations, the merger would bring cost savings. Therefore, the value of the trade would be higher in the case of merger. It would still be profitable to sell the invention through an auction, but with a merger. Suppose that the merger, however, caused fixed costs of size m_c.

As a consequence of a merger the value of the trade is assumed to be

$$R^f h_i.$$

Without a merger the respective value is

$$R^c h_i,$$

so that $R^f > R^c$. In the case of a merger the inventor's expected gain is

$$R^f \int_{\underline{v}}^{\overline{v}} n(F(h_i))^{n-1} f(h_i)(h_i - \frac{\int_{\underline{h}}^{h_i} (F(x_i))^{n-1} dx_i}{(F(h_i))^{n-1}}) dh_i - m_c.$$

Having uniform distribution this value has the expression

$$R^f(\frac{n-1}{n+1}) - m_c.$$

The fixed costs m_c are the seller's costs at an auction. Therefore, in the case considered, the producer always favours the merger. The inventor prefers the merger, if

$$(R^f - R^c)(\frac{n-1}{n+1}) > m_c. \tag{4}$$

Condition (4) shows that the likelihood of a merger increases with the number of producers.

Next we go to the case in which the inventor's and the producer's unobservable input is needed in the commercialization of the sold invention.

3 The model

Suppose there are n producers who are bidding for an inventing firm's invention. The sunk cost, which is required for access to the product market, is assumed to be large enough to foreclose the inventor from the production market. Besides, the inventing firm is assumed to be cash-constrained.[5] The inventing firm is assumed to have only one profit stream, which is the invention concerned. After the sale of an invention it will be commercialized. Let the value of the innovation be $R(h_{i,}e_i, E_i)$, where h_i describes innovation's value for producer i given the commercialization efforts. In auction theory, h_i is called an agent's reservation value. Each producer knows only his type. All the types are assumed to be drawn independently from a distribution $F(h_i)$ with density $f(h_i)$ so that $h_i \in [0,1]$. This is realized by the inventor and all the producers. We suppose that an inventor's own valuation of an invention is below the lowest possible value for any h_i that makes the inventor to sell the possessed invention.

The variables e_i and E_i describe the inventor's and the producer's efforts which are used in the commercialization phase, if producer i wins the auction.

[5]This says that an inventor has no initial cash endowment and thus is unable to sell the invention in such an agreement which includes first a payment to the producer and later gross income in the form of the producer's future profits. A similar assumption concerning the innovator's cash constraint is also included in Aghion and Tirole (1994).

An inventor and each producer observes only his own efforts. The unobservability of efforts creates a moral hazard problem. We also assume that an observation about R cannot be verified. Therefore R is not contractible.

We assume that $\frac{\partial R}{\partial h_i} > 0$, $\frac{\partial R}{\partial e_i} > 0$, $\frac{\partial R}{\partial E_i} > 0$, $\frac{\partial^2 R}{\partial e_i \partial E_i} = 0$, $\frac{\partial^2 R}{\partial e_i^2} \leq 0$ and $\frac{\partial^2 R}{\partial E_i^2} \leq 0$.

If only the producer set the effort, it would be possible to derive the second-best solution of the characterized optimization problem as McAfee and McMillan (1987) who did not explicitly specify the payment scheme. Then it could be possible to find a linear scheme which would correspond to the second-best solution at hand. In our setting, however, both parties contribute to the value of trade by post-trade efforts. Because a contract cannot be based on an observed R, only fixed price agreements or the trades using the firms' stocks are available. This constrains the payment scheme to be linear. Introducing a scheme which shares the post-trade value of innovation between the producer and the inventor requires that this scheme is explicitly specified.

The existence of two effort variables introduces an additonal trade-off into the game. As shown by McAfee and McMillan (1987) in the game in which only the agent (the producer) exerts effort, there is a trade-off between encouraging effort setting (minimizing the costs of moral hazard) and inducing the agent to reveal his type truthfully and in that way restricting the costs of informational rents (minimizing the costs of adverse selection). This trade-off is also included in our setting. Introducing two effort-exerting parties and rent sharing makes a trade-off, however, rather "three-dimensional". The auctioneer (the inventor) must favour that type of solution which encourages himself and the opposite party (the producer) to exert effort in appropriate proportions in the post-trade phase. If the producer is encouraged to exert effort at maximal intensity then the inventing firm itself has no motivation to act efficiently after the trade.

We follow the revelation principle, established by Myerson (1979) and (1982), which states that the principal (the inventor in our model) needs restrict his attention only to those mechanisms in which the agents (the producer in our model) are induced to report their types truthfully. Thus it pays for the inventor - who acts as an auctioneer - to induce the producers to reveal their types truthfully. The bidding mechanism considered is actually a revelation mechanism used to solve adverse selection problems.

Let $P(h_i)$ be the probability that type h_i will be chosen in the bidding mechanism considered.

Let the costs of exerting effort be for an inventor $C(e_i)$ and for a winning producer $C(E_i)$.

The time order of events in the game considered is as follows:

$\mathbf{t}_1$) The invention is born and the nature selects types h_i. Each producer observes his own type.

$\mathbf{t}_2$) The inventor proposes a mechanism which makes each producer to announce his type honestly and specifies the parameters of a linear "payment scheme". If the fixed-price scheme is used or if the linear scheme includes a fixed payment, the inventor is paid a fixed amount before the post-trade effort is exerted.

$\mathbf{t}_3$) Post-trade efforts are exerted and the value of the invention materializes in the product market. In the sharing scheme the ownership of a producer's firm fixes each party's stake of the commercialized innovation.

The producer i makes a bid $b(\widehat{h}_i)$ which corresponds to the announced value $\widehat{h}_i$ of true value h_i. We suppose that for the winning bidder i $b(\widehat{h}_i) = \alpha(\widehat{h}_i)R(h_i, e_i, E_i)$, where $\alpha(\widehat{h}_i)$ is the share of the total value R. The bid whose value is $\alpha(\widehat{h}_i)R(h_i, e_i, E_i)$ is then paid as a combination of fixed payment $q(\widehat{h}_i)Q_i + d(\widehat{h}_i)$ and shared future profits $q(\widehat{h}_i)(R(h_i, e_i, E_i)$ so that

$$b(\widehat{h}_i) = q(\widehat{h}_i)(R(h_i, e_i, E_i) + Q_i) + d(\widehat{h}_i). \tag{5}$$

In this formula, positive Q_i denotes firm $i's$ other profits, and $q(\widehat{h}_i)$ denotes a sharing parameter and $d(\widehat{h}_i)$ denotes a fixed payment which are decided in the auction mechanism. Because the inventor is cash-constrained $d(\widehat{h}_i) \geq 0$, which says that the inventor is not able to pay any extra money to buy from a producer's firm a bigger stake than a share $\alpha(\widehat{h}_i)$. In practice the trade which implements profit sharing can be implemented so that in payment of the invention the seller receives the buyer's stocks (or two firms are merged and the inventor gets an amount of the new firm's shares).

The share $q(\widehat{h}_i)$ can also be presented in the form

$$q(\widehat{h}_i) = \frac{\alpha(\widehat{h}_i)R}{R + Q_i} - \frac{d(\widehat{h}_i)}{R + Q_i}$$

from which it follows that

$$0 \leq q(\widehat{h}_i) \leq \frac{\alpha(\widehat{h}_i)R}{R+Q_i}. \tag{6}$$

If the inventor chooses the highest type, the probability that a type h_i is chosen is $F(h_i)^{n-1}$. The ex ante expected utility for producer i whose type is h_i and who announces his type of being $\widehat{h}_i$ is then

$$E\pi_i^E = [(R(h_i, e_i, E_i)) - b(\widehat{h}_i) - C(E_i)]F(\widehat{h}_i)^{n-1}. \tag{7}$$

In the post-trade phase, before the effort E_i is exerted the winning producer's utility can be expressed in the form

$$\pi_i^E = (1 - q(\widehat{h}_i))(R(h_i, e_i, E_i) + Q_i - D(\widehat{h}_i) - C(E_i) \tag{8}$$

where $D(\widehat{h}_i) = q(\widehat{h}_i)Q_i + d(\widehat{h}_i)$. The producer sets his effort on the level

$$E_i^* = \arg\max_{\mathrm{Ei}} \pi_i^E. \tag{9}$$

Clearly E_i^* also maximizes $E\pi_i^E$ in (7)[6]. Respectively, the inventor's post-trade profits can be presented in the form

$$\pi_i^e = q(\widehat{h}_i)(R(h_i, e_i, E_i)) + D(\widehat{h}_i) - C(e_i) \tag{10}$$

when the type is h_i. The inventor's post-trade efforts will be

$$e_i^* = \arg\max_{e_i} \pi_i^e. \tag{11}$$

Because the inventing firm applies revelation mechanism to the producers, the bids must satisfy the incentive-compatible condition

$$E\pi_i^E(h_i, e_i(h_i), E_i(h_i), h_i) \geq E\pi_i^E(h_i, e_i(\widehat{h}_i), E_i(\widehat{h}_i), \widehat{h}_i). \tag{12}$$

Given the choice of efforts at phase three, the inventor's ex ante expected profits from a truth-telling producer i can be expressed by $E\pi_i^E$ in the form

[6]It must be noticed that in the model considered the inventor cannot induce the producer to select such E_i' which maximizes $R(h_i, e_i^*, E_i)) - C(e_i^*) - C(E_i) - \frac{1-F(h_i)}{f(h_i)} \frac{\partial R}{\partial h_i}$ from (16), in other words the inventor's profits (like in McAfee and McMillan, 1987). The reason for this is that the inventor also exerts effort and that the payment scheme is restricted of being linear.

$$E\pi_i^e = \int_{\underline{h}}^{1} \{[(R(h_i, e_i^*, E_i^*)) - C(e_i^*) - C(E_i^*)]F(h_i)^{n-1} - E\pi_i^E(h_i, \widehat{h}_i)\} f(h_i) dh_i, \tag{13}$$

In (13) $\underline{h}$ denotes a reserve price[7] set by the inventor. The trades with the types whose reservation value is below $\underline{h}$ are unprofitable for the inventor. Above $e_i^* = e_i^*(\widehat{h}_i, q(\widehat{h}_i), \beta)$ and $E_i^* = E_i^*(h_i, \widehat{h}_i, q(\widehat{h}_i), \beta)$ where β denotes the vector of scalars which have an effect on R. In example 1, which is discussed in the next section, $\underline{h} = 0$.

Defining $E\pi_i^E$ as a state variable and using the the envelope theorem, we obtain

$$\frac{dE\pi_i^E}{dh_i} = \left.\frac{\partial E\pi_i^E}{\partial h_i}\right|_{\widehat{h}_i = h_i} = (1 - q(\widehat{h}_i))\frac{\partial R}{\partial h_i} F(h_i)^{n-1} \tag{14}$$

for the incentive incompatibility condition. This condition shows that the producer's profits are an increasing function of his type, because $\frac{\partial R}{\partial h_i} > 0$. This means that the high-type's profits will be larger than the low-type's profits. Integrating (14) we obtain the producer's profits, which in the case considered may be called the producer's informational rents. Using (14), we can derive the Hamiltonian function (where $\widehat{h}_i = h_i$)

$$\begin{aligned} H &= \{[R(h_i, e_i^*, E_i^*)) - C(e_i^*) - C(E_i^*)]F(h_i)^{n-1} - E\pi_i^E(h_i)\} f(h_i) \quad (15) \\ &\quad + \lambda \frac{\partial R}{\partial h_i}(1 - q(\widehat{h}_i))F(h_i)^{n-1}. \end{aligned}$$

to express the inventor's expected profits under constraint (14). In Appendix A it is shown that (15) transforms into

$$H = [R(h_i, e_i^*, E_i^*)) - C(e_i^*) - C(E_i^*) - \frac{1 - F(h_i)}{f(h_i)}(1 - q(\widehat{h}_i))\frac{\partial R}{\partial h_i}]F(h_i)^{n-1} f(h_i) \tag{16}$$

(see also McAfee and McMillan, 1987).

Let $A_b(h_i) \equiv R(h_i, e_i^*, E_i^*)) - C(e_i^*) - C(E_i^*) - \frac{1-F(h_i)}{f(h_i)}(1 - q(\widehat{h}_i))\frac{\partial R}{\partial h_i}$ in (16). If $A_b(h_i)$ is non-negative for all $h_i \geq 0$ then $\underline{h} = 0$. Otherwise $\underline{h}$ is determined from the equation $A_b(\underline{h}) = 0$.

[7] Riley and Samuelson (1981) have shown that in high and second bid auctions it pays, as a rule, for the auctioneer to shade the reserve price above the seller's own valuation.

If $\frac{dA_b(h_i)}{dh_i} \geq 0$, $A_b(h_i) \geq 0$ for all $h_i > \underline{h}$ and then a strategy which maximizes (16) with respect to the inventor's decision parameter q defines the inventor's optimum given $e_i = e_i^*, E_i = E_i^*$ and the bidding mechanism in which the highest bid is accepted. In Appendix A it is shown that the inventor will actually choose the highest type when the value h_i is reported truthfully and when $A_b(h_i) \geq 0$. The sufficient conditions that it is optimal for an agent to reveal his true value are given in Appendix B (in some special cases).

We will next derive the optimal values $q(\widehat{h}_i)$ and fixed part $D(\widehat{h}_i){=}q(\widehat{h}_i)Q_i{+}d(\widehat{h}_i)$ without taking explicitly into account the constraint (6). First we specify more closely R and $C(e_i)$ and $C(E_i)$.

4 Some cases

4.1 Example 1

Suppose that $R = Ah_i + \sqrt{\beta_e}e_i + \sqrt{\beta_E}E_i$ so that $\beta_E > A$. In addition, we assume that $C(e_i) = \frac{1}{2}e_i^2$ and $C(E_i) = \frac{1}{2}E_i^2$. Then $e_i^* = q\sqrt{\beta_e}$ and $E_i^* = (1-q)\sqrt{\beta_E}$. We also assume that distribution $F(h_i)$ is uniform which means that $F(h_i) = h_i$ and $f(h_i) = 1$. Hamiltonian (16) can then be presented in the form

$$H = [Ah_i + q\beta_e + (1-q)\beta_E - \frac{1}{2}q^2\beta_e - \frac{1}{2}(1-q)^2\beta_E - (1-h_i)(1-q)A]{h_i}^{n-1}. \quad (17)$$

Let $q^* = \arg\max_q H$ and $H^* = H(q^*)$. From expression (17) we obtain for q^* the expression

$$q^* = \frac{\beta_e + (1-h_i)A}{\beta_e + \beta_E}. \quad (18)$$

If condition (6) is violated, it is obvious that $q(\widehat{h}_i)$ must be set on the level at which (6) is binding.

Because $1 - h_i \leq 1$ and $\beta_E > A$, $q^* < 1$. From (18) we obtain intuitive results according to which $\frac{\partial q^*}{\partial \beta_e} > 0$ and $\frac{\partial q^*}{\partial \beta_E} < 0$. The more efficient an inventor is with respect to a producer in the commercialization phase, the more weight should be set on the inventor's incentives at the expense of the producer's incentives. Result (18) also hints at some less intuitive implications.

The auctioneer - who is the inventor in the case considered - has an incentive to restrict the informational rents obtained by the producers insofar as the type is below the highest h_i, which is one. From (14) we see that one way to restrict the size of informational rents is to decrease $1-q$ and thus to weaken the producer's incentives to exert effort. This explains why $q^* > 0$ even if $\beta_e = 0$. Suppose that $h_i < 1$. Then an auctioneer must encourage truth-telling by paying types who are higher than h_i more informational rent than for h_i so that the higher types would not announce that their type was h_i. When $h_i = 1$ there is no longer such a threat to be eliminated, wherefore the inventor may abstract from the adverse selection in providing the incentives to exert post-trade effort. This explains why $\frac{\partial q^*}{\partial h_i} < 0$ when $h_i < 1$.

By the envelope theorem

$$\frac{dH}{dh_i} = \frac{\partial H}{\partial h_i} = [A + (1-q)A]{h_i}^{n-1} + (n-1)H{h_i}^{n-2} > 0.$$

This shows that the inventor's payoffs also increase when the type becomes higher. This result corresponds to an intuition. After all, the good fit between the invention and the producer's needs benefits both parties: the producer and the inventor. The post-trade social welfare $R(h_i, e_i^*, E_i^*)) - C(e_i^*) - C(E_i^*)$ has, in example 1, representation

$$Ah_i(\beta_e + \beta_E)^2 + \frac{\beta_e^3}{2} + \frac{\beta_E^3}{2} + \beta_e^2\beta_E + \beta_e\beta_E^2 - \frac{1}{2}(\beta_e + \beta_E)(1-h_i)^2A^2.$$

From this expression it follows that an increase in both β_e or β_E unambiguously increases social welfare (because $\beta_E > A$). The higher the quality of the chosen type is, the higher is social welfare, whereas the impact of an increase in A on social welfare is ambiguous. If h_i is close to zero, this effect can be even negative. This indicates that when Ah_i is small enough the inventor's endeavour to decrease informational rents by weakening the incentives to exert effort (by decreasing q) does not benefit society.

4.2 Example 2

We consider some other cases to indicate that the level of optimal q is very sensitive to the model's assumption concerning the partial derivative $\frac{\partial R}{\partial h_i}$. Let us change the basic model by assuming that $R = A + h_i\sqrt{\beta_e}e_i + \sqrt{\beta_E}E_i$.

Then $e_i^* = \widehat{h}_i q\sqrt{\beta_e}$ and $E_i^* = (1-q)\sqrt{\beta_E}$. Having $\widehat{h}_i = h_i$, the respective Hamiltionian (denoted by H') is of the form

$$H' = [A_i + q\beta_e h_i^2 + (1-q)\beta_E - \frac{1}{2}q^2\beta_e h_i^2 - \frac{1}{2}(1-q)^2\beta_E - (1-h_i)(1-q)q\beta_e h_i]{h_i}^{n-1}. \tag{19}$$

From Hamiltonian (19) we see that it is no longer clear that the size of informational rents can be lowered by lifting q upwards. Define $q' = \arg\max_q H'$. The share q' then has an expression

$$q' = \frac{\beta_e h_i(2h_i - 1)}{\beta_e h_i(3h_i - 2) + \beta_E}. \tag{20}$$

Also now $q' = \frac{\beta_e}{\beta_e+\beta_E}$ when $h_i = 1$ and when only a moral hazard problem constrains maximization. Only those values of q' are feasible which satisfy condition (6). In the basic case $q^* > \frac{\beta_e}{\beta_e+\beta_E}$ when $h_i < 1$, which shows that the inventor restricts the size of informational rents by lifting q^* upwards. In the considered case $q' < \frac{\beta_e}{\beta_e+\beta_E}$, which indicates that now the desire to restrict the informational costs creates an opposite tendency, which lowers q'. In fact the inventor weakens his own incentives to exert effort at the post-trade phase. So, q' can be zero even if $\beta_e > 0$.

4.3 Example 3

Suppose now that $R = A + \sqrt{\beta_e}e_i + h_i\sqrt{\beta_E}E_i$ which means that the producers differ from each other only in their ability to increase that part of the total income that depends on the producer's own post-trade efforts. The maximized Hamiltonian is now of the form

$$H'' = [A_i + q\beta_e + (1-q)\beta_E h_i^2 - \frac{1}{2}q^2\beta_e - \frac{1}{2}(1-q)^2\beta_E h_i^2 - 2(1-h_i)(1-q)^2\beta_E h_i]{h_i}^{n-1}. \tag{21}$$

In solving Hamiltonian (21) we have assumed that the producer's post-trade effort will be $E_i^* = (1-q)\sqrt{\beta_E}h_i$ and thus also a function of true h_i. From (21) we obtain for $q'' = \arg\max_q H''$ the expression

$$q'' = \frac{\beta_e + \beta_E h_i 2(1-h_i)}{\beta_e + \beta_E h_i(2-h_i)}. \tag{22}$$

In the considered case $q'' = \frac{\beta_e}{\beta_e+\beta_E}$ when $h_i = 1$ and $q'' > \frac{\beta_e}{\beta_e+\beta_E}$ when $h_i < 1$. This shows that because the level of the producer's efforts in the case considered affects the informational rents there arises a new motive to weaken the producer's incentives to exert effort. As a result, q'' tends to go below $\frac{\beta_e}{\beta_e+\beta_E}$.

4.4 The producer as an auctioneer - an example 1

Suppose that the roles of an inventor and a producer are switched. Then a producer orders a pre-specified invention from the inventors. When the inventions are ready the inventors bid for an order. The producer acts as an auctioneer. The roles are thus switched and in the model considered the producer's pay-off is maximized. Then an optimal sharing parameter q', which describes the inventor's share of future profits, is

$$q' = \frac{\beta_e - (1 - h_i)A}{\beta_E + \beta_e}. \tag{23}$$

Then the actual q which is chosen is $\max(0, q')$. Again $\frac{\partial q^*}{\partial \beta_e} > 0$ and $\frac{\partial q^*}{\partial \beta_E} < 0$. But now this expression reveals that the auctioneer's tendency to restrict the costs of adverse selection (limit the size of informational rents) presses q' downwards. Actually q' may stay at zero even if $\beta_e > 0$. From formula (18) and (23) we also see that the number of bidders has no direct influence on the optimal scheme.

5 Conclusions

We consider the selling of an invention through auctions. That part of the payment which the winning bidder pays an inventor as a share of future profit stream accrued from an invention is denoted by q. This kind of payment can be implemented by using the buyer's stocks as means of payment, or by merging the innovating and buying firm, and by paying the inventor the shares of a new firm in payment of invention. If it is optimal for the inventor (who acts as an auctioneer) to set $q = 0$, the payment is implemented through a regular fixed price auction.

The examples considered indicate that the intensity parameters β_e and β_E have a rather unambiguous effect on share q. If the inventor's impact on commercialized income increase so that β_e increases, q also increases. An increase in β_E - which describes the strength at which the producer's effort affects commercialized income - has an opposite effect on q. In the neutral case, where $\frac{\partial R}{\partial h_i}$ is a scalar, there arises a tendency to lift q above zero in order to decrease the size of informational rents. But the direction of this tendency is not the same in a non-neutral case. For example, if $\frac{\partial^2 R}{\partial h_i \partial e_i} > 0$, there arises a counterforce which presses q downwards.

Generally, the number of bidders has no direct influence on the optimal scheme. The size of the market affects the forms of the trade, however, indirectly. The larger the number of producers is, the closer the winning bidder can expected to be the most efficient type. This weakens the inventor's motives to lower the producer's (the seller's) incentives to exert effort in order to reduce the informational rents. The scope for those trades in which the invention is sold through a fixed price auction is enlarged (at least in a neutral case considered in example 1).

We have not discussed the implications of constraint (6). It is, however, clear that in many cases the large size of the buyer restricts the scope of such arrangements in which the invention is sold by trading with shares of the firms involved.

5.1 Appendix A

We next assume that the producers announce their true values. Appendix A quite closely follows McAfee and McMillan (1987).[8]. The probability that type h_i wins the auction is

$$P_i(h_i) = \sum_{i=1}^{n} \int_0^1 p_i(h_{-i}, h_i) \prod_{j \neq i}^{n} f(h_j) dh_1, ..., dh_{i-1}, dh_{i+1}, ..., dh_n. \qquad (24)$$

The inventor's expected profits are then

$$E\pi_i^e(h_i) = \sum_{i=1}^{n} \int_0^1 [Eb(h_i, e_i, E_i) - C(e_i)] P_i(h_i) f(h_i) \qquad (25)$$

[8]Our model differs from McAfee and McMillan (1987) in some respects. In our model total income R is also a function of type h_i, wherefore the revelation condition becomes contingent on the chosen sharing parameter.

$$= \sum_{i=1}^{n}\int_0^1 R(h_i, e_i, E_i) - C(E_i) - C(e_i)]P_i(h_i)f(h_i)dh_i$$
$$-\sum_{i=1}^{n}\int_0^1 E\pi_i^E(h_i)f_i(h_i)dh_i$$

where $Eb(h_i, e_i, E_i)$ denotes the expected value for the winning bid and $E\pi_i^E(h_i) = [R(h_i, e_i, E_i) - C(E_i) - Eb(h_i, e_i, E_i)]P_i(h_i)$ and denotes the producer h_i's ex ante expected profits. Let us denote $-\sum_{i=1}^{n}\int_0^1 E\pi_i^E(h_i)f_i(h_i)dh_i$ by B_i. Then B_i also has the expression[9]

$$B_i = \sum_{i=1}^{n}[\Big|_0^1 E\pi_i^E(h_i)((1 - F_i(h_i)) - \int_0^1 \frac{dE\pi_i^E(h_i)}{dh_i}(1 - F_i(h_i))dh_i.$$

The efforts e_i and E_i above are regarded as functions of reported type. Using the envelope theorem, which states that in truthful reporting

$$\frac{dE\pi_i^E}{dh_i} = \frac{\partial E\pi_i^E}{\partial h_i}\Bigg|_{\widehat{h}_i = h_i} = (1 - q(\widehat{h}_i))\frac{\partial R}{\partial h_i}P(h_i),$$

B_i transforms into the form

$$B_i = -\sum_{i=1}^{n}[E\pi_i^E(0) - \int_0^1 (1 - q(\widehat{h}_i))\frac{\partial R}{\partial h_i}(1 - F_i(h_i))P(h_i)dh_i. \qquad (26)$$

Taking into account (24), (25) and (26) $E\pi_i^e$ can finally be expressed in the form

$$\begin{aligned} E\pi_i^e(h_i) &= \sum_{i=1}^{n}\int_0^1 [A_b(h_i, e_i, E_i)P_i(h_i)f(h_j)dh_i - \sum_{i=1}^{n}[E\pi_i^E(0) \qquad (27) \\ &= \int_0^1 ... \int_0^1 [\sum_{i=1}^{n} A_b(h_i, e_i, E_i)p_i(h_{-i}, h_i)\prod_{j=1i}^{n} f(h_j)dh_1, ..., dh_n - \sum_{i=1}^{n}[E\pi_i^E(0), \end{aligned}$$

[9]Here we have used the rule

$$\begin{aligned} \int_{z_0}^{z_1} \pi(z)g(z)dz &= \Big|_{z_0}^{z_1}\pi(z)G(z) + \int_{z_0}^{z_1} G(z)\frac{d\pi}{dz}dz \\ &+ \Big|_{z_0}^{z_1}\pi(z) - \int_{z_0}^{z_1}\frac{d\pi}{dz}dz. \end{aligned}$$

where

$$A_b(h_i, e_i, E_i) = R(h_i, e_i, E_i) - C(E_i) - C(e_i) + \frac{1 - F(h_i)}{f(h_i)}(1 - q(\widehat{h}_i))\frac{\partial R}{\partial h_i}.$$

Pointwise optimization results in that $E\pi_i^E(0) = 0$ and that the inventor sets $p_i(h_{-i}, h_i) = 1$ if $h_i \geq h_j$ (for all j) and $A_b(h_i, e_i, E_i) \geq 0$. Otherwise, $p_i(h_{-i}, h_i) = 0$. This says that the lowest type obtains no rent and that the inventor always chooses the highest type insofar as the trade is of value for the inventor.

5.2 Appendix B

The producer who announces $\widehat{h}_i$ and is of type h_i obtains rents of amount $E\pi_i^E$ (presented in equation (7)). On the other hand, we obtain from (14) with $E\pi_i^E\Big|_{\underline{h}} = 0$, the expression

$$E\pi_i^E = \int_{\underline{h}}^{\widehat{h}_i} [(1 - q(s))AF(s)^{n-1}]ds \tag{28}$$

for the rents in the case in which the producer announces his/her type truthfully. Expression (28) is set equal to $E\pi_i^E(\widehat{h}_i, e_i^*(\widehat{h}_i), E_i^*(\widehat{h}_i), \widehat{h}_i)$ in (7). Following this procedure, in example 1 where $\underline{h} = 0$, the expression

$$\int_0^{\widehat{h}_i} [(1 - q(s))AF(s)^{n-1}]ds$$

should then be equal to

$$F(\widehat{h}_i)^{n-1}[(1 - q(\widehat{h}_i))(Ah_i + q(\widehat{h}_i)\beta_e + \frac{1}{2}(1 - q(\widehat{h}_i))\beta_E) - d(\widehat{h}_i)].$$

After solving $d(\widehat{h}_i)$ from this equation $E\pi_i^E(h_i, e_i^*(\widehat{h}_i), E_i^*(\widehat{h}_i), \widehat{h}_i)$ can be expressed in the form

$$E\pi_i^E = [(1 - q(\widehat{h}_i))[A(h_i - \widehat{h}_i)]F(\widehat{h}_i)^{n-1} + \int_0^{\widehat{h}_i} [(1 - q(s))AF(s)^{n-1}]ds. \tag{29}$$

The simple form of (29) partly reflects the fact that E_i^*, having the expression $(1 - q(\widehat{h}_i))\sqrt{\beta_E}$, is not a function of true h_i. From (29) we obtain

$$\frac{\partial E\pi_i^E}{\partial \widehat{h}_i} = F(\widehat{h}_i)^{n-1}[-\frac{\partial q}{\partial \widehat{h}_i}A(h_i - \widehat{h}_i) - (1 - q(\widehat{h}_i))A \qquad (30)$$
$$+(1 - q(\widehat{h}_i))A] + (n-1)[(1 - q(\widehat{h}_i))[A(h_i - \widehat{h}_i)]f(\widehat{h}_i)F(\widehat{h}_i)^{n-2}$$

from which it follows that

$$\left.\frac{\partial E\pi_i^E}{\partial \widehat{h}_i}\right|_{\widehat{h}_i = h_i} = 0.$$

This result indicates that truthful reporting is a candidate for the maximum. Furthermore, we obtain from (30)

$$\frac{\partial^2 E\pi_i^E}{\partial \widehat{h}_i \partial h_i} = -F(\widehat{h}_i)^{n-1}\frac{\partial q}{\partial \widehat{h}_i}A + (n-1)[(1 - q(\widehat{h}_i))Af(\widehat{h}_i)F(\widehat{h}_i)^{n-2} \geq 0, \quad (31)$$

because $\frac{\partial q}{\partial \widehat{h}_i} < 0$ (see expression (30)). Result (31) implies that $\frac{\partial E\pi_i^E}{\partial \widehat{h}_i} > 0$ when $\widehat{h}_i < h_i$ and that $\frac{\partial E\pi_i^E}{\partial \widehat{h}_i} < 0$ when $\widehat{h}_i > h_i$ which is sufficient for reporting $\widehat{h}_i = h_i$ being optimal for producer i.

6 Literature

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