Center for Economic Studies, University of Munich, 80539 Munich, Germany

CENTER FOR ECONOMIC STUDIES

INFORMATION RENT AND THE HOLDUP PROBLEM: IS PRIVATE INFORMATION PRIOR TO INVESTMENT VALUABLE?

Michaela Erbenová
Steinar Vagstad

Working Paper No. 88

UNIVERSITY OF MUNICH

CES

Working Paper Series

CES Working Paper Series

INFORMATION RENT AND THE HOLDUP PROBLEM: IS PRIVATE INFORMATION PRIOR TO INVESTMENT VALUABLE?

Michaela Erbenová
Steinar Vagstad

Working Paper No. 88

1995

Center for Economic Studies
University of Munich
Schackstr. 4
80539 Munich
Germany
Telephone & Telefax:
++49-89-2180-3112

This paper has benefitted from discussions with and comments from Dieter Bös, Anke Kessler, Dorothea Kübler, Kjell Erik Lommerud, Christoph Lülfesmann, Paul Milgrom, Gaute Torsvik and seminar audiences at the University of Bergen, CERGE-EI and University of Bonn. Parts of the research behind this paper was carried out while the authors were visiting the *Center for Economic Studies (CES)* at the University of Munich. Financial support from the Norwegian Research Council (NFR-Ruhrgas and NFR-KAS) is gratefully acknowledged. The usual disclaimer applies.

CES Working Paper No. 88
September 1995

INFORMATION RENT AND THE HOLDUP PROBLEM: IS PRIVATE INFORMATION PRIOR TO INVESTMENT VALUABLE?

Abstract

Consider a principal-agent model in which the agent must sink an investment before the contract is written. If the agent has private information (e.g. about production costs), this may give rise to an information rent that is sometimes large enough to resolve the inherent holdup problem. In this paper the importance of the information *timing* is analyzed. Does it matter whether the agent learns his private information before or after investment? 'Early' private information has two effects on investments. First, when the agent receives (some) production cost information before investing, then high-cost types of the agent will be less willing to invest than low-cost types. This *direct* effect will trigger a *signaling* effect: if low-cost types invest and high-cost types do not, then investment is a signal of low costs, leading the principal to offer a less favorable contract for the agent. The signaling effect will always increase the holdup problem, while the direct effect may work both ways.

Keywords: investment, opportunism, information

Steinar Vagstad
Norwegian Research Center in Organization and Management
Rosenbergsgt. 39
5015 Bergen
Norway

Michaela Erbenová
Economic Institute - Center for Economic Research and Graduate Education
P.O.Box 882
111 21 Prague 1
Czech Republic

1 Introduction

Economic efficiency is frequently threatened by potential holdup problems, i.e. situations in which socially beneficial investments are not undertaken because the investing party has to pay all the investment costs but receives a too small fraction of the returns.[1] Fundamentally, the origin of the holdup problem is the deterioration of the investor's bargaining position once the investment is sunk. Virtually any ex ante division of the *net* gains from trade would suffice to make the investing party willing to invest, *as long as this division prevails after the investment has been made.* Therefore, measures to alleviate hold-up problems can be interpreted as measures to strengthen the investing party's bargaining position after he has invested.

In this paper we investigate the role of private information to alleviate hold-up problems.[2] The basic idea is that if the investing party has some payoff-relevant private information, this can give rise to an information rent, which may then suffice to cover the investment cost. To highlight the power of private information to resolve holdup problems, we start from the following basic situation: one party — the *agent* — makes the investment, while the other party — the *principal* — subsequently dictates the terms of trade. We assume that no contract can be written before the investment is undertaken. The agent's only source of rent is his private information about some payoff-relevant parameter, which in our case will

---

[1] A hold-up problem (see e.g. Williamson (1975) and Klein *et.al.* (1978)) requires two factors to be present. First, parties to a future transaction must make non-contractible specific investment prior to the transaction to prepare for it, and second the exact form of the transaction cannot be specified with certainty *ex ante* (see Rogerson (1992)). Examples of hold-up problems are i) an electricity producer who hesitates to build a power plant at the mouth of a coal mine because a fraction of the resulting cost savings may be appropriated by the mine owner (Joskow (1985)); ii) a regulated monopoly unwilling to invest in new technology because it has to pay the entire investment cost while the regulating agency may pass the benefits over to the firm's customers (Lyon (1992)); and iii) a worker reluctant to engage in productivity-enhancing training because he fears that his training effort will not be compensated by the expected wage increase.

[2] Many potential holdup problems can be resolved by writing contracts before the investment decision is made. Clearly, if complete contracts can be written and enforced, the holdup problem is easily eliminated. However, also incomplete contracts (implicit contracts included) may often resolve the hold-up problem, by moving the parties' threat points and thereby altering their bargaining positions compared to a situation with no contract at all (see Rogerson (1992) for a recent survey of this approach). Note that the problem normally does not require the investing party to have all the bargaining power. What is needed is that the bargaining power of an investing agent leaves him with sufficient rent to cover the investment.

be production costs. If the expected information rent exceeds the investment cost, the agent will invest.[3]

In this paper we focus on the importance of the information *timing*. Does it matter whether the agent learns his private information before or after the investment decision? We argue that there are two reasons why the timing of the agent's private information may matter. First, if the agent learns before investing that his costs are going to be high (low), he will tend to be less (more) willing to invest than without any cost information before investment, *ceteris paribus*. As a consequence, early production cost information tends to make different types of the agent self-select in such a way that low-cost types are over-represented among the types that invest. We call this effect the *direct* effect of early information. Second, if the principal rationally believes that low-cost types are over-represented, she will be more willing to sacrifice efficiency for high-cost types in order to extract rent from low-cost types.[4] As a result the contracts will be less favorable for the agent and therefore entail less investment. The cause of this effect is that observed investment is a signal of low production costs, and we refer to this effect as the *signaling* effect of early production cost information.

In reality agents normally have some, but not perfect information before they make entry investments. Consequently, we assume that the agent knows an *estimate* of his production cost before he invests, and examine how the equilibrium behaviour changes with the accuracy or *quality* of this estimate.

[3] We are by no means the first to use the idea of alleviating a problem by introducing another. Laffont and Tirole (1993), among others, find that it is sometimes of value for a principal to leave some information rent with the agent. A related observation is made by Caillaud and Hermalin (1992), who also explore the benefits of having an agency problem. More generally, this is a second-best result: when there is a distortion from the first-best (in this case a problem of writing complete contracts) we may benefit from introducing another distortion (in this case an agency problem). Note that although asymmetric information may resolve the holdup problem, it sometimes creates another inefficiency: in our model there is sometimes no production despite investment.

[4] In other words, the principal faces a trade-off between extracting an information rent from the low-cost types of agents and offering a price high enough to make the high-cost agents willing to produce. When the probability of facing a low-cost type of agent is high, her gain from lowering the offer price is obvious. At the same time, however, this increases the risk that high-cost agents will not produce at all.

Our first set of results deals with situations in which the agent is willing to invest if his cost estimate is totally uninformative. (This will be an equilibrium for 'small' investment costs.) If we increase the estimate quality, the agent will eventually decline to invest if the estimate indicates that he has high production costs. This is the direct effect of improved estimate quality, as discussed above. This effect is strengthened by the signaling effect: for a given partition of the possible types of the firm, increasing the accuracy of the estimate leads to a conditioned distribution with more weight on low-cost types. As a consequence, improving the quality or accuracy of the estimate can only increase the holdup problem.[5] We thus find that, roughly speaking, if the estimate is somewhere between "totally uninformative" and "perfect", the agent's equilibrium investment behavior will vary monotonically between the two polar cases.

Our second set of results applies to situations in which the agent is *not* willing to invest if the cost estimate is useless (i.e., situations in which the investment cost is 'high'). In this case the two effects (direct and signaling) work in opposite directions. As before low-cost types will be more willing to invest than high-cost types, and more precise cost information will move densities from high-cost types to low-cost types and therefore lead the principal to offer a less favorable contract. However, now the direct effect makes the agent *more* willing to invest: From a situation in which no types will invest, improved cost information may make low-cost firms willing to invest. However, as the cost estimate becomes more precise, the investment will become a stronger signal that the agent has low production costs, and for sufficiently high estimate quality the signaling effect dominates the direct effect. Consequently, in this case investment is maximized for an intermediate quality of the cost

[5] Note that the signaling effect is driven by the fact that actions taken by privately informed players may convey some information to other players (here it is the investment that may separate types with favorable cost information from agents with less promising cost information). This information can then be exploited to the detriment of the first player's utility (here the information leads the principal to lower the price). Conceptually, this is similar to the well-known ratchet effect. (For a recent study in which this idea is employed, see Dalen (1994)).

estimate even if both polar cases (i.e., the cases of 'totally uninformative' and 'perfect' estimate) yield a unique equilibrium entailing no investment.

Our analysis utilizes a number of simplifying assumptions, such as risk neutrality, uniform cost distribution and a particular information technology. The third set of results shows however that our analysis is largely robust with respect to relaxing these assumptions. We also briefly discuss how our results would be altered if we relax other less restrictive assumptions (e.g., allowing for multiple agents, incentive contracts, bargaining over the terms of the contract, etc.). We find that the direct and signaling effects are present in a variety of settings, and operate much as they do in our initial simple framework.

We end this introduction by providing some links to related literature. In a paper closely connected to our analysis, Besanko and Spulber (1992) study a regulatory relationship in which the regulated firm (i.e. the agent) knows his type before the investment is made. In their model, the effect of the investment is to reduce marginal costs. Then it is reasonable to assume that efficient firms benefit less from the investment than less efficient ones. Therefore, in contrast with our model, a high level of investment is a signal that the principal is facing a high-cost firm. The signaling effect in Besanko and Spulber's framework always serves to increase investments.[6]

If the principal could commit to a mechanism before the investment decision is made, she could have avoided the signaling effect, while the direct effect would still have been present. An effect closely related to our direct effect can be found in Samuelson (1985). He studies an auction in which potential bidders must sink an investment before they can bid. Moreover, he assumes that the mechanism is designed before the investment decisions are made, and that potential bidders are perfectly informed before the investment decision.[7] The auction mechanism then screens high-valuation (i.e., low-cost) bidders, much like in the present model.

Our analysis focuses on whether early information is valuable or not. This raises the question whether the agent has incentives to *acquire* such information before the investment is made. There are some related papers on information acquisition, among which Kessler (1995) is the closest to the present one.[8] Kessler analyzes the agent's incentives to acquire cost information before the contract is offered, in a classical principal-agent framework. She finds that the agent benefits from being ignorant with a positive probability, essentially because this will make the principal offer a less rent-extracting mechanism, which will then benefit the agent when he *has* private information and his costs are low. However, in Kessler's model (as in the rest of this literature) there is no investment, and consequently her framework is not suited for studying hold-up problems.

The paper is organized as follows. The basic model is stated in the next section. In section 3 we characterize the equilibria of the model for different parameter values. Effects of relaxing specific assumptions of our analysis are studied in section 4. Section 5 concludes the paper.

2 The model

Consider a principal who wants an agent to carry out an indivisible task. Before the agent can produce, he has to sink an investment $I>0$. This can e.g. be an entry investment, or the instalment of new cost-saving machinery. If there is no investment, there is either no trade (if we are speaking about an entry investment), or production with an old technology (in the case of cost-saving technology). If the agent has invested, then the principal offers a price

[6] Tirole (1986) and Riordan (1987) also consider investment under asymmetric information in a limited-commitment setting. Contrary to Bensanko and Spulber, they assume that the investor learns his costs only after the investment is sunk. Consequently, upon observing that the agent has invested,the pricipal cannot infer anything about his costs.

[7] See also Levin and Smith (1994), who study an auction in which the potential bidders have *no* private information before they invest.

[8] See also Crèmer and Khalil (1992) and, in particular, Shavell (1994). Shavell discusses whether sellers or buyers should acquire information prior to transacting. He finds that information should be acquired only if such information increases the value of the object to be traded — if the information is mere foreknowledge it should never be acquired. In contrast, in our model the information may have social value also when it is mere foreknowledge, because sometimes the cost uncertainty deters investment, and early information serves to reduce the cost uncertainty.

R (or, in general, a contract) on a take-it-or-leave-it basis.[9] At this stage the investment cost is already sunk, and hence the agent will accept the contract if the price is not smaller than the production costs, C.

Before the agent makes the investment decision, he receives an estimate , $\tilde{C}$, of his production costs. His investment decision can then possibly depend on this estimate. We assume that the agent's expected returns from the investment will be (at least weakly) decreasing in $\tilde{C}$.[10] Then we can describe a rational agent's investment behavior with a cut-off value, θ, such that he will invest if and only if $\tilde{C} \leq \theta$. Clearly, this cut-off value will depend on the exact relation between the estimate and the true production cost, as well as on which beliefs he has about the principal's future choice of price.

The timing of events is summarized in Figure 1.

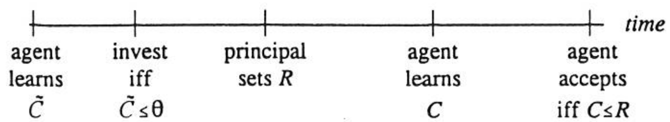


Figure 1: *The timing of events*

Both players are assumed to be risk neutral, with the principal's payoff W and the agent's payoff U given by

$$W = \begin{cases} S - R & \text{if production} \\ 0 & \text{otherwise} \end{cases}$$

[9] Clearly, if the investment is essential for production, it makes no difference whether the principal can observe the investment or not.

[10] This assumption will be satisfied for the information technology to be employed in this paper, and for many others.

$$U = \begin{cases} R - C - I & \text{if production} \\ -I & \text{if investment but no production} \\ 0 & \text{otherwise} \end{cases}$$

where S is the principal's valuation of having the project carried out and both parties' reservation utilities are normalized to zero.

To facilitate the analysis we have chosen the following cost and information structures (to be relaxed in section 4). First, the estimate is drawn from a uniform distribution on [0,1]. With probability π the estimate equals the agent's true cost. With the complementary probability $(1 - \pi)$ the estimate is pure noise, in which case the true production cost is redrawn from the same uniform distribution.[11] Hence, $\pi = 0$ and $\pi = 1$ describe the polar cases in which the agent has no and perfect information about his production costs, respectively, before he invests. π is assumed to be common knowledge and will be called the *quality* of the cost estimate. At this stage the agent does not learn whether the estimate is good or noisy.

Finally, we assume that the estimate and the true cost are observed by the agent only (while the technology and the information structure are common knowledge). Note that there are only three exogenous parameters in this model — S, I and π. In the next section we study how different combinations of these parameters give rise to different equilibrium outcomes. Before we do that, however, we will take a closer look at how beliefs are formed.

Normally, beliefs are described in terms of probability distributions over the other player's possible strategies. In this model, however, it is easily verified that no player will find it profitable to randomize his decisions (even if the other player plays random strategies). As a consequence, equilibrium beliefs must put probability 1 on a single element of the other player's strategy space, and we utilize this feature to simplify the notation.

[11] One example that fits this description could be the following. The agent knows one production technology perfectly well, but with probability $(1-\pi)$ he cannot use this technology, but has to produce with another technology, with unknown production costs.

Let θ_b denote the principal's belief about the agent's cut-off value. Moreover, let R_b denote the agent's belief about the principal's choice of price. Clearly, if the principal believes that all types of the agent have invested (i.e. that $\theta_b = 1$), then she will just face the original uniform distribution of costs. More interesting is the case in which she thinks that different estimates yield different investment decisions; $\theta_b \in [0,1)$. Then with probability π the agent had accurate cost information at the investment stage and therefore production costs in the interval $[0,\theta_b]$. Moreover, since the original distribution was uniform, so is the truncated distribution. With probability $(1-\pi)$, however, the agent's information at the investment stage was just noise. In this case the agent's cost is uniformly distributed on $[0,1]$. Combining this information, we find that the distribution of production costs for an agent that has invested can be described by the following density function:

$$f(C) = \begin{cases} \dfrac{\pi}{\theta_b} + 1 - \pi & \text{if } C \le \theta_b \\ 1 - \pi & \text{otherwise} \end{cases} \tag{1}$$

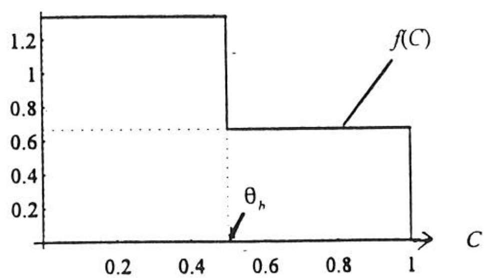


Figure 2: *Cost density faced by the principal*

Figure 2 shows an example of such a density function, where $\pi = 1/3$ and $\theta_b = 1/2$. Note that the investment transforms the initial uniform distribution by putting more weight on costs lower than the (believed) cutoff point and less weight on costs higher than this point. Integrating f yields the following cumulative distribution function (for subsequent use):

$$F(C) = \begin{cases} \left[\dfrac{\pi}{\theta_b} + 1 - \pi\right]C & \text{if } C \le \theta_b \\ \pi + (1 - \pi)C & \text{otherwise} \end{cases} \tag{2}$$

3 Equilibria of the basic model

Let θ^* and R^* denote the equilibrium values of the players' strategy variables (the agent's cut-off value and the principal's choice of price, respectively). There are two types of equilibria to consider — one in which the hold-up problem is completely resolved and one in which it is not. We begin with the former and simpler one.

Complete resolution of the holdup problem

If the principal believes that the agent has chosen strategy $\theta_b = 1$ (i.e., always invest), then the cost distribution she is facing is the original uniform distribution on $[0,1]$. She seeks to maximize her expected utility, which can be written as follows:

$$W = \int_0^R (S - R)dC = (S - R)R \tag{3}$$

with respect to the price R. Equation (3) clearly illustrates the principal's dilemma: Reducing the price increases her surplus $S - R$ from production but decreases the probability R that the agent will accept the offered price.[12] Let $R_1 \in \text{Argmax}_R \{(S - R)R\}$ denote the value of R that maximizes (3). Straightforward maximization yields $R_1 = \min\{1, S/2\}$.[13]

---

[12] Since the cost distribution is uniform on $[0,1]$, R equals the probability that the agent will accept the price R.

[13] Note that R is constant for $S<2$, and linearly increasing for $S>2$. As a consequence, the analysis (as well as the results) are somewhat different for $S<2$ and $S>2$ (see below). For the same reasons, the case in which $S=2$ needs special treatment.

Let us now consider the agent's problem. For $\theta=1$ (i.e., always invest) to be his optimal strategy, it must be the case that he will invest even if he has learned the worst possible cost estimate, i.e., $\tilde{C}=1$. But then his only hope for profit stems from the possibility of having the cost redrawn (since the principal never offers $R>1$). Formally, a necessary and sufficient condition for $\theta=1$ to be an equilibrium strategy is that

$$E[U|\tilde{C}=1] = (1-\pi)\int_0^{R_b}[R_b - C]dC - I = (1-\pi)R_b^2/2 - I \geq 0 \tag{4}$$

Rewriting (4) and using the fact that beliefs must be correct in equilibrium proves the following result:

Proposition 1. *A necessary and sufficient condition for existence of an equilibrium in which the holdup problem is completely resolved (i.e., in which $\theta^* = 1$) is that*

$$\pi \leq 1 - 2\,I/R_1^2. \tag{5}$$

Proposition 1 implies that there is a threshold value for the quality of pre-investment information; if the estimate quality is better than this level, then the hold-up problem cannot possibly be completely resolved. Note that Proposition 1 does not warrant uniqueness of the equilibrium, and as we will see below for some values of π satisfying condition (5) there may also be another equilibrium in which the hold-up problem is *not* completely resolved.

If the right hand side of (5) is negative, the holdup problem cannot possibly be completely resolved for any value of π:

Corollary 1: The holdup problem cannot be completely resolved for any $\pi\in[0,1]$ if $I > R_1^2/2$.

Partial resolution of the holdup problem

Now we turn to the more complicated case in which the hold-up problem is *not* completely resolved, i.e., $\theta^* < 1$. First we look at the agent's optimal investment decision when observing a cost estimate $\tilde{C}$. If the estimate exceeds the expected price R_b, then the agent's only hope of profit stems from the possibility of having received a noisy estimate, which happens with probability $1-\pi$. His expected profit in this case then equals

$$E[U|\tilde{C}\geq R_b] = (1-\pi)\int_0^{R_b}[R_b - C]dC - I = (1-\pi)R_b^2/2 - I \tag{6}$$

and in this case he should invest iff $(1-\pi)R_b^2/2 - I \geq 0$. If this last condition is satisfied, however, then the agent should *always* invest, and this contradicts the assumption that $\theta^* < 1$. Therefore, if the hold-up problem is not completely resolved, then any equilibrium must involve $\theta^* < R^*$.

If, on the other hand, the agent observes an estimate $\tilde{C} < R_b$, then even if his cost estimate is correct he will earn a rent, equal to $R_b - \tilde{C}$. This rent will occur with probability π and adds to the rent stemming from the prospects of having the costs redrawn. Hence

$$E[U|\tilde{C}<R_b] = (1-\pi)R_b^2/2 + \pi(R_b - \tilde{C}) - I \tag{7}$$

Now we turn to the principal's problem. She seeks to maximize

$$W = \int_0^R (S - R)dF(C) = (S - R)F(R) \tag{8}$$

with respect to R, where $F(R)$ is given by expression (2). From the discussion above we know that we do not need to consider $R \leq \theta_b$. Maximization then yields $R = R_2(\pi) \equiv \min\{1,[S -$

$\pi/(1-\pi)]/2\}$. Note that the equilibrium price may depend on the quality of the estimate, but not on the agent's strategy.[14]

Let us characterize the properties of the equilibria in the case of partial resolution of the holdup problem. Clearly, the equilibrium cutoff value must satisfy $E[U \mid \tilde{C} = \theta^*] = 0$. Rearranging (using (7) and the fact that $\theta^* < R$ implies that $R = R_2(\pi)$) we find that θ^* must satisfy $\theta^* = H(\pi)$, where $H(\pi) \equiv R_2(\pi) + \{(1-\pi)[R_2(\pi)]^2 - I\}/\pi$. (The function H is only introduced for expositional convenience.) This is, however, not a sufficient condition for existence of an equilibrium with $\theta^* \in [0,1)$. Before we present our results, we will take a look at some useful properties of the H function. First, since R_2 is continuous for $\pi \in (0,1)$ and differentiable in the same interval except for the point $\pi = (S-2)/(S-1)$ in the case of $S > 2$, so is H.[15] After rearranging, its derivative can be written

$$\frac{dH(\pi)}{d\pi} = \begin{cases} \left[I - \frac{S^2}{8}\right]\frac{1}{\pi^2} - \frac{3}{8(1-\pi)^2} & \text{if } S < \frac{2-\pi}{1-\pi} \\ -\frac{1-2I}{2\pi^2} & \text{if } S > \frac{2-\pi}{1-\pi} \end{cases} \tag{9}$$

The following result applies to cases in which the holdup problem is completely resolved for $\pi = 0$ (the proof is found in the appendix):

Proposition 2. *If $I < R_1^2/2$, there exist estimate qualities $0 < \pi_1 < \pi_2 < 1$ such that*

i) *there exists an equilibrium in which $\theta^* \in [0,1)$ iff $\pi \in (\pi_1, \pi_2]$,*

ii) *for each $\pi \in (\pi_1, \pi_2]$, this equilibrium is unique and satisfies $\{\theta^* = H(\pi), R^* = R_2(\pi)\}$, and*

iii) *θ^* is strictly decreasing in π in this interval.*[16]

---

[14] This property in not general, however, but stems from our choice of information technology. (See the discussion of information technologies in the appendix.)

[15] At the point $\pi = (S-2)/(S-1)$ the graph of $R_2(\pi)$ is kinked (for the same reasons that R_1 is kinked at $S = 2$).

[16] The case in which $I = R_1^2/2$ can be treated analogously, the only exception (in results — the analysis is somewhat different) is that $\pi_1 = 0$. Since this is a knife-edge case without general interest, the analysis is not reported.

The equations defining π_1 and π_2 ($H(\pi_1) = R_2(\pi_1)$ and $H(\pi_2) = 0$, respectively, see the appendix for details) turn out to be second-degree equations in π. Not much insight is gained from inspecting their explicit solutions, however.[17]

Proposition 2 has a very interesting immediate consequence (taking into account Proposition 1):

Corollary 2. *If the holdup problem is completely resolved for $\pi = 0$, then improving the estimate quality will monotonically increase the holdup problem.*

The equilibrium investment strategy is plotted against π in the figure below, for the case of $I = .3$ and $S = 2$ (it is easily verified that $\pi = 0$ implies $\theta^* = 1$ for these parameters).

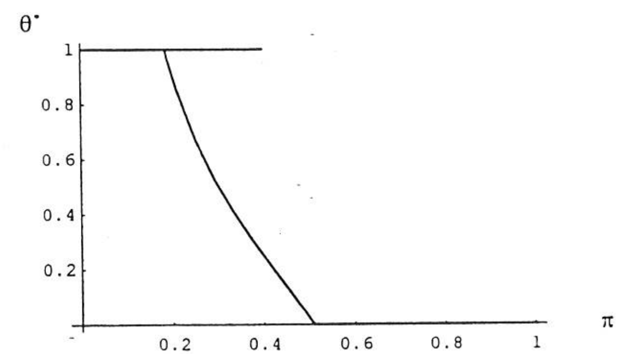


Figure 3: *Equilibrium investment when $\pi = 0$ yields investment*

---

[17] What can be obtained is some relatively obvious comparative statics (that can equally well be obtained from the defining equations): Both π_1 and π_2 are (sometimes weakly) increasing in S and decreasing in I.

Note that for some values of π there are *two* equilibria; one in which the hold-up problem is completely resolved, and one in which it is not. The former equilibrium Pareto-dominates the latter one (due to strategic complementarity). Increasing the estimate quality at best does not affect the best equilibrium (and sometimes makes it infeasible), while it reduces the likelihood of investment in the other equilibrium.

What happens if the holdup problem cannot be completely resolved for any π? (From Corollary 1 we know that this is equivalent to $I > R_1^2/2$.) Now, if the estimate is pure noise (i.e., $\pi = 0$) the agent will not invest. Consequently, improving the estimate quality from this point cannot do any harm. But can it have any positive effects? The answer might be yes, as described by the following Propositions 3 and 4. We distinguish between the cases in which $S>2$ and $S<2$ respectively.[18]

__Proposition 3.__ *If $S > 2$ and $I > R_1^2/2 = 1/2$, equilibria in which $\theta^* \in [0,1)$ exist iff $I \leq \frac{S - 3/2}{S - 1}$. If this condition is satisfied, then*

i) the interval $[2I\text{-}1, \pi_2]$ is non-empty (but possibly only a point, if the condition above holds with equality),

ii) $\{\theta^* = H(\pi), R^* = R_2(\pi)\}$ is an equilibrium with $\theta^* \geq 0$ iff $\pi \in [2I\text{-}1, \pi_2]$, and

iii) maximum investment equals $(S - 3/2 - I)/(S - 2)$ and is attained when $\pi = (S\text{-}2)/(S\text{-}1)$.

For a formal proof see the appendix. The most interesting part of this result is the condition for existence of equilibria in which a positive fraction of agent types choose to invest. For such equilibria to exist, the investment cost I must not be too large relative to the principal's valuation S. The reason is that high investment costs make the agent reluctant to

[18] It can be shown that equilibria with $\theta^* \geq 0$ cannot exist when $I > R_1^2/2$ and $S = 2$. Since this is a knife-edge case without general interest, we have not reported the analysis. See also footnote 11 above on why the cases in which $S<2$ and $S>2$ must be treated differently, and why $S=2$ needs special treatment.

invest, while low valuations make the principal more willing to risk lower prices, which also makes the agent reluctant to invest.

A similar, but more complicated result can be obtained for cases in which $S<2$ (again the proof is in the appendix):

__Proposition 4.__ *If $S < 2$ and $I > R_1^2/2 = S^2/8$, then H is a strictly concave function of π, with a unique maximum π^{**} in $(0,1)$ defined by the first-order condition $dH(\pi)/d\pi = 0$. If $H(\pi^{**}) = 0$, then $\{\theta^* = 0, R^* = R_2(\pi^{**})\}$ is the unique equilibrium with $\theta^* \geq 0$. If $H(\pi^{**}) > 0$, then there exists an interval $[\pi_0, \pi_2]$ such that*

i) $\pi^{**} \in (\pi_0, \pi_2)$.

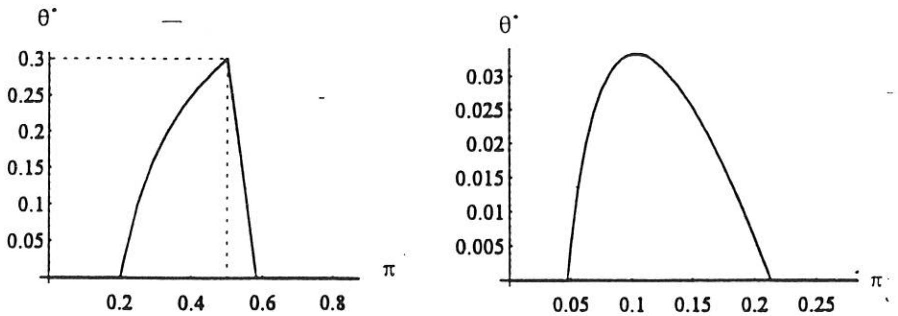
ii) $\{\theta^* = H(\pi), R^* = R_2(\pi)\}$ is an equilibrium with $\theta^* \geq 0$ iff $\pi \in [\pi_0, \pi_2]$, and

iii) θ^* is increasing in π for $\pi \in [\pi_0, \pi^{**})$ and decreasing for $\pi \in (\pi^{**}, \pi_2]$.

The intuition behind this proposition is similar to that for the previous result and it can be shown that existence of equilibria with $\theta^* \geq 0$ again requires that I is not too large compared to S. (Also in this case we can compute explicit expressions for π^{**} and π_0. Alas, not much insight is gained, and the expressions are therefore not presented.)

One may wonder what is the difference between the case in which improved quality of the estimate was always bad for investment (cf. Propositions 1 and 2), and this last case, in which some early information is essential for investment (cf. Propositions 3 and 4). If the holdup problem is (completely) resolved for $\pi = 0$, then improving the agent's cost estimate has only costs. For a given expected price, early cost information makes high-cost firms less willing to invest (the direct effect), and this effect may be reinforced by the principal's reaction (the signaling effect). If the holdup problem is *not* resolved for $\pi = 0$ we can identify a benefit from letting the agent learn his production costs earlier: If we start in a situation in which the agent's expected costs are higher than the (expected) price, then more reliable cost estimates can make low-cost firms willing to invest (the direct effect). However, the signaling effect is also present, and eventually dominates the direct effect.

Figure 4 shows how the equilibrium investment varies with π, for $S = 3$ and $I = .6$ (Fig. 4a) and $S = 1$ and $I = .13$. (Fig. 4b).



(Fig. 4a) (Fig. 4b)

Figure 4: *Equilibrium investment when $\pi=0$ yields no investment*

From the figure we see that early information increases investment up to a certain level, then decreases investment. What characterizes the former part of the curve is that although the investment is signaling low costs, the signal is not precise enough to make the principal offer a (much) lower price. In contrast, on the downward sloping part of the curve, increasing the signal precision leads the principal to lower the price significantly, and this effects dominates the beneficial effects of more precise signals on the agent's willingness to invest.

Before leaving this section we will give a simple necessary condition for an equilibrium with $\theta^* \in [0,1)$ to exist. Obviously, if the expected price does not cover the investment cost, the agent will not invest. Hence, solving $R_2=I$ for π gives us an upper bound on the estimate quality:

<u>*Proposition 5.*</u> *A necessary condition for existence of an equilibrium with $\theta^* \in [0,1)$ is that*

$$\pi \leq \frac{S - 2I}{S + 1 - 2I} = 1 - \frac{1}{1 + S - 2I}$$

By combining Propositions 1 and 5 it is easily seen that if π is 'large', there is never any investment. It is worth noting that this is irrespective of the investment cost and the principal's valuation. If the agent has perfect information about his production costs before he makes the investment decision, he will never sink even very small investments. Consequently, even 'postage costs' may deter investments even for multimillion dollar projects. (See also Proposition 7 below.)

4 Extensions of the basic model

The preceding analysis rests upon a number of simplifying assumptions, among which the assumptions of risk neutral players, the uniform distribution of cost parameters, and the specific information technology seem to be the most striking. In this section we will investigate how robust our analysis is with respect to relaxing each of these assumptions.

<u>Risk averse players.</u>

We will use the following intuitive and broad definition of risk aversion: Increasing a player's risk aversion will make him less willing to pick risky action compared to safe action.[19] This definition encompasses utility functions exhibiting constant relative risk aversion, constant absolute risk aversion, as well as many other functional forms. The main result concerning the effects of risk aversion can be stated as follows:

<u>*Proposition 6.*</u> *Making the principal more risk averse will reduce the holdup problem, while making the agent more risk averse will increase the holdup problem.*

<u>*Proof:*</u> The formal proof builds on the theory of supermodular games, as described by Milgrom and Roberts (1990). First, we have to show that our game is supermodular. A

[19] Technically speaking, increasing the risk aversion amounts to making the player's utility functions (weakly) more concave for each income level, and strictly more concave for some.

sufficient condition for our game to be supermodular is that it exhibits strategic complementarity or, equivalently, that the reaction functions are (weakly) upward sloping (cf. Milgrom and Roberts' Theorem 4). This is easily verified in our case: the agent's marginal returns from investing increases when the principal raises the price, and the principal's marginal gain from raising the price increases (weakly) when the agent becomes more willing to invest (because she will then be facing a cost distribution with more weight on high-cost types). Next we have to show that increasing the principal's risk aversion makes her offer a (weakly) higher price, and that increasing the agent's risk aversion makes him more reluctant to invest. This is also straightforward in our case (cf. the discussion below). To complete the proof we apply Milgrom and Roberts' (1990) Theorem 6 (monotonicity). Q.E.D.

The intuition behind the result is as follows. For the agent, the risky action is to invest, while for the principal the risky action is to set a low price which results in the absence of production. Hence, a more risk averse principal will set a higher price, given the agent's investment strategy. However, as the price goes up, the agent will become more willing to invest, and this will in turn lead to a distribution of production costs that involves higher probability densities for the high levels of production costs, in turn inducing the principal to set even higher prices. By similar reasoning, a more risk averse agent will be less willing to invest and hence observed investment will be a stronger signal of low costs. The principal will then pick a lower price which in turn causes the agent to be even more reluctant to invest. When the dust has settled, Proposition 6 emerges.

<u>The information technology</u>

Although our special information technology simplifies the analysis of the game (and also allows for a clear interpretation of the parameter π), similar effects will also be at work for other information technologies. Roughly speaking, any information technology for which

increased estimate quality implies increased probabilities for costs at and around the estimate itself will lead to similar behaviour (see the appendix for a more thorough treatment).

There are many ways of describing a situation in which the agent has 'some' information about production costs before he invests. In the limiting cases, however, these different ways must collapse to the same descriptions, as there is only one way to describe 'no information' or 'perfect information'. For one of these limiting cases we state the following result:

<u>Proposition 7.</u> *If the agent has perfect information about his production costs before the investment decision, there is never any investment in equilibrium.*

<u>Proof:</u> Let the production costs be distributed over an interval, which we normalize to $[0,1]$.[20] The principal will never offer a price larger than one. Therefore an agent will not invest if he has learnt that his production cost is in the interval $(1-I,1]$. Then, however, there is no reason why the principal should offer a price exceeding $1-I$. Therefore, however, an agent will not invest if his production cost is in the interval $(1-2I,1-I]$ either. By the same line of reasoning (i.e. by iterative elimination of dominated strategies), we reach the conclusion that there cannot be any investment in equilibrium. Q.E.D.

Note in particular that the proof does not rely on assumptions about cost distributions, and the only restriction on the utility functions is that they must be increasing in money.

<u>The cost distribution</u>

[20] Clearly, restricting attention to this particular interval is a normalization entailing no loss of generality, while restricting attention to a bounded set of possible production costs *may* incur some loss of generality. However, it is hard to find practical examples where this restriction imposes any loss of generality, as long as we allow for *any* distribution of costs over the given interval. See also Laffont and Tirole's (1993, pp. 75-76) defense of the use of compensation caps and cost ceilings — the economic equivalents of a lower and upper bar on possible costs — even if costs are not naturally bounded this way.

Intuitively, the uniform distribution assumption should not be crucial for the analysis (although it facilitates computation of explicit solutions to the strategy variables). We saw above (in the proof of Proposition 7) that the iterative elimination of dominated strategies works for any distribution of production costs, not only for the uniform distribution. If the distribution of costs has some other functional form, this will certainly affect the quantitative results, since both players' optimal strategies depend on the distribution of costs. It can be shown (see the appendix) that also for general cost distributions, i) the game exhibits strategic complementarity (i.e., the reaction functions are upward sloping); ii) increasing π may make the principal set a lower price, but never a higher one; and iii) increasing π makes low-cost agents more willing and high-cost agents less willing to invest. Therefore, the signs of the direct and signaling effects are distribution-independent.

5 Concluding remarks

When investing without a contract, an agent faces two different types of risk: genuine uncertainty (e.g. about production costs or market conditions) and risk of opportunistic behavior from the principal. The main message of this paper is that although reducing the agent's cost uncertainty is sometimes essential for investment, it at the same time increases problems of opportunism. The reason is that when the agent is informed before he makes the investment decision, then observed investment is a signal that the agent has low production costs.

In the previous section we considered the most restrictive assumptions employed in the model. We have shown that our conclusions are not altered significantly when relaxing these assumptions. We now conclude with a brief discussion of some of the assumptions not treated in the previous section. These are the distribution of bargaining power, allowing for incentive contracts and competition.

The extreme distribution of bargaining power in our model serves several purposes. First, by assigning the non-investing party all the bargaining power, the holdup problem is

highlighted. Therefore, our analysis focuses on the potential of private information for resolving the holdup problem under the most severe conditions. Second, the assumption eliminates the technical difficulties associated with bargaining problems under asymmetric information. Intuitively, if the bargaining power were more evenly shared, then a given investment strategy would result in a higher price, *ceteris paribus*. However, a higher price would in turn lead to a higher likelihood of investment. Hence, assigning more bargaining power to the agent will reduce the holdup problem. More interestingly for our analysis, also in this case the agent will be more willing to invest after receiving a good signal conveying information about his costs to the principal. Therefore, our results concerning the costs of early information should — at least to some extent — prevail.

One may wonder how our results would change if we endow the principal with more powerful means of controling the agent (see, e.g., Baron and Myerson's (1982) or Laffont and Tirole's (1986) treatment of incentive contracts). Clearly, if the principal had more powerful instruments to extract the agent's information rent, the agent would be more reluctant to invest. Therefore, the observation that the agent has invested will be a stronger signal of low costs, resulting in "less attractive" contracts for the agent (corresponding to lower prices in our model), further aggravating the underinvestment problem. In conclusion, allowing for more efficient ways of extracting rent should strengthen our results.

Will our results also apply to situations involving several potential agents competing for the right to serve the principal (like in, e.g., Laffont and Tirole (1987))? Each firm's expected returns from the entry investment should be non-increasing in the number of potential firms as well as in the number of firms that actually sink the entry investment. Introducing competition will then make an observed entry investment a stronger signal of low costs than in our reference setting. Therefore, the costs of early information will be present also in the more competitive environment. However, these costs may to some extent be balanced by the potential benefits of early information, namely in a beneficial self-selection of firms. The expected costs of firms that have invested will be lower than the expected costs of non-investing firms. A full-fledged analysis of this point is, however, beyond the scope of this paper and is left for the further research.

Appendix

Proof of Proposition 2. By definition, the expected utility of an agent with the cutoff estimate θ must equal zero. Hence θ can be found by setting (7) equal to zero and solve for $\tilde{C}$. Straightforward calculus reveals that $\theta = H(\pi)$. Therefore, an equilibrium in which $\theta^* \in [0,1)$ exists if and only if $\theta = \theta^* = H(\pi)$, $H(\pi) < R_2(\pi)$ and $H(\pi) \geq 0$.

$H(\pi) < R_2(\pi)$ if and only if $(1-\pi)[R_2(\pi)]^2/2 - I < 0$. Since $(1-\pi)[R_2(\pi)]^2$ is strict decreasing in π, $H(\pi) < R_2(\pi)$ if and only if π is larger than some number π_1, which is the unique solution of $(1-\pi)[R_2(\pi)]^2/2 - I = 0$. (The solution exists and must be interior since R_2 is continuous and $\lim_{\pi \to 0}\{(1-\pi)[R_2(\pi)]^2/2 - I\} = R_1^2/2 - I > 0$ by assumption.)

Next, $I < R_1^2/2$ implies that $I < S^2/8$ and that $I < 1/2$, which then implies (using (9)) that H is a strictly decreasing function of π. Consequently, $H(\pi) \geq 0$ if and only if π is smaller than or equal to some number π_2, which is the unique solution of $H(\pi) = 0$. (Again the solution exists and must be interior, since H is continuous; $I < R_1^2/2$ implies that $\lim_{\pi \to 0} H(\pi) = +\infty$ and therefore that $H > 1$ for sufficiently small π; and $\lim_{\pi \to 1} H(\pi) = -\infty$ and, consequently, $H < 0$ for sufficiently large π.)

Finally, non-emptiness (i.e., $\pi_1 < \pi_2$) is guaranteed since H is strictly decreasing and $H(\pi_1) = R_2(\pi_1) > 0$ while $H(\pi_2) = 0$. Q.E.D.

Proof of Proposition 3. As before, necessary and sufficient conditions for an equilibrium with $\theta^* \in [0,1)$ to exist are that $\theta^* = H(\pi)$, $H(\pi) < R_2(\pi)$ and $H(\pi) \geq 0$. Now, since by assumption $I > R_1^2/2 > (1-\pi)[R_2(\pi)]^2/2$, we need not worry about the constraint $H(\pi) < R_2(\pi)$.

$I > 1/2$ implies (using (9)) that H is increasing for $\pi < \pi^* \equiv (S-2)/(S-1)$. For π larger than π^* we cannot use (9) directly to sign the derivative of H. We can, however, safely restrict attention to cases in which there is non-negative investment, that is, $I \leq \pi R_2(\pi) + (1-\pi)[R_2(\pi)]^2/2$. Substituting $\pi R_2(\pi) + (1-\pi)[R_2(\pi)]^2/2$ for I in (9) yields (after rearranging) the following upper bound for $dH(\pi)/d\pi$:

$$\frac{dH(\pi)}{d\pi} \leq \frac{-6\pi + 3\pi^2 + 2S - 4\pi S + 2\pi^2 S - S^2 + 2\pi S^2 - \pi^2 S^2}{8\pi(1-\pi)^2}$$

$$= \frac{-3\pi(2-\pi) - S(S-2)(1-\pi)^2}{8\pi(1-\pi)^2} < 0$$

This implies that θ^* is strictly decreasing for $\pi > \pi^*$. But then π^* must be the quality that maximizes investment, $H(\pi^*)$ is its maximum level, and the existence of an equilibrium requires $H(\pi^*) \geq 0$. Rewriting yields $I \leq (S - 3/2)/(S - 1)$.

The remaining part of this proof is to find the interval for which an equilibrium involving $\theta^* \geq 0$ exists. If $H(\pi^*) = 0$, then the interval collapses to the point $\{\pi^*\}$. If $H(\pi^*) > 0$ then, by continuity of H, the endpoints of the interval are found by solving $H(\pi) = 0$

for π. This equation then has two roots, the lower equals $2I - 1$ and the higher equals π_2 as defined in the proof of Proposition 2. Q.E.D.

Proof of Proposition 4. $S < 2$ implies that $R_2(\pi) = [S - \pi/(1-\pi)]/2$, and that R_2 and thereby H is continuously twice differentiable on $(0,1)$. Differentiating (9) with respect to π yields

$$\frac{d^2H(\pi)}{d\pi^2} = -\left[I - \frac{S^2}{8}\right]\frac{2}{\pi^3} - \frac{3}{4(1-\pi)^3} < 0$$

which proves that H is strictly concave on $(0,1)$. The rest follows trivially.

Q.E.D.

Relaxing the uniform distribution assumption and specific information technology

As stated in the main text, most of our results do not rest on the specific assumptions about information technology and cost distribution. The results are driven by the direct and signaling effects discussed in the introduction. First, for the *direct* effect to work it must be the case that as cost information becomes more reliable, the agent should become more willing to invest if his cost estimate is good, and less willing to invest if he has received a bad (i.e., a high) estimate. Second, the *signaling* effect requires that, given the agent's investment strategy, when the estimate becomes more informative, the principal should find low prices more attractive relative to high prices. Third, for our analysis of risk aversion to hold, the game must exhibit strategic complementarity.

Clearly, with general cost functions we cannot assess quantitative questions as precisely as we can (and do) in the specific model. Now our results are to be interpreted qualitatively, and quantitative conclusions have to be of the form "if the estimate becomes sufficiently precise, the agent will not invest." This applies to the analysis of information technologies in particular.

Taking these disclaimers into account, the analysis is organized as follows. First we relax the uniform distribution assumption, while maintaining the information technology assumption. Then we discuss — more loosely — the information technology.

General cost distributions. Consider the following generalized cost structure: First the agent learns an estimate $\tilde{C}$, drawn from a general distribution denoted G on $[0,1]$ (see footnote 18). With probability π the estimate equals the true cost. With probability $(1 - \pi)$ the estimate is worthless, and the true cost is drawn from (the same distribution) G. Note that the information technology is unchanged — we have only replaced the uniform distribution of costs by a general distribution G. Note in particular that continuity of G is not required.

It is straightforward to check (the proof is omitted) that the agent's reaction function $\theta(R_b; \pi, I)$ is nondecreasing in R_b and thereby (weakly) upward-sloping, and that θ is (weakly) increasing in $\pi \geq 0$ for 'small' values of θ (and thereby small values of R_b) while (weakly) decreasing in π for 'large' values of θ and R_b. This is the direct effect.

It is somewhat more difficult to see how the principal's optimal price varies with the circumstances. If the principal believes that the agent has chosen strategy θ_b, the principal will (by the same reasoning as in the main text) face a cost distribution given by

$$F(C) = \begin{cases} \left[\dfrac{\pi}{G(\theta_b)} + 1 - \pi\right]G(C) & \text{if } C \le \theta_b \\ \pi + (1 - \pi)G(C) & \text{otherwise} \end{cases} \qquad \text{(A.1)}$$

The choice between any two prices R_0 and R (where $R > R_0$ without loss of generality) is determined by comparing the principal's expected payoff corresponding to the two prices. She will prefer R to R_0 if and only if $(S - R)F(R) > (S - R_0)F(R_0)$. Note in particular that the parameters π and θ_b can affect the choice (between these two particular prices) only by altering the ratio $r \equiv F(R)/F(R_0)$: increasing (decreasing) this ratio makes R a more (less) attractive choice relative to R_0.

First consider a change in π. There are different cases to consider. First, if $R_0 < R \le \theta_b$, then (by using (A.1) and rearranging) $r = G(R)/G(R_0)$ is independent of π, so changing π will not affect the choice between the two prices. Second, if $R_0 < \theta_b < R$, we get (again, by using (A.1), differentiating with respect to π and rearranging) $dr/d\pi = G(R_0)[1 - G(R)/G(\theta_b)]/[F(R_0)]^2 \le 0$ (with strict inequality if there is a positive probability that the production costs are in the interval $[\theta_b, R]$). Consequently, increasing π makes the lower price R_0 relatively more attractive. Finally, if $\theta_b \le R_0 < R$, then (using the same procedure) $dr/d\pi = [G(R_0) - G(R)]/[F(R_0)]^2 \le 0$. In conclusion, when π increases, the optimal price may well decrease, but never increase. This is the signaling effect.

Then we consider a change in θ_b. Again there are different cases to consider. First, if $R_0 < R \le \theta_b$, then (as above) $r = G(R)/G(R_0)$ is independent of θ_b. Second, if $R_0 < \theta_b < R$, we have that $F(R)$ is unaffected by changes in θ_b while $F(R_0)$ is decreasing in θ_b. Consequently, increasing θ_b makes the higher price R relatively more attractive. Finally, if $\theta_b \le R_0 < R$, then again we find that the choice is unaffected by θ_b. In conclusion, when θ_b increases, the optimal price may well increase, but never decrease. This is the strategic complementarity (i.e., upward sloping reaction functions).

To sum up, we have now proved that all effects work exactly the same way with general cost distributions as they did with uniformly distributed costs. (It is, for example, easily verified that (equivalents of) all our results can also be found in a model in which G is a two-point distribution on the set $\{0,1\}$.)

Information technology. Our information technology is not chosen because we believe it to be particularly realistic, but because it captures some of the basic properties of informativeness without leading to an overly complicated analysis. We will now discuss information technologies more generally, and try to assess how some of our results may change if we change the information technology. Consider the following examples of alternative information technologies.

Example 1. Divide the interval $[0,1]$ into N pieces, each of length $1/N$. The agent learns which of the N intervals its cost belongs to. Increasing the precision of the estimate now amounts to increasing the number of intervals. It is easily verified that for an equilibrium with investment to exist, the number of intervals must not be too large: $N < 1/I$. If costs are uniformly distributed, we obtain a stricter condition: $N < 1/(2I)$. Consequently, if e.g. $I = 0.3$, then investment is deterred if the agent learns whether his production costs are in the upper or lower half of the interval $[0,1]$. Note in particular that this outcome is inevitable even if the principal is infinitely risk averse and S is infinitely large. The reason is that when

agent types drop out, the distribution the principal is facing has reduced support, so reducing the price entails no risk. Note also that if there is an equilibrium in which agents with costs in the lower $n \le N$ intervals invest, then it can also be supported as an (perfect Bayesian) equilibrium that costs in exactly $0 < m < n$ of the intervals lead to investment.

Example 2. As in example 1, divide the interval $[0,1]$ into N pieces, each of length 1/N. Now the agent observes an estimate $\tilde{C}$, such that with probability π the true cost is uniformly distributed on the interval containing $\tilde{C}$, and with probability $(1 - \pi)$ the true cost is uniformly distributed on $[0,1]$. Now there are two ways to increase the informativeness of the estimate: by increasing π or N. (Note that the information technology in the main text is the limiting case when $N \to \infty$.) This information technology yields results that are similar to those obtained in example 1 and in the main text.

Example 3. Let $C \in \{0,1\}$. The agent learns an estimate $\tilde{C}$ that is uniform on $[0,1]$. Seen from the agent, the production cost equals zero with probability $(1 - \tilde{C})\pi + (1 - \pi)/2$. Again it can be shown that increasing π implies increased information content of the signal. Note that $\pi = 1$ is not equivalent of perfect information.

What do these examples, and numerous other ways of expressing the relation "the agent has some, but not perfect, cost information", have in common? We focus on the following two properties — closely linked to the discussion of the direct and signaling effects in the introductory section: First, for a given investment strategy (represented by θ in our model), increasing the precision of the cost estimate leads the principal to face a distribution of costs with more weight on cost levels below the cutoff estimate, and *less weight on costs higher than this level!* This will eventually lead the principal to choose a price that is not substantially higher than θ. Second, increasing π does not only make low-cost agents more willing to invest and high-cost agents less willing to invest — similar effects apply to agents within the interval $[0,\theta]$.

So, what is special with our information technology (apart from the tractability and easy interpretation)? We will argue the following two features. First, the distribution faced by the agent has a spike at θ^*, in turn making the principal facing a distribution with a sharp difference between costs at or below θ^* on the one hand, and costs above θ^* on the other. Second, our technology does not discriminate between cost levels close to θ^* and cost levels far away (in contrast to example 1 above). This makes the principal's risk from reducing the price independent of the cutoff value. More realistic would it be to assume that an agent observing an estimate θ will put more probability on cost levels at and *around* θ, and less weight on cost levels further away from θ. But this would in turn lead the principal to face a distribution with less probability weight on "very high" costs compared to costs around the cutoff value, making it relatively more tempting for the principal to reduce his price. (In example 1 above the principal indeed faces a distribution with reduced support, making this effect predominant.)

References

Baron, D. and R. Myerson (1982): "Regulating a monopolist with unknown costs," *Econometrica* Vol. 50 (July), pp. 911-30.

Besanko, D. and D.F. Spulber (1992): "Sequential-equilibrium investment by regulated firms," *RAND Journal of Economics* Vol. 23(2), pp. 153-70.

Caillaud, B. and B. Hermalin (1992): "The use of an agent in a signaling model," *Journal of Economic Theory* Vol. 60, pp. 83-113.

Crèmer, J. and F. Khalil (1994): "Gathering information before the contract is offered," *European Economic Review* Vol. 38, pp. 675-82.

Dalen, D.M. (1994): "Efficiency-improving investments and the ratchet effect," *European Economic Review*, forthcoming.

Joskow, P. (1985): "Vertical integration and long-term contracts: The case of coal-burning electric generating plants," *Journal of Law, Economics and Organization* Vol. 1, pp. 33-80.

Kessler, A.S. (1995): "The value of ignorance," Discussion Paper No. A-463, Sonderforschungsbereich 303, University of Bonn.

Klein, B., R.G. Crawford and A. Alchian (1978): "Vertical integration, appropriable rents, and the competitive contracting process," *Journal of Law and Economics* Vol. 21 (October), pp. 297-326.

Laffont, J.-J. and J. Tirole (1986): "Using cost observations to regulate firms," *Journal of Political Economy* Vol. 94, pp. 614-641.

Laffont, J.-J. and J. Tirole (1987): "Auctioning incentive contracts," *Journal of Political Economy* Vol. 95 (5), pp. 921-37.

Laffont, J.-J. and J. Tirole (1993): A theory of incentives in procurement and regulation, The MIT Press.

Levin, D. and J.L. Smith (1994): "Equilibrium in auctions with entry," *American Economic Review* Vol. 84 (3), pp. 585-99.

Lyon, T.P. (1991): "Regulation with 20-20 hindsight: 'Heads I win, tails you lose'?," *RAND Journal of Economics* Vol. 22 (4), pp. 581-95.

Milgrom, P. and J. Roberts (1990): "Rationalizability, learning, and equilibria in games with strategic complementarities," *Econometrica* Vol. 58 (6), pp. 1255-77.

Riordan, M.H. (1987): "Hierarchical control and investment incentives in procurement," Stanford University Working Paper E-87-44.

Rogerson, W.P. (1992): "Contractual solutions to the hold-up problem," *Review of Economic Studies* Vol. 59, pp. 777-94.

Samuelson, W.F. (1985): "Competitive bidding with entry costs," *Economics Letters* Vol. 17, pp. 53-57.

Shavell, S. (1994): "Acquisition and disclosure of information prior to sale," *RAND Journal of Economics* Vol. 25 (1), pp. 20-36.

Tirole, J. (1986): "Procurement and renegotiation," *Journal of Political Economy*, Vol. 94, No.2, pp. 235-59.

Williamson, O. (1975): Markets and hierarchies: Analysis and Antitrust implications, New York: Free Press.

CES Working Paper Series

---

12 Marc Nerlove, Assaf Razin, Efraim Sadka and Robert K. von Weizsäcker, Comprehensive Income Taxation, Investments in Human and Physical Capital, and Productivity, January 1992

13 Tapan Biswas, Efficiency and Consistency in Group Decisions, March 1992

14 Kai A. Konrad and Kjell Erik Lommerud, Relative Standing Comparisons, Risk Taking and Safety Regulations, June 1992

15 Michael Burda and Michael Funke, Trade Unions, Wages and Structural Adjustment in the New German States, June 1992

16 Dominique Demougin and Hans-Werner Sinn, Privatization, Risk-Taking and the Communist Firm, June 1992

17 John Piggott and John Whalley, Economic Impacts of Carbon Reduction Schemes: Some General Equilibrium Estimates from a Simple Global Model, June 1992

18 Yaffa Machnes and Adi Schnytzer, Why hasn't the Collective Farm Disappeared?, August 1992

19 Harris Schlesinger, Changes in Background Risk and Risk Taking Behavior, August 1992

20 Roger H. Gordon, Do Publicly Traded Corporations Act in the Public Interest?, August 1992

21 Roger H. Gordon, Privatization: Notes on the Macroeconomic Consequences, August 1992

22 Neil A. Doherty and Harris Schlesinger, Insurance Markets with Noisy Loss Distributions, August 1992

23 Roger H. Gordon, Fiscal Policy during the Transition in Eastern Europe, September 1992

24 Giancarlo Gandolfo and Pier Carlo Padoan, The Dynamics of Capital Liberalization: A Macroeconometric Analysis, September 1992

25 Roger H. Gordon and Joosung Jun, Taxes and the Form of Ownership of Foreign Corporate Equity, October 1992

26 Gaute Torsvik and Trond E. Olsen, Irreversible Investments, Uncertainty, and the Ramsey Policy, October 1992

27 Robert S. Chirinko, Business Fixed Investment Spending: A Critical Survey of Modeling Strategies, Empirical Results, and Policy Implications, November 1992

28 Kai A. Konrad and Kjell Erik Lommerud, Non-Cooperative Families, November 1992

29 Michael Funke and Dirk Willenbockel, Die Auswirkungen des "Standortsicherungsgesetzes" auf die Kapitalakkumulation - Wirtschaftstheoretische Anmerkungen zu einer wirtschaftspolitischen Diskussion, January 1993

30 Michelle White, Corporate Bankruptcy as a Filtering Device, February 1993

31 Thomas Mayer, In Defence of Serious Economics: A Review of Terence Hutchison; Changing Aims in Economics, April 1993

32 Thomas Mayer, How Much do Micro-Foundations Matter?, April 1993

33 Christian Thimann and Marcel Thum, Investing in the East: Waiting and Learning, April 1993

34 Jonas Agell and Kjell Erik Lommerud, Egalitarianism and Growth, April 1993

35 Peter Kuhn, The Economics of Relative Rewards: Pattern Bargaining, May 1993

36 Thomas Mayer, Indexed Bonds and Heterogeneous Agents, May 1993

37 Trond E. Olsen and Gaute Torsvik, Intertemporal Common Agency and Organizational Design: How much Decentralization?, May 1993

38 Henry Tulkens and Philippe vanden Eeckaut, Non-Parametric Efficiency, Progress and Regress Measures for Panel Data: Methodological Aspects, May 1993

39 Hans-Werner Sinn, How Much Europe? - Subsidiarity, Centralization and Fiscal Competition, July 1993

40 Harald Uhlig, Transition and Financial Collapse, July 1993

41 Jim Malley and Thomas Moutos, Unemployment and Consumption: The Case of Motor-Vehicles, July 1993

42 John McMillan, Autonomy and Incentives in Chinese State Enterprises, August 1993

43 Murray C. Kemp and Henry Y. Wan, Jr., Lumpsum Compensation in a Context of Incomplete Markets, August 1993

44 Robert A. Hart and Thomas Moutos, Quasi-Permanent Employment and the Comparative Theory of Coalitional and Neoclassical Firms, September 1993

45 Mark Gradstein and Moshe Justman, Education, Inequality, and Growth: A Public Choice Perspective, September 1993

46 John McMillan, Why Does Japan Resist Foreign Market-Opening Pressure?, September 1993

47 Peter J. Hammond, History as a Widespread Externality in Some Arrow-Debreu Market Games, October 1993

48 Michelle J. White, The Costs of Corporate Bankruptcy: A U.S.-European Comparison, October 1993

49 Gerlinde Sinn and Hans-Werner Sinn, Participation, Capitalization and Privatization, Report on Bolivia's Current Political Privatization Debate, October 1993

50 Peter J. Hammond, Financial Distortions to the Incentives of Managers, Owners and Workers, November 1993

51 Hans-Werner Sinn, Eine neue Tarifpolitik (A New Union Policy), November 1993

52 Michael Funke, Stephen Hall and Martin Sola, Rational Bubbles During Poland's Hyperinflation: Implications and Empirical Evidence, December 1993

53 Jürgen Eichberger and Ian R. Harper, The General Equilibrium Foundations of Modern Finance Theory: An Exposition, December 1993

54 Jürgen Eichberger, Bayesian Learning in Repeated Normal Form Games, December 1993

55 Robert S. Chirinko, Non-Convexities, Labor Hoarding, Technology Shocks, and Procyclical Productivity: A Structural Econometric Approach, January 1994

56 A. Lans Bovenberg and Frederick van der Ploeg, Consequences of Environmental Tax Reform for Involuntary Unemployment and Welfare, February 1994

57 Jeremy Edwards and Michael Keen, Tax Competition and Leviathan, March 1994

58 Clive Bell and Gerhard Clemenz, The Desire for Land: Strategic Lending with Adverse Selection, April 1994

59 Ronald W. Jones and Michihiro Ohyama, Technology Choice, Overtaking and Comparative Advantage, May 1994

60 Eric L. Jones, Culture and its Relationship to Economic Change, May 1994

61 John M. Hartwick, Sustainability and Constant Consumption Paths in Open Economies with Exhaustible Resources, June 1994

62 Jürg Niehans, Adam Smith and the Welfare Cost of Optimism, June 1994

63 Tönu Puu, The Chaotic Monopolist, August 1994

64 Tönu Puu, The Chaotic Duopolists, August 1994

65 Hans-Werner Sinn, A Theory of the Welfare State, August 1994

66 Martin Beckmann, Optimal Gambling Strategies, September 1994

67 Hans-Werner Sinn, Schlingerkurs - Lohnpolitik und Investitionsförderung in den neuen Bundesländern, September 1994

68 Karlhans Sauernheimer and Jerome L. Stein, The Real Exchange Rates of Germany, September 1994

69 Giancarlo Gandolfo, Pier Carlo Padoan, Giuseppe De Arcangelis and Clifford R. Wymer, The Italian Continuous Time Model: Results of the Nonlinear Estimation, October 1994

70 Tommy Staahl Gabrielsen and Lars Sørgard, Vertical Restraints and Interbrand Competition, October 1994

71 Julia Darby and Jim Malley, Fiscal Policy and Consumption: New Evidence from the United States, October 1994

72 Maria E. Maher, Transaction Cost Economics and Contractual Relations, November 1994

73 Margaret E. Slade and Henry Thille, Hotelling Confronts CAPM: A Test of the Theory of Exhaustible Resources, November 1994

74 Lawrence H. Goulder, Environmental Taxation and the "Double Dividend": A Reader's Guide, November 1994

75 Geir B. Asheim, The Weitzman Foundation of NNP with Non-constant Interest Rates, December 1994

76 Roger Guesnerie, The Genealogy of Modern Theoretical Public Economics: From First Best to Second Best, December 1994

77 Trond E. Olsen and Gaute Torsvik, Limited Intertemporal Commitment and Job Design, December 1994

78 Santanu Roy, Theory of Dynamic Portfolio Choice for Survival under Uncertainty, July 1995

79 Richard J. Arnott and Ralph M. Braid, A Filtering Model with Steady-State Housing, April 1995

80 Vesa Kanniainen, Price Uncertainty and Investment Behavior of Corporate Management under Risk Aversion and Preference for Prudence, April 1995

81 George Bittlingmayer, Industry Investment and Regulation, April 1995

82 Richard A. Musgrave, Public Finance and Finanzwissenschaft Traditions Compared, April 1995

83 Christine Sauer and Joachim Scheide, Money, Interest Rate Spreads, and Economic Activity, May 1995

84 Jay Pil Choi, Preemptive R&D, Rent Dissipation and the "Leverage Theory", May 1995

85 Stergios Skaperdas and Constantinos Syropoulos, Competing for Claims to Property, July 1995

86 Charles Blackorby and Walter Bossert and David Donaldson, Intertemporal Population Ethics: Critical-Level Utilitarian Principles, July 1995

87 George Bittlingmayer, Output, Political Uncertainty, and Stock Market Fluctuations: Germany, 1890 - 1940, September 1995

88 Michaela Erbenová and Steinar Vagstad, Information Rent and the Holdup Problem: Is private Information prior to Investment valuable?, September 1995