Principal -Agent Problems with Type-Dependent Outside Options

by

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Abstract

The literature on adverse selection has until recently concentrated on the case where the agent's outside option is type-independent, implying that all types of agent receive the same payoff should no trade occur with the principal. Unfortunately, this assumption is not innocuous. If it is relaxed, the properties of the optimal contract can change dramatically. This thesis characterizes the impact of type-dependent outside options in three different settings. First, we explore the notion that a worker's prospects in the labour market may be influenced by his employment history. Under these circumstances, employers may incentivise their employees by randomizing over the probability with which current employees are retained. We identify a set of sufficient conditions for this to be the case in a two-period employment relationship, where the employee's ability is private information and both parties are risk-neutral. Although randomization is seldom observed in the real world, our results suggest that employers may optimally introduce some ambiguity over the conditions that need to be fulfilled in order to be retained.

Second, we study competition in price-quality menus within the context of an horizontally differentiated duopoly, where each firm also operates in a local, monopolistic market. It is assumed that the consumer's (unobservable) valuation for quality is determined by the nature of his preferences over horizontal (or brand) product characteristics. We find that, if competition between the two firms is sufficiently fierce: (1) the equilibrium quality schedule exhibits bunching and (2) the equilibrium contract features overprovision of quality for sufficiently low types. Thus, with respect to the monopoly setting, competition may introduce new types of distortions, namely upward distortions.

Third, we analyze the conflict of interests that arises between employers and employees with respect to the adoptiom of innovations that change the nature of the skills relevant for production. If an employer decides to adopt a new technology, he will also replace his specialist workforce. Thus, although a current employee has access to superior information concerning the efficiency of the new technology, he also has an incentive to misreport it. We show that if (1) the employee's expected utility from alternative employment is lower when the new technology is superior and (2) the employer cannot commit to retain the employee if the new technology is adopted, no renegotiation-proof contract exists, which induces the employee to truthfully reveal his information. In the special case where the employee can ex-ante commit to make his information publicly avalaible (commitment to transparency), access to external sources of information can result in the employer's choice of technology being less efficient than otherwise.

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Chapter 1

Introduction

The theory of general equilibrium is universally regarded as the one of the major achievements of economics. According to this theory, the economy is composed of a continuum of agents who interact through the price system. Agents consider themselves too small to influence the equilibrium prices, and therefore behave as price-takers. The power of the theory of general equilibrium resides in the fact that it generalizes Adam Smith's "invisible hand" to a wide variety of settings[1]; so long as the appropriate market can be set up, market forces are sufficient to ensure efficiency. This also applies to situations where uncertainty is present, provided that information is symmetric among economic agents.

In the presence of asymmetric information, however, the theory of general equilibrium loses power. This was first highlighted by Akerlof (1970), Spence (1973), and Rotschild and Stiglitz (1976). These authors showed that when information is asymmetrically distributed among agents, a competitive equilibrium may fail to exist, or may exist but not be Pareto efficient. Following this discovery, several economists decided to turn away from general equilibrium models, and instead concentrate on the problem of exchange under asymmetric information in the simplest possible setting, i.e. between a small number of traders. Soon it became clear that in order to gain a better insight into this type of interaction, new tools had to be adopted: an agent who possesses private

[1] For a recent textbook exposition of the theory of general equilibrium, see Mas–Colell, Whinston and Green (1995).

information is bound to behave strategically. The methodology of game theory was adopted to model such strategic interactions. Contract theory was born.

Contract theory utilizes game theoretical concepts to model the strategic interactions among a small group of economic agents, within a partial equilibrium context. The paradigm most commonly employed for this purpose is the principal-agent model. In this model, there are two economic agents: the informed party, or agent, whose information is relevant for the common welfare, and the uninformed party, called the principal. Bargaining over the terms of trade takes a very simple form: the principal possesses all the bargaining power. He proposes a "take it or leave it" contract[2] specifying the terms of trade to the agent, who may accept or reject the offer, but may not propose another contract.

This thesis concentrates on the class of principal-agent models that study situations where the agent's private information concerns his characteristics, or type (adverse selection models). The literature on adverse selection has until recently concentrated on the case where all types of agent receive the same payoff should no trade occur with the principal; in other words, the agent's outside option is type-independent. This simplifying assumption has allowed theorists to make remarkably robust predictions: with respect to the full-information, efficient outcome, the optimal contract prescribes no distortions for the "best" type agent, and downward distortions for all other types (as in Mussa and Rosen, 1978). Moreover, if the agent's type distribution satisfies a common monotone hazard property, the optimal menu of contracts involves full separation of types.

Unfortunately, the assumption of type-independent outside options is often not realistic; whenever trading with the principal implies some foregone opportunity for the agent (arising for instance by the possibility of trading with other principals), it is natural to expect that the opportunity cost incurred when trading with the principal should vary with the agent's type. Even more importantly, the assumption of type-independent outside options is not innocuous. If this assumption is relaxed, the properties of the

[2]Implicitly, it is assumed that contracts can be enforced by courts of law, that would impose (arbitrarily large) penalties if one of the contractual partners adopts a behaviour that deviates from the one specified in the contract.

equilibrium contract can change dramatically. This was first highlighted by Lewis and Sappington (1989), within the context of the regulation of a public firm. They showed that if the firm's (unobservable) marginal cost is inversely correlated with its fixed cost, the firm faces *countervailing incentives* : on one hand, it would like to quote a high marginal cost, in order to set a high price; on the other hand, it would like to quote high fixed costs (and a low marginal cost), in order to receive a higher refund. The presence of these countervailing incentives implies that bunching and overprovision[3] feature in the optimal incentive contract.

A full characterization of the adverse selection problem in the presence of type-dependent outside options can be found in Maggi and Rodriguez-Clare (1995) and Jullien (2000). These authors show that, at equilibrium, pooling or separation, upward, downward or no distortions may all emerge, depending on the shape of the agent's outside option. The general lesson to be learned is that whenever trading with the principal implies some foregone opportunity for the agent: (1) this is likely to matter and (2) no general predictions can be made concerning the properties of the equilibrium contract. This suggests that the investigation into the impact of type-dependent outside options in agency settings should be conducted at a more specific level. By reducing the level of generality, we may be able to draw more detailed conclusions.

This thesis characterizes the impact of the presence of type-dependent outside options in three separate settings. The second chapter explores the notion that a worker's prospects in the labor market may be influenced by his employment history. Dismissal from a previous job, for example, may send a negative signal concerning the worker's ability, thereby narrowing his prospects. Alternatively, the fact that a worker has accumulated previous work experience may make him more valuable in the eyes of potential employers. In a two-period model, this implies that the agent's (type-dependent) outside option *before* he contracts with the principal differs from his outside option *after* one period of employment. We find that if the *difference* between the agent's ex-ante

[3] Although Lewis and Sappington do not explicitly consider the case where the agent has type-dependent outside options, it is clear that their analysis can be readily applied to the situation where the agent's outside option is type-dependent, and inversely related to the agent's type. This can be seen by noticing that the agent's net utility (i.e. his gross utility minus his outside option) when interacting with the principal has the same form as the regulated firm's profit in the Lewis and Sappington's example.

and ex-post outside option (i.e. the opportunity cost of dismissal) varies according to the agent's type, the optimal contract may involve randomization over the probability with which the worker is retained after the first period of employment. This is because randomization over the probability of retention equips the employer with the means to discriminate more efficiently among different types of employees. For instance, if more able types fear dismissal more than less able ones, the principal may utilize randomization as a mean to decrease the agent's incentives to under-report his ability. Thus, randomization allows the principal to exploit the countervailing incentives generated by the opportunity cost of dismissal. We identify the sufficient conditions for randomization to be optimal, and characterize the optimal contract when these conditions are fulfilled.

In practice, of course, contracts including randomization are extremely difficult to enforce or verify by courts of law. This does not, however, rule out the possibility of stochastic contracts being implemented. The principal may for instance be motivated by reputational concerns[4], which could be sufficient to guarantee that at equilibrium he will indeed randomize over retention, with the right probability. Importantly, though, the practical problems of including randomization in any legal contract imply that the contract between the principal and the agent will contain some ambiguity (or incompleteness) over the conditions that need to be fulfilled in order to guarantee retention. Thus, employment contracts may contain some vagueness (or incompleteness) even in environments where all aspects are verifiable. Indeed, as recognized by Macauley (1963) and Bernheim and Whinston (1998), this apparently unjustified incompleteness is often observed in reality.

The third chapter studies competition in price-quality menus within the context of an horizontally differentiated duopoly, where each firm also operates within a local, monopolistic market. It is assumed that the consumer's (unobservable) valuation for quality is determined by the nature of his preferences over horizontal (or brand) product characteristics. That is, a consumer who prefers one brand over the other will derive

[4]This would for instance be the case in a setting where a long-lived principal interacts over time with many short-lived agents, who are informed about the principal's actions in previous periods.

more utility from an increase in quality if this occurs within the context of his favorite brand, as opposed to the other brand. Equivalently, a consumer with a strong preference for quality when purchasing a certain brand would have a low valuation for quality when purchasing the rival brand. This implies that the outside option of a consumer located in the competitive market is a decreasing function of his preferences over quality.

From the point of view of each firm, the presence of two markets results in the consumer's outside option being either equal to zero (when he is located in the monopolistic market), or taking a positive value (when he is located in the competitive market), with a certain probability. In addition to the standard "efficiency versus informational rents" considerations, the principal's contractual choice is therefore influenced by an extra effect, arising from the fact that by increasing the utility that the agent obtains from trading with him, the principal can enlarge the mass of types with whom he contracts. With respect to the standard monopoly scenario, this "market share" effect results in the principal offering higher quality levels to low types. If competition between the two firms is sufficiently fierce, the presence of this extra effect implies that: (1) the equilibrium quality schedule exhibits bunching and (2) the equilibrium contract prescribes overprovision of quality to low types. Thus, with respect to the monopoly setting, more competitive environments may feature new types of distortions (namely: upward distortions). This suggests that the relationship between "toughness of competition" and welfare may not necessarily be monotonic.

The fourth chapter concentrates on the conflict of interest that arises between employers and employees with respect to the adoption of innovations that change the nature of the skills relevant for production. This conflict of interests arises because if the principal decides to adopt the innovation, he will also replace his specialist workforce with new employees, who possess more appropriate competencies. Unfortunately, specialist workers are often also the only ones who can adequately assess the efficiency of a new technology. We model this by assuming that the agent is the only one to know whether the technology in which he specializes is the most efficient, or whether other technologies exist, that are more productive. The setting therefore differs from the standard adverse selection model, in that the agent's private information concerns his *relative*, rather than *absolute*, productivity. This implies that, conditional on working with for the principal, different types of agent obtain the same utility from any given production-payment contract. The only difference among different types of agents concerns their expected utility from alternative employment (their outside option). We find that if (1) the agent's outside option is lower when the technology in which the agent specializes is not the most efficient and (2) the principal cannot commit to employ the agent if he decides to adopt another technology, no renegotiation-proof contract exists that induces the agent to reveal his information. The implication is that the principal chooses to adopt the least efficient technology with a positive probability. Thus, when it comes to the adoption of radical new technologies, larger firms, where ownership and expertise tend to be separated, are disadvantaged in comparison to smaller, entrepreneurial firms.

The chapter also characterizes the decision rule that the principal obeys when he cannot rely on the agent's expertise. We show that if prior beliefs are against the new technology (as it is often the case), technological stagnation and excessive conservatism tend to emerge. Finally, the chapter studies the special case where the agent may undertake some action, which ex-ante ensures that his information will be ex-post available to the principal. This may for instance be achieved by allowing neutral and incorruptible third parties to scrutinize any evidence in support of the agent's statement. We call this action "commitment to transparency". We find that commitment to transparency always results at equilibrium if, conditional on it not taking place, the principal follows a fixed rule of technology adoption. This happens, for instance, when the principal has no access to external sources of information. On the other hand, if the principal conditions his choice of technology on the realization of some given signal (external advisors), then commitment to transparency may fail to occur, and the inefficient technology is adopted with a positive probability.

Chapter 2

Randomization with Type-dependent Outside Options

2.1 Introduction

One might concede that a worker's employment history influences his prospects in the labour market. Dismissal from a previous job, for example, may send a negative signal concerning the worker's ability, thereby narrowing his prospects. Thus, a worker's employment prospects *before* he contracts with a given employer may differ from his prospects *after*, say, one period of employment. When this is the case, employers may randomize over the probability of termination in order to incentivize their employees. We explore this hypothesis within the context of a two-period employment relationship, where the employee's ability (or type) is private information and both parties are risk-neutral, and identify the sufficient conditions for randomization over the probability of termination to feature in the optimal mechanism. Interestingly, we find that randomization over dismissal is also a useful tool when the employee's employment prospects (or outside option) after the first period are greater than before; this may be, for instance, owing to his having acquired valuable skills during this period. In fact, the direction in which dismissal alters the employee's outside option does not appear to play an important role in the analysis. What matters, on the other hand, is the degree to which the *difference* between the agent's outside option before contracting and his outside option after one period of employment varies across different levels of ability. We call this difference the opportunity cost of dismissal. The degree to which this opportunity cost varies across types determines the payoffs employees of different ability can expect to earn from contracts involving different probabilities of dismissal, which accordingly modifies their incentive to misrepresent their true type. Indeed, one of the conditions that we identify as sufficient for randomization to be optimal is the requirement that dismissal counteract the incentives which dominate under the offer of an efficient contract. If the dominant incentive is for the employee to understate his ability, then this requirement means that less able types fear dismissal less (respectively, benefit from experience more) than more able types. The opposite holds if the dominant incentive is for the employee to overstate his ability. In both cases, the possibility of dismissal softens the worker's incentive compatibility constraint, thus decreasing the informational rents in need of being allocated to induce a given level of production. Thus, randomization over the probability of dismissal proves to be a useful tool, equipping the employer with the means to discriminate between different types of employees. Significantly, as mentioned above, this condition alone does not however guarantee the optimality of randomization. For the optimality of randomization to be guaranteed, it is also necessary to ensure that the worker's participation constraint cannot always be met by means of a deterministic contract. We find that this can only be the case when the worker is offered no informational rents. Our principal findings can therefore be summarized as follows: in order for randomization to be optimal, it is sufficient that

· the opportunity cost of dismissal counteract the incentives which dominate under the offer of an efficient contract and

· randomization maximizes the employer's expected profit when the employee is kept onto his reservation utility.

We characterize the optimal menu of contracts being offered when these conditions are met, finding that it prescribes efficient output production for all types, with randomization being offered to sufficiently high or low types, depending on the direction in which the worker's incentive compatibility constraint binds. With respect to the situation where all types are retained with probability one, randomization improves the efficiency of the optimal menu of contracts in two ways: by enlarging the range of types who engage in surplus-creating production at equilibrium, and by increasing production whenever trade occurs.

In practice, of course, contracts including randomization are extremely difficult to enforce or verify by courts of law. This does not, however, rule out the possibility of stochastic contracts being implemented. The principal may for instance be motivated by reputational concerns[1], which could be sufficient to guarantee that at equilibrium he will indeed randomize over retention, with the right probability. Importantly, though, the practical problems of including randomization in any legal contract imply that the written contract between the principal and the agent will contain some ambiguity over the conditions that need to be fulfilled in order to guarantee retention. Thus, employment contracts may contain some vagueness (or incompleteness) even in environments where all aspects are verifiable. Indeed, as recognized by Macauley (1963) and Bernheim and Whinston (1998), this apparently unjustified incompleteness is often observed in reality.

2.1.1 Related literature

In the presence of adverse selection, the literature identifies the optimality of randomization with reference to situations where either

· different types have different attitudes towards risk or

· the agent's type-space is multidimensional.

The first category is examined by Arnott and Stiglitz (1988), Brito, Hamilton, Slutsky and Stiglitz (1995) and Stiglitz (1982), who formalize the notion that, when the agent's attitude towards risk is correlated with his type, randomization can be optimally utilized to loosen the agent's incentive compatibility constraint. This is also the case in the present setting, but the rationale for our results is very different: in the present paper, all parties are assumed to be risk-neutral, and randomization proves useful because the impact of dismissal upon the agent's future employment prospects varies in accordance with his ability. Moreover, randomization here occurs over the probability with which trade takes place in the second period, rather than over the terms of trade.

[1]This would for instance be the case in a setting where a long-lived principal interacts over time with many short-lived agents, who are informed about about the principal's actions in previous periods.

The second category is studied by Baron and Myerson (1982), Che and Gale (2000) and Rochet (1984). These papers show that stochastic mechanisms, where the decision to produce or not to produce is used as a screening device, may prove useful when the agent's type is bi- rather than uni-dimensional. Again, the setting considered by those papers differs from the present one, where the agent's type is assumed to be uni- rather than bi-dimensional.

Importantly, the papers cited above concentrate on static settings, and thus find it difficult to generate an intuitive interpretation of randomization. In contrast, the present paper considers a dynamic setting, where randomization can intuitively translate into the introduction of some contractual ambiguity concerning the conditions under which retention occurs.

The present paper therefore adds to the literature on stochastic mechanisms, in that it provides a novel rationale for their optimality, and establishes a link between this literature and that which studies adverse selection in the presence of type-dependent participation constraints. Jullien (2000) and Maggi and Rodriguez-Clare (1995) provide a general theory of type-dependent reservation utility with a continuum of types, and show that the properties of the optimal mechanism may differ considerably with respect to the so-called standard setting, where the agent's reservation utility is assumed to be type-independent. Our paper extends this intuition by showing how the presence of type- (and history-) dependent outside options may result in randomization over trade in the second period being optimal. It is worth noting that our intuition builds on Acemoglu and Pischke (1998), who introduce and empirically test the notion that dismissal may negatively influence a worker' s future employment prospects.

Finally, the subject matter studied in this paper is related to the literature on career concerns (Fama 1980, Gibbons and Murphy, 1992, Holmstrom 1999, Dewatripont, Jewitt and Tirole, 1999a and b). In contrast with that literature, however, we consider a setting where the informational asymmetry between the principal and the agent only concerns the agent's type, rather than both his type and his actions. Moreover, in the present setting the agent's career concerns arise from the fact that outside employers can observe his employment history, rather than his previous production.

2.2 The model

We consider a two-period setting in which an employer (the principal) contracts with an employee (the agent) over the production of a certain amount of output in each period. Production is assumed to be observable and verifiable. The agent's marginal cost of production, or type, is denoted by θ, and is unobservable by the principal. We assume that θ is drawn from a distribution $f(\theta)$ with associated density $F(\theta)$, over a finite support $\Phi = [\underline{\theta}, \overline{\theta}]$, where $\frac{F(\theta)}{f(\theta)}$ is increasing in θ and $\frac{1-F(\theta)}{f(\theta)}$ is decreasing in θ. At the beginning of the second period, the principal decides whether to retain the agent or not. We assume that the principal can credibly commit to condition his decision to retain the worker upon the outcome of a publicly observable randomizing device. We also assume that if the agent accepts the contract, he is contractually bound to work for the principal whenever the outcome of randomization prescribes so.

A contract between the agent and the principal can therefore be denoted as $\{\pi, q_1, q_2, w_1, w_2\}$, where q_1 is the amount of output that the agent must produce in period one, π is the probability with which the agent is retained after the first period, q_2 is the amount of output that the agent must produce in period two if he is retained and $w_i, i = 1, 2$ is the monetary payment that the agent receives for producing output q_i. We denote as $\overline{q}$ the highest possible amount of output that can be produced in any period. Thus, $q_i \in [0, \overline{q}]$ for $i = 1, 2$. Notice that we rule out the possibility of randomization at the beginning of period one being optimal. The rationale for this originates from the notion that if the agent is not employed by the principal in the first instance, his employment history would not be affected should the outcome of randomization prescribe no trade with the principal. Because we are assuming risk neutrality by both parties, a contract including randomization under these circumstances is therefore indistinguishable from a deterministic contract where payment and output production are replaced by their certainty equivalents.

The principal's problem consists of designing the optimal menu of contracts (or mechanism), from which the agent may pick his preferred choice. From the revelation principle, we know that this search can be confined to the set of direct revelation mechanisms, whereby the agent is requested to report his type and is offered a contract which is contingent upon this report.

The timing of actions is as follows:

0. The principal offers the worker a menu of contracts $\left\{\pi(\widehat{\theta}), q_1(\widehat{\theta}), q_2(\widehat{\theta}), w_1(\widehat{\theta}), w_2(\widehat{\theta})\right\}$ which are conditional upon the agent's declared type $\widehat{\theta}$. If the agent declines the contract, he receives his ex-ante outside option and the principal receives nothing.

1. First period: if the agent has accepted the contract in period 0, he produces output $q_1(\widehat{\theta})$ and receives wage $w_1(\widehat{\theta})$.

2. At the end of the first period, the agent is retained with a probability $\pi(\widehat{\theta})$, or dismissed with probability $(1 - \pi(\widehat{\theta}))$.

3. Second period: if the agent is retained, he produces output $q_2(\widehat{\theta})$ against a payment $w_2(\widehat{\theta})$. If the agent is not retained, he receives his ex-post outside option.θ

We assume that the agent's type and his expected payoff from alternative employment are perfectly correlated. If an agent of type θ does not accept the principal's contract at time zero, he expects to earn $B(\theta)$ in each period from alternative employment. For simplicity, we set the discount factor to 1. The present value of the agent's reservation utility when his type is θ is therefore given by $2B(\theta)$, while the second-period ex-ante outside option is $B(\theta)$. If the agent is not retained after the first period, his expected payoff from alternative employment in the second period is given by $C(\theta)$, which may be different from $B(\theta)$; $C(\theta)$ therefore indicates the agent's ex-post (as opposed to ex-ante) outside option in period 2. We allow $C(\theta)$ to be both higher or lower than $B(\theta)$; if work experience strengthens the agent's prospects in the labour market more than dismissal (and updating concerning his ability) weakens them, we should expect $C(\theta) > B(\theta)$. Otherwise, we should expect $C(\theta) < B(\theta)$. Because both $B(\theta)$ and $C(\theta)$ refer to the agent's expected utility from alternative employment, as a function of his marginal cost of production when working for the principal, we expect $B'(\theta)$ and $C'(\theta)$ to have the same sign. A situation where this sign is negative reflects a positive correlation between the agent's ability when working for the principal and his ability elsewhere. This is for instance the case if the job requires the agent to possess general and transferable skills. On the other hand, if both $B'(.)$ and $C'(.)$ are positive, a negative correlation exists between the agent's ability when working with the principal and his ability when working elsewhere. This may reflect the relationship-specific nature of the skills necessary for the job.

We impose the following assumption:

A1 $C''(\theta) = B''(\theta) = 0 \ \ \forall\theta$

As will become clear later, this assumption allows us to considerably simplify the analysis.

If an agent of type θ accepts a contract $\{\pi, q_1, q_2, w_1, w_2\}$, his net expected utility $u(\theta)$ is given by

$$(w_1 - \theta q_1) + \pi \ (w_2 - \theta q_2) + (1-\pi) \ C(\theta) - 2B(\theta) \tag{2.1}$$

$(w_1 - \theta q_1)$ +	π	$(w_2 - \theta q_2)$ +	$(1-\pi)$	$C(\theta)$	−	$2B(\theta)$
payoff in first period	prob.of being retained	payoff in second period if retained	prob.of being dismissed	E(payoff) in second period if dismissed		reservation utility

If the agent accepts a contract $\{\pi, q_1, q_2, w_1, w_2\}$, the principal's expected profit U_P is equal to[2]

$$(vq_1 - w_1) + \pi \ (vq_2 - w_2) \tag{2.2}$$

$(vq_1 - w_1)$ +	π	$(vq_2 - w_2)$
payoff in first period	prob. that agent is retained	payoff in second period if agent is retained

where $v > \overline{\theta}$. Notice that we are assuming that if the agent is not retained, the principal's payoff in the second period is zero[3]. Also, both parties are risk neutral with respect to monetary transfers and output production. In order to simplify the analysis, we impose the following assumptions:

A2.a) $\overline{q}(v - \theta) > \max\{C(\theta), B(\theta)\} \forall\theta$

[2] For clarity of exposition and tractability, we assume that both the agent's utility and the principal's payoff are linear in q. Our results should however still hold if this assumption was relaxed.

[3] Relaxing this assumption would increase the desirability of randomization.

A2.b) $C(\theta) < 2B(\theta) \forall \theta$

A2.c) $\overline{q}(v - \theta) + C(\theta) > 2B(\theta) \forall \theta$

In words, assumption 2.a) says that if the agent produces the highest possible amount of output in any given period, it is always efficient for him to interact with the principal. Assumption 2.b) ensures that if the agent does not produce anything in either period, it is not efficient for him to accept the principal's contract. Finally, assumption 2.c) guarantees if the agent produces $\overline{q}$ in the first period and is not retained in period two, it is efficient for him to accept the principal's contract.

In what follows, we first solve for the first best (efficient) menu of contracts. This allows us to identify the nature of the inefficiencies arising from the unobservability of the agent's type. We then derive the optimal mechanism if the agent's outside option is type-independent. Third, we allow for type-dependence of the agent's outside option, and first consider the case in which the principal is obliged to retain all agents with probability one (efficient retention rule). Finally, we allow for randomization. The reason why we introduce two intermediate steps before presenting our contribution is that these intermediate steps allow us to better highlight the role played by the presence of type-dependent outside options, and to better understand the rationale behind the optimality of randomization in their presence. All the proofs can be found in the appendix.

2.3 First best

If the agent's type θ is perfectly observable, the principal selects the contract he offers to each type θ by maximizing

$$vq_1(\theta) - w_1(\theta) + \pi(\theta)\left(vq_2(\theta) - w_2(\theta)\right) \quad (2.3)$$

subject to

$$q_i(\theta) \in [0, \overline{q}], i = 1, 2 \quad (2.4)$$

$$\pi(\theta) \in [0, 1] \quad (2.5)$$

and the agent's participation constraint

$$u(\theta) \geq 0 \; \forall \theta \tag{PC}$$

$w_1(\theta)$ can also be written as

$$u(\theta) + \theta q_1(\theta) - \pi(\theta)(w_2(\theta) - \theta q_2(\theta)) - (1 - \pi(\theta))C(\theta) + 2B(\theta) \tag{2.6}$$

substituting for $w_1(\theta)$ in (3.25) profit we get

$$(q_1(\theta) + \pi(\theta)q_2(\theta))\,(v - \theta) + (1 - \pi(\theta))C(\theta) - 2B(\theta) - u(\theta) \tag{2.7}$$

Because there are no informational asymmetries, the principal sets the agent onto his participation constraint, so that: $u(\theta) = 0$. The principal's expected payoff is therefore given by

$$(q_1(\theta) + \pi(\theta)q_2(\theta))\,(v - \theta) + (1 - \pi(\theta))C(\theta) - 2B(\theta) \tag{2.8}$$

The FOC with respect to $\pi(\theta)$ is:

$$(v - \theta)q_2(\theta) - C(\theta) \tag{2.9}$$

In this setting, this is always positive. The FOC with respect to $q_2(\theta)$ is

$$\pi(\theta)(v - \theta) \tag{2.10}$$

while the FOC with respect to $q_1(\theta)$ is

$$v - \theta \tag{2.11}$$

Again, both expressions are always positive. The optimal contract therefore prescribes:

$$\pi(\theta) = 1 \text{ and } q_1(\theta) = q_2(\theta) = \overline{q} \; \forall \theta \tag{OM*}$$

Result 1: *The efficient contract specifies that the principal should hire the agent for both periods with probability one, and that the agent should produce $\overline{q}$ in each period.*

In the first best contract, the agent is required to produce $\overline{q}$ and is retained after the first period with probability one. Randomization is never optimal because it introduces ex-post inefficiency without bringing any advantage. Because there are no informational asymmetries, the agent does not receive any informational rents. The payment he receives is just sufficient to cover his cost of production and keep him indifferent between contracting with the principal and accepting his ex-ante outside option.

2.4 Second best

From the revelation principle, we know that if the agent's type is not observable, the principal's search for an optimal mechanism may be restricted to the set of contracts which induce truthtelling (incentive compatibility).

Proposition 1 *The following conditions are necessary and sufficient for incentive compatibility*[4]*:*

IC.I $u'(\theta) = -q_1(\theta) - \pi(\theta)q_2(\theta) + C'(\theta)(1 - \pi(\theta)) - 2B'(\theta)$ *at any point of differentiability*

IC.II $q_1(\theta) + \pi(\theta)\left(q_2(\theta) + C'(\theta)\right)$ *is non-increasing in* θ.

Conditions IC.I and IC.II are the first and the second order conditions for local incentive compatibility. In the appendix, we derive these conditions and show that together they ensure global incentive compatibility.

In what follows, we indicate the mechanism derived by imposing only condition IC.I as the WSC mechanism (where WSC stands for "without second-order condition"). Whenever the WSC mechanism satisfies IC.II, solving the relaxed problem allows us to identify the optimal mechanism.

[4] *These conditions are sufficient only when there is full participation and the participation constraint holds. When exclusion is allowed, they are still verified on the participation set but may not suffice to ensure global incentive compatibility (Jullien 2000).*

2.4.1 Type-independent outside options

As a benchmark, we characterize the second best mechanism when $B(\theta) = C(\theta) = 0$ for all types. In that case, the principal's expected profit when the agent's type is θ is given by

$$vq_1(\theta) - w_1(\theta) + \pi(\theta)(vq_2(\theta) - w_2(\theta)) \tag{2.12}$$

$w_1(\theta)$ can also be written as

$$u(\theta) + \theta q_1(\theta) - \pi(\theta)(w_2(\theta) - \theta q_2(\theta)) \tag{2.13}$$

substituting for $w_1(\theta)$ in (3.15) we get

$$[q_1(\theta) + \pi(\theta)q_2(\theta)] - u(\theta) \tag{2.14}$$

Notice that participation by the agent can always be ensured by offering the "null" contract: $q_1(\theta) = q_2(\theta) = \pi(\theta) = u(\theta) = 0$. For the principal, this contract yields the same payoff as no contract. There is therefore no loss of generality in assuming that the principal contracts with all types.

The first order condition for incentive compatibility requires

$$u'(\theta) = -q_1(\theta) - \pi(\theta)q_2(\theta) \leq 0 \tag{IC.I.1}$$

To induce truthtelling, informational rents have to be offered to all types but the least efficient with whom the principal decides to interact. The principal is faced with a trade off between the payoff which he can obtain when contracting with a given type and the informational rents which have to be offered to lower types. By having the agent's participation constraint bind when his type is $\overline{\theta}$, the principal can ensure participation by all types. From the incentive compatibility constraint, we can therefore write

$$u(\theta) = \int_{\theta}^{\overline{\theta}} (q_1(\theta) + \pi(\theta)q_2(\theta))\, d\theta - 2\left(B(\theta) - B(\overline{\theta})\right) \tag{2.15}$$

The principal's problem can be written as

$$\max_{\pi(\theta)\in[0,1],\ q_1(\theta),\ q_2(\theta)\in[0,\overline{q}]} \int_{\underline{\theta}}^{\overline{\theta}} [(q_1(\theta)+\pi(\theta)q_2(\theta))(v-\theta) - 2B(\theta) -$$

$$-\int_{s}^{\overline{\theta}} (q_1(s)+\pi(s)q_2(s))\, ds]\, f(\theta)d\theta \qquad \text{(PP.1)}$$

Notice that the principal only cares about expected total production. We denote $q_1(\theta)+\pi(\theta)q_2(\theta)$ as $Q(\theta)$ and rewrite the principal's problem as

$$\max_{Q(\theta)\in[0,2\overline{q}]} \int_{\underline{\theta}}^{\overline{\theta}} \left(Q(\theta)(v-\theta) + 2\left(B(\theta) - B(\overline{\theta})\right) - \int_{\theta}^{\overline{\theta}} Q(s)ds \right) f(\theta)d\theta \qquad \text{(PP.1')}$$

After integration by parts, this becomes

$$\max_{Q(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} \left[(Q(\theta)(v-\theta) + 2\left(B(\theta) - B(\overline{\theta})\right) f(\theta) - F(\theta)Q(\theta) \right] d\theta \qquad \text{(PP.1'')}$$

The first-order condition with respect to $Q(\theta)$ is

$$(v-\theta) - \frac{F(\theta)}{f(\theta)} \qquad (2.16)$$

Because $u'(\theta) = -Q(\theta)$, by marginally decreasing $Q(\theta)$ the principal is able to decrease the informational rents that have to be offered to types below θ, but also decreases the efficiency of trade with type θ. The optimal WSC contract sets $Q(\theta) = 0$ if the first effect is stronger than the second and $Q(\theta) = 2\overline{q}$ otherwise. This is the case whenever

$$v - \theta \geq \frac{F(\theta)}{f(\theta)} \qquad (2.17)$$

Define θ_1 by $v = \theta_1 + \frac{F(\theta_1)}{f(\theta_1)}$. Given our assumptions on the distribution of types, $\theta + \frac{F(\theta)}{f(\theta)}$ is strictly increasing in θ. The optimal WSC mechanism therefore prescribes[5]:

$$\begin{Bmatrix} \text{for } \theta > \theta_1 : Q(\theta) = 0 \text{ and } u(\theta) = 0 \\ \text{for } \theta \leq \theta_1 : Q(\theta) = 2\overline{q} \text{ and } u(\theta) = 2\overline{q}(\theta_1 - \theta) \end{Bmatrix} \tag{OM.1}$$

It can be easily verified that this mechanism satisfies incentive compatibility[6]. Notice that for types $> \theta_1$, the optimal contract prescribes no trade between the agent and the principal. Finally, notice that $Q(\theta) = 2\overline{q}$ corresponds to $q_1(\theta) = q_2(\theta) = \overline{q}$, $\pi(\theta) = 1$; randomization is therefore never optimal.

Result 2: *If the agent's participation constraint is type-independent, the optimal mechanism specifies that the agent engages in productive trade with the principal only when his type less or equal to θ_1. When this is the case, the agent is retained in the second period with probability one, and is asked to produce $\overline{q}$ in each period. Randomization is therefore never optimal.*

If the agent's outside options are type-independent, the introduction of informational asymmetries implies that the optimal contract must provide informational rents to all types but the highest with whom the principal decides to interact. This introduces a trade-off between efficiency and informational rents and induces the principal to forego interacting with the agent whenever his type is too high. Informational asymmetries therefore result in an inefficiently low amount of productive trade between the agent and the principal. Importantly, randomization is never optimal.

2.4.2 Optimal mechanism when $\pi(\theta) = 1$ for all types

We now reintroduce the type-dependent participation constraint, and, again for benchmarking purposes, characterize the optimal mechanism when the principal is constrained to retain all types with whom he engages in surplus-creating trade with probability one (efficient retention rule). If $\pi(\theta)$ is constrained to be equal to one for all types, the

[5]For clarity of exposition, we prefer to define the optimal contract in terms of $\pi(\theta), q_i(\theta)$, $i = 1, 2$ and $u(\theta)$. Notice however that for given $\pi(\theta)$ and $q_i(\theta)$, $u(\theta)$ implicitely defines $w_i(\theta)$, the compensation which the agent receives if employed.

[6]In this case, IC.II is satisfied if $Q(\theta)$ is non-increasing in θ .The optimal WSC contract is such that $Q'(\theta) = 0$ whenever the $Q(.)$ schedule is differentiable. There is a discontinuity at θ_1, where $Q(.)$ jumps from $2\overline{q}$ for $\theta \to \theta_1^-$ to 0 for $\theta \to \theta_1^+$. Because the discontinuity involves a downward jump, it does not violate incentive compatibility.

principal's expected profit when the agent's type is θ is given by

$$vq_1(\theta) - w_1(\theta) + vq_2(\theta) - w_2(\theta) \tag{2.18}$$

$w_1(\theta)$ can also be written as

$$u(\theta) + \theta q_1(\theta) - w_2(\theta) + \theta q_2(\theta) + 2B(\theta) \tag{2.19}$$

substituting for $w_1(\theta)$ in (3.17) we get

$$(q_1(\theta) + q_2(\theta))(v - \theta) - u(\theta) - 2B(\theta) \tag{2.20}$$

In contrast with the previous case, participation by the agent can no longer be ensured by offering the "null" contract. To induce him to participate, the principal has to match the agent's (strictly positive) reservation utility. The implication is that it may be optimal for the principal to exclude some types from participating in the mechanism. Following Jullien (2000), we avoid the participation issue by endowing the principal with new trade possibilities which (i) can mimic exclusion while maintaining interaction and (ii) do not allow the principal to extract a positive surplus from the agent. We therefore assume that there exist a second trade technology, which ensures that the agent can be kept onto his reservation utility without any cost (or benefit) for the principal. This assumption allows us to restrict attention to the situation where the principal contracts with all types. In what follows, we refer to this second technology as the "no-surplus" technology, and refer to the main technology as the "surplus-creating" technology.

Ignoring the second order condition for incentive compatibility, the principal's problem can therefore be written as

$$\max_{\phi(\theta)\in(0,1),q_1(\theta),q_2(\theta)\in[0,\overline{q}]} \int_{\underline{\theta}}^{\overline{\theta}} \left[(q_1(\theta) + q_2(\theta))(v - \theta) - u(\theta)\right] f(\theta)\phi(\theta)d\theta \tag{PP.2}$$

subject to

$$\begin{aligned} u'(\theta) &= -(q_1(\theta)+q_2(\theta)) - 2B'(\theta) && \text{(IC.I.2)} \\ u(\theta) &\geq 0 && \text{(PC)} \end{aligned}$$

where $\phi(\theta) = 0$ if the "no-surplus" technology is employed, and is equal to 1 otherwise. Denote $q_1(\theta) + q_2(\theta)$ by $Q(\theta)$. The first order condition for incentive compatibility can be rewritten as

$$u'(\theta) = -Q(\theta) - 2B'(\theta) \qquad \text{(IC.I.2')}$$

When the efficient contract is offered (i.e. $Q(\theta) = 2\overline{q}$), this becomes

$$u'(\theta) = -2\left(B'(\theta) + \overline{q}\right) \qquad \text{(IC.I*)}$$

The direction in which informational rents increase when the principal offers the efficient contract vary according to the sign of $B'(\theta)+\overline{q}$. Thus, the nature of the trade off between efficiency and informational rents changes, depending on whether $B'(\theta) + \overline{q}$ is positive or negative. We consider each case in turn.

$B'(\theta) + \overline{q} > 0$

When this is the case, we know that if the principal offers the efficient output allocation (i.e. $Q(\theta) = 2\overline{q}$), informational rents are decreasing in θ; that is, more able types earn a higher net utility from trading with the principal than less able types.

Because informational rents are moving in the same direction as in the case with type-independent reservation utility, the trade-off between informational rents and efficiency is the same; this implies that, for $\theta > \theta_1$, the principal finds it optimal to reduce production, in order to save on informational rents that have to be offered to more able types. In the absence of type-dependent reservation utilities this results in setting $Q(\theta) = 0$. With type-dependent reservation utilities, however, foregoing production (and switching to the no-surplus technology) may not be necessary: the principal can achieve the same result by setting $u(\theta) = u'(\theta) = 0$. We distinguish between two cases:

1. $B'(\theta) > 0:$

In that case, $u'(\theta) = 0$ could only be achieved within the context of the surplus-creating technology by asking the agent to produce a negative quantity, something that is not feasible. In fact, $u'(\theta)$ is < 0 for all $Q(\theta) \in [0, 2\overline{q}]$. The agent's participation constraint binds only for the highest type who creates a positive surplus. Denote this type as θ_H; from incentive compatibility, we know that[7]

$$u(\theta) = \int_{\theta}^{\theta_H} Q(\theta) d\theta + 2(B(\theta^H) - B(\theta)) \tag{2.21}$$

Because $B(\theta)$ is increasing in type, by decreasing θ_H the principal can decrease the rents that have to be offered to lower types. This implies that the optimal contract might specify $\phi(\theta) = 1$ only for $\theta \leq \theta_H < \theta_1$[8]. Thus, the presence of type-dependent reservation utilities does not increase (and might even decrease) the contract's efficiency. This is a consequence of the fact that the agent's reservation utility moves in the opposite direction as informational rents, thus reinforcing the incentives present in the standard setting.

2. $B'(\theta) < 0:$

When the agent's reservation utility decreases in θ, the principal can implement $u(\theta) = u'(\theta) = 0$ for all $\theta \in [\theta_1, \overline{\theta}]$ by setting $u(\overline{\theta}) = 0$ and asking the agent to produce $Q(\theta) = -2B'(\theta)$ whenever his type belongs this set. In that case, the agent produces a positive amount without affecting the rents that have to be offered to lower θ's. To ensure that the principal's problem is non-trivial and tractable, we restrict attention to

[7] Because $u'(\theta)$ is < 0 for all $Q(\theta) \in [0, 2\overline{q}]$, and because incentive compatibility requires $u(\theta)$ to be continuous, if the surplus-creating technology is utilized for trade with types in $[\theta^H, \theta^H - \varepsilon]$ for any $\varepsilon > 0$, then it must also be utilized for all types below $\theta^H - \varepsilon$.

[8] Because we are considering the case where $B(\theta) + \overline{q} > 0$, the exclusion of high types from surplus-creating trade does not violate incentive compatibility. To see that, consider a type $\theta > \theta_H$, who kept onto his reservation utility in the optimal meachanism. For this type, incentive compatibility requires $B(\theta) \geq \overline{q}(\theta_H - \theta) + B(\theta_H)$. Given that $B(\theta) > B(\theta_H)$, this condition is always respected. Notice however that a mechanism prescribing surplus-creating trade for high types but not for lower types would not be incentive compatible. In that case, incentive compatibility would require $B(\theta) \geq \overline{q}(\widehat{\theta} - \theta) + B(\widehat{\theta})$ for some $\widehat{\theta} > \theta$. In the limit, as $\theta \rightarrow \widehat{\theta}$, this condition becomes $0 \geq B'(\theta) + \overline{q}$, which is never the case, given that we are considering the case where $B'(\theta) + \overline{q} > 0$.

situations where

$$-B'(\theta)(v-\theta) - B(\theta) > 0 \;\; \forall\theta \tag{2.22}$$

That is, we assume that the principal can always gain a positive profit by asking the agent to produce $Q(\theta) = -2B'(\theta)$ while keeping him onto his reservation utility, offering $u(\theta) = 0$. Because it allows the principal to earn a positive profit without affecting the informational rents that have to be offered to satisfy incentive compatibility, this option is always preferable to no (surplus-creating) trade. Given that, it is easy to see that the optimal WSC contract must prescribe $\phi(\theta) = 1 \; \forall\theta$ and:

$$\left\{\begin{array}{l}\text{for } \theta > \theta_1\text{: } Q(\theta) = -2B'(\theta) \text{ and } u(\theta) = 0; \\ \text{for } \theta \leq \theta_1\text{: } Q(\theta) = 2\overline{q} \text{ and } u(\theta) = 2\left[\overline{q}(\theta_1 - \theta) + B(\theta_1) - B(\theta)\right]\end{array}\right\} \tag{OM.2.1}$$

It can be easily verified that under assumption 1 this mechanism is incentive compatible[9]. The optimal mechanism therefore prescribes surplus-creating trade with all types, and is therefore more efficient than that derived in the absence of type-dependent reservation utilities. This is the case because the agent's reservation utility increases in the same direction as informational rents. The trade-off between informational rents and efficiency is therefore softened by the necessity to provide the agent with a level of gross utility which increases in his ability, in order to ensure his participation.

$B'(\theta) + \overline{q} < 0$

When this is the case, $u'(\theta) = 0$ could only be achieved within the context of the surplus-creating technology by asking the agent to produce $Q(\theta) > 2\overline{q}$, something that is not feasible. In fact, $u'(\theta)$ is > 0 for all $Q(\theta) \in [0, 2\overline{q}]$. That is, informational rents are decreasing in the agent's ability: because his reservation utility is strongly increasing in his ability, the agent's dominant incentive is that of understating his type. The principal can ensure participation by all types types by having the agent's participation constraint bind for the lowest θ who produces a positive surplus. Denote this type as

[9] In this case, IC.II is satisfied if $Q(\theta) + C'(\theta)$ is non-increasing in θ. Because we are assuming that $C''(\theta) = 0$, this is trivially the case for $\theta < \theta_1$. For $\theta > \theta_1$, IC.II is satisfied provided that $-2B'(\theta)$ is non-increasing in θ.This is always the case given assumption1. Finally, we consider the discontinuity in $Q(\theta)$ which occurs at $\theta = \theta_1$. Because this discontinuity involves a downward jump, it does not violate incentive compatibility.

θ_L. From the incentive compatibility constraint[10], we can write

$$u(\theta) = \int_{\theta_L}^{\theta} Q(\theta)d\theta - 2\left(B(\theta) - B(\theta^L)\right) \tag{2.23}$$

By increasing θ_L, the principal can reduce the rents that have to be offered to higher types. Thus, the optimal contract may exclude sufficiently low types from surplus-creating trade (i.e., may prescribe $\theta_L > \underline{\theta}$). For a given θ_L, the principal's problem can be written as

$$\max_{Q(\theta)\in[0,2\overline{q}]} \int_{\theta_L}^{\overline{\theta}} \left(Q(\theta)(v-\theta) + 2\left(B(\theta) - B(\underline{\theta})\right) + \int_{\underline{\theta}}^{\theta} Q(s)ds \right) f(\theta)d\theta \tag{PP.2.2}$$

After integration by parts, this becomes

$$\max_{Q(\theta)\in[0,2\overline{q}]} \int_{\theta_L}^{\overline{\theta}} \left[\left(Q(\theta)(v-\theta) - 2\left(B(\theta) - B(\underline{\theta})\right)\right) f(\theta) + (1-F(\theta))Q(\theta) \right] d\theta \tag{PP.2.2'}$$

The first order condition with respect to $Q(\theta)$ is

$$(v-\theta)f(\theta) + (1-F(\theta)) \tag{2.24}$$

which is always strictly positive. It follows that the optimal[11] contract[12] prescribes:

$$\left\{ \begin{array}{l} \text{for } \theta \geq \theta_L\text{: } \phi(\theta) = 1,\ Q(\theta) = 2\overline{q} \text{ and } u(\theta) = 2\left[\overline{q}(\theta-\theta_L) + B(\theta_L) - B(\theta)\right] \\ \text{for } \theta < \theta_L\text{: } \phi(\theta) = 0 \end{array} \right\} \tag{OM.2.2}$$

Because informational rents are increasing in θ, the principal can reduce them by

[10] Because $u'(\theta)$ is > 0 for all $Q(\theta) \in [0, 2\overline{q}]$, and because incentive compatibility requires $u(\theta)$ to be continuous, if the surplus-creating technology is utilized for trade with types in $[\theta_L, \theta_L + \varepsilon]$ for any $\varepsilon > 0$, then it must also be utilized for all types below $\theta_L + \varepsilon$.

[11] The principal's profit when trading with the agent is $2\left(\overline{q}(v-\theta_L) - B(\theta_L)\right) > 0$.

[12] This contract would not violate incentive compatibility; consider a type $\theta < \theta^L$ who is kept onto his reservation utility. For this type, incentive compatibility requires $B(\theta) - B(\theta^L) \geq \overline{q}(\theta^L - \theta)$. Because $B(.)$ is decreasing in type, a sufficient condition for the above inequality to be satisfied for all $\theta < \theta^L$ is that $-B'(\theta) \geq \overline{q}$. Notice however that by the same reasoning, a mechanism prescribing surplus-creating trade for low types, but not for higher types would not be incentive comaptible.

producing a higher level of output. Within the present setting, this results in the optimal contract being efficient for all $\theta \geq \theta_L$. This is however a consequence of the linearity in quantity production of the two parties' utility functions, and would not occur in the presence of concavities. As shown by Maggi and Rodriguez-Clare (1995) and Jullien (2000), in that case the optimal contract would prescribe overproduction for all but the least able type.

The results obtained in this subsection are summarized below:

Result 3: *When the principal is constrained to retain all types with whom he trades with probability one, the presence of type-dependent reservation utilities alters the features of the optimal contract in the following way:*

(i) *when the agent's reservation utility decreases in his ability (i.e. $B'(\theta) > 0$), the optimal contract is equally or less efficient than that described in result 2. That is, the optimal contract prescribes (surplus-creating) trade between the principal and the agent only when the agent's type is less or equal to θ_H, for some $\theta_H \leq \theta_1$. When trade occurs, the agent produces the efficient quantity.*

(ii) *when the agent's reservation utility is increasing in his ability (i.e. $B'(\theta) < 0$), the presence of type dependent reservation utilities may improve the efficiency of the optimal contract. If $B'(\theta)+\overline{q} > 0$, this is always the case. The optimal mechanism differs from that described in result 2 in that all types engage in surplus-creating trade with the principal. Full efficiency is however not reached, as types in $[\overline{\theta}, \theta_1]$ produce an inefficiently low quantity of output. These types are offered no informational rents. On the other hand, if $B'(\theta) + \overline{q} < 0$, the presence of type-dependent reservation utilities may result in low types being excluded from (surplus-creating) trade. Whenever surplus is created, however, quantity production is efficient.*

When the agent's reservation utility decreases in his ability (i.e. $B'(\theta) > 0$), the incentives arising from the presence of a type-dependent reservation utility reinforce those present in the standard setting (i.e. under the assumption that the agent's reservation utility is type-independent). This may result in additional inefficiency.

On the other hand, when the agent's reservation utility increases in his ability (i.e.

$B'(\theta) < 0$), the incentives arising from the presence of a type-dependent reservation utility run counter those present in the standard setting. If $B'(\theta) + \overline{q} > 0$, implying that the incentives provided by the presence of a type-dependent reservation utility are not too strong, the principal can keep the agent onto his reservation utility for a whole set of types. This enables him to enlarge the range of types with whom he contracts, without influencing the informational rents that have to be offered to induce truthtelling.

2.4.3 Allowing for randomization

In the previous section, we have derived the optimal mechanism when the principal is constrained to retain all types with whom he trades with probability one (efficient retention rule). We have found that in some instances, the optimal mechanism may include more exclusion (and less efficiency) than in the case where the agent's outside options are type-independent. In those instances, relaxing the requirement that $\pi(\theta) = 1$ for all types may improve the efficiency of the optimal contract by allowing the principal to trade with the agent while at the same time keeping him onto his reservation utility. Randomization may be necessary in order for this to be the case. Alternatively, randomization may not required to keep the agent onto his reservation utility, but may allow the principal to earn a higher expected payoff while doing so. Notice that the optimality of relaxing the requirement that $\pi(\theta) = 1$ for all types is not sufficient to ensure the optimality of randomization. In order for randomization to be optimal, we need to ensure that it is preferred to setting $\pi(\theta) = 0$. We now explore these intuitions more formally.

The principal's expected profit when the agent's type is θ is given by

$$vq_1(\theta) - w_1(\theta) + \pi(\theta)(vq_2(\theta) - w_2(\theta)) \tag{2.25}$$

$w_1(\theta)$ can also be written as

$$u(\theta) + \theta q_1(\theta) - \pi(\theta)\left(w_2(\theta) - \theta q_2(\theta)\right) - (1 - \pi(\theta))C(\theta) + 2B(\theta) \tag{2.26}$$

Substituting for $w_1(\theta)$ in (2.25) we get

$$(q_1(\theta) + \pi(\theta)q_2(\theta))(v - \theta) + (1 - \pi(\theta))C(\theta) - 2B(\theta) - u(\theta) \tag{2.27}$$

Ignoring the second-order condition for incentive compatibility, we can write the principal's problem as

$$\max_{\substack{\phi(\theta)\in(0,1),\ q_1(\theta),q_2(\theta)\in[0,\overline{q}] \\ \pi(\theta)\in[0,1]}} \int_{\underline{\theta}}^{\overline{\theta}} [(q_1(\theta) + \pi(\theta)q_2(\theta))(v - \theta) + (1 - \pi(\theta))C(\theta) - 2B(\theta) - u(\theta)] f(\theta)\phi(\theta)d\theta \tag{PP}$$

subject to

$$u'(\theta) = C'(\theta) - 2B'(\theta) - q_1(\theta) - \pi(\theta)\left(C'(\theta) + q_2(\theta)\right) \tag{IC.I}$$

and

$$u(\theta) \geq 0 \tag{PC}$$

Notice that $\pi(\theta)$ enters the problem in a linear fashion. Thus, randomization may be optimal if and only if either

· randomization is necessary in order to satisfy the second order condition for incentive compatibility or

· setting $\pi(\theta) = 0$ or $\pi(\theta) = 1$ would violate the agent's participation constraint.

As shown in the appendix, the latter case may arise only if $u(\dot{\theta}) = 0$, and setting $\pi(\theta) = 0$ or $\pi(\theta) = 1$ would violate the agent's participation constraint when his type is arbitrarily close (above or below, depending on the direction in which incentive compatibility binds) to θ. In that case, randomization is utilized to keep the agent onto his reservation utility, thus ensuring that $u'(\theta) = 0$. This brings us to the following proposition:

Proposition 2 *In the optimal mechanism, the principal may find it optimal to randomize over the probability with which type θ is retained after the first period if and only if*

(i) *randomization is necessary in order to satisfy the second order condition for incentive compatibility or*

(ii) $u(\theta) = 0$, and *setting* $\pi(\theta) = 0$ *or setting* $\pi(\theta) = 1$ *would violate the agent's participation constraint when his type is arbitrarily close to* θ. *When this is the case, randomization is utilized to ensure that* $u'(\theta) = 0$.

In what follows, we concentrate on the optimal WSC mechanism, and derive the necessary conditions for it to prescribe randomization. We then characterize the optimal WSC mechanism whenever these conditions are met, and show that it satisfies the second-order condition for incentive compatibility and is therefore globally optimal. In other words, we do not provide an exhaustive description of all the circumstances under which randomization may be optimal, but instead identify a set of sufficient conditions for this to be the case.

Optimal WSC mechanism

When the agent is kept onto his reservation utility, the optimal WSC contract for any type θ is found by substituting for $q_1 = C'(\theta) - 2B'(\theta) - \pi\left(C'(\theta) + q_2\right)$ into the principal's expected payoff, and by maximizing the resulting expression with respect to π and q_2, subject to the following constraints

C1 $(i)\ q_2 \geq 0$
$(ii)\ q_2 \leq \overline{q}$

C2 $(i)\ \pi \geq 0$
$(ii)\ \pi \leq 1$

C3 $(i)\ C'(\theta) - 2B'(\theta) - \pi\left(C'(\theta) + q_2\right) \geq 0$
$(ii)\ C'(\theta) - 2B'(\theta) - \pi\left(C'(\theta) + q_2\right) \leq \overline{q}$

The principal's expected payoff when $u(\theta) = 0$ is given by

$$q_1(v - \theta) + \pi q_2(v - \theta) + (1 - \pi)C(\theta) - 2B(\theta) \tag{2.28}$$

Substituting for $q_1 = C'(\theta) - 2B'(\theta) - \pi\left(C'(\theta) + q_2\right)$ and rearranging we get

$$C'(\theta) - 2B'(\theta) - \pi C'(\theta)(v - \theta) + (1 - \pi)C(\theta) - 2B(\theta) \tag{2.29}$$

The first-order condition with respect to π is

$$-C'(\theta)(v-\theta)-C(\theta) \tag{2.30}$$

Whenever the expression (2.30) is positive, the principal's expected profit from contracting with θ when $u(\theta)=u'(\theta)=0$ is increasing in π, and vice-versa. The sign of (2.30) therefore determines whether the principal will optimally select the highest, or the lowest value of $\pi\,(\theta)$ which satisfies constraints C1, C2 and C3. If this value is non-degenerate, the optimal WSC mechanism prescribes randomization whenever the agent is kept onto his reservation utility. The following proposition identifies the conditions under which this is the case.

Proposition 3 *The necessary conditions for the optimal WSC contract offered to a given type θ to include randomization are:*

(i) *If $B'(\theta)+\overline{q}>0$, i.e. the incentive compatibility constraint binds upwards:*

- ***a.*** $C'(\theta)(v-\theta)+C(\theta)>0$*: the principal's expected profit from contracting with θ when $u(\theta)=u'(\theta)=0$ is decreasing in π;*
- ***b.*** $C'(\theta)-2B'(\theta)-\overline{q}>0$*: the agent's informational rents when $q_1(\theta)=\overline{q}$, $\pi(\theta)=0$ increase in the opposite direction to those offered when $q_1(\theta)=q_2(\theta)=\overline{q}$, $\pi(\theta)=1$.*

(ii) *If $B'(\theta)+\overline{q}<0$, i.e. the incentive compatibility constraint binds downwards:*

- ***a.*** $C'(\theta)(v-\theta)+C(\theta)<0$*: the principal's expected profit from contracting with θ when $u(\theta)=u'(\theta)=0$ is increasing in π;*
- ***b.*** $C'(\theta)-2B'(\theta)-\overline{q}<0$*: the agent's informational rents when $q_1(\theta)=\overline{q}$, $\pi(\theta)=0$ increase in the opposite direction to those offered when $q_1(\theta)=q_2(\theta)=\overline{q}$, $\pi(\theta)=1$.*

When these conditions hold, the optimal WSC mechanism includes randomizations whenever the agent is kept onto his reservation utility. In that case, the contract offered *to any type θ specifies:*

$$q_1(\theta) = q_1(\theta) = \overline{q},\ \pi(\theta) = \frac{C'(\theta) - 2B'(\theta) - \overline{q}}{C'(\theta) + \overline{q}}$$

When this contract is offered, the principal's profit when contracting with type θ is given by $\overline{q}(v-\theta)(1+\pi(\theta)) + C(\theta)(1-\pi) - 2B(\theta) \rightarrow > 0$ from assumption 2.c.

Corollary 1 *Randomization may only be optimal when $C'(\theta) \neq B'(\theta)$. A necessary condition for this to be the case is that $C(\theta) \neq B(\theta)$.*

The intuition for proposition 3 goes as follows. First, consider the case where $B'(\theta) + \overline{q} > 0$; the requirement that $C'(\theta)(v-\theta) + C(\theta) > 0$ ensures that, conditional on $u'(\theta) = 0$, the principal: a) does not find it optimal to select $\pi(\theta) = 1$ (case where $B'(\theta) < 0$) or b) can earn nonnegative profits (case where $B'(\theta) > 0$). The condition that $C'(\theta) - 2B'(\theta) - \overline{q} > 0$ ensures that $u'(\theta) = 0$ is not consistent with setting $\pi(\theta) = 0$ [13].

Now consider the case where $B'(\theta) + \overline{q} < 0$. Recall that in this case, $u'(\theta) = 0$ is not feasible when $\pi(\theta) = 1$. The condition that $C'(\theta) - 2B'(\theta) - \overline{q} < 0$ ensures that $u'(\theta) = 0$ can be implemented when $\pi(\theta)$ is sufficiently small. The requirement that $C'(\theta)(v-\theta) + C(\theta) < 0$ ensures that, conditional on $u'(\theta) = 0$, the principal does not find it optimal to select $\pi(\theta) = 0$.

Finally, notice that with respect to the case where $\pi(\theta) = 1$ for all types, randomization may improve efficiency in two ways: by enlarging the range of types with whom the principal engages in surplus-producing trade at equilibrium, and by increasing production, whenever trade occurs.

The following proposition characterizes the optimal WSC mechanism whenever the necessary conditions identified by proposition 3 are met. In the appendix, we show that this mechanism satisfies the second order condition for incentive compatibility, and is therefore globally optimal.

[13] Recall that incentive compatibility requires $u'(\theta) = C'(\theta) - 2B'(\theta) - q_1(\theta) - \pi(\theta)(C'(\theta) + q_2(\theta))$. When $\pi(\theta) = 0$, $u'(\theta) > 0$ for any $q_1(\theta)$.

Proposition 4 *When the necessary conditions identified in proposition 3 hold, the optimal mechanism prescribes surplus-creating trade with all types, and has the following characteristics:*

(i) *if $B'(\theta)+\overline{q}>0$: there exist a $\theta_R \in [\underline{\theta},\theta_1[$ such that*

$$\left\{\begin{array}{l}\text{for } \theta \leq \theta_R\text{: } q_1(\theta)=q_2(\theta)=\overline{q},\ \pi(\theta)=1,\ u(\theta)=2\left[\overline{q}(\theta_R-\theta)+B(\theta_R)-B(\theta)\right] \\ \text{for } \theta > \theta_R\text{: } q_1(\theta)=q_2(\theta)=\overline{q},\ \pi(\theta)=\frac{C'(\theta)-2B'(\theta)-\overline{q}}{C'(\theta)+\overline{q}},\ u(\theta)=0\end{array}\right\}$$

(ii) if $B'(\theta)+\overline{q}<0$: there exist a θ^R such that

$$\left\{\begin{array}{l}\text{for } \theta \geq \theta^R\text{: } q_1(\theta)=q_2(\theta)=\overline{q},\ \pi(\theta)=1,\ u(\theta)=2\left[\overline{q}\left(\theta-\theta^R\right)+B(\theta_R)-B(\theta)\right] \\ \text{for } \theta < \theta_R\text{: } q_1(\theta)=q_2(\theta)=\overline{q},\ \pi(\theta)=\frac{C'(\theta)-2B'(\theta)-\overline{q}}{C'(\theta)+\overline{q}},\ u(\theta)=0\end{array}\right\}$$

When the dominant incentive is for him to understate (respectively, overstate) his ability, the agent is offered a stochastic contract whenever his ability is sufficiently low (high). The rationale for this result stems from the fact that randomization is optimal only when the agent is kept onto his reservation utility. Because keeping the agent onto his reservation utility involves an efficiency loss, this will only occur when the informational rents that would otherwise have to be offered to preserve incentive compatibility are sufficiently high.

Discussion

Proposition 4 tells us that the conditions which are necessary for the optimal WSC contract to include randomization are also sufficient for randomization to feature in the globally optimal contract. We now discuss the economic implications of some of these conditions.

First, consider the case where $B'(\theta)+\overline{q}>0$, implying that the incentive compatibility constraint binds upwards. In that case, a necessary condition for randomization to be included in the optimal WSC mechanism is that $C'(\theta)-2B'(\theta)-\overline{q}>0$; notice that $C'(\theta)-2B'(\theta)-\overline{q}>0$ implies that $C'(\theta)-B'(\theta)>B'(\theta)+\overline{q}>0$. Thus, for the optimal WSC mechanism to include randomization when $B'(\theta)+\overline{q}<0$ it is necessary that $C'(\theta)>B'(\theta)$. When $C(\theta)<B(\theta)$, $C'(\theta)>B'(\theta)$ implies that the opportunity loss that results if the agent is not retained in the second period is higher

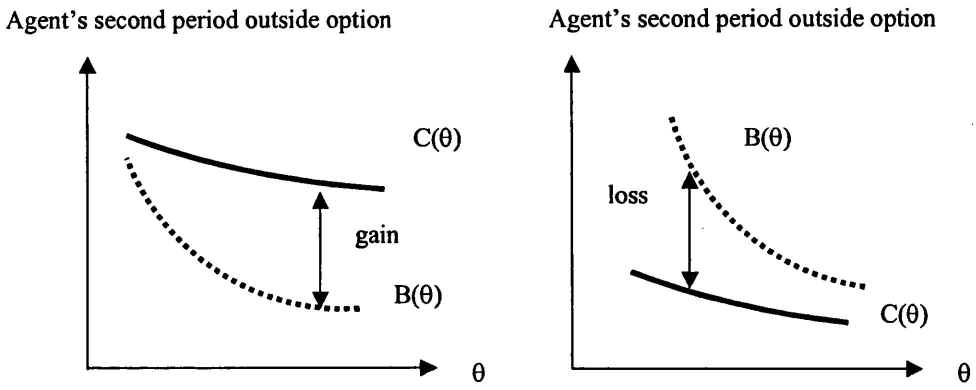

Figure 2-1: Agent's second period outside option when $0 > C'(\theta) > B'(\theta)$.

for more able types. Thus, more able types fear dismissal more than less able ones. When $C(\theta) > B(\theta)$, on the other hand, $C'(\theta) > B'(\theta)$ implies that the opportunity gain realized after dismissal is higher for less able types. That is, less able types benefit from on-the-job experience more than more able ones, and are willing to sacrifice more in order to obtain this experience. Both situations are depicted in figure 2-1 for the case where both $B(.)$ and $C(.)$ are negatively sloped. Figure 2-2 depicts the case where they are positively sloped. The common feature is that randomization allows the principal to increase the production allocated to less able types (higher θ's), without affecting the rents allocated to lower types.

When $B'(\theta)+\overline{q} < 0$, i.e. the incentive compatibility constraint binds downwards, on the other hand, randomization is included in the optimal WSC mechanism if and only if $C'(\theta) - 2B'(\theta) - \overline{q} < 0$. Notice that $C'(\theta) - 2B'(\theta) - \overline{q} < 0$ implies $C'(\theta) - B'(\theta) < B'(\theta) + \overline{q} < 0$, i.e. $C'(\theta) < B'(\theta)$. Thus, for the optimal WSC mechanism to prescribe randomization when $B'(\theta)+\overline{q} < 0$ it is necessary that the agent's second period ex-post outside option be steeper than his ex-ante one. Less able types should therefore fear dismissal more (respectively benefit form experience less) than more able types. This is depicted in figure 2-3 in the case where both $B(.)$ and $C(.)$ are negatively sloped[14].

[14]Notice that $B'(\theta) + \overline{q} < 0$ implies that $B'(\theta)$ must be < 0.

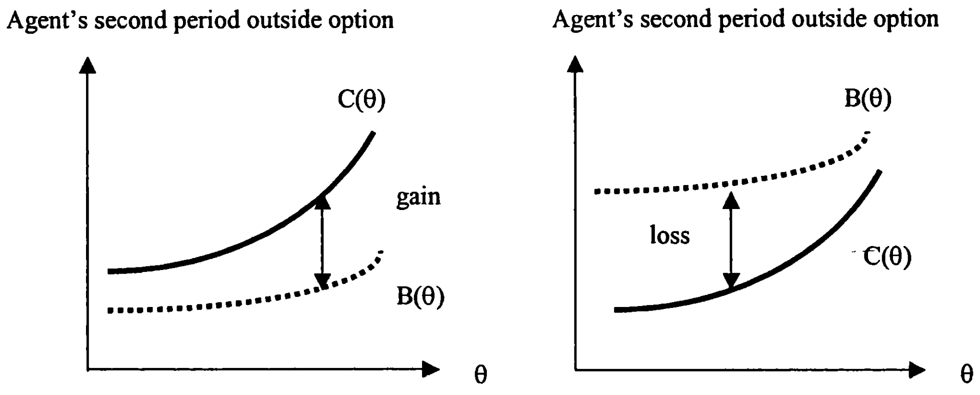

Figure 2-2: Agent's second period outside option when $C'(\theta) > B'(\theta) > 0$.

Randomization allows the principal to increase the production allocated to more able types (lower θ's), without affecting the rents allocated to higher types.

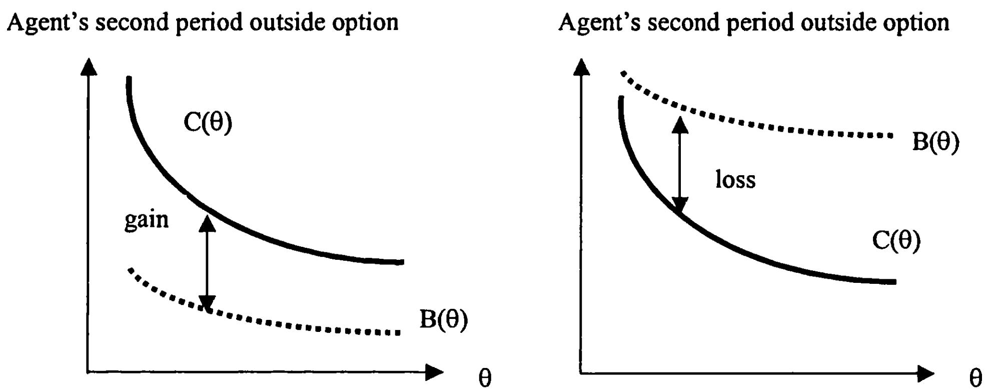

Figure 2-3: Agent's second period outside option when $C'(\theta) < B'(\theta) < 0$.

2.5 Concluding remarks

We have derived the sufficient conditions for randomization to be optimal when the agent's labour market prospects are affected by his employment history, and we have characterized the optimal mechanism when these sufficient conditions hold. When understood literally, randomization is seldom observed; however, our results show that employers may introduce an element of ambiguity on the conditions in need of being met to prevent dismissal. Hence, employment contracts may be purposely vague (or incomplete), even in environments where all aspects of activity are verifiable (and contracting costs are negligible). Indeed, as Bernheim and Whinston (1998) and Macauley (1963) have observed, contracts often fail even to specify verifiable obligations of the parties involved. This paper may be seen as contributing to the rationale of such "excessively incomplete" contracts.

2.6 Appendix

Proof of proposition 1:

If an agent of type θ accepts the contract designed for type $\widehat{\theta}$ he receives utility

$$u(\theta,\widehat{\theta}) = u(\widehat{\theta}) + q_1(\widehat{\theta})(\widehat{\theta}-\theta) + \pi(\widehat{\theta})q_2(\widehat{\theta})(\widehat{\theta}-\theta) + (1-\pi(\widehat{\theta}))(C(\theta)-C(\widehat{\theta})) + 2B(\widehat{\theta}) - 2B(\theta) \tag{2.31}$$

where $u(\widehat{\theta})$ is the utility level that type $\widehat{\theta}$ obtains when truthfully declaring his type.

The optimal declared type $\widehat{\theta}$ chosen by type θ satisfies

$$u'(\widehat{\theta}) + q_1'(\widehat{\theta})(\widehat{\theta}-\theta) + q_1(\widehat{\theta}) + \left(\pi'(\widehat{\theta})q_2(\widehat{\theta}) + \pi(\widehat{\theta})q_2'(\widehat{\theta})\right)(\widehat{\theta}-\theta) + \tag{2.32}$$

$$+\pi(\widehat{\theta})q_2(\widehat{\theta}) - \pi'(\widehat{\theta})(C(\theta)-C(\widehat{\theta})) - (1-\pi(\widehat{\theta}))C'(\widehat{\theta}) + 2B'(\widehat{\theta}) = 0$$

For the truth to be an optimal response for all θ it must therefore be the case that

$$u'(\theta) = -q_1(\theta) - \pi(\theta)q_2(\theta) + C'(\theta)(1-\pi(\theta)) - 2B'(\theta) \tag{2.33}$$

It is also necessary to satisfy the local second order condition. Conditional on differentiability, this corresponds to

$$u''(\widehat{\theta}) + q_1''(\widehat{\theta})(\widehat{\theta}-\theta) + 2q_1'(\widehat{\theta}) + \frac{\partial\left((\pi'(\widehat{\theta})q_2(\widehat{\theta}) + \pi(\widehat{\theta})q_2'(\widehat{\theta}))\right)}{\partial\widehat{\theta}}(\widehat{\theta}-\theta) +$$

$$+2\left(\pi_1'(\widehat{\theta})q_1(\widehat{\theta})+\pi_1(\widehat{\theta})q_1'(\widehat{\theta})+\pi_2'(\widehat{\theta})q_2(\widehat{\theta})+\pi_2(\widehat{\theta})q_2'(\widehat{\theta})+\pi_2'(\widehat{\theta})C'(\widehat{\theta})\right)- \tag{2.34}$$

$$-\pi_2''(\widehat{\theta})(C(\theta)-C(\widehat{\theta}))+(1-\pi_2(\widehat{\theta}))C''(\widehat{\theta})+2B''(\widehat{\theta})\leq 0 \text{ when } \widehat{\theta}=\theta$$

Thus, we require:

$$u''(\theta)+2\left(q_1'(\theta)+\pi'(\theta)(q_2(\theta)+C'(\theta))+\pi(\theta)q_2'(\theta)\right)-(1-\pi(\theta))C''(\theta)+2B''(\theta)\leq 0 \tag{2.35}$$

From the first order condition, we derive

$$u''(\theta)=-q_1'(\theta)-\pi'(\theta)q_2(\theta)-\pi(\theta)q_2'(\theta)+C''(\theta)(1-\pi(\theta))-\pi'(\theta)C'(\theta)-2B''(\theta) \tag{2.36}$$

Substituting for $u''(\theta)$ in (2.34) we get

$$q_1'(\theta)+\pi'(\theta)q_2(\theta)+q_2'(\theta)\pi(\theta)+\pi'(\theta)C'(\theta)\leq 0 \tag{2.37}$$

Allowing for discontinuities, this condition can be rewritten as

$$q_1(\theta)+\pi(\theta)\left(q_2(\theta)+C'(\theta)\right) \text{ is non-increasing in } \theta \tag{2.38}$$

where it should be recalled that we are assuming $C''(\theta)=0\ \forall\theta$. Conditions (2.33) and (2.38) constitute the local incentive compatibility constraints. We now verify that the agent does not want to lie globally. For this we require

$$u(\theta)\geq u(\widehat{\theta})+q_1(\widehat{\theta})(\widehat{\theta}-\theta)+\pi(\widehat{\theta})q_2(\widehat{\theta})(\widehat{\theta}-\theta)+(1-\pi(\widehat{\theta}))(C(\theta)-C(\widehat{\theta}))+2B(\widehat{\theta})-2B(\theta) \tag{2.39}$$

for any $(\theta,\widehat{\theta})$ in $[\underline{\theta},\overline{\theta}]$. Assume that $\widehat{\theta}>\theta$; from (2.33) we can write $u(\widehat{\theta})$ as

$$u(\theta)+\int_{\theta}^{\widehat{\theta}}\left(-q_1(s)-\pi(s)\left(q_2(s)+C'(s)\right)\right)ds+C(\widehat{\theta})-C(\theta)-2B(\widehat{\theta})+2B(\theta) \tag{2.40}$$

Substituting for $u(\widehat{\theta})$ in (2.39) and rearranging we get

$$0 \geq \int_{\theta}^{\widehat{\theta}} \left(-q_1(s) - \pi(s)\left(q_2(s) + C'(s)\right)\right) ds + q_1(\widehat{\theta})(\widehat{\theta}-\theta) + \pi(\widehat{\theta})\left(q_2(\widehat{\theta})(\widehat{\theta}-\theta) - C(\theta) + C(\widehat{\theta})\right) \tag{2.41}$$

This can also be written as

$$0 \geq \int_{\theta}^{\widehat{\theta}} \left(q_1(\widehat{\theta}) - q_1(s) + \pi(\widehat{\theta})q_2(\widehat{\theta}) - \pi(s)q_2(s) + C'(s)\left(\pi(\widehat{\theta}) - \pi(s)\right)\right) ds \tag{2.42}$$

The above condition is surely true if

$$q_1(\widehat{\theta}) + \pi(\widehat{\theta})q_2(\widehat{\theta}) + C'(\theta)\pi(\widehat{\theta}) \leq q_1(\theta) + \pi(\theta)q_2(\theta) + C'(\theta)\pi(\theta) \tag{2.43}$$

for all $\theta \leq \widehat{\theta}$. Because $C''(\theta) = 0\ \forall\theta$, $C'(\theta) = C'(\widehat{\theta})$, so (2.43) can be rewritten as

$$q_1(\widehat{\theta}) + \pi(\widehat{\theta})q_2(\widehat{\theta}) + C'(\widehat{\theta})\pi(\widehat{\theta}) \leq q_1(\theta) + \pi(\theta)q_2(\theta) + C'(\theta)\pi(\theta) \tag{2.44}$$

for all $\theta \leq \widehat{\theta}$. Condition (2.44) therefore requires that $q_1(\theta) + \pi(\theta)\left(q_2(\theta) + C'(\theta)\right)$ be non-increasing in θ. This is exactly condition (2.38). Thus, for $\widehat{\theta} > \theta$ the local incentive constraints also imply global incentive compatibility. The case where $\widehat{\theta} < \theta$ is analogous.■

Proof of Proposition 2:

If the optimal WSC mechanism prescribes that, within the context of the surplus-creating technology, the agent's participation constraint *only binds for one type*, then this mechanism must necessarily satisfy

$$\max_{\pi(\theta), q_1(\theta), q_2(\theta)} \int_{\theta_L}^{\theta_H} \{[(v-\theta)\left(q_1(\theta) + \pi(\theta)q_2(\theta)\right) + C(\theta)(1-\pi(\theta)) - 2B(\theta)]\, f(\theta) -$$
$$-\mu(\theta)\left(q_1(\theta) + \pi(\theta)q_2(\theta) - C'(\theta)(1-\pi(\theta)) + 2B'(\theta)\right)\}\, d\theta$$

where

$$\mu(\theta) \equiv \begin{cases} F(\theta) \text{ if } B'(\theta) + \overline{q} > 0 \\ F(\theta) - 1 \text{ if } B'(\theta) + \overline{q} < 0 \end{cases}$$

The first order condition with respect to $\pi(\theta)$ is given by

$$[q_2(\theta)(v - \theta) - C(\theta)] f(\theta) - \mu(\theta) \left(q_2(\theta) + C'(\theta)\right) \tag{2.45}$$

This condition does not contain $\pi(\theta)$. Thus, the principal optimally sets $\pi(\theta) = 1$ or 0, depending on the sign of (2.45). We conclude that, apart for the case in which it is necessary in order for the second-order condition for incentive compatibility to be satisfied, randomization may only be optimal the optimal mechanism prescribes that the agent's participation constraint *binds for more than one type.*

We now prove that if in the optimal mechanism randomization is offered to type θ in order to ensure that the agent's participation constraint[15] is met, it must be the case that θ's participation constraint is binding.

The possibility of $\pi(\theta) = 0$ or $\pi(\theta) = 1$ violating the agent's participation constraint may arise only if

1. either $u(\theta) = 0$, and setting $\pi(\theta) = 0$ or $\pi(\theta) = 1$ would violate the agent's incentive compatibility constraint when his type is adjacent (either above or below, depending on the direction in which incentive compatibility binds) to θ or

2. $u(\theta) > 0$, and there exist (at least) a type $\widehat{\theta} < \theta$ (if the incentive compatibility constraint binds upwards) or $> \theta$ (if the incentive compatibility constraint binds downwards) such that setting $\pi(\theta) = 0$ or $\pi(\theta) = 1$ would violate the agent's incentive compatibility constraint when his type is $\widehat{\theta}$.

Without loss of generality, consider the case where $B'(\theta) + \overline{q} > 0$, implying that incentive compatibility binds upwards. Assume that $u(\theta) > 0$, and that, if the principal offers $\pi(\theta) = 0$ or $\pi(\theta) = 1$ (denoted as $\pi^*(\theta)$), this would violate the agent's participation constraint when this type is $\widehat{\theta}$, where $\widehat{\theta}$ is below but not adjacent to θ. If $\pi(\theta) = \pi^*(\theta)$ results in the agent's PC being violated when his type is θ, then a type

[15] Within the context of the surplus-creating technology.

$\widetilde{\theta}' > \widehat{\theta}$ but $< \theta$ must exist, such that $u(\widetilde{\theta}') = 0$ when $\pi(\theta) = \pi^*(\theta)$. Also, it must be the case that $u'(\widetilde{\theta}') > 0$. Notice that, because $B'(\theta) + \overline{q} > 0$, informational rents are decreasing in type (i.e. $u'(.) < 0$) whenever the efficient contract is being offered. This implies that by modifying $\widetilde{\theta}'$'s contract so as to ensure that $u'(\widetilde{\theta}') = 0$, the principal could increase efficiency, without altering the informational rents that have to be offered to types below $\widetilde{\theta}'$. Moreover, if type $\widetilde{\theta}'$'s rather than type θ' s contract is modified in order to ensure the agent's participation, informational rents are saved on all types in $\left[\widehat{\theta},\theta\right]$.■

Proof of Proposition 3

We derive the optimal contract for any type θ, subject to the agent being kept onto his reservation utility.

1. $C'(\theta)(v - \theta) + C(\theta) > 0$

   When this is the case, the optimal contract is derived by setting the lowest possible π, conditional on constraints

C1 $(i)\ q_2 \geq 0$
$(ii)\ q_2 \leq \overline{q}$

and

C3 $(i)\ C'(\theta) - 2B'(\theta) - \pi\,(C'(\theta) + q_2) \geq 0$
$(ii)\ C'(\theta) - 2B'(\theta) - \pi\,(C'(\theta) + q_2) \leq \overline{q}$

being met. Notice that if constraint C3 was ignored, the principal would optimally select $\pi = 0$, $q_1 = C'(\theta) - 2B'(\theta)$, earning $(C'(\theta) - 2B'(\theta))\,(v - \theta) + C(\theta) - 2B(\theta)$ when contracting with type θ. From assumption 2.b), this amount is strictly smaller than $(C'(\theta) - 2B'(\theta))\,(v - \theta)$. By definition, the maximum profit that the principal can obtain when constraint C3 is applied is $\leq$ to that obtained when constraint C3 is ignored, i.e. $(C'(\theta) - 2B'(\theta))\,(v - \theta)$. It follows that a necessary condition to ensure that the principal can earn non-negative profits when $u'(\theta) = 0$ is that $C'(\theta) - 2B'(\theta) > 0$. When this is the case, the following instances may arise

1. (a) $C'(\theta) - 2B'(\theta) \leq \overline{q}$

In this case, the principal can set $\pi = 0$ without violating C3. The optimal WSC mechanism specifies: $\pi = 0$, $q_1(\theta) = C'(\theta) - 2B'(\theta)$ whenever the agent is kept onto his reservation utility.

(b) $C'(\theta) - 2B'(\theta) > \overline{q}$

In this case, setting $\pi = 0$ would violate constraint C3(ii). By increasing π above zero, a lower $C'(\theta) - 2B'(\theta) - \pi\,(C'(\theta) + q_2)$ is obtained if and only if $C'(\theta) + q_2 > 0$. A necessary requirement for this to be the case for some $q_2 \in [0, \overline{q}]$ is that $C'(\theta) + \overline{q} > 0$. Also, notice that constraint C3(ii) can be met for $\pi \leq 1$ if and only if

$$2B'(\theta) + \overline{q} + q_2 \geq 0 \tag{2.46}$$

(i.e. $C'(\theta) - 2B'(\theta) - \pi\,(C'(\theta) + q_2) \leq \overline{q}$ when $\pi = 1$). A necessary condition for this to be the case for some $q_2 \in [0, \overline{q}]$ is that

$$B'(\theta) + \overline{q} \geq 0 \tag{2.47}$$

We therefore distinguish between the following cases:

i. $B'(\theta) + \overline{q} \geq 0$ and $C'(\theta) + \overline{q} > 0$

In this case constraint C3(ii) is binding, and the optimal WSC mechanism specifies $q_1(\theta) = \overline{q}$, $\pi(\theta) = \frac{C'(\theta) - 2B'(\theta) - \overline{q}}{C'(\theta) + q_2(\theta)}$ whenever the agent is kept onto his reservation utility. Because the principal aims at setting π as low as possible, he sets $q_2(\theta) = \overline{q}$.

ii. $B'(\theta) + \overline{q} < 0$ and/or $C'(\theta) + \overline{q} \leq 0$

In this case, constraint C3 cannot be met for any $\pi \in [0, 1]$. It is therefore not possible for the principal to keep the agent onto his reservation utility for a whole set of types.

2. $C'(\theta)(v - \theta) + C(\theta) < 0$

When this is the case, the optimal contract is derived by setting the highest possible π, conditional on constraints C1 and C3 being met. Notice that if constraint

C3 was ignored, the principal would optimally set $\pi = 1$, $q_1 = -2B'(\theta) - q_2$, earning $-2B'(\theta)(v-\theta)+C(\theta)-2B(\theta)$ when contracting with type θ. From assumption 1b, this is strictly smaller than $-2B'(\theta)(v-\theta)$. Thus, a necessary condition to ensure that the principal can earn non-negative profits when $u'(\theta) = 0$ is that $B'(\theta) < 0$. When this is the case, the following instances may arise:

(a) $B'(\theta) + \overline{q} \geq 0$

When this condition holds, we know that there exist some values of q_2 in $[0, \overline{q}]$ such that $C'(\theta) - 2B'(\theta) - \pi (C'(\theta) + q_2) \leq \overline{q}$ when $\pi = 1$. In other words, the principal can set $\pi = 1$ without violating C3. Any optimal WSC mechanism therefore prescribes that, whenever the agent is kept onto his reservation utility: $\pi(\theta) = 1$, $q_1(\theta) + q_2(\theta) = -2B'(\theta)$, where $q_2(\theta)$ is such that $-2B'(\theta) - q_2(\theta) \leq \overline{q}$.

(b) $B'(\theta) + \overline{q} < 0$

In that case, the principal is unable to implement $\pi = 1$ without violating C3. This can be seen by noticing that when $\pi = 1$, constraint C3 requires

$$-2B'(\theta) - q_2 \leq \overline{q} \tag{2.48}$$

i.e.

$$-2B'(\theta) - \overline{q} \leq q_2 \tag{2.49}$$

Because we are considering the case where $B'(\theta) + \overline{q} < 0$, we know that

$$-2B'(\theta) - \overline{q} > \overline{q} \tag{2.50}$$

This implies that the above condition cannot be satisfied.

By decreasing π below one, a lower $C'(\theta) - 2B'(\theta) - \pi (C'(\theta) + q_2)$ is obtained if and only if $C'(\theta) + q_2 < 0$. Notice that constraint C3(ii) can be met for $\pi \geq 0$ if and only if $C'(\theta) - 2B'(\theta) \leq \overline{q}$. This condition can also be written as

$$-2B'(\theta) - \overline{q} \leq -C'(\theta) \tag{2.51}$$

Because we are considering the case where $B'(\theta)+\overline{q} < 0$, we know that $-2B'(\theta)-\overline{q} > \overline{q}$. A necessary requirement for $C'(\theta) - 2B'(\theta) \leq \overline{q}$ (i.e. $-2B'(\theta) - \overline{q} \leq -C'(\theta)$) is therefore that

$$-C'(\theta) \geq \overline{q} \tag{2.52}$$

We therefore distinguish between the following cases;

i. $C'(\theta) - 2B'(\theta) \leq \overline{q}$ (implying that $C'(\theta) + \overline{q} < 0$)

   Constraint C3(ii) binds. The optimal WSC mechanism specifies $q_1(\theta) = \overline{q}$, $\pi(\theta) = \frac{C'(\theta)-2B'(\theta)-\overline{q}}{C'(\theta)+q_2(\theta)}$ whenever the agent is kept onto his reservation utility. Because the principal aims at setting $\pi(\theta)$ as high as possible, he sets $q_2(\theta) = \overline{q}$.

ii. $C'(\theta) - 2B'(\theta) > \overline{q}$

   Constraint C3 cannot be satisfied for any $\pi \in [0,1]$. The principal is unable to keep the agent onto his reservation utility for a whole set of types.■

Proof of proposition 4

First, consider the case where $B'(\theta) + \overline{q} > 0$, i.e. the agent's incentive compatibility constraint binds upwards. After integration by parts, the principal's problem can be written as

$$\max_{\substack{q_1(\theta),q_2(\theta)\in[0,\overline{q}] \\ \pi(\theta)\in[0,1]}} \int_{\theta_L}^{\theta_H} \{[(q_1(\theta) + \pi(\theta)q_2(\theta))(v-\theta) + (1-\pi(\theta))C(\theta) - 2B(\theta)] f(\theta) - \\ - F(\theta)\left[q_1(\theta) + \pi(\theta)q_2(\theta) + C'(\theta)(1-\pi(\theta) - 2B'(\theta)\right]\} d\theta \tag{2.53}$$

The effect of a marginal reduction in $q_1(\theta)$ upon the principal's expected profit is given by

$$F(\theta) - (v-\theta)f(\theta) \tag{2.54}$$

while the effect of a marginal reduction in $q_2(\theta)$ is

$$\pi(\theta)\left[F(\theta) - (v-\theta)f(\theta)\right] \tag{2.55}$$

Thus, whenever $\theta > \theta_1$ the principal finds it optimal to reduce production in order to save on informational rents.

Now consider $\pi(\theta)$; the effect upon the principal's expected profit of a marginal reduction in $\pi(\theta)$ is

$$F(\theta)(C'(\theta) + q_2(\theta)) - f(\theta)\left[q_2(\theta)(v - \theta) - C(\theta)\right] \tag{2.56}$$

The first term expresses the gain in terms of smaller informational rents that have to be offered to types below θ. Notice that with respect to the situation in which the agent's outside options are normalized to zero we have an extra term: $C'(\theta)$, expressing the change in the agent's second-period outside option for a marginal change in type. This extra term appears because the degree to which decreasing $\pi(\theta)$ (while modifying transfers to keep $u(\theta)$ constant) makes θ's contract less attractive for (marginally) lower types also depends on the difference the second-period outside option that those types receive, and that which θ receives.

The second term expresses the loss arising form the fact that (surplus-creating) trade with type θ happens with a lower probability. Again, with respect to the case in which outside options are type-independent, we have an extra term: $C(\theta)$. This term appears because a higher $C(\theta)$ decreases the degree to which type θ needs to be compensated for the fact that he may not be retained after the first period.

Whenever expression (2.56) is positive, the principal finds it optimal to reduce $\pi(\theta)$, in order to save on informational rents that should be offered to lower types. We now show that there exist a $\theta_R \in [\underline{\theta}, \theta_1[$ such that expression (2.56) is $= 0$ if $\theta = \theta_R$, negative if $\theta < \theta_R$ and positive if $\theta > \theta_R$.

Rewrite condition (2.56) as

$$\frac{F(\theta)}{f(\theta)}(C'(\theta) + q_2(\theta)) - \left[q_2(\theta)(v - \theta) - C(\theta)\right] \tag{2.57}$$

Consider $\theta \geq \theta_1$. For those types:

$$\frac{F(\theta)}{f(\theta)} \geq v - \theta \tag{2.58}$$

Thus, condition (2.56) is higher or equal than

$$(v-\theta)\left(C'(\theta)+q_2(\theta)\right)-\left[q_2(\theta)(v-\theta)-C(\theta)\right] \tag{2.59}$$

which is equal to

$$C'(\theta)(v-\theta)+C(\theta) \tag{2.60}$$

The condition $C'(\theta)(v-\theta)+C(\theta)>0$ is therefore sufficient to guarantee that expression (2.56) is positive for all $\theta \geq \theta_1$.

Now consider $\theta < \theta_1$. For those types, $q_1(\theta) = q_2(\theta) = \overline{q}$[16], so condition (2.56) is positive whenever

$$\frac{F(\theta)}{f(\theta)} > \frac{\overline{q}(v-\theta)-C(\theta)}{\overline{q}+C'(\theta)} \tag{2.61}$$

where it should be recalled that we are considering the case where $\overline{q}+C'(\theta)>0$.

From our assumptions, $\frac{F(\theta)}{f(\theta)}$ is increasing in θ. Because we are assuming that $C''(\theta) = 0$, on the other hand, $\frac{\overline{q}(v-\theta)-C(\theta)}{\overline{q}+C'(\theta)}$ is decreasing in θ[17]. Evaluated at $\theta = \underline{\theta}$ expression (2.56) is equal to

$$-\left[\overline{q}(v-\underline{\theta})-C(\underline{\theta})\right] \tag{2.62}$$

which is negative from assumption 2.a.

Evaluated at $\theta = \theta_1$ expression (2.56) is

$$C'(\theta)(v-\theta)+C(\theta)>0 \tag{2.63}$$

We conclude that there exist a $\theta_R \in [\underline{\theta}, \theta_1[$ such that expression (2.56) is $=0$ if $\theta = \theta_R$, negative if $\theta < \theta_R$ and positive if $\theta > \theta_R$.

Whenever the agent's type is $> \theta_R$, the principal selects the lowest $\pi(\theta)$ compatible

[16]Strictly speaking, if $\pi(\theta) = 0$ the optimal $q_2(\theta)$ can take any value in $[0,\overline{q}]$. Because we are investigating the conditions under which $\pi(\theta)$ is >0 for all types, we however restrict attention to the case where the optimal $q_2(\theta)$ is $=\overline{q}$ for all $\theta \leq \theta_1$.

[17]If we differentiate $\frac{\overline{q}(v-\theta)-C(\theta)}{\overline{q}+C'(\theta)}$ with respect to θ we obtain

$$-\frac{\left(\overline{q}+C'(\theta)\right)^2}{\left(\overline{q}+C'(\theta)\right)^2} = -1$$

with the agent's participation constraint. Consider type $\overline{\theta}$; at equilibrium, constraint IC.I does not impose any restriction upon $u\left(\overline{\theta}\right)$. Given that, the principal optimally sets $u\left(\overline{\theta}\right) = 0$ (the minimum required to ensure type $\overline{\theta}$'s participation). In order to satisfy the agent's participation constraint when his type is arbitrarily close to $\overline{\theta}$, we require $\overline{\theta}$'s contract to satisfy $u'\left(\overline{\theta}\right) \leq 0$. Now, because we are above type θ_R, we know that the principal's expected profit is strictly decreasing in $\pi\left(\overline{\theta}\right)$; the principal is ready to sacrifice $\pi\left(\overline{\theta}\right)$, in order to save on the informational rents that have to be offered to lower types. Whenever $u'\left(\overline{\theta}\right) < 0$, the principal always has an incentive to decrease $\pi(\theta)$ further, so long as this is possible. At $\pi(\theta) = 0$, $u'\left(\overline{\theta}\right) > 0$ (from assumption (i).b, in proposition 3). Thus, the optimal contract must involve $u'\left(\overline{\theta}\right) = 0$. From proposition 3, we know that the optimal contract conditional on $u'\left(\overline{\theta}\right) = 0$ is given by $q_1\left(\overline{\theta}\right) = q_2\left(\overline{\theta}\right) = \overline{q}$, $\pi\left(\overline{\theta}\right) = \frac{C'(\overline{\theta})-2B'(\overline{\theta})-\overline{q}}{C'(\overline{\theta})+\overline{q}}$. Now consider type $\theta = \overline{\theta} - \varepsilon$, for ε arbitrarily small. Because $u\left(\overline{\theta}\right) = u'(\overline{\theta}) = 0$, we know that $u\left(\overline{\theta} - \varepsilon\right) = 0$; the same reasoning as for type $\overline{\theta}$ applies; indeed, the same reasoning applies for all types $> \theta_R$.

When the agent's type is $\leq \theta_R$, on the other hand, the principal sets $\pi(\theta) = 1$; in other words, the principal optimally offers the agent informational rents, rather than keeping him on his reservation utility. This can be seen as follows:

Denoting as θ_H the highest type who is offered informational rents, incentive compatibility requires that for all $\theta < \theta_H$ (to whom the contract $q_1(\theta) = q_2(\theta) = \overline{q}$, $\pi(\theta) = 1$ is offered):

$$u(\theta) = 2\left[B(\theta_H) - B(\theta) + \overline{q}(\theta_H - \theta)\right] \tag{2.64}$$

Thus, by decreasing θ_H the principal can reduce the informational rents that have to be offered to lower types. The effect of a marginal reduction in θ_H upon the principal's expected profit is

$$2F(\theta_H)\left(B'(\theta_H) + \overline{q}\right) - f(\theta_H)\left(1 - \frac{C'(\theta_H) - 2B'(\theta_H) - \overline{q}}{C'(\theta_H) + \overline{q}}\right)\left[\overline{q}(v - \theta_H) - C(\theta_H)\right] \tag{2.65}$$

In expression (2.65), the gains from lower informational rents are given by

$$2F(\theta_H)\left(B'(\theta_H)+\overline{q}\right) \tag{2.66}$$

while

$$f(\theta_H)\left(1-\frac{C'(\theta_H)-2B'(\theta_H)-\overline{q}}{C'(\theta_H)+\overline{q}}\right)\left[\overline{q}(v-\theta_H)-C(\theta_H)\right] \tag{2.67}$$

expresses the loss that the principal incurs by offering

$$q_1(\theta_H)=q_2(\theta_H)=\overline{q}, \pi(\theta_H)=\frac{C'(\theta_H)-2B'(\theta_H)-\overline{q}}{C'(\theta_H)+\overline{q}} \tag{2.68}$$

(i.e. the best contract satisfying $u'(\theta_H)=0$) instead of

$$q_1(\theta_H)=q_2(\theta_H)=\overline{q},\ \pi(\theta_H)=1 \tag{2.69}$$

Whenever expression (2.65) is positive, the principal finds it optimal to marginally decrease θ_H and vice-versa.

Rearranging (2.65), we see that the expression can be rewritten as

$$2\frac{B'(\theta_H)+\overline{q}}{C'(\theta_H)+\overline{q}}\left[F(\theta_H)\left(C'(\theta_H)+\overline{q}\right)-f(\theta_H)\overline{q}(v-\theta_H)-C(\theta_H)\right] \tag{2.70}$$

Because we are considering the case where both $B'(\theta)+\overline{q}$ and $C'(\theta)+\overline{q}$ are >0, (2.70) has the same sign as (2.56), and is equal to zero at $\theta=\theta_R$. Thus, at equilibrium the optimal θ_H is equal to θ_R. Thus, the optimal WSC mechanism when $B'(\theta)+\overline{q}>0$ and the necessary conditions identified in proposition 3 are met is given by:

$$\left\{\begin{array}{l}\text{for } \theta\le\theta_R\text{: } q_1(\theta)=q_2(\theta)=\overline{q},\ \pi(\theta)=1,\ u(\theta)=2\left[\overline{q}(\theta_R-\theta)+B(\theta_R)-B(\theta)\right]\\ \text{for } \theta>\theta_R\text{: } q_1(\theta)=q_2(\theta)=\overline{q},\ \pi(\theta)=\frac{C'(\theta)-2B'(\theta)-\overline{q}}{C'(\theta)+\overline{q}},\ u(\theta)=0\end{array}\right\}$$

We now show that this mechanism is incentive compatible. IC.II requires

$$q_1(\theta)+\pi(\theta)\left(q_2(\theta)+C'(\theta)\right) \text{ non-increasing in } \theta \tag{IC.II}$$

For $\theta\le\theta_R$, IC.II is trivially satisfied. For for $\theta>\theta_R$, IC.II can be rewritten as

$$C'(\theta)-2B'(\theta) \text{ non-increasing in } \theta \tag{2.71}$$

Because we are assuming $B''(\theta) = C''(\theta) = 0\ \forall\theta$, this is always the case. Last, we consider the discontinuity in $\pi(.)$ which occurs at θ_R. IC.II is satisfied if

$$\pi(\theta_R+\varepsilon)\left(\overline{q}+C'(\theta_R+\varepsilon)\right) \leq \pi(\theta_R-\varepsilon)\left(\overline{q}+C'(\theta_R-\varepsilon)\right) \tag{2.72}$$

for $\varepsilon \to 0$. Because $C''(\theta) = 0$, and because we are considering the case where $\overline{q}+C'(\theta) > 0\ \forall\theta$, (2.72) is satisfied if

$$\pi(\theta_R+\varepsilon) \leq \pi(\theta_R-\varepsilon) \tag{2.73}$$

which is the case, because the discontinuity involves a downward jump.

We now consider the case where $B'(\theta)+\overline{q} < 0$, i.e. the agent's incentive compatibility constraint binds downwards. After integration by parts, the principal's problem can be written as

$$\max_{\substack{q_1(\theta),q_2(\theta)\in[0,\overline{q}]\\ \pi(\theta)\in[0,1]}} \int_{\theta_L}^{\theta_H} \{[(q_1(\theta)+\pi(\theta)q_2(\theta))(v-\theta)+(1-\pi(\theta))C(\theta)-2B(\theta)]\, f(\theta)+ \\ +(1-F(\theta))\left[q_1(\theta)+\pi(\theta)q_2(\theta)+C'(\theta)(1-\pi(\theta)-2B'(\theta)\right]\}\, d\theta \tag{2.74}$$

The effect of a marginal increase in $q_1(\theta)$ upon the principal's expected profit is given by

$$1-F(\theta)+(v-\theta)f(\theta) \tag{2.75}$$

The above expression is always positive. Therefore, we conclude that the optimal WSC mechanism prescribes $q_1(\theta) = \overline{q}$. By a similar reasoning, we also conclude that the optimal WSC mechanism prescribes $q_2(\theta) = \overline{q}$ whenever $\pi(\theta) > 0$.

Now consider the optimal $\pi(\theta)$; the effect upon the principal's expected payoff of a marginal decrease in $\pi(\theta)$ is[18]

$$-(1-F(\theta))\left(C'(\theta)+\overline{q}\right)-f(\theta)\left[\overline{q}(v-\theta)-C(\theta)\right] \tag{2.76}$$

Whenever expression (2.76) is positive, the principal finds it optimal to reduce $\pi(\theta)$, in

[18] Because we are investigating the conditions under which $\pi(\theta) > 0$ for all types, we set $q_2(\theta) = \overline{q}$ $\forall\theta$.

order to save on informational rents that should be offered to higher types.

We now show that there exist a θ^R such that (2.76) is $= 0$ when $\theta = \theta^R$, negative if $\theta > \theta^R$ and positive if $\theta < \theta^R$.

Rewrite (2.76) as

$$-\frac{1-F(\theta)}{f(\theta)}\left(C'(\theta)+\overline{q}\right)-\left[\overline{q}(v-\theta)-C(\theta)\right] \tag{2.77}$$

The expression is positive whenever

$$\frac{1-F(\theta)}{f(\theta)} > \frac{\overline{q}(v-\theta)-C(\theta)}{-\left(C'(\theta)+\overline{q}\right)} \tag{2.78}$$

where it should be recalled that we are considering the case where $C'(\theta)+\overline{q}$ is negative. The lefthandside of (2.78) is decreasing in θ by assumption. The righthandside of (2.78), on the other hand, is increasing in θ[19]. Thus, (2.76) is strictly decreasing in θ. Evaluated at $\theta = \overline{\theta}$, expression (2.76) is equal to

$$-\left[\overline{q}(v-\theta)-C(\theta)\right] \tag{2.79}$$

which is negative from assumption 2.a). Thus, there exist a θ^R [20]such that (2.76) is negative when $\theta > \theta^R$ and positive when $\theta < \theta^R$.

When the agent's type is $< \theta^R$, the principal selects $\pi(\theta)$ so as to ensure that $u'(\theta) = 0$. This results in setting $q_1(\theta) = q_2(\theta) = \overline{q}$, $\pi(\theta) = \frac{C'(\theta)-2B'(\theta)-\overline{q}}{C'(\theta)+\overline{q}}$[21]. When the agent's type is $\geq \theta^R$, on the other hand, the principal sets $\pi(\theta) = 1$, i.e. does not keep the agent onto his reservation utility. This can be seen as follows:

Denoting as θ^L the lowest type who is offered informational rents, incentive com-

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[19]Because $C''(\theta) = 0$, if we differentiate $\frac{\overline{q}(v-\theta)-C(\theta)}{-(C'(\theta)+\overline{q})}$ with respect to θ we obtain

$$\frac{\left(C'(\theta)+\overline{q}\right)^2}{\left(C'(\theta)+\overline{q}\right)^2} = 1$$

[20]Which may be below $\underline{\theta}$, in which case (2.76) is negative for all types in our domain.

[21]The rationale is akin to that for the case where $B'(\theta)+\overline{q} > 0$.

patibility requires that for all $\theta > \theta^L$:

$$u(\theta) = 2\left[B\left(\theta^L\right) - B(\theta) + \overline{q}\left(\theta^L - \theta\right)\right] \tag{2.80}$$

Thus, by increasing θ^L the principal can reduce the informational rents that have to be offered to higher types. The effect of a marginal increase in θ^L upon the principal's expected profit is

$$-2\left(1 - F\left(\theta^L\right)\right)\left(B'\left(\theta^L\right) + \overline{q}\right) - f\left(\theta^L\right)\left(1 - \frac{C'\left(\theta^L\right) - 2B'\left(\theta^L\right) - \overline{q}}{C'\left(\theta^L\right) + \overline{q}}\right)\left[\overline{q}\left(v - \theta^L\right) - C\left(\theta^L\right)\right] \tag{2.81}$$

In expression (2.81), the gain from lower informational rents is given by

$$-2\left(1 - F\left(\theta^L\right)\right)\left(B'\left(\theta^L\right) + \overline{q}\right) \tag{2.82}$$

while

$$f\left(\theta^L\right)\left(1 - \frac{C'\left(\theta^L\right) - 2B'\left(\theta^L\right) - \overline{q}}{C'\left(\theta^L\right) + \overline{q}}\right)\left[\overline{q}\left(v - \theta^L\right) - C\left(\theta^L\right)\right] \tag{2.83}$$

expresses the loss that the principal incurs by offering

$$q_1\left(\theta^L\right) = q_2\left(\theta^L\right) = \overline{q},\ \pi\left(\theta^L\right) = \frac{C'\left(\theta^L\right) - 2B'\left(\theta^L\right) - \overline{q}}{C'\left(\theta^L\right) + \overline{q}} \tag{2.84}$$

(i.e. the best contract such that $u'\left(\theta^L\right) = 0$) instead of

$$q_1\left(\theta^L\right) = q_2\left(\theta^L\right) = \overline{q},\ \pi\left(\theta^L\right) = 1 \tag{2.85}$$

Whenever (2.81) is positive, the principal finds it optimal to increase θ^L and vice-versa. Rearranging, we see that (2.81) can be written as

$$2\frac{B'\left(\theta^L\right) + \overline{q}}{C'\left(\theta^L\right) + \overline{q}}\left\{-(1 - F\left(\theta^L\right)\left(C'\left(\theta^L\right) + \overline{q}\right) - f\left(\theta^L\right)\left[\overline{q}\left(v - \theta^L\right) - C\left(\theta^L\right)\right]\right\} \tag{2.86}$$

Because we are considering the case where $B'\left(\theta^L\right) + \overline{q}$ and $C'\left(\theta^L\right) + \overline{q}$ are both negative, (2.86) has the same sign as (2.76), and is $= 0$ at $\theta = \theta^R$. Thus at equilibrium the optimal θ^L is equal θ^R.

Thus, the optimal WSC mechanism when $B'(\theta)+\overline{q} < 0$ and the necessary conditions identified in proposition 3 are met is given by:

$$\left\{\begin{array}{l}\text{for } \theta \geq \theta^R\text{: } q_1(\theta) = q_2(\theta) = \overline{q},\ \pi(\theta) = 1,\ u(\theta) = 2\left[\overline{q}\left(\theta - \theta^R\right) + B(\theta_R) - B(\theta)\right] \\ \text{for } \theta < \theta^R\text{: } q_1(\theta) = q_2(\theta) = \overline{q},\ \pi(\theta) = \frac{C'(\theta) - 2B'(\theta) - \overline{q}}{C'(\theta)+\overline{q}},\ u(\theta) = 0\end{array}\right\}$$

We now show that this mechanism is incentive compatible. IC.II requires

$$q_1(\theta) + \pi(\theta)\left(q_2(\theta) + C'(\theta)\right) \text{ non-increasing in } \theta \tag{IC.II}$$

For $\theta \geq \theta^R$, IC.II is trivially satisfied. For for $\theta < \theta_R$, IC.II can be rewritten as

$$C'(\theta) - 2B'(\theta) \text{ non-increasing in } \theta \tag{2.87}$$

Because we are assuming $B''(\theta) = C''(\theta) = 0\ \forall\theta$, this is always the case. Last, we consider the discontinuity in $\pi(.)$ which occurs at θ^R. IC.II is satisfied if

$$\pi(\theta_R + \varepsilon)\left(\overline{q} + C'(\theta_R + \varepsilon)\right) \leq \pi(\theta_R - \varepsilon)\left(\overline{q} + C'(\theta_R - \varepsilon)\right) \tag{2.88}$$

for $\varepsilon \rightarrow 0$. Because $C''(\theta) = 0$, and because we are considering the case where $\overline{q}+C'(\theta) < 0\ \forall\theta$, (2.72) is satisfied if

$$\pi(\theta_R + \varepsilon) \geq \pi(\theta_R - \varepsilon) \tag{2.89}$$

which is the case, because the discontinuity involves an upward jump. ■

Chapter 3

Nonlinear Pricing and Multimarket Duopolists

3.1 Introduction

Two of the most active areas of research in industrial organization are that which studies horizontal product differentiation within an oligopolistic setting (such as in Hotelling (1929) and that which explores the degree to which a monopoly may take advantage of its position by operating nonlinear pricing (such as in Mussa and Rosen(1978)).

This paper belongs to the recent body of literature (mainly Stole (1995), Rochet and Stole (2002) and Armstrong and Vickers (2001) which tries to unify these two streams of research by studying nonlinear pricing within the context of an horizontally differentiated duopoly. We add to this literature by explicitly superimposing two empirically sound features upon the basic model, and showing that this has rather dramatic implications for the equilibrium contracts.

The first distinctive feature of this paper concerns the assumption that the consumer's marginal valuation of quality is determined by his preferences over horizontal product characteristics: a consumer who prefers one brand over the other will derive more utility from an increase in quality if this takes place within the context of his favorite brand, as opposed to the other brand. Equivalently, the difference in utility that a consumer experiences when he switches from his favorite brand to another is positively correlated with his preference for quality when purchasing the favorite brand. This implies that consumers who purchase goods of higher quality also have stronger brand preferences and vice-versa.

The motivation for this way of modeling preferences is empirical, and comes from the observation that, in some markets, consumers who purchase higher qualities are more "brand loyal" than those who purchase lower qualities. This is well documented within the context of the car market[1]: Goldberg (1995), for instance, combines a disaggregate model of demand with an aggregate oligopoly model of supply to characterize the American automobile market in 1983-89. She finds evidence that cross (i.e. within brands) price elasticity is highest for intermediate and standard automobiles, while is lowest for sport and luxury cars. These findings are confirmed by Berry, Lewinsohn and Pakes (1995), who develop a framework which allows to estimate demand parameters from product-level and aggregate consumer-level data. They apply these techniques to the US automobile market, showing that the most elastically demanded products are those in the most crowded market segments: the compact and subcompact models. Finally, Feenstra and Lewinsohn (1995) take the approach of utilizing aggregate data, and model the American car market as an oligopoly in which products are differentiated along multiple dimensions. Again, their findings suggests that cross price elasticities in the high quality segment are lower than those in the low quality segment.

We indicate the consumer's preferences over horizontal product characteristics by his position over an hypothetical segment. Crucially, we concentrate on settings where the two competing firms are located at the extremities of this segment[2]. There is therefore a one-to-one correspondence between the dispersion of the consumer's preferences and the degree of differentiation between the varieties (or brands) sold by the two firms; situations where preferences over horizontal characteristics are relatively homogeneous are therefore also characterized by a low degree of differentiation between the varieties

[1] Indeed, Verboven (1996) calls this feature a "stylized fact" within the car market.

[2] D'aspremont et al. (1979) show that, for quadratic trasportation costs, the equilibium of the two-stage game where (1) firms simultaneously choose their locations and (2) taking their locations as given, firms compete in prices, has the two firms locating at the extremities of the segment. Our assumption can be interpreted as hypothetising the validity of this result when, in the second stage of the game, firms compete in price-quality menus.

sold by the two firms, and vice-versa.

The second distinctive feature of this paper concerns the assumption that each firm operates both within a local (where it is a monopolist) and a competitive market (where it competes against another firm). This division between markets may be interpreted either in a literal way (i.e. as modelling markets which are geographically separated[3]) or as capturing the fact that consumers may differ in their switching costs. From the point of view of each firm, the presence of two markets results in the consumer's reservation utility being either equal to zero (when the consumer is located in the local market) or taking a positive value (when the consumer is located in the competitive market) with a certain probability. This implies that, in addition to the standard "efficiency versus informational rents" considerations, the principal's contractual choice is influenced by an extra effect arising from the act that by increasing the utility that the agent obtains from trading with him, the principal can enlarge the mass of types with whom he contracts. With respect to the standard monopoly scenario, this "market share" effect results in the principal optimally offering higher quality levels. We find that, if the degree of substitutability between the products sold by the two firms is sufficiently high, the "market share" effect is strictly positive for sufficiently low types, but abruptly disappears as soon as the agent's utility schedule crosses his (highest possible) reservation utility. The implication is that the equilibrium quality schedule exhibits bunching; if this was not the case, the quality schedule would experience a downward discontinuity, thus violating incentive compatibility. The firm's ability to discriminate among different types of consumers is therefore inhibited by the presence of two types of markets (one where it is a monopolist, one where it competes against another firm). This is our first result.

Our second and main result concerns the welfare properties of different competitive environments. We find that, if the distribution of consumer's types is sufficiently narrow (and, accordingly, the degree of substitutability between the varieties sold by the two firms is sufficiently high), the equilibrium contract exhibits overprovision for sufficiently low types. This is because, at equilibrium, the strength of the "market share"

[3] This is a common feature in markets for natural resources, such as gas.

effect is directly proportional to the degree of homogeneity in consumer preferences; as the degree of homogeneity in consumer preferences augments, high quality allocations therefore become increasingly attractive. The implication of our second result is that more fiercely competitive environments may not necessarily be characterized by higher efficiency. Although the downward distortions in the qualities offered to high types may decrease in more competitive environments, other types of distortions (namely: upwards distortions) may appear.

3.1.1 Related literature

The literature that studies of oligopolistic competition in contracts when consumers' tastes are unobservable focuses on the behavior of firms who only operate within one market, and mainly consists of Stole (1995), Rochet and Stole (2002) and Armstrong and Vickers (2001).

Stole (1995) shares our assumption that a consumer's valuation of quality is determined by the nature of his preferences over horizontal (brand) product characteristics, but assumes that the consumer's preferences over vertical product characteristics are perfectly observable. He finds that the equilibrium quality schedule exhibits the same features as that which would be offered by a monopolist.

Rochet and Stole (2002) and Armstrong and Vickers (2001) consider a duopoly setting in which the (unobservable) preferences over vertical and horizontal product characteristics are uncorrelated. This is in contrast with the present setting, where a correlation exists between a consumer's marginal valuation of quality and his preferences over horizontal product characteristics. They find that, conditional on full market coverage[4], the symmetric equilibrium is entirely efficient; that is, all types consume the efficient quality level[5]. This is a very strong result, which may be interpreted as implying that, when firms compete in price-quality menus, any form of competition (even if imperfect) results in welfare being maximized. More fiercely competitively environments should therefore exhibit a (weakly) higher degree of efficiency than less competitive ones.

[4] I.e. conditional on all consumers purchasing from either firm.

[5] Inderst ([?]) finds the same result in the context of a matching model of buyer-seller exchange.

This work puts these papers into perspective, by emphasizing the role that demand and supply characteristics play in reaching their conclusions.

Finally, Biglaser and Mezzetti (1993) study the game between two asymmetric firms, who compete through contract offers to attract a worker. Both the worker's innate productivity and his effort are assumed to be his private information. They find that, at equilibrium, the optimal contract results in the effort of low-ability types being greater than the efficient level. Their conclusions are therefore qualitatively similar to ours, although they are derived in a fundamentally different environment.

The remainder of this paper is organized as follows: we first introduce the general model (section 2) and then proceed to discuss our results (section 3). Section 4 concludes. All the proofs can be found in the appendix.

3.2 The model

Players

There are three players in the game: the consumer (agent) and the two producers/firms (principals), denoted as l and r[6]. The consumer may consume either zero or one unit of an indivisible good, which can be produced by either firm. More specifically, each firm can only produce a certain variety of the good: firm l can only produce variety (or brand) L, while firm r can only produce variety R. Also, each firm can produce the good at any quality level $q \in [0, Q[$, where Q is assumed to be finite but very large. Quality is an objectively measurable product characteristic[7].

Contracts

A contract between a principal and the agent consists of a pair $\{q, p\}$, specifying the quality $q \in]0, Q]$ of the good that is traded and a monetary transfer $p \in \mathbb{R}^+$ that the agent pays upon purchase. Notice that we restrict attention to deterministic

[6] Standing for "left" and "right".

[7] To fix ideas, we may think of the product as a computer, and model the two firms as producing either PC's or MacIntoshes. In that case, quality could for instance refer to the speed at which the computer can perform a certain operation.

mechanisms. That is, we rule out the possibility for the principal of offering contracts which randomize over the probability of trade with the agent.

Markets

There are three markets, denoted as m_l, m_r and m_c[8]. Market m_l (respectively, m_r) is firm l' s (respectively, firm r's) local market. That is, firm l is market m_l's sole producer (and firm r is market m_r's sole producer). Market m_c, on the other hand, is supplied by both firms. Thus, each firm may operate in two markets: its local market, and market m_c.

Information structure

The consumer's private information is two-dimensional. First of all, it concerns his preferences over product characteristics, which cannot be observed by the principals. Second, it concerns his market location, which may ex-ante be either m_l, m_r or m_c. Conditional on contracting with the agent, firms update their beliefs, and conclude that the agent must be located either in their local market, or in market m_c. We introduce the following notation: conditional on contracting with the agent, firm i's beliefs ($i = r, l$) are as follows:

$$\left\{ \begin{array}{rl} s = & \text{probability with which the agent is located in firm } i\text{'s local market} \\ 1 - s = & \text{probability with which the agent is located in market } m_c \end{array} \right\}$$

for some $s \in [0, 1]$. Thus, s indicates the relative size of the local markets[9], with respect to market m_c.

Preferences

The agent's preferences over horizontal product characteristics (or brand preferences) are indicated by his position over an hypothetical segment of length $z > 0$, measured between 0 and z. Ex-ante, the consumer's location over this segment is drawn

[8] Where c stands for "competitive".

[9] In order to keep things as simple as possible, we only consider the case in which the two firms are perfectly symmetric, i.e. $s_l = s_r = s$.

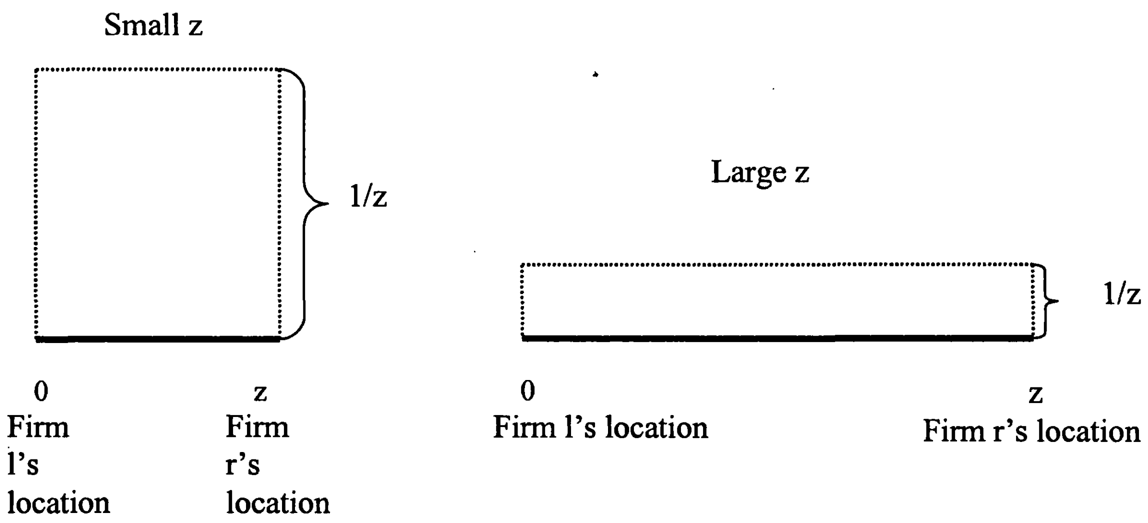

Figure 3-1: Distribution of preferences over horizontal product characteristics.

according to a uniform[10] distribution. The intensity of the consumer's horizontal preferences with respect to a given brand is inversely proportional to the distance between the consumer's and the brand's location on the segment. We assume that brands L and R are located at the extremities of the segment; that is, we set brand L's position at zero, and brand R's position at z (maximal differentiation). The parameter z is therefore a measure of both the dispersion of the consumer's preferences and the degree of horizontal differentiation between the varieties sold by the two firms. A small z characterizes markets where consumer preferences are relatively homogeneous and the varieties sold by the two firms are close substitutes. Vice-versa, a large z characterizes markets where consumer preferences are strongly heterogeneous, and the varieties sold by the two firms are very dissimilar.

The consumer's preferences over vertical product characteristics are entirely determined by his brand preferences. That is, the consumer's marginal valuation of quality varies across brands according to the nature and intensity of his horizontal preferences. Denoting as $k_i(x)$, $i = l, r$ the marginal valuation of quality when consuming the good

[10]The assumption that the consumer's horizontal preferences are uniformly distributed ensures the perfect symmetry exists between the two producers, which in turn simplifies our analysis.

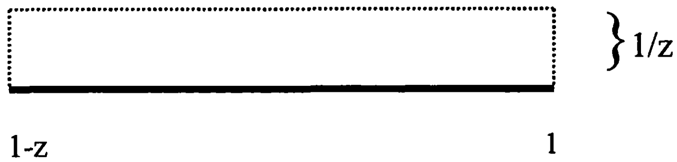

Figure 3-2: Consumer's marginal valuation of quality, within each market.

produced by firm i of a consumer located at x, we have

$$\left\{\begin{array}{l} k_l(x) = 1 - x \text{ and} \\ k_r(x) = 1 - z + x \end{array}\right\}$$

From the point of view of each firm, the consumer's marginal valuation of quality within each market is therefore uniformly distributed in $[1 - z, 1]$. This is depicted in figure 3-2.

Notice that there exists a one-to-one correspondence between $k_l(x)$ and $k_r(x)$, given by:

$$k_r(x) = 2 - z - k_l(x)$$

and

$$k_l(x) = 2 - z - k_r(x)$$

If the agent is located at $x < z/2$ he favours the variety produced by l, while if he is located at $x > z/2$ he favours the variety produced by r; if the agent is located at $x = z/2$, he is indifferent between the two varieties.

Payoffs

Agent

The utility of a consumer located at x consuming a good of quality q at price p depends upon the good's brand, and is given by:

$$u(x, p, q) = \begin{cases} k_l(x)q - p \text{ if he buys from firm } l \text{ and} \\ k_r(x)q - p \text{ if he buys from firm } r \end{cases}$$

If the consumer does not consume the good at all, his utility is equal to 0.

Notice that the agent's *gross* utility from consumption only depends upon his horizontal preferences, and is independent of the market in which the agent is located. Conditional on contracting with the agent, producers are therefore unable to utilize price-quality offers to discriminate between agents who have the same preferences over horizontal product characteristics, but belong to different markets[11]. Although the agent's private information is two-dimensional, his type-space[12] is consequently unidimensional, and only concerns his preferences over horizontal product characteristics.

Principals

A principal's payoff is given by

$$U_P = \begin{cases} p - \frac{q^2}{2} \text{ if he sells quality } q \text{ at price } p \\ 0 \text{ if he doesn't sell anything} \end{cases}$$

Notice that the two principals are perfectly symmetric.

Agent's outside option

The agent's outside option when contracting with a given principal is defined as the highest utility which the agent could obtain when not dealing with this principal. Thus, the agent's outside option varies according to the market in which he is located. If the agent is located in market m_l, for instance, his outside option when contracting with firm l is given by 0; this is because firm l is the sole active producer in market m_l. The same applies to the agent 's outside option when located in market m_r. If the consumer is located in market m_c, on the other hand, his outside option (as a function of x, his positioning over the segment representing horizontal product characteristics) is given by

$$\begin{Bmatrix} \max\{0,\, u_r(x)\} \text{ when contracting with firm } l \\ \max\{0,\, u_l(x)\} \text{ when contracting with firm } r \end{Bmatrix}$$

[11] More precisely, producers are unable to discriminate between consumers located in their local market and in market m_C.

[12] Defined as any private information that is relevant to the agent's decision-making, conditional on purchasing from a given principal.

where $u_i(x)$, $i = l, r$ denotes the highest utility which an agent positioned at x can obtain when contracting with firm i.

Timing/structure of the game

The timing of the game is at follows:

1. Nature determines the agent' s market location and his horizontal preferences; the two firms simultaneously propose a menu of contracts from which the agent may chose.
2. The agent either refuses to contract with either firm (in which case the game ends immediately and all players obtain a payoff of zero) or selects a quality-price pair from the menu of one of the two firms.
3. The selected firm produces the good (at the stipulated quality level), and trades it with the agent. The agent consumes the good, and the firm receives its monetary payment.

Strategies

Principals

Each principal's problem consists of designing a menu of contracts (or mechanism), from which the agent may chose his preferred choice, should he purchase the principal's product variety. At equilibrium each firm selects the optimal mechanism, taking the other firm's mechanism as given. From the revelation principle, we know the search for the optimal menu of contracts may be confined to the set of direct revelation mechanisms, whereby the agent is requested to report his type, and is offered a contract which is contingent upon this report. This defines the principals' strategy space.

Agent

A strategy for the agent specifies

· the identity of the principal with whom he decides to contract, and

· his reported type when contracting with this principal.

Throughout the analysis we concentrate on symmetric equilibria.

3.3 Implications

Consider firm $i = l, r$. The utility obtained by a consumer of type $k_i = k$ consuming quality q of the variety sold by i at price p is given by

$$u(x, p, q) = kq - p$$

Denote as $u_i(k)$ the utility which a consumer of type $k_i = k$ obtains when contracting with firm i. If the consumer is located in market m_i, his outside option when contracting with i is zero. On the other hand, if the consumer is located in market m_c his outside option is given by

$$B_i(k) \equiv \max(0,\ u_j(2 - z - k))$$

where $u_j(2 - z - k)$ is the highest payoff which a consumer with marginal valuation $k_j = 2 - z - k$ obtains when contracting with firm $j = r, l$. Conditional on him not belonging to market m_j, the consumer's reservation utility is therefore given by

$$\left\{ \begin{array}{l} 0 \text{ with probability } s \\ B_i(k) \geq 0 \text{ with probability } 1 - s \end{array} \right\} \tag{3.1}$$

The measure $M_i(u_i(k), k)$ of consumers of type k who contract with firm i is given by:

$$M_i(u_i(k), k) = \begin{cases} 0 \text{ if } u_i(k) < 0 \\ \frac{s}{z} \text{ if } B_i(k) > u_i(k) > 0 \\ \frac{1}{z} \text{ if } u_i(k) \geq B_i(k) \end{cases} \tag{3.2}$$

Notice that by offering the "null" contract: $q_i(k) = u_i(k) = 0$, the principal can always ensure the agent's participation whenever he is located in market m_i. For the principal, this contract yields the same payoff as no contract. There is therefore no loss of generality in assuming that the principal always contracts with the agent whenever he is located in his local market. This implies that we may restrict our attention to the case where the principal contracts with all types with a positive probability. Defining firm i's marginal type $\widetilde{k_i}$ as the type for whom[13]

$$u_i\left(\widetilde{k_i}\right) = B_i\left(\widetilde{k_i}\right)$$

we can therefore write

$$M_i(u_i(k), k) = \begin{cases} \frac{s}{z} \text{ for } k \in \left[1 - z, \widetilde{k_i}\right[\\ \frac{1}{z} \text{ for } k \in \left[\widetilde{k_i}, 1\right] \end{cases} \tag{3.3}$$

Conditional on the agent's truthfully declaring his type, the firm's profit when contracting with type k is given by $p_i(k) - \frac{q_i(k)^2}{2}$. Substituting for $p_i(k) = kq_i(k) - u_i(k)$ this becomes

$$kq_i(k) - u_i(k) - \frac{q_i(k)^2}{2} \tag{3.4}$$

Firm i's programme is to maximize

$$\int_{1-z}^{1} M_i(u_i(k), k)\left[kq_i(k) - u_i(k) - \frac{q_i(k)^2}{2}\right] dk \tag{P}$$

subject to incentive compatibility:

$$k = \arg\max_{\widehat{k}} \quad kq_i\left(\widehat{k}\right) - p_i\left(\widehat{k}\right) \tag{IC}$$

Lemma 1: *The following conditions are necessary and sufficient for incentive compatibility:*

1. IC.I $u_i'(k) = q_i(k)$ *at any point of differentiability*

2. IC.II $q_i(k)$ *is non-decreasing in* k.

Corollary 1: *Conditions IC.I and IC.II imply that at equilibrium* $u_i(.)$ *is a continuous function.*

[13] We are implicitely assuming that $u_i(.)$ and $B_i(.)$ do not overlap for more than one type. This may however be the case if $u_i(.) = B_i(.) = 0$. In that case, the marginal type should be defined as the lowest type for whom $u_i(.) = B_i(.)$.

In what follows, we refer to the mechanism derived by imposing condition IC.I only as the WSC mechanism (where WSC stands for "without second-order condition"). Whenever the WSC mechanism satisfies IC.II, solving the relaxed problem allows us to identify the optimal mechanism. On the other hand, if the WSC mechanism violates IC.II, the solution to the principal's problem is found by explicitly incorporating constraint IC.II, and involves bunching over a set of types (see for instance Laffont and Martimort, pp.140-141).

Lemma 1 identifies the conditions which need to hold for both firms at equilibrium. This allows us to make some inferences concerning the agent's reservation utility, when he is located in market m_c. From above, we know that

$$B_i(k) \equiv \max(0, u_j(2-z-k))$$

This implies that

$$B_i'(k) = \begin{cases} \text{either } 0 \text{ or} \\ -u_j'(2-z-k) \end{cases}$$

From lemma 1, we know that

$$u_j'(2-z-k) = q_j(2-z-k) \rightarrow \quad \geq 0$$

where $q_j(2-z-k)$ denotes the product quality which a consumer of type $k_j = 2-z-k$ is offered when contracting with firm j. Moreover, the utility schedules offered by the two firms at equilibrium must be continuous. This brings us to the following lemma:

Lemma 2: *In any equilibrium of the game, the agent's reservation utility when he is located in market m_c is continuous and non-increasing in his type.*

Notice that continuity is ensured for $s > 0$, but may break down when $s = 0$, i.e. the firms only operate in market m_c. The reason for this is that, under such circumstances, the mass of types below $\widetilde{k}_i$ who contract with firm $i = l, r$ is equal to 0. Thus, for a given price-quality menu offered by firm $j = r, l$, optimality does not impose any restriction upon firm i's quality schedule over that range. Moreover, firm i may strategically alter its quality schedule in order to influence firm j optimal response. This considerably

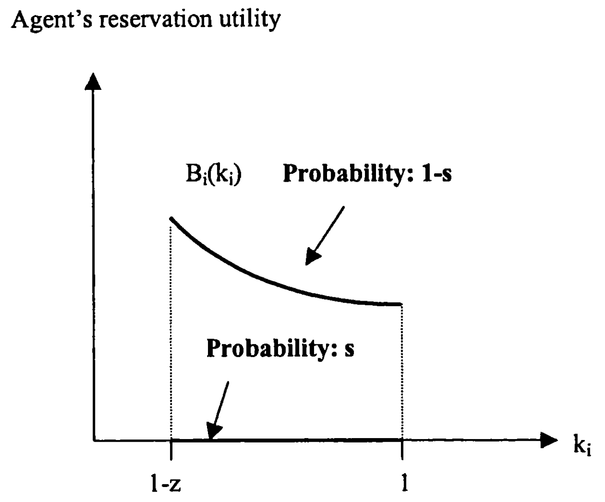

Figure 3-3: A possible reservation utility schedule.

complicates the analysis, and is the reason why we restrict s to be strictly positive.

Lemma 2 implies that it is impossible for the principal to keep the agent onto his reservation utility over a whole set of types while selling a product of strictly positive quality. Surplus-creating trade between the principal and the agent therefore results in the agent obtaining a strictly positive informational rent whenever his type is above $1 - z$. Figure 3-3 depicts a possible reservation utility (or outside option) schedule.

Lemma 3: *At equilibrium, market m_c is fully covered: all consumers located in that market engage in surplus-creating trade.*

Corollary 2: *In any symmetric equilibrium, each firm's marginal type is* $1 - \frac{z}{2}$.

Lemma 3 implies that at equilibrium:

· either the lowest type with whom each firm trades is below $1 - \frac{z}{2}$ or

· the lowest type with whom each firm trades is equal to $1 - \frac{z}{2}$.

We now explore the properties of the optimal WSC mechanism. If we ignore IC.II, the principal's problem can be written as

$$\max_{u_i(k),q_i(k)} \int_{1-z}^{1} M_i\left(u_i\left(k\right), k\right) \left[kq_i\left(k\right) - u_i\left(k\right) - \frac{q_i\left(k\right)^2}{2}\right] dk \qquad \text{(P)}$$

subject to

$$u_i'(k) = q_i(k) \tag{IC.I}$$

From IC.I, we have:

$$u_i(k) = u_i(1-z) + \int_{1-z}^{k} q_i(x)\,dx \tag{3.5}$$

for all k. The principal's problem may therefore be rewritten as

$$\max_{u_i(1-z),q_i(k)} \int_{1-z}^{1} M_i\left(u_i(1-z) + \int_{1-z}^{k} q_i(x)\,dx, k\right)\left[kq_i(k) - \frac{q_i(k)^2}{2} - u_i(1-z) - \int_{1-z}^{k} q_i(x)\,dx\right] dk \tag{P'}$$

This is equivalent to

$$\max_{u_i(1-z),q_i(k)} \int_{1-z}^{1} \left\{M_i\left(u_i(1-z) + \int_{1-z}^{k} q_i(x)\,dx, k\right)\left[kq_i(k) - \frac{q_i(k)^2}{2} - u_i(k)\right] - \Phi_i(k)\,q_i(k)\right\} dk \tag{P''}$$

where $\Phi_i(k) \equiv \int_{k}^{1} M_i(u_i(k), k)$ indicates the mass of types above k with whom the principal contracts.

In the canonical setting, where the principal is assumed to be a monopolist, the lowest type being served typically earns no rents; because the agent's reservation utility is equal to zero for all types, offering no rents to the lowest type being served is consistent with full participation, and is therefore optimal. Here, on the other hand, $u_i(1-z) = 0$ is not sufficient to ensure the agent's full participation; the implication is that by increasing $u_i(1-z)$ above zero, the principal can enlarge the mass of types with whom he contracts at equilibrium ("market share" effect). We conclude that the principal may optimally set $u_i(1-z) > 0$. The "market share" effect of a higher $u_i(1-z)$ is illustrated in figure 3-4.

A similar reasoning applies to the choice of quality allocations; in addition to the standard "efficiency versus informational rents " trade-off, the principal is here con-

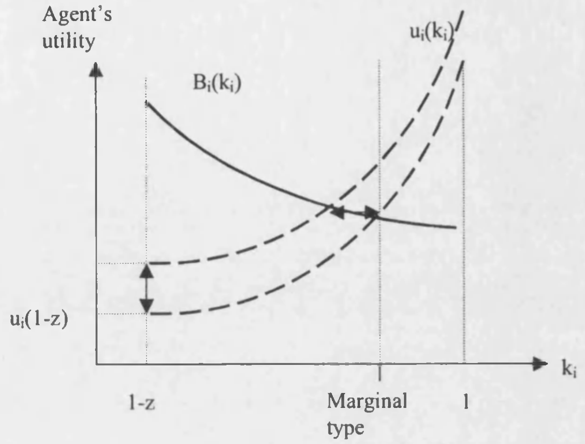

Figure 3-4: Market share effect of increasing $u_i(1-z)$

fronted with an extra effect, arising from the fact that by increasing $q_i(k)$, he can enlarge the mass of types above k with whom he contracts. This is illustrated in figure 3-5. With respect to a monopoly scenario, the presence of the "market share" effect results in the principal optimally offering higher quality levels.

Interestingly, as noted by Rochet and Stole (2002), whenever the optimal $u_i(1-z)$ is strictly above zero, the optimal WSC quality level offered to type $1-z$ is efficient, while that offered to all types above $1-z$ but below the marginal type is *above* the efficient level. The intuition for this can be seen as follows: at an interior solution, the optimal $u_i(1-z)$ balances the principal's desire to enlarge his market share on one hand, and his desire to minimize the rents that have to be offered to the agent in order to ensure incentive compatibility on the other.

Now consider the principal's choice of $q_i(1-z)$; this choice is determined by the interplay of three factors: the desire to expand the market share, the desire to minimize the informational rents that have to be offered to the agent, and the the desire to maximize the total surplus obtained when contracting with type $1-z$. Because $u_i(1-z)$ has been chosen optimally, the first two factors annul each other. In his contractual offer to type $1-z$, the principal has therefore no incentive to deviate from the efficient

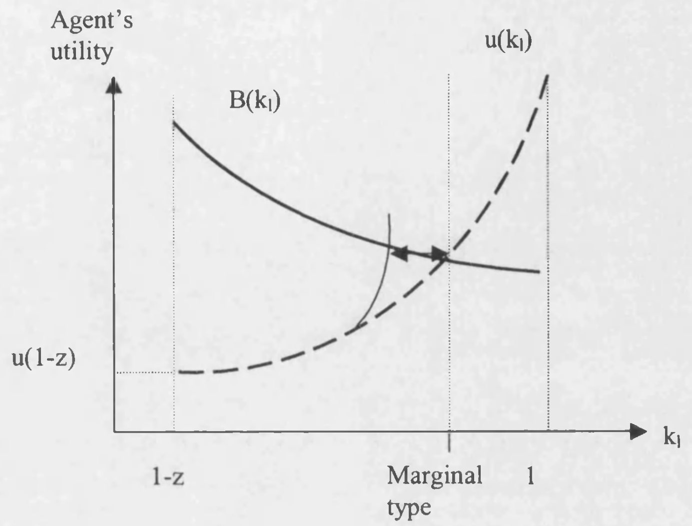

Figure 3-5: Market share effect of increasing $q_i(k_i)$, when k_i is below the marginal type,

quality level.

Finally, consider any type $k \in \left[1-z, \widetilde{k_i}\right]$; evaluated at k, the market share effect has the *same* strength as for type $1-z$, while the informational rents that result from an increase in $q_i(k)$ are *lower* than those arising from an increase in $q_i(1-z)$. It follows that the principal's incentive to increase quality must be higher for type k than for type $1-z$. Given that $q_i(1-z)$ is equal to the efficient level, we conclude that $q_i(k)$ must be *above* the efficient level.

Importantly, as can be seen from figures 3-4 and 3-5, the "market share" effect of increasing quality is only present for those types who are located below the firm's marginal type $\widetilde{k_i}$. For types above the marginal type, this extra effect is absent, and the optimal quality is selected in the same way as in the canonical setting. The implication is that, whenever the marginal type *is not* the lowest type with whom the principal trades, the optimal WSC quality schedule exhibits a downward jump at $k = \widetilde{k_i}$. Clearly, this violates condition IC.II. Thus, the optimal quality schedule must include bunching over a whole set of types. On the other hand, if the marginal type *is* the lowest type with whom the principal trades, the optimal quality schedule exhibits the same properties as that offered by a monopolist. The following proposition summarizes our results.

Proposition 1: *If the marginal type is also the lowest type with whom firms engage in surplus-creating trade, the optimal quality schedule exhibits the same properties as that offered by a monopolist.*

If the marginal type is not the lowest type with whom firms engage in surplus-creating trade, the optimal quality schedule for both firms exhibits pooling over some interval $[k_0, k_1]$. *The quality consumed by types below* k_1 *exceeds what would be offered by a monopolist, while that consumed by types higher or equal than* k_1 *is equal to that which a monopolist would offer.*

In equilibria where the marginal type is not the lowest type with whom firms engage in trade, pooling emerges, implying that the presence of two types of markets reduces the principal's ability to discriminate among different types. Although the "market-share" effect is only present for types located below the marginal type[14], through pooling the quality offered to types in $\left[\widetilde{k}_i, k_1\right]$ is also pushed above what would be offered in a monopoly. While the familiar result of "efficiency at the top" and underprovision for sufficiently high types remains, the presence of a rival firm in market m_c provides a competitive stimulus, which results in higher quality being allocated to sufficiently low types. This is however the case only if the marginal type is not the lowest type with whom firms engage in surplus-creating trade trade at equilibrium. The following proposition shows that this is always the case whenever z is sufficiently low.

Proposition 2: *When* $z < \frac{2}{\frac{1}{s}+1}$ *(depicted in figure 3-6), the marginal type* $1 - \frac{z}{2}$ *is not the lowest type with whom firms engage in surplus-creating trade at equilibrium.*

The intuition for the result essentially stems from the fact that, at equilibrium, the marginal type's valuation of quality (given by $1 - \frac{z}{2}$) is inversely related to z. As z grows smaller, the attractiveness of types located below the marginal type increases[15], implying that the principal finds it optimal to trade with them.

Notice that the threshold z below which pooling necessarily occurs is an increasing

[14] It should be remembered that the firm's marginal type depends on the mechanism being offered. Here, we are referring to the firm's marginal type in the optimal WSC mechanism.

[15] Because their marginal valuation for quality increases.

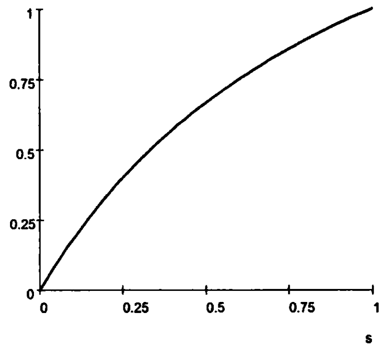

Figure 3-6: $\frac{2}{\frac{1}{s}+1}$

function of s. This implies that, as the relative size of each firm's local market with respect to market m_c increases, the range of z for which pooling occurs increases as well. This is the case because a higher s increases the attractiveness of trade with lower types, who are exclusively located in the local market. The next proposition studies the efficiency properties of different competitive environments. In particular, it addresses the question of whether a small z (indicating "tougher" competition) necessarily translates in higher efficiency.

Proposition 3: *For any s, there exists a value $z(s)$ such that whenever $z < z(s)$ the equilibrium exhibits overprovision for sufficiently low types. The function mapping s into $z(s)$ is concave, with $\lim_{s\to 0} z(s) = \lim_{s\to 1} z(s) = 0$.*

Proposition 3 tells us that the presence of a rival firm in market m_c may induce each firm to inefficiently inflate the quality offered to low types (figure 3-7). This is the case whenever z is sufficiently small, implying that the distribution of consumer's types is sufficiently narrow (and accordingly the degree of substitutability between the varieties sold by the two firms is sufficiently high). The rationale for this result stems from the fact that, by increasing $u_i(1-z)$ or $q_i(k)$ for $k < \widetilde{k}_i$, any principal $i = l, r$ is able to increase the range of types he attracts in market m_c from $\left[\widetilde{k}_i, 1\right]$ to $\left[\widetilde{k}_i - \varepsilon, 1\right]$, for some $\varepsilon > 0$. The density of the additional mass of types that the principal attracts is equal to $\frac{1-s}{z}$, and is therefore inversely related to z. Thus, in our model, the strength of the

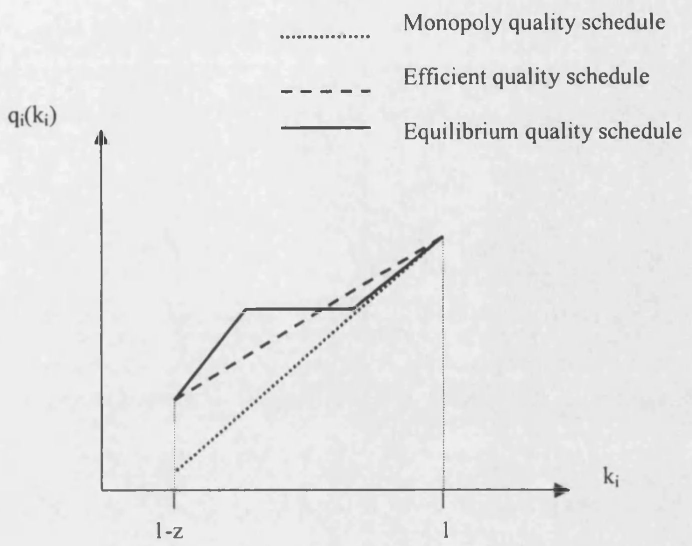

Figure 3-7: A possible equilibrium schedule when $z < z(s)$.

"market share" effect is directly proportional to the degree of homogeneity in consumer preferences. Recall from the earlier discussion that if the principal finds it optimal to set $u_i(1-z) > 0$, this necessarily implies that the optimal quality schedule features overprovision for sufficiently low types. Thus, overprovision *may not* occur for any type if and only if $u_i(1-z) = 0$ at equilibrium. The argument then consists in showing that, when z is sufficiently low, in any equilibrium where $u_i(1-z) = 0$ and overprovision does not occur for any type, the agent's reservation utility would be sufficiently low to give firm j an incentive to set $u_j(1-z) > 0$[16]. Clearly, this cannot be the case in any symmetric equilibrium. We conclude that when z is sufficiently low overprovision must necessarily occur for some types.

An important implication of proposition 3 concerns the welfare properties of different competitive environments. In particular, it tells us that in this environment the relationship between "toughness of competition" and welfare is not necessarily monotonic.

[16] Notice that the cost of increasing $u(1-z)$ (in terms of the rents that are offered to the agent in order to maintain incentive compatibility) is independent of z, while the benefit of increasing $u(1-z)$ (the market share effect) is inversely related to z.

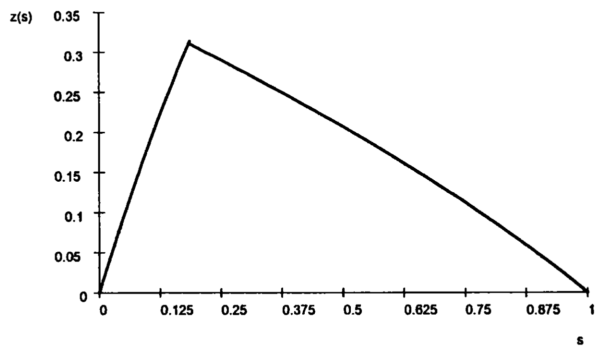

Figure 3-8: Level of z below which overprovision undoubtedly occurs.

Although efficiency emerges under perfect competition, this does not necessarily imply that environments where competition is stronger are characterized by higher welfare than environments where competition is weaker[17]. Indeed, a stronger competitive environment may result in inefficiently high quality being offered to some types. A thorough characterization of the welfare properties of a given competitive environment should therefore explicitly weight this possible efficiency loss against the gain which may arise from a reduced downward distortion of the quality offered to other types.

Finally, notice that the "threshold" level of z below which overprovision undoubtedly occurs is concave in s, the relative size of the local market (figure 3-8).

For $s \rightarrow 0$ and $s \rightarrow 1$, overprovision cannot be proven to occur for any z. When s is very low, the "market-share" effect is very strong, but we cannot rule out the possibility that both firms only trade with types at or above their marginal type. Conversely, when s is very high, any symmetric equilibrium exhibits pooling, but the "market-share" effect is not very strong. Thus, overprovision is more easily derived for intermediate values.

[17]This is however the case in other types of environments; for instance, in the standard Cournot setting, as the number of frims competing in the market grows infinitely large, the market price tends to the perfectly competitive price.

3.4 Concluding remarks

This paper contributes to the literature that studies nonlinear pricing within a duopoly setting in which products are spatially differentiated (a la Hotelling). Its novelty consists in combining two empirically sound features (namely the presence of two types of markets and the assumption that intra-brand price elasticity of demand should be higher for lower quality goods) and showing that these have important implications for the relationship between "toughness of competition" and welfare. In particular, we find that a strongly competitive environment will induce firms to inefficiently inflate the quality levels that they are offering to sufficiently low types. Thus, although perfect competition results in efficient quality allocations, stronger competition may not necessarily result in higher efficiency. This suggests that the relationship between "toughness of competition" and welfare may not be monotonic.

3.5 Appendix

Proof of lemma 1:

The proof is standard and will be omitted.■

Proof of corollary 1:

A situation where $u_i(.)$ experiences a downward jump would violate condition IC.II.

Now consider a situation where $u_i(.)$ experiences an upward jump. Denote the type at which the jump occurs as k^J, and the size of the jump as $\Delta > 0$. Consider type $k^J - \varepsilon$. If this type declares to be type $k^J + \varepsilon$, he obtains utility

$(k^J - \varepsilon) q(k^J + \varepsilon) - p(k^J + \varepsilon) \rightarrow = u(k^J + \varepsilon) + q(k^J + \varepsilon)((k^J - \varepsilon) - (k^J + \varepsilon))$
$\rightarrow = u(k^J + \varepsilon) - 2\varepsilon q(k^J + \varepsilon)$. As $\varepsilon \rightarrow 0$, this converges to $u(k^J - \varepsilon) + \Delta \rightarrow > u(k^J - \varepsilon)$. We therefore conclude that an upward jump would also violate incentive compatibility.■

Proof of lemma 2:

In text.■

Proof of lemma 3:

First, notice that in any symmetric equilibrium where market m_c is fully covered, each firm's marginal type is given by $1-\frac{z}{2}$, while in any symmetric equilibrium where market m_c is *not* fully covered, each firm's marginal type is *above* $1-\frac{z}{2}$. We now prove that this second scenario can never emerge; assume that firm j 's marginal type is $\widetilde{k}_j > 1-\frac{z}{2}$. From firm i's point of view, this implies that $B_i(k_i)=0$ for all

$$k_i > 2 - z - \widetilde{k}_j \tag{3.6}$$

Consider a type $\widehat{k}_i \leq 2-z-\widetilde{k}_j$ (implying that $B(\widehat{k}_i)=0$) . From incentive compatibility, we know that $u(k_i) = u\left(\widehat{k}_i\right) + \int_{\widehat{k}_i}^{k_i} q(x)\,dx$ for all $k_i > \widehat{k}_i$. Also, because $B_i(k_i)=0$ for $k_i \geq \widehat{k}_i$, we know that, conditional on engaging in surplus-creating (i.e. trade involving a strictly positive quality) with type $\widehat{k}_i$, the mass of types above $\widehat{k}_i$ with whom the principal contracts is given by $\frac{1-\widehat{k}_i}{z}$, and the measure of consumers of type $\widehat{k}_i$ with whom the principal trades is given by $\frac{1}{z}$. The optimal WSC quality allocation to $\widehat{k}_i$ is therefore given by

$$\widehat{k}_i - q_i = 1 - \widehat{k}_i \tag{3.7}$$

i.e.

$$q_i = 1 - 2\widehat{k}_i \tag{3.8}$$

This implies that a mechanism where the principal trades[18] with the agent whenever his type is above $\max\left(\frac{1}{2},\ 2-z-\widehat{k}_j\right) \rightarrow$ smaller than $1-\frac{z}{2}$ [19], offering $q_i(k_i) = 1-2k_i$, is superior to the mechanism where the principal only trades with types $\geq \widetilde{k}_i \rightarrow\ > 1-\frac{z}{2}$. Thus, any equilibrium where market m_c is not fully covered is necessarily dominated. This establishes that in any equilibrium market m_c must fully covered.■

Proof of proposition 1:

[18] We refer to surplus-creating trade.

[19] This is because we are restricting attention to the case where $z \leq 1$.

The optimal WSC mechanism solves:

$$\max_{u_i(1-z),q_i(k)} \int_{1-z}^{1} \left\{ M_i \left(u_i (1-z) + \int_{1-z}^{k} q_i (x)\, dx, k \right) \left[kq_i (k) - \frac{q_i (k)^2}{2} - u_i (k) \right] - \Phi_i (k)\, q_i (k) \right\} dk \tag{P''}$$

where $\Phi_i (k) \equiv \int_k^1 M_i (u_i (k), k)$ indicates the mass of types above k with whom the principal contracts.

The first order condition with respect to $q_i (k)$ is[20]

$$\underbrace{M_i (u_i (k), k) (k - q_i) - \Phi_i (k) +}_{\textit{efficiency/ informational rents trade-off}} \underbrace{\int_k^1 \left[M_i' (u_i (x), x) \tfrac{\partial u_i(x)}{\partial q_i(k)} \left(xq_i (x) - \tfrac{q_i(x)^2}{2} - u_i (x) \right) \right] dx}_{\textit{market share effect}} \tag{3.9}$$

Denote as $\widetilde{k}_i$ firm i's marginal type beforehand, and as $\widetilde{k}_i'$ firm i's marginal type after the (marginal) movement in $q_i (k)$. For $k < \widetilde{k}_i$:

$$M_i' (u_i (x), x) \frac{\partial u_i (x)}{\partial q_i (k)} \text{is} = \frac{1 - s_i}{z} \text{ for } k \in \left[\widetilde{k}_i', \widetilde{k}_i \right] \text{ and is} = 0 \text{ otherwise}$$

For $k \geq \widetilde{k}_i$:

$$M_i' (u_i (x), x) \frac{\partial u_i (x)}{\partial q_i (k)} \text{ is } = 0$$

The market share effect of a marginal increase in $q_i (k)$ is therefore given by:

$$\begin{aligned} &\cdot \text{ for } k < \widetilde{k}_i\text{:} \quad \int_{\widetilde{k}_i'}^{\widetilde{k}_i} \left(xq_i (x) - \tfrac{q_i(x)^2}{2} - u_i (x) \right) \tfrac{1-s_i}{z} dx \\ &\cdot \text{ for } k \geq \widetilde{k}_i\text{:} \quad 0 \end{aligned} \tag{3.10}$$

Notice that for very small movements in $q_i (k)$, $\int_{\widetilde{k}_i'}^{\widetilde{k}_i} \left(xq_i (x) - \tfrac{q_i(x)^2}{2} - u_i (x) \right) \tfrac{1-s_i}{z} dx$ can

[20] See Rochet and Stole (2002), p.309.

be approximated by

$$\left(\widetilde{k}_i q_i\left(\widetilde{k}_i\right) - \frac{q_i\left(\widetilde{k}_i\right)^2}{2} - B_i\left(\widetilde{k}_i\right)\right)\frac{1-s_i}{z} \tag{3.11}$$

Also notice that $M_i\left(u_i\left(k\right), k\right)$ is equal to

$$\begin{array}{l} \cdot \text{ for } k < \widetilde{k}_i\text{: } \frac{s}{z} \\ \cdot \text{ for } k \geq \widetilde{k}_i\text{: } \frac{1}{z} \end{array} \tag{3.12}$$

and $\Phi_i\left(k\right)$ is given by

$$\begin{array}{l} \cdot \text{ for } k < \widetilde{k}_i\text{: } \frac{1}{z}\left(1-\widetilde{k}_i\right) + \frac{s_i}{z}\left(\widetilde{k}_i - k\right) \rightarrow \quad = \frac{1-s_i k-\widetilde{k}_i(1-s_i)}{z} \\ \cdot \text{ for } k \geq \widetilde{k}_i\text{: } \frac{1}{z}\left(1-k\right) \end{array} \tag{3.13}$$

We can therefore write the first order condition with respect to $q_i\left(k\right)$ as

$\cdot$ for $k < \widetilde{k}_i$:

$$\underbrace{\frac{s_i}{z}\left(k-q_i\right) - \frac{1-s_i k-\widetilde{k}_i(1-s_i)}{z}}_{\textit{increasing in } k} + \underbrace{\left(\widetilde{k}_i q_i\left(\widetilde{k}_i\right) - \frac{q_i\left(\widetilde{k}_i\right)^2}{2} - B_i\left(\widetilde{k}_i\right)\right)\frac{1-s_i}{z}}_{\textit{independent of } k} \tag{3.14}$$

$\cdot$ for $k \geq \widetilde{k}_i$:

$$\underbrace{\frac{1}{z}\left(k-q_i\right) - \frac{1-k}{z}}_{\textit{increasing in } k} \tag{3.15}$$

Within both $\left[1-z, \widetilde{k}_i\right]$ and $\left[\widetilde{k}_i, 1\right]$, the benefit of a marginal increment in quality increases in the agent's type. Thus, the optimal WSC mechanism must prescribe a positive relationship between quality and type within those intervals. As we approach $\widetilde{k}_i$ from below, however, this monotonicity breaks down, and a downward discontinuity appears. This is a consequence of the fact that the "extra market-share" effect is strictly positive for $k < \widetilde{k}_i$, but abruptly disappears at $k = \widetilde{k}_i$, where the agent's utility schedule crosses the $B(k)$ schedule. Thus, the optimal WSC mechanism violates condition IC.II. This implies that at equilibrium the optimal quality schedule must include pooling over an interval $\left[k_i^0, k_i^1\right]$, where $\widetilde{k}_i > k_i^0 \geq 1-z$ and $1 > k_i^1 \geq \widetilde{k}_i$. We denote as $\overline{q}_i$ the pooling quality level offered by firm i to types in $[k_0, k_1]$

We denote as $\overline{q}_i$ the pooling quality level offered by firm i to types in $[k_0, k_1]$ at equilibrium, and as $q_i^{WSC}(k)$ the quality allocated by firm i to type k in the optimal WSC mechanism. We know that at an optimum, the following conditions must hold (see for instance Laffont and Martimort, p.140-141):

$$\overline{q}_i = q_i^{WSC}\left(k_i^0\right) = q_i^{WSC}\left(k_i^1\right) \tag{3.16}$$

and

$$\int_{k_i^0}^{k_i^1} \left\{ M_i\left(u_i(k), k\right)\left[k - \overline{q}_i\right] - \Phi_i(k) + \int_k^1 \left[M_i'\left(u_i(x), x\right) \frac{\partial u_i(x)}{\partial q_i(k)} \left(x\overline{q}_i - \frac{\overline{q}_i^2}{2} - B_i(x) \right) \right] dx \right\} dk = 0 \tag{3.17}$$

From above, condition (3.17) can be rewritten as

$$\begin{aligned} &\int_{k_i^0}^{\widetilde{k}_i} \left[\tfrac{s_i}{z}\left(k - \overline{q}_i\right) - \tfrac{1 - s_i k - \widetilde{k}_i(1-s_i)}{z} + \left(\widetilde{k}_i \overline{q}_i - \tfrac{\overline{q}_i^2}{2} - B_i\left(\widetilde{k}_i\right) \right) \tfrac{1-s_i}{z} \right] dk + \\ &+ \int_{\widetilde{k}_i}^{k_i^1} \left[\tfrac{1}{z}\left(k - \overline{q}_i\right) - \tfrac{1-k}{z} \right] dk = 0 \end{aligned} \tag{3.18}$$

Notice that we have six equations (three equations per firm), but ten unknowns , namely k_l^0, k_r^0, k_l^1, k_r^1, $\overline{q}_l$, $\overline{q}_r$, $\widetilde{k}_l$, $\widetilde{k}_r$, $B_l\left(\widetilde{k}_l\right)$ and $B_r\left(\widetilde{k}_r\right)$. If we restrict our attention to the symmetric case where $s_i = s_j$, the number of unknown falls to four (i.e. k^0, k^1, $\overline{q}$ and $B\left(1 - \frac{z}{2}\right)$[21]), but the number of equations correspondingly falls to three. The implication is that it is not possible for us to solve the system. Notice however that from the point of view of each firm, the $B(k)$ schedule is given. Firms are therefore able to compute the optimal pooling quality, and the interval over which pooling optimally occurs.

We now consider a scenario where firm i is a monopolist in both markets m_i and

[21] In the symmetric case, the marginal type is $1 - \frac{z}{2}$ for both types.

m_c. When contracting with firm i, the agent has zero reservation utility, and his type is uniformly distributed with density $\frac{1}{z}$. Under such circumstances, the first order condition with respect to $q_i(k)$ is

$$\frac{1}{z}(k-q)-\frac{1-k}{z} \tag{3.19}$$

the same as (3.15). Thus, the quality level offered to types $\geq k_i^1$ in a monopoly is the same as what is offered in the duopoly. Now consider types $\leq k_i^0$; by comparing expressions (3.15) and (3.14) it is easy to see that for those types the quality level offered in the duopoly is higher than what they would be offered if firm i was a monopoly. Finally, consider types in $[k_i^0, k_i^1]$. From above, we know that $\overline{q}_i = q_i^{WSC}(k_i^1) = q_i^M(k_i^1)$, where $q_i^M(k_i^1)$ denotes the quality level that type k_i^1 would be offered in a monopoly. From condition (3.15): $q_i^M(k)$ is equal to $2k-1$ and is therefore increasing in k. It follows that $\overline{q}_i$ must necessarily be $> q_i^M(k)$ for all types in $[k_i^0, k_i^1[$.

Proof of proposition 2:

From proposition 2, we know that at equilibrium market m_c is fully covered. It must therefore be the case that:

· either the lowest type with whom each firm trades is below $1-\frac{z}{2}$ or

· the lowest type with whom each firm trades is equal to $1-\frac{z}{2}$.

Take the second scenario. From the point of view of, say, firm i, this implies that $B_i(k_i) = 0$ for all $k_i \geq 1-\frac{z}{2}$, and $B_i(k_i) > 0$ for all $k_i < 1-\frac{z}{2}$. Consider type $k_i = \lim_{\varepsilon \to 0} 1-\frac{z}{2}-\varepsilon$. The first order condition with respect to $q_i\left(1-\frac{z}{2}-\varepsilon\right)$ can be written as:

$$\underbrace{M_i\left(1-\tfrac{z}{2}-\varepsilon\right)\left(1-\tfrac{z}{2}-\varepsilon-q_i\right)-\tfrac{1}{2}}_{\textit{efficiency/ informational rents trade-off}} + \underbrace{MS}_{\textit{market share effect}} = 0 \tag{3.20}$$

where $\frac{1}{2}$ is the mass of types located above $1-\frac{z}{2}-\varepsilon$ with whom the principal contracts, $M_i\left(1-\frac{z}{2}-\varepsilon\right)$ (the measure of consumers of type $k_i = \lim_{\varepsilon\to 0} 1-\frac{z}{2}-\varepsilon$ contracting with the principal) is $\geq \frac{s}{z}$[22] and the market share effect, is ≥ 0. Rearranging (3.20) we

[22] It is equal to $\frac{s}{z}$ if $u_i(1-\frac{z}{2}-\varepsilon) < B_i(1-\frac{z}{2}-\varepsilon)$, and it is equal to $\frac{1}{z}$ otherwise.

obtain

$$q_i\left(1-\frac{z}{2}-\varepsilon\right)=1-\frac{z}{2}-\varepsilon-\frac{\frac{1}{2}-MS}{M_i\left(.\right)} \tag{3.21}$$

Thus, the optimal $q_i\left(1-\frac{z}{2}-\varepsilon\right)$ is >0 whenever:

$$1-\frac{z}{2}>\frac{\frac{1}{2}-MS}{M_i\left(.\right)} \tag{3.22}$$

Inequality (3.22) always holds for $\frac{1}{2}-MS<0$; for $\frac{1}{2}-MS>0$, a sufficient condition for (3.22) to hold is that

$$1-\frac{z}{2}>\frac{\frac{1}{2}}{\frac{s}{z}} \tag{3.23}$$

i.e.

$$1-\frac{z}{2}-\frac{1}{2s}z>0 \tag{3.24}$$

Inequality (3.24) always holds for

$$z<\frac{2}{\frac{1}{s}+1}$$

Thus, whenever $z<\frac{2}{\frac{1}{s}+1}$, any symmetric strategy equilibrium is such the lowest type with whom each firm engages in trade is below $1-\frac{z}{2}$.■

Proof of proposition 3:

Assume that $z<\frac{2}{\frac{1}{s}+1}$; the principal solves

$$\max_{u_i(1-z),q_i(k)}\int_{1-z}^{1}\left\{M_i\left(u_i\left(1-z\right)+\int_{1-z}^{k}q_i\left(x\right)dx,k\right)\left[kq_i\left(k\right)-\frac{q_i\left(k\right)^2}{2}-u_i\left(k\right)\right]-\Phi_i\left(k\right)q_i\left(k\right)\right\}dk \tag{P''}$$

subject to $q_i\left(k\right)$ non-decreasing in k.

The first order condition with respect to $u_i\left(1-z\right)$ is

$$-\left\{\left[\widetilde{k}_i-\left(1-z\right)\right]\frac{s}{z}+\left(1-\widetilde{k}_i\right)\frac{1}{z}\right\}+\left(\widetilde{k}_i\overline{q}-\frac{\overline{q}^2}{2}-u_i\left(\widetilde{k}_i\right)\right)\frac{1-s}{z} \tag{3.25}$$

where $\overline{q}$ is the pooling quality level offered to an interval of types (to which $\widetilde{k}_i$ belongs) in order to satisfy constraint IC.II. Because we are considering a symmetric equilibrium, $\widetilde{k}_i = 1 - \frac{z}{2}$ for both firms, and condition (3.25) can be written as

$$-\frac{1+s}{2} + \left(\left(1-\frac{z}{2}\right)\overline{q} - \frac{\overline{q}^2}{2} - u_i\left(1-\frac{z}{2}\right)\right)\frac{1-s}{z} \tag{3.26}$$

The solution to the principal's problem takes the form of an interior optimum if a non-negative value of $u_i(1-z)$ exists, which sets expression (3.26) to zero. If, on the other hand, expression (3.26) is negative for all feasible values of $u_i(1-z)$, then the optimal $u_i(1-z)$ is equal to zero (corner solution).

The first order condition with respect to $q(1-z)$ is

$$(1-z) - q - \frac{1+s}{2} + \left(\left(1-\frac{z}{2}\right)\overline{q} - \frac{\overline{q}^2}{2} - u_i\left(1-\frac{z}{2}\right)\right)\frac{1-s}{z} = 0 \tag{3.27}$$

Notice that if expression (3.26) is equal to zero, implying that the optimal $u_i(1-z)$ is an interior solution, expression (3.27) reduces to

$$(1-z) - q = 0 \tag{3.28}$$

i.e.

$$q(1-z) = 1 - z \rightarrow \;\; = q^*(1-z) \tag{3.29}$$

Thus, when the optimal $u_i(1-z)$ is an interior solution, the quality level allocated to type $k = 1-z$ is efficient. Now consider type $k = 1-z+\varepsilon$, where $\frac{z}{2} > \varepsilon > 0$ (implying that $1-\frac{z}{2} > 1-z+\varepsilon > 1-z$). The first order condition with respect to $q(1-z+\varepsilon)$ is

$$(1-z+\varepsilon) - q - \frac{1+s}{2} + \frac{\varepsilon s}{z} + \left(\left(1-\frac{z}{2}\right)\overline{q} - \frac{\overline{q}^2}{2} - u_i\left(1-\frac{z}{2}\right)\right)\frac{1-s}{z} = 0 \tag{3.30}$$

When the optimal $u_i(1-z)$ is an interior solution, expression (3.30) reduces to

$$(1-z+\varepsilon) - q + \frac{\varepsilon s}{z} = 0 \tag{3.31}$$

i.e.

$$q(1-z+\varepsilon) = (1-z+\varepsilon) + \frac{\varepsilon s}{z} > q^*(1-z+\varepsilon)$$

The implication is that, when the optimal $u_i(1-z)$ is an interior solution (and therefore $q_i(1-z) = q_i^*(1-z)$), the optimal WSC mechanism prescribes overprovision for all (interior) types below $1-\frac{z}{2}$, and the overall optimal quality schedule (with pooling) includes overprovision for some types[23]. A situation where the optimal mechanism prescribes underprovision for all interior types is therefore inconsistent with $u_i(1-z) > 0$, and can only emerge when $u_i(1-z) = 0$ at equilibrium. We now explore this scenario, and show that, when $z < \frac{2}{3}$, a situation where:

· $u_i(1-z) = 0$ and

· $q_i(k) \leq q_i^*(k)$ for all k

cannot be an equilibrium. Thus, when z is sufficiently low, any equilibrium must necessarily include overprovision for at least some types.

As we have seen above, by marginally increasing $u_i(1-z)$, the principal incurs a loss of $\frac{1+s}{2}$ (the probability with which he captures the consumer) and obtains an expected gain given by

$$\left[\overline{q}\left(1-\frac{z}{2}\right) - \frac{\overline{q}^2}{2} - B\left(1-\frac{z}{2}\right)\right]\frac{1-s}{z} \tag{3.32}$$

By symmetry, at equilibrium $B\left(1-\frac{z}{2}\right) = u\left(1-\frac{z}{2}\right)$. If $u(1-z) = 0$, this must be equal to

$$\int_{1-z}^{1-\frac{z}{2}} q(k)\,dk \tag{3.33}$$

From IC.II, we know that $q(k) \leq \overline{q}$ for $k \leq 1-\frac{z}{2}$. This implies that if $u(1-z) = 0$ we must have

$$B\left(1-\frac{z}{2}\right) \leq \overline{q}\left(1-\frac{z}{2}-1+z\right) = \overline{q}\frac{z}{2} \quad . \tag{3.34}$$

The principal's gain of marginally increasing $u(1-z)$ must therefore be higher or equal than

$$\left(\overline{q}(1-z) - \frac{\overline{q}^2}{2}\right)\frac{1-s}{z} \tag{3.35}$$

If expression (3.35) is $> \frac{1+s}{z}$, we conclude that $u\left(1-\frac{z}{2}\right) = 0$ can certainly not be an

[23]This must be the case because at equilibrium $\overline{q}$ is equal to both $q^{WSC}(k_0)$ and $q^{WSC}(k_1)$.

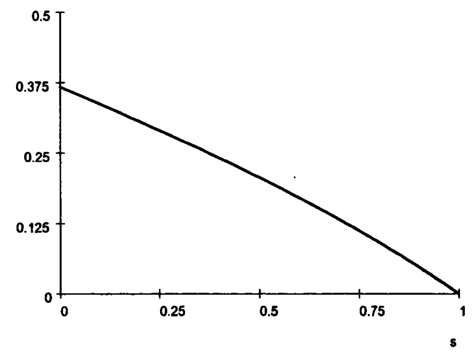

Figure 3-9: $\frac{1}{3s-3}\left(2s+2\sqrt{2}\sqrt{-s^2+3}-6\right)$

equilibrium. This is the case whenever

$$\left(\overline{q}\,(1-z)-\frac{\overline{q}^2}{2}\right)\frac{1-s}{z}>\frac{1+s}{2} \tag{3.36}$$

i.e.

$$-\frac{\overline{q}^2}{2}\frac{1-s}{z}+\overline{q}\frac{(1-s)\,(1-z)}{z}-\frac{1+s}{2}>0 \tag{3.37}$$

The expression on the lefthandside of (3.37) reaches a maximum at $\overline{q}=1-z$. Notice that this is equal to the optimal WSC quality allocation for type $1-\frac{z}{2}$[24], and therefore represents a lower bound on $\overline{q}$.

Now consider $\overline{q}=q^*\left(1-\frac{z}{2}\right)=1-\frac{z}{2}$. When $\overline{q}=1-\frac{z}{2}$, condition (3.37) becomes

$$-\frac{\left(1-\frac{z}{2}\right)^2}{2}\frac{1-s}{z}+\left(1-\frac{z}{2}\right)\frac{(1-s)\,(1-z)}{z}-\frac{1+s}{2}>0 \tag{3.38}$$

Inequality (3.38) always holds provided that $z<\frac{1}{3s-3}\left(2s+2\sqrt{2}\sqrt{-s^2+3}-6\right)$ (figure 3-9).

We conclude that, whenever $z<\min\left(2s+2\sqrt{2}\sqrt{-s^2+3}-6,\ \frac{2}{\frac{1}{s}+1}\right)$, an equilibrium where

· $u\,(1-z)=0$ and

· $\overline{q}\leq q^*\left(1-\frac{z}{2}\right)$

[24] This can be seen from (3.15).

cannot exist. The optimal mechanism must therefore prescribe

· either $u(1-z) > 0$ or

· $u(1-z) = 0$ and $\overline{q} > q^{*}\left(1 - \frac{z}{2}\right)$.

In both cases, overprovision occurs for some types[25].■

[25] When $u(1-z) = 0$ and $\overline{q} > q^{*}\left(1 - \frac{z}{2}\right)$, overprovision occurs for type $k = 1 - \frac{z}{2}$ and, by continuity, must also occur for types sufficiently close to $1 - \frac{z}{2}$.

Chapter 4

Incentive Problems in the Introduction of New Technologies when the Advisor is an Interested Party

4.1 Introduction

Every once in a while, industries are hit by innovations that change the nature of the abilities, skills and knowledge which are relevant for production. In those circumstances, it is often the case that if the employer decides to adopt the new technology, he will also replace his specialist workforce/technicians with new ones, who possess more appropriate competencies. This generates a conflict of interests between the employer and his specialist workforce. Unfortunately, specialist workers are often the only ones that can adequately assess the efficiency of a new technology, whereas employers can, at most, only aspire to an imperfect signal. Current employees, therefore, are often also experts in that they carry private information pertaining to the efficiency of their participation in the production process. Anecdotal evidence suggests that the consequences of this informational asymmetry for technology adoption may be rather dramatic. The case of DuPont versus Celanese, drawn from Foster (1986), provides a good illustration.

> In the late 1970's, polyester emerged as a possible alternative to nylon technology in the production of tire-cords. The market leader, DuPont, asked engineers at its tire-cord development centre to test the new polyester cords. The centre was run by engineers from the Nylon Department. They tested the product, and declared that it had good potential, but still needed a bit of development. After a year or so, when the polyester designers returned for more testing, they were told that their product was absolutely fantastic and superior to anything made of nylon. Unfortunately, DuPont had just approved a new investment in a nylon tire-cord facility and would have all the necessary tire-cord capacity it needed for some time. All that the top management could promise the Polyester Department was that when the nylon capacity was used up, DuPont would invest funds in polyester tire-cord. In spite of the fact that polyester was four times more efficient than nylon in delivering technical innovation, DuPont stuck to nylon for a few more years. The net result was that it lost its dominant position in the market; in five years, Celanese (a relatively small new entrant) managed to capture over 75 percent of the tire-cord market.

Indeed, the notion that established firms tend to have difficulties in adjusting to competence-destroying technologies (those that alter the skills and knowledge required for production), in spite of having a leading role in the introduction of competence-enhancing technologies (those that do not render the skills required to master older technologies obsolete), is well documented within the management literature. In a study of the cement, minicomputer and airline industries, Anderson and Tushman (1986) show that competence-enhancing technological discontinuities are typically initiated by existing firms, while competence-destroying discontinuities are initiated by new firms. In the case of cement, for instance, they report that :

> The revolution that brought powdered coal and rotary kilns rendered almost obsolete the know-how required to operate wood-fired vertical kilns. A totally new set of competencies was required to make cement, and most vertical kilns operators went out of business. (..) On the other hand, the introduction of Edison and Dundee kilns extended the capability of coal-fired rotary kiln technology. Existing

cement-making techniques were not made obsolete, and the incumbent firms in the industry proved most able to make the necessary capital expenditures.

Similar effects were observed in the minicomputers industry after the introduction of integrated-circuit technology (competence-destroying) as opposed to that of semiconductor memory (competence-enhancing). Further evidence in this direction is reported by Christensen and Rosenbloom (1995) within the rigid disk drive industry, by Cooper and Schendel (1976) in a study of seven different industries, and by Clark and Henderson (1990) within the photolitographic equipment industry.

Whilst there are no pretences to provide an exhaustive explanation for this empirical regularity, this paper hopes to nonetheless to make a contribution by emphasizing the role which agency problems may play in explaining the failure of established firms. Indeed, the idea that "managerial inertia" can be considered a source of inefficiency has been informally presented by Foster (1985) and Kaplan, Murray and Henderson (2001). Foster, for example, argues that

> Many R&D vice-presidents, having earned their titles by successfully guiding their companies into new technologies, are not disposed to abandon their favorites easily. Indeed, they often inadvertently block the investigation of new threatening technologies in the name of existing product lines.

In contrast to those works - which adopt a behavioral approach, claiming that cultural barriers, and the tendency to stick to existing mental models, may be at the root of the issue - this paper emphasizes the role played by the conflict of interests existing between employers and employees with respect to the adoption of competence-destroying new technologies. We investigate whether this conflict is irreconcilable, or whether it can be reconciled by means of an appropriate contractual agreement. We address this question within the context of a principal-agent model, where the agent is a specialist employee with access to private knowledge concerning the profitability of new technology, and the principal owns the resources which are necessary for production. Importantly, the model differs from the standard adverse selection setting, in that the agent's private information concerns his *relative*, rather than his *absolute*, productivity; conditional on working for the principal, different types[1] of agent obtain the same utility from any given production-payment contact. The only difference among different types of agent concerns their expected utility from alternative employment (or job-market prospects). This implies that the principal is unable to utilize appropriate production-payment contracts in order to discriminate among agent types.

We show that if

· the agent's expected utility from alternative employment is lower when the new technology is superior to the old one and

· the principal cannot commit to employing the agent if the new technology is adopted

no renegotiation-proof contract exists that induces the agent to reveal his information to the principal. The implication is that the principal chooses to adopt the least efficient technology with a positive probability. Thus, when it comes to the efficient adoption of radical new technologies, larger firms, where ownership and expertise tend to be separated, are disadvantaged in comparison to smaller, entrepreneurial firms.

The rationale for the result stems from the fact that any renegotiation-proof contract between the agent and the principal cannot tie the agent's compensation to the performance of the adopted technology, but can only take the form of a fixed payment, which is contingent upon the agent's employment status. This is because once the technology choice has been operated, surplus maximization is achieved only if the principal is the profits' residual claimant. Unfortunately, this implies that truthtelling cannot be implemented: any wage which is sufficiently high to make the agent forego his outside option[2] when the new technology is inefficient, will necessarily him to declare that the old technology superior (even when it isn't). This is because, in doing so, the agent can ensure that his current job is retained. Oppositely, any redundancy payment sufficiently high to compensate the agent for losing his employment will induce him to declare that the *new* technology superior (even when this isn't). This is because, in doing so, the agent can ensure his own redundancy, thereby entitling him to a high redundancy payment. The result is therefore reminiscent of Holmstrom (1982): the budget-balancing

[1] Defined as embodying any private information that is relevant to his decision making.

[2] Arising form alternative employment.

constraint makes it impossible to provide the right incentives to both the principal and the agent simultaneously.

This paper also characterizes the decision rule that the principal obeys when he cannot rely on the agent's expertise. We show that if prior beliefs are against the new technology (as it is often the case), technological stagnation and excessive conservatism may emerge.

Finally, this paper studies the special case where the agent can undertake some action, which ex-ante ensures that his information will be ex-post available to the principal. That is, the agent can ensure that his investigation into the efficiency of the new technology is conducted in a transparent manner. This may for instance be done by allowing neutral and incorruptible third parties to scrutinize any evidence which supports the agent's statement[3]. Crucially, it is assumed that transparency is verifiable, but cannot be contracted upon. We find that commitment to transparency always results at equilibrium if, conditional on it not taking place, the principal follows a fixed rule of technology adoption. This happens, for instance, when the principal has no access to external sources of information, or if the expected profitability of the new technology is very high/ low. On the other hand, if the principal conditions his choice of technology on the realization of a given signal, then commitment to transparency may fail to occur, and the inefficient technology is adopted with a positive probability.

4.1.1 Related literature

The literature on expertise (see for instance Milgrom and Roberts (1986), Scharfstein and Stein (1990), Prendergast and Stole (1996), Dewatripont and Tirole (1999), Ottaviani and Sorensen (2003)) is mainly concerned with models of cheap talk, where the consonance between the principal's and the advisor's interests is exogenously given. In the present paper, on the other hand, we allow this consonance to be endogenously determined by means of a contractual agreement between the two parties. Our primary

[3]The underlying assumption is that it may be possible for third parties to verify the veracity of the agent's statement. This may true even in cases where the third party could not independently verify the matter. Whenever a scientific article is submitted for publication in an academic journal, for istance, the journal referees are able to judge the validity of the article. This does not however imply that they could have easily written the article themselves.

concern is to assess whether a contract exists, which could eliminate any conflict of interests.

To our knowledge, the only paper that formalizes the idea that agency problems may cause inefficiencies in the adoption of innovations within a complete contract framework is that by Dearden, Ickes and Samuelson (1990). The nature of the dilemma under study, however, is very different to that considered in the present setting. In Dearden, Ickes and Samuelson, innovations are productivity-enhancing (rather than competence-destroying) and the agent's effort and innovation adoption are assumed to be unobservable by the principal. Furthermore, the agent's private information concerns the job's productivity. This is in contrast with the present model, where informational asymmetries concern the relative efficiency of the agent's participation in the production process, and technology adoption is determined by the principal.

4.2 The model

Players

There are two players in the game, the principal P and the agent A. The agent possesses skills and expertise, while the principal owns resources and means of production. We assume that the principal as a monopolist seller within a given market.

Technology

A technology is defined as a research path/trajectory. There are two freely available technologies: the old and the new one. The principal has to chose between these two technologies (he cannot chose both). The old technology is man operated, while the new technology is entirely computerized[4]. The agent is the only person in the world who is able to handle the old technology[5]. For simplicity, we model handling the old technology as a (perfectly observable and verifiable) zero-one activity, and assume that the agent can perform this activity without incurring any personal cost.

[4]This ensures that there is no other worker to compete with the agent. Alternatively, we could assume that such a worker exists, but he is not informed about the state of the world.

[5]This assumption is designed to capture the idea that the principal and the agent may have been interacting in the past, and may have undergone some relationship-specific investments.

States of the world

There are two states of the world:

· state O: the old technology is more efficient;

· state N: the new technology is more efficient.

At the beginning of the game, nature draws the state of the world; we denote as q the probability that the state is N, and by $1-q$ the probability that the state is O, where $q \in]0,1[$. The value of q is common knowledge.

Productivity

Technology succeeds in delivering a good according to a probability distribution which depends upon the technology's productivity and on the amount of resources invested in the technology. The probability with which the good is delivered is a function of the chosen technology $a \in \{N, O\}$, the true state of the world $\omega \in \{N, O\}$ and the realization of the principal's choice of capital stock as $k \in \mathbb{R}^+$. Generally, it will be the case that k will be different according to the principal's choice of technology. We make a distinction between the old and the new technology as follows: under the old technology, the probability of success depends on k in a manner that is unaffected by the state of the world. In other words, if the firm stays with the old technology, there is some positive chance of success $z_0 g(k)$, irrespective of the state of the world. That is:

$$\Pr(success \mid \omega, a = O, K = k) = z_0 g(k) \tag{4.1}$$

for both $\omega = N$ and $\omega = O$.

Under the new technology, on the other hand, the probability of success depends on k in a manner that is different under state N as opposed to state O. That is:

$$\Pr(success \mid \omega = N, a = N, K = k) = z_1 g(k) \tag{4.2}$$

$$\Pr(success \mid \omega = O, a = N, K = k) = 0 \tag{4.3}$$

where $g(.)$ is a strictly increasing concave function with $g(0) = 0$, $g'(0) \to +\infty$, z_1, z_0 are two finite positive constants, with $z_1 > z_0$ and both z_1 and z_0 are common knowledge. Thus, the new technology is risky, but also potentially more efficient than the old one.

Information structure

i. Agent's information

We assume that the agent always costlessly receives a private signal which reveals the state of the world. Prior to receiving the signal, the agent can take a costless action that ensures that the principal will observe the agent's signal (transparency). Crucially, we assume that transparency is observable but not verifiable, and can therefore not be contracted upon.

ii. Principal's information

We assume that the principal can costlessly receive a public signal $s \in \{O, N\}$ about the true state of the world. This signal is received at the same time as the agent's signal.

If $\omega = N$ the principal's signal is

$$\begin{aligned} s &= N \quad \text{with probability } p \\ s &= O \quad \text{with probability } 1-p \end{aligned}$$

where $p \in \left[\frac{1}{2}, 1\right]$. If $\omega = O$ the principal's signal is

$$\begin{aligned} s &= O \quad \text{with probability } r \\ s &= N \quad \text{with probability } 1-r \end{aligned}$$

where $r \in \left[\frac{1}{2}, 1\right]$.

The variables p and r express the reliability of the principal's signal in either state of the world. Consider $p > r$; in that case, the signal is more accurate when the state of the world is N than when the state of the world is O. In other words, it is easier to show that the new technology is superior to the old one than it is to show the opposite. Notice that if $p = 1$ the principal's signal is perfectly informative when $s = O$. The case where $r > p$ depicts the opposite situation. The case where $r = p$ describes a scenario where the signal is equally reliable in either state of the world. We assume that r and p cannot be simultaneously equal to either 1[6] or $1/2$[7].

From above:

$$\Pr(s = N) = pq + (1 - r)(1 - q) \tag{4.4}$$

and

$$\Pr(s = O) = 1 - \Pr(s = N) = r(1 - q) + q(1 - p) \tag{4.5}$$

Applying Bayes' rule we derive:

$$P_N^N \equiv \Pr(\omega = N \mid s = N) = \frac{qp}{pq + (1 - r)(1 - q)} \tag{4.6}$$

$$P_N^O \equiv \Pr(\omega = O \mid s = N) = \frac{(1 - r)(1 - q)}{pq + (1 - r)(1 - q)} \tag{4.7}$$

$$P_O^O \equiv \Pr(\omega = O \mid s = O) = \frac{(1 - q)r}{r(1 - q) + q(1 - p)} \tag{4.8}$$

$$P_O^N \equiv \Pr(\omega = N \mid s = O) = \frac{q(1 - p)}{r(1 - q) + q(1 - p)} \tag{4.9}$$

Timing/structure of the game

The timing of the game is as follows:

1. the state of nature is realized;
2. the principal and the agent sign a contract;
3. the agent commits/doesn't commit to transparency;
4. the agent and the principal receive their signals;
5. if he has not committed to transparency, the agent advises the principal;
6. the principal decides which technology he would like to adopt. If this is the old technology, he asks the agent to get actively involved in production;

[6] If this was the case, the principal's signal would be perfeclty informative.
[7] If this was the case, the principal's signal would be entirely uninformative.

7. if the principal has made a proposal at date 6, the agent either accepts or rejects the offer;

8. the principal decides which technology to adopt and the amount of resources to be invested in it;

9. the chosen technology is operated and the good is / is not produced; payoffs are realized[8].

A strategy for the agent therefore consists of a decision $t \in \{\text{yes, no}\}$ to commit to transparency at time 2 and of a declaration $d \in \{O, N\}$ [9] to be made at time 5.

The principal's strategy consists of a contract offered at time 2, of a decision $c \in \{\text{yes, no}\}$ to consult his signal, of a choice $a \in \{O, N\}$ on which technology to adopt and of an amount $k \geq 0$ of resources to invest in the chosen technology.

Principal's payoff

The principal's valuation of the good is given by V, where V is assumed to be finite and strictly positive. If the good is not delivered the principal's payoff is zero. Recall that we introduced above the idea that the probability of success in delivering the good under either technology depends on the level of the level of capital investment k. When the principal devotes an amount k of resources to technology a, his expected payoff (without including the agent's payment) is therefore given by

$$\Pr(success \mid \omega, a, k)V - k \tag{4.10}$$

From above, this is equal to $zg(k)V - k$, where

$$z = \begin{cases} z_0 \text{ if the old technology is selected;} \\ \begin{cases} z_1 \text{ if the new technology is selected and the state of the world is N;} \\ 0 \text{ if the new technology is selected and the state of the world is O.} \end{cases} \end{cases}$$

[8] We are assuming that the true state of the world never becomes common knowledge. This is unlikely to be the case in reality. Relaxing this assumption implies that the principal may offer a contract which is conditional on the realized state of the world. Allowing for such contract should however not fundamentally alter the results obtained in the paper. The reason for this is that often the amount of time that lapses before the profitability of the new technology becomes observable is very long. This, coupled with the fact that the agent has limited liability makes it unlikely that such contract would have a large impact the agent's incentives .

[9] Allowing the agent to make no declaration does not change the results.

If z is known to be $= \hat{z} \geq 0$, the optimal amount of resources $k^*(\hat{z})$ to be allocated to the old technology is implicitly defined by $g'(k^*(\hat{z})) = 1/\hat{z}V$.

We introduce the following notation:

$\pi_O^* \equiv z_O g(k^*(z_0))V - k^*(z_0)$, $\pi_N^* \equiv z_1 g(k^*(z_1))V - k^*(z_1)$.

In order to ensure that $zg(k^*(z)) < 1$ for both $z = z_0$ and $z = z_1$, we assume that

Assumption 1 $g(k^*(z_1)) < \frac{1}{z_1}$

Notice that

$$zg(k^*(z))V - k^*(z) \geq 0$$

for all $z \geq 0$[10]. Also, $zg(k^*(z))V - k^*(z)$ is increasing in z[11].This implies that

$$\pi_N^* > \pi_O^* \tag{4.11}$$

Thus, when the state of the world is N, it is efficient for the principal to adopt the new technology.

Agent's payoff

Because we have assumed that the agent can costlessly operate the old technology, the agent's payoff if he receives a monetary payment τ is simply given by τ, independently of his employment status.

Agent's outside options

We introduce the idea that the old and the new technology are used not only in the monopoly market under discussion, but also in other markets (in which the principal does not compete). There is therefore an outside labour market in which the agent can find alternative employment. This alternative employment represents the agent's

[10] This can be seen from the fact that the inequality can be written as

$$g(k^*(z)) \geq k^*(z)g'(k^*(z))$$

Because we are assuming that $g(.)$ is strictly concave, with $g(0) = 0$, this is always the case.

[11] If we totally differentiate $zg(k^*(z))V - k^*(z)$ with respect to z we get: $g(k^*(z))V$.

(non-negative) outside option when interacting with the principal. We allow the agent's outside option to differ in different states of the world. Denoting the agent's outside option in state i, $i = N, O$, as B_i, we assume that

Assumption 2 $\pi^*_O > B_O$

This ensures that, when $\omega = O$, it is optimal for the principal to select the old technology (and employ the agent). It is worth noting that the case in which the principal does not invest in either technology cannot arise here, as he can always guarantee a strictly positive expected profit by adopting the old technology, and invest $k^*(z_0)$ resources in it.

Contracts

We model the principal as having all the bargaining power in the relationship. At the beginning of the game, he makes a take-it-or-leave-it offer to the agent.

The agent's involvement/lack of involvement in the productive activity is observable and verifiable. In order for the agent to be actively involved in running the chosen technology both the agent and the principal need to agree. We assume that the court cannot penalize either party for failing to agree[12]. Thus, the agent can ex-post refuse to be actively employed by the principal. Similarly, the principal cannot commit to employ the agent unless he strictly needs him, which is the case only if he decides to adopt the old technology.

For simplicity, we assume that advice which the agent may give to the principal concerning the technology he should adopt is observable but not verifiable. Relaxing this assumption does not modify the results[13].

It follows that the contract between the agent and the principal takes a very simple form, and specifies:

[12]This comes from the fact that courts are unable to distinguish between situations in which the employee is laid-off and situations in which he quits the job. Because employment is on *at will* basis (the contrary would correspond to slavery), this implies that either party can terminate the relationship without any penalty.

[13]What matters is that the agent's knowledge of the true state of the world should not be verifiable.

· a payment scheme in case the agent is actively employed by the principal and

· a payment scheme in case the agent is not actively employed by the principal.

We assume that the amount of resources which the principal invests in any given technology is not verifiable/contractible upon. This captures the idea that resources are often not easily measurable. Also, we concentrate on contracts which are immune to Pareto-improving renegotiation. As shown in the appendix, this in implies that implementable payment schemes necessarily take the form of fixed payments: once the choice of technology has occurred, joint surplus is always maximized if the principal is the sole residual claimant.

A contract between the agent and the principal is therefore described by a couple (w, w_{ne}), where w denotes the fixed payment which the agent receives for operating the old technology if he is actively employed by the principal, and w_{ne} denotes the fixed payment which the agent receives if he does not actively work for the principal[14]. We can think of w as the agent's wage, and of w_{ne} as his redundancy payment. As shown in the appendix, renegotiation-proofness requires the optimal contract to include $w \geq B_O$. This implies that in any equilibrium the agent always accepts the principal's proposal to be actively employed. Without loss of generality we can therefore eliminate stages 6 and 7 from the game.

Finally, we assume that the agent possesses no personal wealth. Thus, both w_{ne} and $w \geq 0$. Because signing the contract does not commit the agent to interact with the principal, and $w_{ne} \geq 0$, there is no loss of generality in assuming that the agent always accepts to sign the contract offered by the principal.

4.3 Implications

4.3.1 No commitment to transparency

We start off by concentrating on the subgame in which the agent has not committed to transparency, investigating the existence of a pure-strategy, separating equilibrium

[14]The subscript ne stands for "not employed".

of the revelation game between the agent and the principal. That is, we verify whether an equilibrium exists, in which at date 5 the agent's advise when $\omega = O$ differs from his advise when $\omega = N$. Without loss of generality, we consider the situation in which $d(O) = O$ and $d(N) = N$. In that case, the principal's optimal adoption strategy is given by $a(O) = O$ and $a(N) = N$.

Truthtelling by the agent in state N requires:

$$\underbrace{w_{ne} + B_N}_{\text{payoff when truthtelling}} \geq \underbrace{w}_{\text{payoff when cheating}} \tag{4.12}$$

The expression on the lefthandside of (4.12) includes B_N, the agent's outside option in state N, because we are assuming the if the agent declares the state of the world to be N, he will not be actively employed by the principal, and will therefore look for alternative employment.

Truthtelling in state O requires:

$$\underbrace{w}_{\text{payoff when truthtelling}} \geq \underbrace{w_{ne} + B_O}_{\text{payoff when cheating}} \tag{4.13}$$

where B_O appears on the righthandside of (4.13) for the reasons discussed above. Notice that condition (4.13) is also the agent's participation constraint, whenever the state of the world is O. This equivalence arises because in a truthtelling equilibrium, if the agent declares the state of the world to be N, the principal will not find it optimal to actively employ him.

For conditions (4.12) and (4.13) to be simultaneously satisfied, we need[15]

$$B_N \geq B_O \tag{4.14}$$

If $B_N \geq B_O$, the principal can induce truthtelling by setting $w_{ne} = 0$, $w = B_O$. Notice that in this case no informational rents are necessary to ensure that the principal's

[15]It should be noted that the necessaity of inequality (4.14) for truthtelling does not depend on the absence of moral hazard in this setting. Even if moral hazard was present, any renegotiation-proof contract would prescribe that the agent receives a fixed payment if the new technology is adopted (in which case he is not actively involved in the productive process). This would be sufficient to guarantee the result.

and the agent's interests with respect to technology adoption are aligned; if the state of the world is N, they both prefer the agent to work elsewhere, and vice-versa. It follows that the informational asymmetry between the agent and the principal has no consequences for the efficiency of technology adoption.

On the other hand, if inequality (4.14) does not hold, the conflict of interests between the principal and the agent is irreconcilable. For a given wage rate, truthtelling requires the redundancy payment to be both sufficiently high to compensate for the loss of employment in state N and sufficiently low to guarantee that the agent wishes to remain employed in state O. If the agent's prospects in the external labour market are higher in state O than in state N, this is not possible; any redundancy payment that is sufficiently high to compensate the agent for losing his employment will necessarily induce him to declare the new technology superior, even when it isn't. This is because by doing so he can ensure that he is made redundant, and is therefore entitled to a high redundancy payment.

Vice-versa, for a given redundancy payment, thruthtelling requires the wage rate to be both sufficiently high to guarantee that the agent wishes to remain employed in state O and sufficiently low to ensure that he does not wish to be employed in state N. When $B_O > B_N$, this is not possible; any wage rate that is sufficiently high to induce the agent to forego B_O is state O will necessarily induce him to declare that the old technology is superior, even when it isn't. This is because,by doing so, the agent can ensure that he keeps his current job.

It is worth pointing out that this result shares interesting similarities with the underinvestment result arising in the hold-up problem[16].

In the standard hold-up story, the agent has to undergo some initial (unobservable) investment before dealing with the principal (figure 4-1). This implies that ex-post, when the principal offers the contract/bargains with the agent, the agent's investment has already been sunk. Underinvestment then arises because the principal cannot commit to reward the agent ex-ante for his nonobservable investment.

Now consider our setting. In any truthtelling equilibrium, the agent makes his

[16] See for instance Grout (1984).

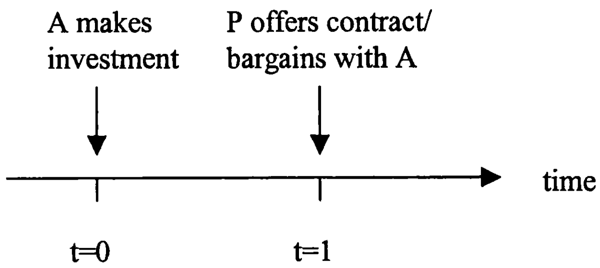

Figure 4-1: Timing in the hold-up problem.

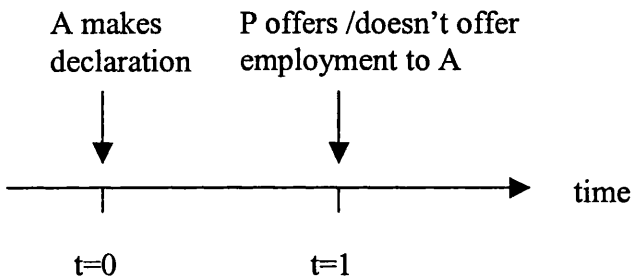

Figure 4-2: Timing in the present setting.

(noncontractible[17]) declaration concerning the state of the world before the principal decides which technology to adopt (figure 4-2). This implies that ex-post, when the principal takes his decision, the agent has already revealed his information. Crucially, we are assuming that no commitment device exists that obliges the principal to employ the agent if the new technology is adopted. Whenever $B_O > B_N$, this implies that telling the truth is necessarily costly, and results in truthtelling sharing the same characteristics as the investment in the hold-up setting. The impossibility of a truthtelling equilibrium is therefore a consequence of the principal's inability to reward the agent ex-ante for telling the truth, and is analogous to the underivestment result in the hold-up problem.

As mentioned earlier, the agent's outside options derive from the presence of an outside labour market. That is, other principals exist, with whom the agent may interact.

[17]Recall that, because we are assuming that his knowledge is not verifiable, the agent's truthtelling is not contractible upon.

Inequality (4.14) may therefore be justified if we assume that

· either no relationship or a negative correlation exists between the old/new technology's efficiency in the industry under scrutiny and in other, alternative industries where the agent may look for employment or

· potential employers are entirely uninformed about the true state of the world.

If, on the other hand, we allow for the notion that if the new technology proves superior in this industry, it will also prove superior in other industries, and if we assume that at least some of the agent's potential employers have superior information about the state of the world, then it is natural to assume that the agent's prospects in the labour market should be higher when the state of the world is O rather than N. In that case, inequality (4.14) does not hold, implying that no renegotiation-proof contract exists that induces the agent to thruthfully reveal his information to the principal. In that case, we have two possibilities. If commitment to transparency is not feasible, the principal should condition his decision on technology on his information only. Given that, the optimal contract prescribes $w_{ne} = 0$, $w = B_O$. If commitment to transparency is feasible, on the other hand, the principal may select the optimal contract by taking into account the implications that this has in terms of the agent's incentives to commit. We explore both cases in the following sections.

Finally, notice that our conclusions crucially rest on the assumptions that the new technology is competence-destroying rather than competence-enhancing, and that the principal cannot credibly commit to keep the agent employed if the new technology is adopted. Consider the case where either of these assumptions fails to hold. Then, the agent would remain employed also when the new technology is adopted. Denote by w_N the wage that the agent receives if the principal adopts the new technology, and by w_O the wage that the agent receives if the principal decides to adopt the old technology. In that case, incentive compatibility requires

$$w_O \geq w_N \qquad (4.15)$$

$$w_N \geq w_O \qquad (4.16)$$

and the agent's participation constraints are

$$w_O \geq B_O \tag{4.17}$$

$$w_N \geq B_N \tag{4.18}$$

The principal can therefore induce truthtelling (and participation) by setting $w_O = w_N = \max(B_O, B_N)$.

The following proposition summarizes the results obtained so far.

Proposition 1: *If $B_O \leq B_N$, that is, the agent's expected utility from alternative employment is either independent of the state of nature or is higher when the new technology is more efficient than the old one, the principal can extract the agent's information without having to offer any informational rents. If $B_O > B_N$, on the other hand, a conflict of interests exists between the principal and the agent, which is irreconcilable. That is, no renegotiation-proof contract exists which induces the agent to truthfully reveal his information.*

Proposition 1 implies that when commitment to transparency is not feasible, the availability for the principal of an external source of information can only increase efficiency.

In what follows we concentrate the case where $B_O > B_N$, normalize B_N to zero and denote B_O as B.

4.3.2 The principal's decision

In the preceding section we have established that, when $B_O > B_N$ the agent will never truthfully reveal his information. Thus, conditional on the agent not committing to transparency, the principal will not condition his choice of technology upon the agent's declaration but will either:

· always adopt the old technology, or

· always adopt the new technology, or

· follow his signal, adopting the new technology when $s = N$ and keeping the old technology when $s = O$.

We now identify the conditions under which the principal will find it optimal to follow each strategy.

Conditional on $s = N$, if the principal adopts the new technology he will chose to invest an amount of resources k_N^N that maximizes

$$P_N^N z_1 g(k) V - k \tag{4.19}$$

$k_N^N(z_1, p, q)$ (henceforth k_N^N for brevity) is therefore implicitly defined by $g'(k_N^N) = 1/P_N^N z_1 V$. Notice that for the principal the situation is ex-ante equivalent to one in which he knows with certainty that the new technology has productivity $P_N^N\ z_1$.

Conditional on $s = O$, if the principal adopts the new technology he will chose to invest an amount of resources k_N^O that maximizes

$$P_O^N z_1 g(k) V - k \tag{4.20}$$

and is therefore implicitly defined by $g'(k_O^N) = 1/P_O^N z_1 V$. Notice that for the principal the situation is ex-ante equivalent to one in which he knows with certainty that the new technology has productivity $P_O^N\ z_1$.

Because the old technology's productivity is perfectly known, the amount of resources the principal invests when he selects the old technology is equal to k_O^*, independently of s. Thus, the principal's expected profit when he selects the old technology is always equal to $\pi_O^* - B$.

Conditional on $s = N$, the principal adopts the new technology if

$$P_N^N\ z_1 g(k_N^N) - k_N^N \geq \pi_O^* - B \tag{4.21}$$

and keeps the old technology otherwise.

If $r = 1$: $P_N^N = 1$ and $P_N^N\ z_1 g(k_N^N) - k_N^N = \pi_N^*$, implying that condition (4.21) is always satisfied. If $r < 1$, on the other hand, condition (4.21) always holds for $q \to 1$ (in which case $P_N^N \to 1$) but never holds for $q \to 0$ (in which case $P_N^N \to 0$) .

Because the lefthandside of (4.21) is strictly increasing in q[18], there therefore exist a $q^L(p, r, z_1, z_0, B) > 0$ such that condition (4.21) does not hold for $q < q^L$ and holds for $q \geq q^L$.

Conditional on $s = O$, the principal keeps the old technology if

$$P_O^N \; z_1 g(k_O^N) - k_O^N \leq \pi_O^* - B \tag{4.22}$$

and adopts the new technology otherwise[19].

If $p = 1$: $P_O^N = 0$, implying that condition (4.22) is always satisfied. If $p < 1$, on the other hand, condition (4.22) always holds for $q \to 0$ (in which case $P_O^N \to 0$) but never holds for $q \to 1$ (in which case $P_O^N \to 1$). Because the lefthandside of (4.22) is strictly increasing in q[20], there therefore exist a $q^H(p, r, z_1, z_0, B) < 1$ such that condition (4.22) does not hold for $q > q^H$ and holds for $q \leq q^H$.

Notice that q^H is always higher than q^L. This follows from the fact that[21]

$$P_N^N \; z_1 g(k_N^N) - k_N^N > P_O^N \; z_1 g(k_O^N) - k_O^N \tag{4.23}$$

This brings us to the following proposition:

Proposition 2: *Conditional on the agent not committing to transparency, the principal follows his own signal only when the prior probability q with which the new technology may be superior to the old one takes an intermediate value. If q is sufficiently low, the principal always adopts the old technology, while if q is sufficiently high he always adopts the new technology. That is, there exist a $q^L(p, r, z_1, z_0, B)$ and a $q^H(p, r, z_1, z_0, B)$ (denoted as q^L and q^H for brevity) such that:*

- *if $q \in \left[q^L, q^H\right]$: the principal follows his signal.*
- *if $q < q^L$: the principal always adopts the old technology.*
- *if $q > q^H$: the principal always adopts the new technology.*

---

[18] This can be seen from the fact that $\frac{\partial\left(P_N^N z_1 g(k_N^N) - k_N^N\right)}{\partial q} = \frac{p(1-r)}{(pq+(1-r)(1-q))^2} z_1 g(k_N^N) \geq 0$.

[19] We assume that if the principal is indifferent, ha always adopts the old technology.

[20] This can be seen from the fact that $\frac{\partial\left(P_O^N z_1 g(k_O^N) - k_O^N\right)}{\partial q} = \frac{r(1-p)}{(r(1-q)+q(1-p))^2} z_1 g(k_O^N) \geq 0$.

[21] We can see that by noticing that $zg(k^*(z)) - k^*(z)$ is increasing in z and $P_N^N > P_O^N$

The intuition behind the result is rather straightforward. If the prior probability with which the new technology is superior to the old one is very low/high, the principal's posterior beliefs on the efficiency of new technology will accordingly be low/high, independently of the realization of the signal. In that case, the dominant strategy for the principal is to follow a fixed rule of technology adoption. On the other hand, if the prior probability takes an intermediate value, the signal's realization plays an important role in altering the principal's posterior beliefs. Thus, the principal finds it optimal to condition his choice of technology adoption upon this realization. Notice that , caeteris paribus, a higher z_1/z_0 decreases both q^L and q^H, making it more likely that the principal always adopts the new technology. Similarly, a lower z_1/z_0 increase both q^L and q^H, making it more likely that the principal always adopts the old technology. The rationale for this is that the opportunity cost of adopting the old technology when the state of the world is N is an increasing function of z_1/z_0.

Proposition 2 implies that whenever the prior probability with which the new technology may be superior to the old one is sufficiently small and/or the efficiency gain which may be realized by adopting the new technology is not very large, we should expect firms to stick to old, familiar technologies. Empirical evidence shows that, in most industries, the statistical probability with which a superior, competence-destroying technology may emerge at any point in time is rather small. From proposition 2, this yields the empirical prediction that larger firms, where the agency problem may be expected to be more acute, should be more prone to excessive conservatism and technological stagnation than smaller, entrepreneurial firms.

4.3.3 Optimality of commitment

We now study the situation where the agent may ex-ante be able to commit to transparency. We analyze the conditions under which this may happen, taking into account the fact that the agent's decision is influenced by the principal's optimal strategy.

Intermediate priors

We first consider the case where, if the agent does not commit to transparency, the principal follows his own signal , adopting the new technology if $s = N$ and adopting the old one if $s = O$. From proposition 2, we know that this happens only if the prior probability with which the new technology is superior to the old one takes an intermediate value, that is, $q \in [q^L, q^H]$.

In this case, the agent's ex-ante expected utility if he does not commit to transparency is given by

$$\Pr(s = N) \underbrace{\left(w_{ne} + P_N^O\, B\right)}_{\text{expected payoff if s=N}} + \Pr(s = O) \underbrace{w_e}_{\text{payoff if s=O}} \tag{4.24}$$

The agent's ex-ante expected utility if he commits to transparency is equal to $w_{ne}q + (1-q)w$ The agent therefore decides to commit to transparency if

$$w_{ne}q + (1-q)w \geq \Pr(s = N)\left(w_{ne} + P_N^O\, B\right) + \Pr(s = O)w \tag{4.25}$$

substituting and simplifying, this yields

$$(w - w_{ne})\left((1-r)(1-q) - q(1-p)\right) \geq B\ (1-r)(1-q) \tag{4.26}$$

We distinguish between three cases:

(i) $(1-r)(1-q) > q(1-p)$

In this case, condition (4.26) requires $w > B + w_{ne}$. The cheapest way for the principal to achieve this is by setting

$$w_{ne} = 0,\, w = \frac{B(1-q)}{(1-q) - q\frac{1-p}{1-r}} \geq B \tag{4.27}$$

The agent gets an informational rent in state O, which decreases as $(1-r)(1-q)-q(1-p)$ gets smaller. Notice that if $p = 1$, i.e. the signal $s = O$ is perfectly informative, we are always in this case; the principal can induce transparency by offering no informational rents, i.e. by setting $w_{ne} = 0$, $w = B$. This represents the lower bound on the informational rents that need to be offered when $(1-r)(1-q) > q(1-p)$.

(ii) $q(1-p) > (1-r)(1-q)$

In this case condition (4.26) requires $w \leq w_{ne}$. The cheapest way for the principal to induce transparency is to set

$$w = B,\ w_{ne} = \frac{Bq}{q - (1-q)\frac{1-r}{1-p}} \geq B \tag{4.28}$$

Thus, the agent gets an informational rent in state N, which gets smaller as $q(1-p) - (1-r)(1-q)$ increases. Notice that if $r = 1$, i.e. the signal $s = N$ is perfectly informative, we are always in this case. The principal can induce truthtelling by setting $w = w_{ne} = B$. This represents the lower bound on the informational rents which need to be offered when $q(1-p) > (1-r)(1-q)$.

(iii) $(1-r)(1-q) = q(1-p)$

If this is the case, the agent can never be induced to commit to transparency.

We denote as $q^*(p,r)$(henceforth q^*) the value of q implicitly defined by the above equality:

$$q^*(p,r) = \frac{1-r}{2-r-p} \tag{4.29}$$

Notice that when the principal's signal is equally reliable in either state of the world, that is, $p = r$, $q^* = \frac{1}{2}$ independently of the precision of the principal's signal.

The following proposition summarizes the results so far.

Proposition 3: *Whenever the principal conditions his choice of technology adoption in the absence of transparency upon the realization of his signal, the nature of the informational rents that have to be offered in order to induce commitment varies according to the value of q. When $q < q^*$, the principal must offer a wage which is strictly higher than the minimum required to ensure the agent' s participation ex-post. When $q > q^*$, the principal must offer a strictly positive redundancy payment.*

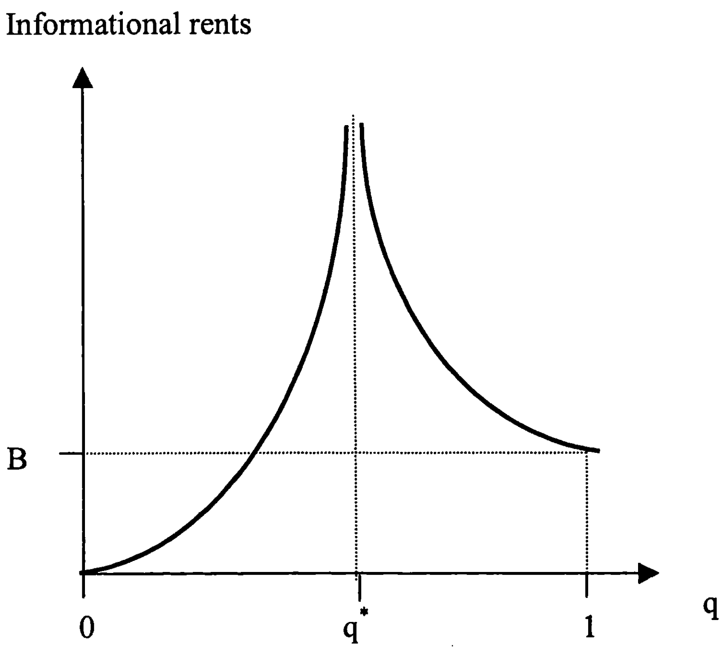

Figure 4-3: Informational rents needed to induce transparency, assuming that both r and p are $\neq 1$.

If the principal's signal is perfectly informative in one of its realizations, i.e. if either p *or* r *is equal to one, the magnitude of the informational rents needed to induce commitment to transparency is independent of* q. *If* $p = 1$, *i.e. the signal* $s = O$ *is perfectly informative: transparency always occurs; if* $r = 1$, *i.e. the signal* $s = N$ *is perfectly informative: transparency occurs if and only if* $(\pi_N^* - \pi_O^*) \geq B\frac{p}{1-p}$.

On the other hand, if both p *or* r *are different to one, the magnitude of the informational rents required to induce commitment increases as* q *approaches* q^*, *and becomes infinitely large when* $q = q^*$. *Thus, when* $q = q^*$ *no contract exists which may induce the agent to commit to transparency.*

Figure 4-3 depicts the informational rents needed to induce transparency, assuming that both r and p are $\neq 1$. These rents become infinitely large as q approaches q^*. In that case, the principal will never find it optimal to induce transparency at equilibrium. By continuity, this must also be the case whenever q is sufficiently close to q^*. This brings us to the following lemma:

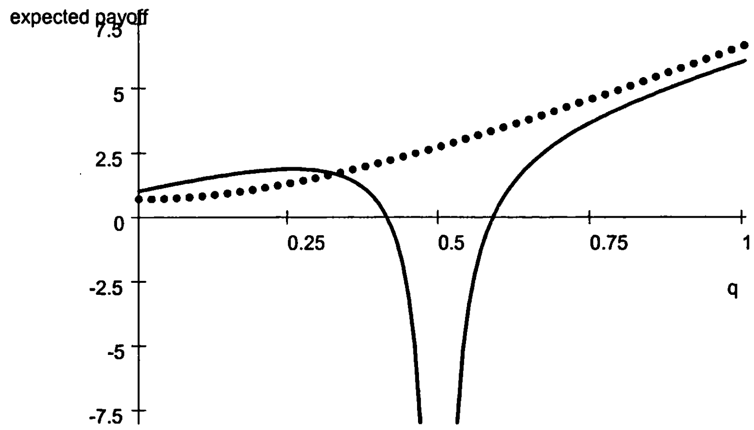

Figure 4-4: Principal's expected payoff when he follows his signal (dotted line) and when he induces transparency (bold line), assuming that $g(k) = \sqrt{k}/10$, $V = 20$, $z_1 = 3$, $z_0 = 2$, $B = 3$ and $p = r = 0.7$

Lemma 1: *Unless the principal's signal is perfectly informative in one of its realization, i.e. unless either r or p is equal to one, there exist an interval* $[\underline{q}(p,r), \overline{q}(p,r)]$ *around* $q^*(p,r)$ *such that if q belongs to that interval, the informational rents which the principal should offer in order to ensure transparency are so high that the principal finds it optimal not to do so.*

The degree to which this affects the probability of obtaining transparency at equilibrium depends on the overlap between $[\underline{q}, \overline{q}]$ and $[q^L, q^H]$. We denote the set of values of q such that these two intervals overlap as Ω. Whenever $q \in \Omega$: commitment never occurs at equilibrium. Figure 4-4 depicts the principal's expected payoff when he follows his signal (dotted line) and when he induces transparency (bold line), assuming that $g(k) = \sqrt{k}/10$, $V = 20$, $z_1 = 3$, $z_0 = 2$, $B = 3$ and $p = r = 0.7$. In that case, $q^* = 0.5$, $q^H \simeq 0.54$, $q^L \simeq 0.18$, $\underline{q} \simeq 0.33$ and $\overline{q} = q^H$. The principal therefore finds it optimal not to induce transparency whenever $q \in \Omega = [0.33, 0.54]$.

From proposition 3, we know that Ω is always empty whenever $p = 1$. When $r = 1$, on the other hand, Ω is empty if $(\pi_N^* - \pi_O^*) \geq B\frac{p}{1-p}$, and is equal to $]0, 1[$ otherwise.

More generally, it is easy to see that Ω is always non-empty whenever

$$q^H > q^* > q^L \tag{4.30}$$

As the following proposition shows, this is the case whenever r and p are sufficiently large, and $\frac{z_1}{z_0}$ takes an intermediate value.

Proposition 4: *Whenever $q \in \Omega$, commitment never occurs at equilibrium. This is because the informational rents that are required to induce commitment are too high for the principal to be willing to pay them. Provided that $\frac{z_1}{z_0}$ is sufficiently smaller than $\frac{1}{1-r}$, Ω is surely non-empty if $\frac{z_1}{z_0} \geq \frac{1}{p}$.*

Proposition 4 tells us that when the principal's signal is sufficiently informative, and z_1/z_0 is neither too large nor too small, a range of priors exist such that, whenever the prior probability with which the new technology may be superior to the old one belongs to this range, commitment does not occur at equilibrium. Notice that the conditions which are sufficient to guarantee that such a range exists also increase the desirability for the principal of consulting his signal.

Discussion

In order to understand the intuition behind the direction and magnitude of informational rents it is instructive to rewrite condition (4.23) as

$$(w - B - w_{ne})(1-r)(1-q) \geq q(1-p)(w - w_{ne}) \tag{4.31}$$

By committing to transparency the agent prevents the principal from making mistakes, i.e. from adopting the new technology in state O (mistake of type O) or adopting the old technology in state N (mistake of type N).

Consider the first type of mistake: if the principal follows his signal, this type of mistake happens with probability $q(1-p)$. The difference between the utility that the agent obtains when a type O mistake occurs and that under transparency is $(B + w_{ne} - w)$. Now consider the second type of mistake. The probability with which it happens is given by $(1-q)(1-r)$, while the difference in the agent's utility from the transparency scenario is $(w - w_{ne})$.

Assume that $w > w_{ne}$: then the agent's failure to commit to transparency results in an opportunity gain (equal to $w - w_{ne}$) if the principal incurs a type N error and in an opportunity cost (given by $w - B - w_{ne}$) if the principal incurs a type O error[22]. If the probability with which type O error happens is higher than than with which type N occurs, by setting $w > w_{ne}$ the principal therefore increases the desirability of transparency.

The opposite occurs if $w_{ne} > w$: in that case, by failing to commit to transparency the agent incurs an opportunity cost (equal to $w_{ne} - w$) if the principal makes a type N mistake and an opportunity gain (given by $B + w_{ne} - w$) if the principal makes a type O mistake. Thus, if the probability with which a type N mistake takes place is higher than that with which a type O takes place, by setting $w_{ne} > w$ the principal increases the desirability of transparency.

The closer the ex-ante probabilities with which either type of mistake occurs, the higher the informational rents that the principal has to offer to induce the agent to commit. If these two probabilities are exactly the same, commitment cannot be induced. This arises from the fact that, because B is strictly positive:

· if $w > w_{ne}$ the agent minds type O error less than he benefits from type N:

$$\underset{\text{cost from type O error}}{w - w_{ne} - B} < \underset{\text{gain from type N error}}{w - w_{ne}} \tag{4.32}$$

· if $w_{ne} \geq w$, the agent benefits from type O error more than he suffers from type N:

$$\underset{\text{cost from type N error}}{w_{ne} - w} < \underset{\text{gain from type O error}}{B + w_{ne} - w} \tag{4.33}$$

Thus, if the probabilities with which the two errors take place are the same, the agent will always find it preferable not to commit to transparency. Notice that this will never be the case if either r or p is equal to one.

We now see why it is the case that the precision of the principal's signal affects the agent's incentives to commit only to the extent to which p and r are sufficiently far

[22]This follows from the fact that $w \geq B$.

apart. This happens because the difference between p and r affects $q(1-p)/(1-q)(1-r)$, the ratio of the probabilities of a type O to a type N error. If $p = r$, this ratio becomes entirely independent of the signal's precision. In that case, the informational rents that have to be offered in order to induce transparency only depend on the players' prior beliefs, summarized by the variable q. Generally, for p and r close to each other, the ratio of probabilities is close to $q/(1-q)$.

High/low priors

We now explore the situation in which, if the agent does not commit to transparency, the principal always adopts the new technology ($q > q^H$). This implies that the principal will never employ the agent. In that case, the agent will commit to transparency whenever

$$qw_{ne} + (1-q)w \geq w_{ne} + (1-q)B \tag{4.34}$$

i.e.

$$w \geq w_{ne} + B \tag{4.35}$$

The above condition can be met by setting $w_{ne} = 0$ and $w = B$. Thus, informational rents are not necessary to induce the agent to commit to transparency. Notice that, in terms of the incentives which need to be provided to induce commitment, the situation is equivalent to that where the principal follows his own signal, and $p = 1$ (i.e. the signal $s = O$ is perfectly informative). This is because, when $p = 1$, the only type of mistake which the principal may commit by following his own signal is a mistake of type N, the same as in the present case. The principal's expected profit from inducing transparency is given by

$$q\pi_N^* + (1-q)\left(\pi_O^* - B\right) \tag{4.36}$$

The principal's expected profit from adopting the new technology is on the other hand given by

$$qz_1 g(k^N)V - k^N \tag{4.37}$$

where $k^N \equiv \arg\max qz_1 g(k)V - k$. From the definition of π_N^*, this is always inferior to the expected profit the principal can gain by inducing commitment.

Finally, we consider the situation where if the agent does not commit to transparency, the principal always utilizes the old technology ($q < q^L$). In that case, the agent will commit whenever

$$qw_{ne} + (1-q)w \geq w \tag{4.38}$$

i.e.

$$w_{ne} \geq w \tag{4.39}$$

In order to induce information revelation, the principal has to offer the agent some informational rents when $\omega = N$. The least costly contract to achieve transparency is given by $w = w_{ne} = B$. Notice that, in terms of the incentives which need to be provided to induce commitment, the situation is equivalent to that where the principal follows his own signal, and $r = 1$ (i.e. the signal $s = N$ is perfectly informative). This is because, when $r = 1$, the only type of mistake which the principal may commit by following his own signal is a mistake of type O, the same as in the present case. Also, notice that the requirement that $w_{ne} = B$ corresponds to the lower bound on the informational rents required to induce commitment when the principal follows his own signal, and $q(1-p) > (1-r)(1-q)$ (case ii).

The principal's expected profit under commitment is given by $(1-q)\pi_O + q\left[\pi_N^* - B\right]$. The principal will find it optimal to pay the informational rent and induce truthtelling whenever

$$(1-q)(\pi_O^* - B) + q\left[\pi_N^* - B\right] \geq (\pi_O^* - B) \tag{4.40}$$

i.e.

$$\pi_N^* \geq \pi_O^* \tag{4.41}$$

From assumption 2 this is always the case. We conclude that if the principal does not condition his choice of technology on his signal the requirements necessary to ensure commitment are such that the principal always finds in his interest to meet them. This is summarized in the following proposition:

Proposition 5: *If the prior probability with which the new technology may be superior to the old one is sufficiently high/low, so that the principal's choice of technology in the absence of commitment does not depend upon the realization of his signal, or if the principal has no access to any signal, commitment always occurs at equilibrium. This implies that the principal's technology choice is always efficient.*

When the principal follows a fixed rule of technology adoption in the absence of transparency, mistakes can only be of one kind. For instance, when the principal would otherwise adopt the new technology, transparency prevents him from incurring in type O errors. Vice-versa, when the principal would otherwise adopt the old technology, transparency prevents him from making type N errors. In this case, commitment by the agent can always be induced by appropriately manipulating the contract on offer. This in contrast to the case where the principal follows his own signal. In that case, we have seen that if $q = q^*$ no contract exists which may induce commitment by the agent. Moreover, when the principal follows a fixed rule of adoption, the rents which induce commitment correspond to the lower bounds identified in the case where the principal follows his own signal. A situation where he has no access to external sources of information is thus more favorable for the principal than one where he has the option of consulting external advisors, who are however only imperfectly informed.

4.4 Concluding remarks

This paper studies the consequences and implications of the conflict of interests that exists between employers and employees in the presence of innovations that alter the set of skills involved in the production process. We find that, under some circumstances, this conflict is irreconcilable. A crucial role in deriving this result is played by the agent's outside opportunities in the labor market, and by the principal's ability (or lack of ability) to commit to keeping the agent employed even if the new technology is adopted. The implication of this result is that, when it comes to the efficient adoption of radical new technologies, larger firms, where ownership and expertise tend to be separated, are disadvantaged with respect to smaller, entrepreneurial firms. Indeed, our model predicts that agency problems may result in excessive conservatism, and reluctance with respect to change. Finally, we study the special case where it may be possible for the agent to ex-ante commit to transparency. We find that if the employer has access to an external source of information, efficiency may decrease.

4.5 Appendix

Informed potential employers

We consider the simplest possible case, in which only one perfectly informed potential employer (denoted by E) exists. We denote the value of output to E is given by V', which is possibly different form V. In every other respect, E is similar to P. Assume that the only contract that P can write with E is contingent on E's declaration[23]. Denote by t_i, $i = O, N$ the transfer that E receives if he declares the state of the world to be i. We investigate the possibility of E truthfully revealing his information.

In any truthtelling equilibrium, if E declares the state of the world to be N the principal adopts the new technology and does not employ the agent. In that case, when dealing with E, the agent does not have any outside option and is therefore ready to accept any (positive and) arbitrarily small payment. Thus, E's expected payoff when the state of the world is O but he declares it to be N is given by $z_O g(k_O)V' - k_O > 0$, where k_O is implicitly defined by $g'(k_O) = 1/z_O V'$. In any truthtelling equilibrium the contract between P and E must therefore satisfy

$$t_N \geq t_O \qquad \text{in state } N \tag{4.42}$$

$$t_O \geq t_N + z_O g(k_O)V' - k_O \quad \text{in state } O \tag{4.43}$$

This is clearly not possible.

Renegotiation-proof payment schemes

The optimality of offering a fixed payment when the agent is actively employed follows form the fact that the old technology's productivity is common knowledge and

[23] Allowing for more sophisticated contracts should not change the result (to be checked).

that the principal can perfectly monitor the agent.

We now show that any Pareto-optimal severance package takes the form of a lump sum payment. This can be seen as follows:

Consider the situation in which at date 6 the principal decides to adopt the new technology and, as a consequence, not to actively employ the agent. Assume that the agent's compensation package in that case consists of a fixed payment a and an extra payment b conditional on the good being delivered. The principal's total expected payoff is

$$z_1 g(\widehat{k})\,[V-b]-\widehat{k}-a \tag{4.44}$$

and the agent's expected payoff is

$$a+bz_1g(\widehat{k}) \tag{4.45}$$

where $\widehat{k}$ is implicitly defined by $g'(\widehat{k})=1/z_1\,[V-b]$

Now consider the scenario in which the principal buys his residual claimant rights back from the agent, against a fixed payment $F=bz_1g(\widehat{k})$[24]. In that case, the principal's expected payoff is given by

$$z_1g(k^*(z_1))V-k^*(z_1)-a-F \tag{4.46}$$

It is easy to verify that the principal prefers this second scenario whenever

$$\pi_N^*>z_1g(\widehat{k})V-\widehat{k} \tag{4.47}$$

By definition, $\pi_N^*\equiv\arg\max\,[z_1g(k)V-k]$, so the inequality necessarily holds. We conclude that a contract specifying $b>0$ is not renegotiation-proof, in the sense that it is not immune that Pareto-improving renegotiation.

Optimal w

We now show that any optimal contract must have $w\geq B_O$. If at time 2 the agent commits to transparency, or in any thruthelling equilibrium, if the state of the world

[24] Implying that the agent is as well off as before.

is O the principal would like to retain the agent. Thus, the optimal contract must necessarily specify $w \geq B_O$.

Now consider equilibria in which the agent does not commit to transparency and does not truthfully disclose his information at time 5. Because the principal can always ex-post refuse to actively employ the agent, we need only to consider the subgame in which the principal wishes to adopt the old technology, and makes a proposition to the agent at time 6. First, assume that $B_N \leq w < B_O$ and consider a separating equilibrium, in which the agent does not accept the offer if $\omega = O$ and accepts it if $\omega = N$. Clearly, this is not renegotiation-proof: if the agent refuses the offer the principal has an incentive to renegotiate the initial contract and offer $w \geq B_O$. Now consider a separating equilibrium in which the agent accepts the offer when $\omega = O$ and refuses it otherwise. In this case, upon refusal/acceptance the principal would optimally stick to his initial offer, which would make the agent's strategy suboptimal.

We are therefore left with pooling equilibria. Notice that from an ex-ante point of view, the pooling equilibrium in which the agent refuses the principal's offer in both states of the world is always (weakly) dominated by the one in which the agent always accepts. Acceptance in both states of the world is however optimal for the agent only if $w \geq B_O$.

Proof of proposition 3:

We only need to prove the following part: "*if $p = 1$, i.e. the signal $s = O$ is perfectly informative: transparency always occurs;* if $r = 1$, *i.e. the signal $s = N$ is perfectly informative: transparency occurs if and only if $(\pi_N^* - \pi_O^*) \geq B\frac{p}{1-p}$*".

Consider the case where $p = 1$. Then the principal can induce transparency by setting $w_{ne} = 0$, $w = B$. His expected profit from inducing transparency is therefore given by

$$q\pi_N^* + (1-q)(\pi_O^* - B) \tag{4.48}$$

while his expected profit from following his own signal is given by

$$[1 - \Pr(s = O)] \left(P_N^N z_1 g(k_N^N) V - k_N^N\right) + \Pr(s = O)(\pi_O^* - B) \tag{4.49}$$

when $p = 1$, $\Pr(s = O) = r(1-q)$, and $P_N^N = \frac{q}{1-r+rq}$ so the above expression can be written as

$$(1-r+rq)\left(\frac{q}{1-r+rq}z_1 g(k_N^N)V - k_N^N\right) + r(1-q)\left(\pi_O^* - B\right) \tag{4.50}$$

The principal induces transparency if

$$q\pi_N^* + (1-q)\left(\pi_O^* - B\right) \geq qz_1 g(k_N^N)V - (1-r+rq)\,k_N^N + r(1-q)\left(\pi_O^* - B\right) \tag{4.51}$$

i.e.

$$q\pi_N^* + \left(\pi_O^* - B\right)(1-q)(1-r) \geq qz_1 g(k_N^N)V - (1-r+rq)\,k_N^N \tag{4.52}$$

Because $(1-r+rq) > q$, a sufficient condition for this inequality to hold is that

$$q\pi_N^* + \left(\pi_O^* - B\right)(1-q)(1-r) \geq q\left(z_1 g(k_N^N)V - k_N^N\right) \tag{4.53}$$

From the definition of π_N^*, this is always the case.

We now consider the case where $r = 1$. When $r = 1$, $\Pr(s = O) = 1 - pq$ and $P_N^N = 1$. The principal's expected profit if he consults his own signal is therefore given by

$$pq\pi_N^* + (1-pq)\left(\pi_O^* - B\right) \tag{4.54}$$

Alternatively, the principal can induce truthtelling by setting $w = w_{ne} = B$. In that case, his expected profit is

$$q\pi_N^* + (1-q)\pi_O^* - B \tag{4.55}$$

The principal therefore finds it optimal to induce commitment if and only if

$$q\pi_N^* + (1-q)\pi_O^* - B \geq pq\pi_N^* + (1-pq)\left(\pi_O^* - B\right) \tag{4.56}$$

This can be rewritten as

$$q(1-p)\left(\pi_N^* - \pi_O^*\right) \geq pqB \tag{4.57}$$

i.e.

$$(\pi_N^* - \pi_O^*) \geq \frac{p}{1-p}B$$

■

Proof of proposition 4

We only need to prove that "*Provided that* $\frac{z_1}{z_0}$ *is sufficiently smaller than* $\frac{1}{1-r}$, Ω *is surely non-empty if* $\frac{z_1}{z_0} \geq \frac{1}{p}$.".

In order to do that, we explore the conditions under which, when $q = q^*$, the principal optimally follows his own signal, should the agent fail to commit to transparency.

Recall that $q^* \equiv \frac{1-r}{2-r-p}$; when $q = q^*$, therefore, $P_O^N = 1 - r$ and $P_N^N = p$.

When $s = N$, the principal therefore finds it optimal to adopt the new technology if

$$pz_1 g(k_N^N)V - k_N^N \geq \pi_O^* - B \tag{4.58}$$

Because $zg(k^*(z))V - k^*(z)$ is increasing in z, the above inequality surely holds if $pz_1 \geq z_0$, i.e. $z_1/z_0 \geq 1/p$.

When $s = O$, the principal finds it optimal to adopt the old technology if

$$(1-r)z_1 g(k_O^N)V - k_O^N \leq \pi_O^* - B \tag{4.59}$$

The necessary condition for this to be the case is that $(1-r)z_1 < z_0$. Provided that $z_0 - (1-r)z_1$ is sufficiently large with respect to B, this condition is also sufficient.■

Chapter 5

Concluding remarks

This thesis characterizes the impact of type-dependent outside options in adverse selection models, within the context of three separate settings. In each instance, we find that the properties of the equilibrium contract are considerably altered. As suggested by Lewis and Sappington (1989), type-dependent outside options introduce new incentives for the agent, which may countervail those arising in the standard model. Chapter 2 identifies the conditions under which an employer can generate such countervailing incentives by randomizing over the probability with which the employee is retained after the first period of employment. It is shown that this crucially depends on the way in which the impact of dismissal on the agent's employment prospects changes according to the agent's ability. Although it introduces ex-post inefficiencies, randomization may also equip the employer with the means to discriminate more easily among different worker types, and may therefore be optimal whenever this screening effect is sufficiently strong. In that case, the presence of type-dependent outside options increases the efficiency of the optimal contract.

This result is unfortunaly not generalizable. Chapter 3 identifies a setting where the presence of a type-dependent outside option - arising from the presence of another seller in the market - results in the principal introducing new types of distortions with respect to the scenario where he is the only seller. This is because the competitive pressure originating from the presence of a rival firm induces the principal to raise the quality of the goods offered to some types *above* its efficient level. The implication is that more competition may not necessarily be desirable.

Finally, chapter 4 studies a situation where the presence of type-dependent outside options may create a conflict of interests between the principal and the agent. The central question is then whether a contract between the two parties exists, which would re-align their interests. We find that this is never true within a reasonable class of contracts, implying that the equilibrium outcome may be inefficient with a positive probability. In that case, the presence of type-dependent outside options unambiguously decreases total welfare.

Together, these chapters confirm that, in the presence of type-dependent outside options, no general predictions can be made concerning the welfare properties of the equilibrium contract. Moreover, the equilibrium outcome is heavily affected by the properties of the agent's outside option - whether it increases or decreases with the agent's type, the steepness with which it does so, and so on. This suggests that a return to richer settings, where several parties simultaneously interact with each other, may be the only way to achieve sharper predictions.

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