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## Essays on The Optimality of Delaying Quality Tests and the Reverse Hold-up Problem

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To the Graduate Council:

I am submitting herewith a dissertation written by Natalia Gritsko entitled "Essays on The Optimality of Delaying Quality Tests and the Reverse Hold-up Problem." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

Rudy Santore, Major Professor

We have read this dissertation and recommend its acceptance:

William S. Neilson, Michael K. Price, Tracie Woidtke

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

# Essays on The Optimality of Delaying Quality Tests and the Reverse Hold-up Problem

A Dissertation Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Natalia Gritsko

May 2014

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## DEDICATION

This dissertation is dedicated to my family.

Thank you for all your love and support.

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# Abstract

This dissertation consists of two chapters that examine the optimality of delaying quality tests of new products and the effects of cancellation payments on the hold-up problem.

Chapter 1 analyzes the possibility of delaying quality testing of a new product when the market consists of an early adopter and a follower who receive some private information about the quality. In our social learning framework, delaying a test can lead to better informed decisions regarding conducting the test by the regulator because she, along with other market participants, gains more information about the product quality by observing early adopter's informative actions. Our results suggest that waiting can be optimal when testing costs are not extremely high or low, and when *ex ante* there is high probability that both consumers will buy a high quality product and abstain from buying a low quality product. However, once the opposite action by the early adopter is observed (e.g. buying what is likely to be a low quality product), this increases the probability of the follower taking the same action. This can result in high expected losses, and delaying the test becomes no longer optimal. It should be conducted in order to correct the follower's course of action.

Chapter 2 examines the effects of various levels of a fixed cancellation payment in a cost-plus type contract on the hold-up problem. The case of high cancellation payment that results in the agent making inefficiently high investment is referred to as the reverse hold-up problem and is of main interest. We also derive the levels of cancellation payment for which optimal level of investment by the agent can be

induced and for which a standard hold-up problem arises. We report the results of the laboratory experiment designed to test our theoretical predictions. We find that, in general, participants follow the equilibrium strategy, and when the cancellation payment is set sufficiently high, the principal is held up by the agent most of the time. We find no evidence of fairness concerns that could explain participants' choices.



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# Chapter 1

## Now, Tomorrow, or Never: The Optimality of Delaying Quality Tests

### 1.1 Introduction

When a new product is developed, it often has to go through quality and safety inspections prior to being introduced to the market. The government uses regulatory interventions and agencies such as the US Food and Drug Administration (FDA) to control quality and safety of various products like food, drugs, appliances, and devices. Such regulations can be associated with high costs of conducting them. Since the 1980s, the government has been trying to improve the effectiveness of regulations regarding food safety in order to reduce budget costs of government programs and to improve their efficiency (Jacobs, 1997). In some cases, however, the quality control is not performed until after a new product is introduced to the market. For example, in 2009 the FDA required formal approval of intranasal Zicam products due to long

lasting or sometimes even permanent loss of smell associated with its use after more than a hundred consumer reports<sup>1</sup>.

This paper studies the optimality of delaying quality testing of a new product of unknown quality in the market where consumers receive private imperfect information about its true quality. Delaying testing allows for additional information about the quality of the product to penetrate the market through early customers' informative decisions. By observing these decisions and inferring customers' private information, the regulator, who wants to maximize social welfare, is able to improve her estimate regarding the product's true quality and about later customers' behavior. Thus, our model allows not only the customers, but the regulator to learn from observing the consumers' actions when quality testing is delayed. As a result, she is able to make better informed decisions, and social welfare can be increased.

We explore the possibility of social learning when information becomes available on the market. Much of previous work that utilized social learning setting has focused on strategic firm's decisions that affect information transfers and social learning by future customers in order to maximize profits (Gill and Sgroi (2012), Liu and Schiraldi (2012), Gill and Sgroi (2008), Bose et al. (2006, 2008)). The only study we are aware of that considers the effects of a particular strategy on social welfare is paper by Sgroi (2002) which analyzes the consequences of forcing a subset of players to take actions before everybody else does. Our research is similar in a sense that optimal waiting allows for social learning. However, unlike their study, the social planner does not undertake any costly actions to enhance social learning in our paper.

We analyze a simple model of quality testing of the producer of a good with two groups of buyers (early adopters and followers<sup>2</sup>) who learn from each other's

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<sup>1</sup>[http://www.nbcnews.com/id/31388177/ns/health-cold\\_and\\_flu/t/nasal-spray-can-cause-loss-smell-fda-warns](http://www.nbcnews.com/id/31388177/ns/health-cold_and_flu/t/nasal-spray-can-cause-loss-smell-fda-warns)

<sup>2</sup>Two groups of consumers, leaders and followers, are considered in the model by Kircher and Postlewaite (2008). In their study, leaders emerge endogenously and their role is enhanced by the firms rewarding them with better service. The rest of the consumers are less knowledgeable and learn from observing the leaders' choices. In our paper, the group of leaders is given exogenously. Also, to simplify the analysis, we normalize the size of each group of consumers to one. Another

decisions. To simplify the analysis, we normalize the size of each group to one. The quality of the good is unknown to the buyers and the regulator<sup>3</sup> and can be either high or low. The buyers are Bayesian decision makers who take actions under incomplete and asymmetric information. Each decision maker's information set consists of some common prior belief about the true quality, her private signal, and the observed actions of the early adopters in the case when a decision maker is a follower. We assume that there are two time periods in the model. Thus, delaying a test implies conducting it only after observing certain early adopter's purchasing decisions. It is assumed that regulation fully reveals the true quality.

Delayed testing can be welfare enhancing by allowing to incur high testing costs only when there is a need for it. Observing the early adopter's purchasing decision provides additional information to the follower about the quality of the good. It increases her probability to buy it when the early adopter buys which is the optimal course of action when the product is of high quality. Similarly, after observing the early adopter abstaining from buying the good, the follower is more likely to abstain as well, which is optimal when the good is of low quality. In both cases, there is no need for testing, and costs associated with it can be avoided. On the other hand, after seeing the first consumer buying (not buying) what is more likely to be a low (high) quality product, the follower will do the same either with some positive probability or always. The social planner should intervene and correct the follower's actions by revealing the true quality.

The economic research on quality and safety control concentrates a lot on methods to measure costs and benefits related to safety issues (Antle (1999), Kolstad et al. (1990), Hammitt (2005)). Several papers study factors that affect product quality levels. Hamilton et al. (2003) develop a model that explains how public support for product quality regulations depends on preferences for private and public goods.

---

difference form Kircher and Postlewaite (2008) is that we analyze the optimal actions by the social planner rather than firms.

<sup>3</sup>We abstract away from a firm's ability to convey information about the quality of its products by developing reputation (Shapiro (1983)).

Marette et al. (2000) consider specific policy instruments (minimum safety standards, labeling, etc.) and show that they have different effects on the safety of the products supplied on the market and on the overall welfare, depending on the information structure. Our paper concentrates on the optimal timing of quality control among other aspects of quality regulation.

This paper is also related to the literature on audit mechanisms and firms' compliance. Among recent studies, Liu and Neilson (2009) analyze the dynamic audit mechanism with fixed enforcement budget and conclude that it makes leverage effect more prominent by evoking tournaments among firms. Gilpatric et al. (2011) develop two models of endogenous audit in which the regulator evaluates firms' relative compliance levels in order to select some of them for audit. One model assumes firms selection based on rank with regulator's auditing resources being fixed and commonly known. The second model is more general as it assumes that probability of being audited depends on how a firm's compliance compares to the average compliance of the peers. In this case, the audit capacity is not fixed meaning it is not known to the firms. Our paper explores the possibility of delayed regulation in the absence of budget constraints. We expect that having a limited budget would reinforce the finding that waiting may be optimal.

This paper is organized as follows. Section 1.2 provides the model setup. Section 1.3 considers an optimistic case and provides the conditions under which the set of testing costs exists such that delaying a test is optimal. Section 1.4 analyzes a pessimistic case and establishes the conditions under which there is a set of testing costs for which delaying a test is the best choice. Section 1.5 offers some conclusions.

## 1.2 Model

Consider two groups of risk-neutral buyers: early adopters and followers. For simplicity of the analysis, we are going to assume that each group consists of one representative consumer  $i = 1, 2$ . Each consumer makes a binary action choice every



time period whether to purchase a good of unknown quality which corresponds to action  $B$ , or not purchase which corresponds to action  $NB$ . The number of periods is 2, let  $t \in [1, 2]$  denote the time period. The quality of the good is unknown to the buyers, however, it is commonly known to be of high quality ( $Q_H$ ) with probability  $\alpha$ , or low quality ( $Q_L$ ) with probability  $1 - \alpha$ .

We follow Gill and SgROI (2012) by assuming that the good is produced by a monopolist who knows its true quality, but is not able to verifiably deliver this information to the consumers since a low-quality monopolist can costlessly mimic a high-quality monopolist. The price of the good of unknown quality is  $P^4$  and  $V_H > P > V_L$ , where  $V_H$  is the value of high quality good,  $V_L$  is the value of low quality good. We assume that price is fixed because the time periods are sufficiently short and it is too costly to change the price often. Consumption is more rewarding when the good is of high quality, while not purchasing is better when it is of low quality. The payoffs are given by  $M(B|Q_H) = V_H - P$ ,  $M(B|Q_L) = V_L - P$ ,  $M(NB|Q_H) = M(NB|Q_L) = 0$ . Without loss of generality we will normalize the values:

$$\frac{V_H - V_L}{V_H - V_L} > \frac{P - V_L}{V_H - V_L} > \frac{V_L - V_L}{V_H - V_L},$$

and redefine the price as  $p = \frac{P - V_L}{V_H - V_L}$ . Then  $1 > p > 0$ , and the payoffs become  $M(B|Q_H) = 1 - p$ ,  $M(B|Q_L) = -p$ . If no other information was available to the consumers, then buying would be optimal when  $\alpha > p$ .

We assume that each buyer  $i$  receives a private informative signal about the quality of the good. Private signals are independent conditional on the true quality of the product. The signal can be high ( $s_H$ ) or low ( $s_L$ ), with the high signal being observed with probability  $\gamma$  when the product is of high quality, and with probability  $1 - \gamma$  otherwise, i.e.  $P(s_H|Q_H) = P(s_L|Q_L) = \gamma$ , and  $P(s_H|Q_L) = P(s_L|Q_H) = 1 - \gamma$ , where  $\gamma > \frac{1}{2}$ . The private signal is assumed to be imperfect, i.e.  $\gamma < 1$ .

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<sup>4</sup>Bikhchandani, et al. (1992), Gill and SgROI (2008), Liu and Schiraldi (2012), SgROI (2002) assume fixed cost of adoption of a new product.

There is a regulator in the model who can perform a quality testing of the producer of the good at fixed cost  $c$ . It is assumed that the quality testing can perfectly reveal the true quality of the product. For example, if it is conducted before anybody has made a decision, then the true quality of the product is revealed to both buyers and they buy only if the quality is  $Q_H$ . Testing prevents two purchasing decisions when the true quality of the good is low or it induces purchasing decisions when the true quality of the good is high. The regulator has to choose an optimal rule, i.e. she has to decide whether to test before anybody has made a decision at  $t = 0$ , at  $t = 1$ , or never test.

Given the above notation, we can define the early adopter's posterior beliefs about the true quality of the good after receiving a high or a low signal:

$$Pr(Q_H|s_H) = \frac{\alpha\gamma}{\alpha\gamma + (1 - \alpha)(1 - \gamma)},$$

$$Pr(Q_H|s_L) = \frac{\alpha(1 - \gamma)}{\alpha(1 - \gamma) + (1 - \alpha)\gamma}.$$

The signal of the early adopter is not observable by the follower, however, she can perfectly observe the early adopter's purchasing decision. When the product price is not extremely high or low, the early adopter makes a decision based entirely on her signal, thus the follower can infer the signal from the observed action of the predecessor. The follower's posterior beliefs about the true quality of the good after receiving a high or a low signal given the early adopter's signal are

$$Pr(Q_H|s_H, s_H) = \frac{\alpha\gamma^2}{\alpha\gamma^2 + (1 - \alpha)(1 - \gamma)^2},$$

$$Pr(Q_H|s_H, s_L) = Pr(Q_H|s_L, s_H) = \frac{\alpha\gamma(1 - \gamma)}{\alpha\gamma(1 - \gamma) + (1 - \alpha)\gamma(1 - \gamma)} = \alpha,$$

$$Pr(Q_H|s_L, s_L) = \frac{\alpha(1-\gamma)^2}{\alpha(1-\gamma)^2 + (1-\alpha)\gamma^2}.$$

A consumer will buy the product if her expected payoff from it is positive. If we denote the posterior probability that the product is of high quality after a given signal or a sequence of signals as  $\mu$ , then a consumer's purchasing decision is defined by

$$\mu > p.$$

A consumer's purchasing decision depends not only on her private signal, but also on the price of the product. However, when the price is extremely high or low, the signal becomes irrelevant to the consumer's decision, and she either always buys the product or always abstains from buying. This holds for both the early adopter and the follower. Such actions carry no information, and the regulator will not gain better knowledge about the quality by observing them. Thus delaying the test in this case is never optimal.

By considering all possible signals observed by both consumers we obtain four cases which are going to be characterized below (see *Appendix*). Signals matter for the consumers' decisions when the price is not extreme. The early adopter makes her purchasing decision based on her private signal. It is also the case for the follower when her private signal coincides with that of the early adopter. When there are two contradicting signals, the follower may or may not buy the product. We call the case optimistic if she does, and we call it pessimistic otherwise.

*Case 1.* When the product's price  $p$  is less than  $\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}$ , the first consumer will buy the product even if her signal is  $s_L$ . The second consumer is not able to obtain any additional information from such action. She finds herself in the position of the first consumer, thus her decision will be based entirely on her own signal. She will purchase the product even if her signal is  $s_L$ .

*Case 2.* When  $p$  belongs to  $[\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}, \alpha]$ , the first consumer follows her signal. The second consumer buys when both signals are  $s_H$  or when her signal contradicts the signal of the first consumer, and she abstains from buying if both consumers receive  $s_L$ . We will refer to *Case 2* as the optimistic case.

*Case 3.* When  $p$  belongs to  $(\alpha, \frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}]$ , the first consumer follows her signal. The second consumer buys when both consumers receive  $s_H$ , and she abstains from buying when signals are contradicting or when both signals are  $s_L$ . We will refer to *Case 3* as the pessimistic case.

*Case 4.* When  $p$  is greater than  $\frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}$ , the first consumer abstains from buying even if her signal is  $s_H$ . Similar to *Case 1*, the second consumer is not receiving any new information by observing such action, and she will make her decision based only on her private signal. She will abstain from buying even if her signal is  $s_H$ .

We are going to analyze optimistic and pessimistic cases. In both cases, the regulator has the following options of when to test the good: before the early adopter has made a decision at  $t = 0$ , after the early adopter has bought it, after the early adopter has abstained from buying, or never test.

For cases 2 and 3 we are going to establish the conditions under which delayed testing is optimal. Cases 1 and 4 are trivial since the regulator's decision options reduce to either testing at  $t = 0$  or never<sup>5</sup>.

## 1.3 Optimistic Case

We first consider the optimistic case which is defined by the follower's decision to purchase the good if the signals received by the early adopter and the follower are opposite. We define the expected payoffs from four decision options that the regulator has. The notation is as follows:  $OP^{t=0}$  is the total expected payoff resulting

---

<sup>5</sup>The regulator's choice will be determined by the level of cost  $c$ . In *Case 1*, testing is better than no testing if  $c \leq 2(1-\alpha)p$ , or when the cost of testing is no greater than the expected loss resulting from purchases of a low quality good. In *Case 4*, it has to be that  $c \leq 2\alpha(1-p)$  for the testing to be optimal, or when testing cost is no greater than the expected gain that could have been obtained if a high quality good was purchased.

from testing prior to the early adopter's decision,  $OP^{1B}$  is the total expected payoff resulting from testing conditional on the early adopter decision to buy,  $OP^{1NB}$  is the total expected payoff resulting from testing conditional on the early adopter decision to not buy, and  $OP^{No}$  is the total expected payoff when there is no test performed.

$$OP^{t=0} \equiv 2\alpha(1-p) - c,$$

$$OP^{1B} \equiv \alpha(1-p)[3\gamma - \gamma^2] - (1-\alpha)p[1 - \gamma^2] - [\alpha\gamma + (1-\alpha)(1-\gamma)]c,$$

$$OP^{1NB} \equiv \alpha(1-p)[1 + \gamma] - (1-\alpha)p[2 - 2\gamma] - [\alpha(1-\gamma) + (1-\alpha)\gamma]c,$$

$$OP^{No} \equiv \alpha(1-p)[3\gamma - \gamma^2] - (1-\alpha)p[2 - \gamma - \gamma^2],$$

### 1.3.1 Testing After the Early Adopter Buys

In this section we derive the conditions under which the regulator performs a test if and only if the early adopter buys the product. We start with establishing the threshold levels of testing costs for which performing a test after the early adopter's decision to buy dominates testing before anybody has made their decisions or never testing. We denote these threshold levels  $\underline{c}_{1B}$  and  $\bar{c}_{1B}$  respectively<sup>6</sup>:

$$\underline{c}_{1B} = \frac{(1-\gamma)[\alpha(2-\gamma)(1-p) + (1-\alpha)(1+\gamma)p]}{Y},$$

$$\bar{c}_{1B} = \frac{(1-\gamma)(1-\alpha)p}{1-Y},$$

where  $Y \equiv \alpha + \gamma - 2\alpha\gamma$  and  $Y \in (0, 1)$ . Thus, delaying a test until the first consumer buys dominates testing at  $t = 0$  when the cost is sufficiently high  $c > \underline{c}_{1B}$ , and it dominates no testing when the cost is sufficiently low  $c < \bar{c}_{1B}$ . Note that when  $\underline{c}_{1B} \geq \bar{c}_{1B}$ , delayed testing is dominated by the other two options: testing at  $t = 0$  or never. Proposition 1.1 provides the conditions under which  $\underline{c}_{1B} < \bar{c}_{1B}$ .

---

<sup>6</sup> $\underline{c}_{1B}$  is derived by setting  $OP^{t=0} = OP^{1B}$ ,  $\bar{c}_{1B}$  is derived by setting  $OP^{No} = OP^{1B}$

**Proposition 1.1.** *There exists a range of costs  $(\underline{c}_{1B}, \bar{c}_{1B})$  for which testing after the early adopter buys is optimal in the optimistic case when the following conditions are satisfied:*

$$p \in (p_{1B}^*, \alpha], \quad (1.1)$$

$$\text{where } p_{1B}^* = \frac{\alpha(2-\gamma)(1-Y)}{(1-\alpha)Y + (3\alpha - \gamma - 1)(1-Y)}, \quad (1.2)$$

$$\alpha < \frac{3-4\gamma}{4-8\gamma}, \quad (1.3)$$

$$\gamma > 0.75. \quad (1.4)$$

*Proof.* We first are going to derive the condition on price for which the range of costs  $(\underline{c}_{1B}, \bar{c}_{1B})$  exists. It has to be that  $\underline{c}_{1B} < \bar{c}_{1B}$ , or

$$\frac{(1-\gamma)[\alpha(2-\gamma)(1-p) + (1-\alpha)(1+\gamma)p]}{Y} < \frac{(1-\gamma)(1-\alpha)p}{1-Y},$$

which holds when  $p > p_{1B}^*$ .

Since the optimistic case is defined by the range of prices  $[\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}, \alpha]$ , it has to be the case that  $p_{1B}^*$  is smaller than the upper bound  $\alpha$ . This holds when  $\alpha < \frac{3-4\gamma}{4-8\gamma}$ . Since  $\alpha \in (0, 1)$ , there exists a value of  $\alpha$  that satisfies the latter inequality when  $\gamma > \frac{3}{4}$ .

Also,  $p_{1B}^*$  is greater than the lower bound  $\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}$ <sup>7</sup>, and thus  $p > p_{1B}^*$  is binding condition on price.

We now are going to show that for  $c \in (\underline{c}_{1B}, \bar{c}_{1B})$  the regulator performs a test if and only if the first consumer buys the product. It has to be that  $OP^{1B} > OP^{1NB}$  for testing after the first consumer's decision to buy to be the optimal strategy. This holds when

$$c > \frac{(1-\gamma)^2(p-\alpha)}{(2\gamma-1)(2\alpha-1)} (\equiv c'). \quad (1.5)$$

---

<sup>7</sup>  $p_{1B}^* > \frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}$  for  $\alpha > \frac{-2\gamma^3+3\gamma^2-1}{(1-2\gamma)(2\gamma^2-\gamma-2)}$  which always holds because the right-hand side of the latter inequality is negative.

Note that  $c' < \underline{c}_{1B}$  when

$$p > \frac{\alpha(2 - \gamma)(2Y - 1) - \alpha(1 - \gamma)Y}{(1 - \gamma)Y + (2Y - 1)\alpha(2 - \gamma) - (1 - \alpha)(1 + \gamma)}, \quad (1.6)$$

which is always satisfied because the right-hand side of (1.6) is less than zero when conditions (1.3) and (1.4) hold. Also note that according to condition (1.1),  $p > p_{1B}^* > 0$ . Thus, when  $(\underline{c}_{1B}, \bar{c}_{1B})$  exists and  $c$  belongs to that range, condition (1.5) is satisfied and testing after the first consumer has bought is the best strategy.  $\square$

Having the price set high enough in accordance with condition (1.1) will justify any testing cost in the range  $(\underline{c}^{1B}, \bar{c}^{1B})$  since the expected net loss from delayed testing is given by  $(1 - \alpha)(1 - \gamma)p$  and is increasing in  $p$ . Conditions (1.3) and (1.4) imply that waiting for the first  $B$  decision is optimal if the precision of the buyers' signals is sufficiently high and the probability that the true quality of the good is  $Q_H$  is low. This implies that *ex ante* probability that the buyers will abstain from buying potentially low quality good is high. The expected losses are low in this case. This explains why the regulator prefers to wait for the early adopter to act instead of testing the good at  $t = 0$ . However, once the early adopter has purchased, the follower will update her beliefs given that choice, and *ex post* it is certain in this optimistic case that she will also buy potentially low quality good. The expected losses increase. This induces the regulator to step in and choose delayed testing over no testing in order to avoid high expected losses.

### 1.3.2 Testing After the Early Adopter Does Not Buy

In this section we derive the conditions under which the regulator conducts a test in the optimistic case if and only if the early adopter abstains from buying the product. As in previous subsection, we start with establishing the threshold levels of testing costs for which a test after the first consumer's decision to abstain dominates a test

before she has made her decision or no test at all. We use  $\underline{c}_{1NB}$  and  $\bar{c}_{1NB}$  to denote these two levels respectively:

$$\underline{c}_{1NB} = \frac{(1 - \gamma)[\alpha(1 - p) + 2(1 - \alpha)p]}{1 - Y},$$

$$\bar{c}_{1NB} = \frac{(1 - \gamma)[\alpha(1 - \gamma)(1 - p) + (1 - \alpha)\gamma p]}{Y}.$$

The threshold levels determine three ranges of testing costs such that for  $c > \underline{c}_{1NB}$  waiting until the early adopter has abstained to test is better than testing at  $t = 0$ , and for  $c < \bar{c}_{1NB}$  such waiting is preferred over no test. Proposition 1.2 provides the conditions under which the range of costs exists for which waiting for the first consumer's decision to not buy is optimal in the optimistic case.

**Proposition 1.2.** *There exists a range of costs  $(\underline{c}_{1NB}, \bar{c}_{1NB})$  for which testing after the early adopter has abstained from buying is optimal in the optimistic case when one of two sets of conditions in Table 1.1 is satisfied.*

**Table 1.1** Conditions for Proposition 1.2.

Condition on $p$	Condition on $\alpha$	Condition on $\gamma$
$p \in (p_{1NB}^*, \alpha]$	$\alpha \in (\frac{1-4\gamma}{4-8\gamma}, \frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)})$	$\gamma > 0.75$
$p \in [\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}, \alpha]$	$\alpha \geq \frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)}$	$\gamma > \frac{1}{4}(-1 + \sqrt{17})$

$$\text{where } p_{1NB}^* = \frac{\alpha[Y - (1 - \gamma)(1 - Y)]}{\alpha[Y - (1 - \gamma)(1 - Y)] + (1 - \alpha)[\gamma(1 - Y) - 2Y]}. \quad (1.7)$$



*Proof.* We first are going to derive the condition on price for which the range of costs  $(\underline{c}_{1NB}, \bar{c}_{1NB})$  exists. It has to be that  $\underline{c}_{1NB} < \bar{c}_{1NB}$ , or

$$\frac{(1-\gamma)[\alpha(1-p) + 2(1-\alpha)p]}{1-Y} < \frac{(1-\gamma)[\alpha(1-\gamma)(1-p) + (1-\alpha)\gamma p]}{Y},$$

which holds for  $p > p_{1NB}^*$ .

Prices that satisfy the condition  $p > p_{1NB}^*$  have to be in the range of  $[\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}, \alpha]$  for the optimistic case. If  $p_{1NB}^*$  is greater than the upper bound, then no value of price exists in the optimistic scenario for which  $\underline{c}_{1NB} < \bar{c}_{1NB}$ . Thus,  $p_{1NB}^*$  has to be smaller than the upper bound  $\alpha$ , which holds when

$$\alpha > \frac{1-4\gamma}{4-8\gamma}. \quad (1.8)$$

Since  $\alpha \in (0, 1)$ , there exists a value of  $\alpha$  which satisfies condition (1.8) when  $\gamma > 0.75$ .

Whether the lower bound  $\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}$  or  $p_{1NB}^*$  is greater depends on the level of prior probability  $\alpha$ . In particular, the value of  $p_{1NB}^*$  is greater and condition  $p > p_{1NB}^*$  is binding when  $\alpha < \frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)}$ <sup>8</sup>. Latter condition on  $\alpha$  together with condition (1.8) limit the range of values that  $\alpha$  can take, and together with price range and condition on  $\gamma$  establish the first set of conditions for the range of costs  $(\underline{c}_{1NB}, \bar{c}_{1NB})$  to exist.

The lower bound  $\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}$  becomes binding when  $\alpha > \frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)}$ . This condition on  $\alpha$  is stricter than condition (1.8), and it can be satisfied only when  $\gamma$  is greater than  $\frac{1}{4}(-1 + \sqrt{17})$ <sup>9</sup>. This results in the second set of conditions for the range of costs  $(\underline{c}_{1NB}, \bar{c}_{1NB})$  to exist.

We now are going to show that for  $c \in (\underline{c}_{1NB}, \bar{c}_{1NB})$  the regulator performs a test if and only if the first consumer does not buy the product. It has to be that  $OP^{1NB} > OP^{1B}$  for testing after the early adopter has abstained to be the optimal

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<sup>8</sup>Note, that  $\frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)} > \frac{1-4\gamma}{4-8\gamma}$  for  $\gamma > 0.75$ .

<sup>9</sup>When  $\gamma \leq \frac{1}{4}(-1 + \sqrt{17})$ , the condition on  $\alpha$  is not satisfied because  $\frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)} \geq 1$ .

strategy. This holds when

$$c > c'. \quad (1.9)$$

Note that  $p \leq \alpha$  since this is the optimistic case, thus the numerator of  $c'$  is no greater than zero. Also,  $\alpha > \frac{1-4\gamma}{4-8\gamma} > \frac{1}{2}$ , thus the denominator of  $c'$  is positive. Condition (1.9) holds for any  $c$ , and testing after the first customer's decision to not buy is the best strategy

□

According to the above results, endogenous testing after the early adopter has abstained from buying the good is an optimal strategy when price is high enough, however, Proposition 1.2 allows for a larger range of prices compared to the case of testing after the first consumer's buying decision. Intuitively, testing after first NB decision not only allows to avoid the expected loss of  $(1 - \alpha)\gamma(1 - \gamma)p$  resulting from buying a low quality good, but also generates the expected gain of  $\alpha(1 - \gamma)^2(1 - p)$  from buying a high quality good which otherwise would not be purchased because of two consecutive low signals. The expected gain is decreasing in price, and the avoided loss is increasing in price. For higher values of prior probability  $\alpha$ , the effect of gain may dominate and lower values of price may be optimal. Thus, a greater range of possible values of  $p$  is justified.

The signal has to be precise enough and the prior probability has to be sufficiently high for the delayed test after the early adopter has abstained to be preferred. *Ex ante* the expected losses resulting from not testing are low since a high signal will be received with high probability when the product is good. The early adopter is more likely to buy it. However, after she receives a low signal and does not buy the good, the regulator tries to avoid *ex post* high losses to the follower which come from not gaining the benefit of buying in the good state after observing a low signal, and from a buying decision in the bad state after observing a high signal.

Propositions 1.1 and 1.2 establish the conditions under which there exist two ranges of costs such that delayed quality testing is optimal. However, these two ranges

cannot exist simultaneously because the conditions in Proposition 1.1 and Proposition 1.2 are mutually exclusive. Only one of the two strategies can be optimal at a time. In particular, we consider two conditions on  $\alpha$ : condition (1.3) from Proposition 1.1 and the less strict condition on the lower bound of  $\alpha$  from Proposition 1.2:

$$\alpha < \frac{3 - 4\gamma}{4 - 8\gamma} \qquad \alpha > \frac{1 - 4\gamma}{4 - 8\gamma},$$

where  $\frac{3-4\gamma}{4-8\gamma} < \frac{1-4\gamma}{4-8\gamma}$  for  $\gamma > 0.75$ . If, for example, the value of  $\alpha$  satisfies condition (1.3), then it may be optimal to wait for the first purchasing decision to conduct quality testing, but it will never be optimal to conduct it if the first observed decision was to abstain from buying. This can be explained by sufficiently low prior probability that the product is of high quality and sufficiently precise consumer signals, which together imply that NB is more likely to be a socially optimal decision, and in this case no regulator's intervention is needed after observing it.

Table 1.2 provides numerical examples which compare the welfare resulting from all testing decisions by the regulator in the optimistic case for given parameter values. Notice that when testing after the first consumer's purchasing decision is optimal, testing after the first abstaining decision results in the smallest total payoffs. The opposite holds for the case when testing after the first consumer has abstained is optimal.

## 1.4 Pessimistic Case

We now turn to the discussion of the optimality of the delayed testing in the pessimistic case. This case is determined by the follower's decision to abstain from buying the good of unknown quality when conflicting signals are received by the early adopter and the follower. We start with defining the expected payoffs resulting from the regulator's four testing decisions.  $PP$  is used to denote pessimistic payoff and the

**Table 1.2** Total expected payoffs for given parameter values in the optimistic scenario.

	After 1B		After 1NB	
$\gamma$	0.78	0.9	0.78	0.9
Condition on $\alpha$	$\alpha < 0.054$	$\alpha < 0.188$	$\alpha \in (0.946, 1.001)$	$\alpha \geq 0.949$
$\alpha$	0.01	0.1	0.99	0.99
Price range	(0.0074, 0.01]	(0.044, 0.1]	(0.973, 0.99]	(0.917, 0.99]
$p$	0.009	0.1	0.98	0.98
$\underline{c}$	0.0079	0.033	0.0112	0.0044
$\bar{c}$	0.0087	0.05	0.0117	0.01
$c$	0.008	0.04	0.0115	0.005
$OP^{t=0}$	0.01182	0.140	0.0281	0.0346
$OP^{No}$	0.01171	0.144	0.0282	0.0345
$OP^{1B}$	<b>0.01187</b>	<b>0.146</b>	0.0215	0.0311
$OP^{1NB}$	0.00752	0.120	<b>0.0283</b>	<b>0.0351</b>

Note: The numbers in bold demonstrate the dominance of delayed testing over testing at  $t=0$  and no testing at all since the resulting total expected payoff is the highest.

superscripts are defined the same way as in the optimistic case.

$$PP^{t=0} \equiv 2\alpha(1-p) - c,$$

$$PP^{1B} \equiv 2\alpha(1-p)\gamma - (1-\alpha)p[1-\gamma] - [\alpha\gamma + (1-\alpha)(1-\gamma)]c,$$

$$PP^{1NB} \equiv \alpha(1-p)[1+\gamma^2] - (1-\alpha)p[2-3\gamma+\gamma^2] - [\alpha(1-\gamma) + (1-\alpha)\gamma]c,$$

$$PP^{No} \equiv \alpha(1-p)[\gamma+\gamma^2] - (1-\alpha)p[2-3\gamma+\gamma^2],$$

### 1.4.1 Testing After the Early Adopter Buys

Similar to the optimistic case, we derive the conditions under which the regulator performs a test if and only if the early adopter buys the product. A test after the early adopter has bought is optimal when the value of testing cost belongs to some interval  $(\underline{s}_{1B}, \bar{s}_{1B})$ , where :

$$\underline{s}_{1B} = \frac{(1-\gamma)[2\alpha(1-p) + (1-\alpha)p]}{Y},$$

$$\bar{s}_{1B} = \frac{(1-\gamma)[\alpha\gamma(1-p) + (1-\alpha)(1-\gamma)p]}{1-Y}.$$

Delaying the test until the first consumer buys in this pessimistic case dominates testing at  $t = 0$  when  $c > \underline{s}_{1B}$ , otherwise the test would be cheap enough to be conducted early. Waiting dominates the option of no testing when  $c < \bar{s}_{1B}$ , otherwise it becomes too costly to perform any tests. When  $\underline{s}_{1B} \geq \bar{s}_{1B}$ , delayed testing is dominated by the other two strategies. Proposition 1.3 provides the conditions under which  $\underline{s}_{1B} < \bar{s}_{1B}$ .

**Proposition 1.3.** *There exists a range of costs  $(\underline{s}_{1B}, \bar{s}_{1B})$  for which testing after the early adopter buys is optimal in pessimistic case when one of two sets of conditions in Table 1.3 is satisfied:*

**Table 1.3** Conditions for Proposition 1.3.

Condition on $p$	Condition on $\alpha$	Condition on $\gamma$
$p \in (\alpha, \tilde{p}_{1B})$	$\alpha \in (\frac{2\gamma^3 - \gamma^2 - 3\gamma + 2}{(1-2\gamma)(-2\gamma^2 + \gamma + 2)}, \frac{3-4\gamma}{4-8\gamma})$	$\gamma > 0.75$
$p \in (\alpha, \frac{\alpha\gamma}{\alpha\gamma + (1-\alpha)(1-\gamma)}]$	$\alpha \leq \frac{2\gamma^3 - \gamma^2 - 3\gamma + 2}{(1-2\gamma)(-2\gamma^2 + \gamma + 2)}$	$\gamma > 0.781$

$$\text{where } \tilde{p}_{1B} = \frac{\alpha(2(1-Y) - \gamma Y)}{(1-\alpha-\gamma)Y + (3\alpha-1)(1-Y)}. \quad (1.10)$$

*Proof.* See Appendix A. □

Consumers with sufficiently precise signals are likely to avoid buying the product which is likely to be bad. This justifies waiting by the regulator: if the early adopter does not buy, the follower will abstain with certainty, and no testing is necessary. If, however, the first buyer observes a high signal, she is going to buy the good, which will trigger a purchasing decision by the follower if her signal is also high. The expected losses from this decision pattern become high, and the regulator is going to chose to incur the cost of conducting a test in order to avoid the expected losses leading to a decrease in the social welfare.

The price of the good has to be sufficiently low to justify any cost of testing  $c \in (\underline{s}_{1B}, \bar{s}_{1B})$ . However, Proposition 1.3 allows for greater range of prices compared to the condition on price defined for the case of testing after the first NB decision (section 1.4.2). The benefit of endogenous testing after the first B decision,  $\alpha\gamma(1-\gamma)(1-p) + (1-\alpha)(1-\gamma)^2p$ , includes the expected gain from buying a good of high quality and the avoided expected loss from buying a good of low quality. The former is decreasing in price, while the latter is increasing in price. Thus, values of  $p$  in the upper range may be optimal if the effect of avoiding the loss dominates. This is

unlike the case of testing after the first consumer's has abstained from buying, when the benefit is comprised of the gain only.

### 1.4.2 Testing After the Early Adopter Does Not Buy

In this section we establish the conditions under which the regulator performs a test if and only if the early adopter does not buy the product. To begin, we define two threshold levels of testing cost:

$$\underline{s}_{1NB} = \frac{(1 - \gamma)[\alpha(1 + \gamma)(1 - p) + (1 - \alpha)(2 - \gamma)p]}{1 - Y},$$

$$\bar{s}_{1NB} = \frac{(1 - \gamma)\alpha(1 - p)}{Y}.$$

Delaying a test until the first consumer's decision to not buy in this pessimistic case dominates testing at  $t = 0$  when  $c > \underline{s}_{1NB}$ , and it dominates the option of no testing when  $c < \bar{s}_{1NB}$ . When parameters of the model are such that  $\underline{s}_{1NB} \geq \bar{s}_{1NB}$ , waiting is not optimal. Proposition 1.4 provides the conditions under which  $\underline{s}_{1NB} < \bar{s}_{1NB}$ .

**Proposition 1.4.** *There exists a range of costs  $(\underline{s}_{1NB}, \bar{s}_{1NB})$  for which testing after the early adopter has abstained from buying is optimal in the pessimistic case when the following conditions are satisfied:*

$$p \in (\alpha, \tilde{p}_{1NB}), \tag{1.11}$$

$$\text{where } \tilde{p}_{1NB} = \frac{\alpha((\gamma + 1)Y - (1 - Y))}{\alpha((\gamma + 1)Y - (1 - Y)) - (1 - \alpha)(2 - \gamma)Y}, \tag{1.12}$$

$$\alpha > \frac{1 - 4\gamma}{4 - 8\gamma}, \tag{1.13}$$

$$\gamma > 0.75. \tag{1.14}$$

*Proof.* See Appendix A.

□

Testing after the early adopter's decision to abstain can be optimal when the cost of adoption is sufficiently low because such testing allows to obtain additional expected benefit  $\alpha(1-\gamma)(1-p)$ . This benefit arises due to the change in the follower's purchasing decision: she would have followed the early adopter's choice to not buy unless she learned that the true quality of the good is high. The benefit is decreasing in  $p$ , thus lower price will lead to greater increase in the expected payoff resulting from delayed testing.

According to Proposition 1.4, waiting until the first consumer abstains is optimal when the signal precision, the prior probability that the true quality of the good is  $Q_H$ , and potential losses from not purchasing a high quality product are sufficiently high. In this pessimistic case, when the first consumer abstains from buying, the follower is not going to buy even if her signal is  $s_H$ . Even though *ex ante* it is more likely that the early adopter receives a high signal and ends up buying the good, *ex post* after her low signal, the follower will not buy as well, thus the expected losses increase. This provides the incentive for the regulator to conduct the test in order to avoid high expected losses.

Similar to the optimistic case, Propositions 1.3 and 1.4 establish the conditions under which there exist two ranges of costs such that delayed quality testing is dominating, and these conditions cannot be satisfied simultaneously. Thus only one strategy of delayed testing can be optimal.

Table 1.4 provides numerical examples which compare the welfare resulting from four testing decisions by the regulator in the pessimistic case for given parameter values. Testing after the first abstaining decision results in the smallest total payoffs when testing after the first purchasing decision is optimal. The opposite holds for the case when testing after the early adopter does not buy is optimal.

We can discuss the situations when delaying a quality test is not optimal. Given the conditions on testing costs in Propositions 1.1 - 1.4, delaying a test is dominated



**Table 1.4** Total expected payoffs for given parameter values in the pessimistic scenario.

	After 1B		After 1NB	
$\gamma$	0.78	0.9	0.78	0.9
Condition on $\alpha$	$\alpha \in (-0.0008, 0.0536)$	$\alpha \leq 0.051$	$\alpha > 0.946$	$\alpha > 0.813$
$\alpha$	0.01	0.05	0.99	0.99
Price range	(0.01, 0.027)	(0.05, 0.32]	(0.99, 0.993)	(0.99, 0.998)
$p$	0.015	0.2	0.992	0.995
$\underline{s}$	0.0098	0.0314	0.0074	0.0023
$\bar{s}$	0.0107	0.0393	0.0077	0.0046
$s$	0.01	0.035	0.0075	0.003
$OP^{t=0}$	0.0097	0.045	0.00834	0.0069
$OP^{No}$	0.00969	0.0475	0.00833	0.0074
$OP^{1B}$	<b>0.0098</b>	<b>0.0481</b>	0.00437	0.0052
$OP^{1NB}$	0.0041	0.0214	<b>0.00838</b>	<b>0.0075</b>

Note: The numbers in bold demonstrate the dominance of delayed testing over testing at  $t=0$  and no testing at all since the resulting total expected payoff is the highest.

by testing prior to any purchasing decisions when the costs are sufficiently low and are smaller than the value of the lower bound specified in the propositions. On the other hand, when the costs are high and greater than the upper bound, then never testing is better.

Another case when delayed testing is not optimal is when the ranges of costs specified in Propositions 1.1 - 1.4 do not exist. In particular, delayed testing can never be optimal when private signal is sufficiently imprecise ( $\gamma < 0.75$ ). When the signal is sufficiently precise and the prior belief that the product is of high quality is sufficiently high ( $\alpha > \frac{3-4\gamma}{4-8\gamma}$ ), then testing after observing the first consumer buying can not be optimal in both optimistic and pessimistic cases because this will be a socially desirable action. When private signal is precise and prior probability is low, testing after observing the first consumer buying is not optimal for sufficiently low prices in the optimistic case ( $p \in [\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}, p_{1B}^*]$ ), and for sufficiently high prices in the pessimistic case ( $p \in [\tilde{p}_{1B}, \frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}]$ ), because these prices will imply sufficiently low benefit of delayed testing.

Testing after the first consumer has abstained from buying is not optimal when signal is precise enough and the prior belief that the product is of high quality is sufficiently low ( $\alpha < \frac{1-4\gamma}{4-8\gamma}$ ). When, however, the signal is sufficiently precise and prior probability is sufficiently high, then delaying a test until the first consumer does not buy is not optimal for the same range of prices in the optimistic case ( $p \in [\frac{\alpha(1-\gamma)}{\alpha(1-\gamma)+(1-\alpha)\gamma}, p_{1B}^*]$ ), and in the pessimistic case ( $p \in [\tilde{p}_{1B}, \frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}]$ ).

## 1.5 Concluding Remarks

The regulation literature often concentrates on designing regulatory mechanisms that can increase social welfare, however, the idea that the regulator can postpone tests in order to learn more from the market has been generally ignored in the literature. We study the optimality of delaying quality testing of a good when the regulator and the consumers are uncertain about its true quality. We allow the regulator as well as other

market participants to gain access to a greater pool of information about the product quality by observing early customers' informative decisions. The optimality of a delay depends on, the level of testing cost, the consumers' prior beliefs, the quality of their private signals, and the price of the good. When *ex post* the consumers are likely to make socially desirable decisions, there is no need for quality testing, and the costs associated with it are eliminated.

Our model sheds some light on the reasons for the government regulation strategies in certain cases. Quality control after observed buying decisions becomes important once the expected losses to the later consumers who will buy low quality products are high enough. In terms of Zicam example, after having a large number of people buying it, regulation became optimal as it prevented potential losses related to health issues of the future consumers. Testing after observed decisions to abstain can be relevant in the situations when the government aims to promote the adoption of new technologies or practices, for example, in agricultural sector<sup>10</sup>.

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<sup>10</sup> Kislev and Schori-Bachrach (1973) found using data from Israel that new technologies were first adopted by small subgroups of farmers. Government testing of the quality of new technology in such situation could deliver additional information and speed up the adoption. Botelho et al. (2012) showed that adoption of a particular apple variety by Portuguese farmers was affected by amount and reliability of information and technical guidance which is supportive of the policy of government intervention. The approval by the FDA of rbST (recombinant bovine Somatotropin) in milk production over 10 years after it became available can be related to the small number of early adopters (Butler and Henriques, 2001). If the government believed that the new technology was promising, intervention was needed to reveal better information about the new technology.

# Chapter 2

## Fixed Cancellation Payments and the Hold-up Problem

### 2.1 Introduction

Contracts with fixed cancellation payments are frequently observed in practice, for example, government procurement contracts, buyout clauses in sports contracts, and severance agreements which compensate CEOs in the event of termination. In sports, contracts often include termination penalties imposed on the party that initiates separation. These penalties are usually set fixed, and even though they decrease if separation occurs in later periods of time relative to the length of the contract, the amounts are often significantly high <sup>1</sup>. CEO exit packages can also reach large amounts <sup>2</sup>. These payments are thought to provide CEOs with incentives to increase

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<sup>1</sup>For example, the University of Tennessee has to pay a total of about 5 million dollars through 2016 to its former football coach Derek Dooley after firing him in 2012 (source: <http://www.govolxtra.com/news/2013/mar/01/derek-dooley-and-fired-assistants-will-cost-ut/>). Auburn University was obligated to pay its former football coach Gene Chizik 7.5 million dollars (source: <http://www.usatoday.com/story/sports/ncaaf/2012/11/25/coaches-buyouts-sec-gene-chizik-auburn-derek-dooley-tennessee/1725765/>).

<sup>2</sup>Among others, Bob Nardelli, The Home Depot Inc. CEO, received 223 million dollars after leaving the company in 2007. The CEO of CVS Caremark Corp., Thomas Ryan, received 185 million dollars in severance pay in 2011 (source: <http://moneymorning.com/2013/03/18/top-10-ceo-severance-packages/>).

firms' profitability. However, according to Mansi et al. (2013), severance agreements are associated with increased firm risk and lower operating performance. Huang (2011) states in her study that severance agreements result in overinvestment in research and development, weak corporate governance, and more frequent CEO dismissal. In this paper, we refer to this situation as the reverse hold-up problem - the case when inefficiently high level of effort is exerted or when inefficiently high investments are made by an agent in the light of high payment to her by a principal when a contract is cancelled. The goal of this study is to investigate theoretically and experimentally the effects of a principal's fixed cancellation payment to an agent on the agent's incentives to exert effort. In particular, we analyze how setting a cancellation payment at various levels affects the hold-up problem. We show that for optimal levels of cancellation payment the hold-up problem is mitigated, and that low payment leads to a standard hold-up problem. However, if the amount of payment is set too high, it can have opposite effect and the reverse hold-up problem is observed.

The hold-up problem arises when, due to incomplete contracts, the proceeds of relationship-specific investments are divided between the parties through ex post renegotiation. Since the agent is no longer guaranteed her expected payoff, she has no incentive to invest efficiently (Williamson, 1985). The formal model of the hold-up problem was developed by Hart and Moore (1988) who established that contract renegotiation led to inefficient investments. However, it has been shown that the hold-up problem can be overcome by including in the contract appropriately designed renegotiation conditions. Chung (1991) and Aghion et al. (1994) achieved a first-best outcome by assigning a default option in case of renegotiation and by providing one of the players with residual rights over the proceeds. Nöldeke and Schmidt (1995) showed that the hold-up problem could be solved with a simple option contract under the assumption that courts were able to verify the delivery of the good. In the above papers, socially desirable decisions are induced by changed threatpoint payoffs in the bargaining game. Che and Sakovics (2004) offered a noncontractual solution to the hold-up problem by making investments and negotiations dynamic. In their paper,

punishments for low investments result in decreased disagreement payoffs and thus can lead to equilibria with higher investments. Our study concentrates on cancellation payments as a potential solution to the hold-up problem. The similarity of this paper to the above literature is that conditional on the investment being made the threat point is changed.

We consider a model with an agent who has to make an unverifiable investment that enhances a principal's valuation of the good being traded. The parties cannot write an explicit contract before the investment stage, however they can enter an implicit contract which cannot be legally enforced. The contract is in the form of a cost-plus type contract. This type of contracts is common when there are uncertainties associated with the cost of performance and is used by federal agencies<sup>3</sup> as well as in the engineering and construction industries. After observing the level of investments made by the agent, the principal can always renegotiate the terms of the implicit contract. In this case, the principal pays a fixed amount to the agent and the surplus is divided through Nash bargaining. If the agent does not enter the contract, she is entitled to the value of outside option.

We derive equilibrium predictions assuming that the principal and the agent have selfish preferences. We first establish the conditions that determine the principal's decision to accept the existing implicit contract or to renegotiate it. We then proceed with analyzing the agent's decisions. Our results are as follows. When high investment is socially desirable, it can be induced by sufficiently high fixed cancellation payment. In this case, the principal accepts any contract in order to avoid high payment to the agent, and the agent anticipating this invests high if the outside option is sufficiently low. When the situation is opposite and low investment is socially efficient due to increased cost of making high investment, this leads to the reverse hold-up problem.

When the amount of cancellation payment is reduced to some medium level, the principal's strategy changes. She still accepts low-investment contracts and renegotiates high-investment ones in order to avoid high payments to the agent due

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<sup>3</sup>For example, by the Department of Defense for weapon programs that require new technologies.

in case of accepting high-investment contract. Knowing that, the agent invests high if doing so generates sufficiently high value, or otherwise if the amount of cancellation payment at least covers the difference of her payoffs under low and high-investment contracts. If low level of investment is socially desirable, the reverse hold-up problem arises. If the amount of cancellation payment is reduced, the agent's incentive to invest high is distorted and her private optimum now coincides with the social optimum. This also implies the standard hold-up problem when high investment is optimal.

Finally, with no cancellation payment or when it is too low, unless the outside option is high enough, the agent enters a contract, and the principal always renegotiates it. Considering the case when high investment is socially desirable, it is shown that optimum can be achieved only if high investment generates sufficiently high value and that cancellation payment has no effect on the agent's investment decision. When not enough value is generated, the standard hold-up problem is observed. Conversely, high investments result in the reverse hold-up problem when low investments are socially optimal.

We test the validity of our predictions using a controlled laboratory experiment. In particular, our experiment studies the effects of different levels of cancellation payment on agent's investment behavior. Data from the experiment are consonant with the comparative static predictions of our theory and suggest the promise of cancellation payments as a means to attenuate hold-up. There exists evidence in the literature that suggests that higher than optimal levels of investments observed in the experiments can be attributed to fairness concerns<sup>4</sup>. To test for the existence of social preferences in our study, we conduct additional treatments in which off-equilibrium option leads to equitable outcomes. We do not observe significant change in investment behavior resulting from this modification in three out of five treatments. The subgame perfect equilibrium is played significantly more often in one of the remained treatments, and it is played significantly less often in the last treatment.

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<sup>4</sup>See, for example, Hackett (1994), Charness and Rabin (2002), Nelson (2002), Ellingsen and Johannesson (2004a, 2004b), Falk et al. (2008), Dufwenberg et al. (2013). See von Siemens (2009) for theoretical explanation of investment incentives based on fairness preferences.

More closely related to our study is the contribution by Sloof et al. (2006). In their experiment, the effects of four breach remedies (liquidated damages, expectation damages, reliance damages, and specific performance) on investment behavior are analyzed. In our paper, the fixed payment is analogous to liquidated damages. They test theoretical predictions that investments are efficient under liquidated damages and are too high under reliance and expectation damages. Thus, they consider only optimally set liquidated damages unlike this study which analyzes too high and too low fixed payments. Also, in the experiment by Sloof et al. (2006), overinvestment is observed on average in liquidated-damages treatment, whereas we observe subgame perfect equilibrium outcomes most of the time in cases when fixed payment is set to induce optimal investments.

The paper proceeds as follows. Formal model is developed in Section 2.2. The details of the experimental design are presented in Section 2.3. We parametrize the model, describe the treatments and state the predictions in Section 2.4. Results are discussed in Section 2.5. Section 2.6 concludes.

## 2.2 Model

We consider a static model of bilateral trade of a unit of some good between a principal and an agent. In order to deliver the good, the agent has to make a relationship-specific investment  $e \in \{e_L, e_H\}$  with  $e_L$  being low level of investment and  $e_H$  being high level of investment. The investment is observable by both parties, but cannot be verified. Thus, there is no explicit contract *ex ante*. The cost of investment  $e$  is  $c(e)$ , where  $c(e_L) = c_L < c(e_H) = c_H$ . The investment is cooperative<sup>5</sup> meaning that the value of the good to the principal depends on the agent's investment level  $e$  and is given by strictly concave function  $V(e)$ , where  $V(e_L) = V_L < V(e_H) = V_H$ .

At stage  $t = 1$ , the agent decides between entering or not entering the implicit contract. Conditional on entering the contract, the agent must choose her level of

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<sup>5</sup>Following Che and Hausch (1999).



investment. If the agent does not enter the contract, she receives the value of an outside option  $\eta$ . At stage  $t = 2$  after observing the agent's investment level, the principal can either accept the implicit contract or renegotiate it. In the case of renegotiation, the original implicit contract is canceled, there a fixed amount  $K$  is paid by the principal to the agent. Renegotiation takes the form of Nash bargaining over the value of trade to the principal and the threat point to the agent.

We consider cost-plus type contracts, where the agent is covered the cost of production plus additional payment to allow for a profit. In the case of accepting the implicit contract, the payoff to the agent is given by  $u_A = (\alpha - 1)c(e)$ , where  $\alpha > 1$ , and the payoff to the principal is given by  $v_A = V(e) - \alpha c(e)$ . In the case of renegotiation, the agent's payoff is  $u_R = \frac{1}{2}[V(e) + K] - c(e)$ , and the principal's payoff is  $v_R = \frac{1}{2}[V(e) - K]$ . At stage  $t = 2$ , the agent will always want to complete the exchange of the good even if the principal chooses to renegotiate since by walking away the agent incurs a loss of  $c(e)$ .

The problem is a dynamic game with complete information with corresponding solution concept being subgame perfect equilibrium. The agent's strategy determines an investment  $e$ ; the principal's strategy determines her acceptance decision conditional on the observed investment  $e$ . Subgame perfect equilibria are determined by backward induction. We are going to derive equilibrium predictions assuming that the principal and the agent have preferences defined solely over their own monetary payoffs. The principal chooses to accept an implicit contract with a given level of investment by the agent over renegotiating it if the fixed payment in the case of renegotiation is higher than the threshold level:

$$K \geq 2\alpha c(e) - V(e). \quad (2.1)$$

**Proposition 2.1.** *Equilibrium bargaining when  $2\alpha c_H - V_H \geq 2\alpha c_L - V_L$*

1. When  $K \geq 2\alpha c_H - V_H$ , the principal accepts any contract while the agent chooses high investment conditional on entering the contract. The agent enters if  $\eta \leq (\alpha - 1)c_H$ <sup>6</sup>.
2. When  $2\alpha c_H - V_H > K \geq 2\alpha c_L - V_L$ , the principal accepts only low-investment contracts and renegotiates high-investment contracts. The agent chooses high investment when either  $V_H \geq V_L + 2(c_H - c_L)$  or otherwise when  $2\alpha c_H - V_H > K \geq 2(\alpha - 1)c_L + 2c_H - V_H$ . She enters such contract if  $\eta \leq \frac{1}{2}(V_H + K) - c_H$ . The agent chooses low investment when  $2(\alpha - 1)c_L + 2c_H - V_H > K \geq 2\alpha c_L - V_L$ , and she enters the contract if  $\eta \leq (\alpha - 1)c_L$ .
3. When  $K < 2\alpha c_L - V_L$ , the principal renegotiates any contract. The agent chooses high investment when  $V_H \geq V_L + 2(c_H - c_L)$  and low investment otherwise. She enters a low-investment contract if  $\eta \leq \frac{1}{2}(V_L + K) - c_L$  and a high-investment contract if  $\eta \leq \frac{1}{2}(V_H + K) - c_H$ .

When  $2\alpha c_H - V_H < 2\alpha c_L - V_L$ , the principal accepts only high-investment contracts and renegotiates low-investment ones if  $2\alpha c_L - V_L > K \geq 2\alpha c_H - V_H$ . The agent always chooses high investment, and she enters the contract if  $\eta \leq (\alpha - 1)c_H$ .

*Proof.* See Appendix B. □

The principal's decision depends on the fixed payment  $K$  and on the threshold values for two different levels of agent's investment. When there is a possibility of renegotiation, the agent will strategically make a choice that leads to it if either the value of her investments or if the amount of cancellation payment are sufficiently large.

When  $V_H - c_H > V_L - c_L$  such that  $e_H$  is socially optimal, the standard hold-up problem exists if the conditions are such that the agent chooses low investment or stays

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<sup>6</sup>We assume that when indifferent between entering and not entering the contract, the agent chooses to enter.

out of the contract. When  $V_H - c_H < V_L - c_L$ , low investment  $e_L$  is socially optimal. In this case, the last equilibrium prediction for the case when  $2\alpha c_L - V_L > 2\alpha c_H - V_H$  in Proposition 2.1 becomes irrelevant. The reverse hold-up problem arises when the conditions induce the agent to choose high investment. In particular, sufficiently high cancellation payment or high value of the investment will lead to the reverse hold-up problem.

## 2.3 Experimental design

A total of 176 subjects participated in our laboratory experiment. All subjects were students of the University of Tennessee-Knoxville. The computerized experiment was programmed in Java. The experiment was conducted in 10 sessions consisting of 10 rounds each in the UT Experimental Economics Laboratory during the Spring 2011 semester. The laboratory consisted of 24 networked computer workstations in separate cubicles. No subject could participate in more than one session. Participants were paid on average \$14.19.

Subjects participated in ten different types of games. Each game required two players. At the beginning of each session, half of the subjects were randomly assigned to the role of Player 1 and the others to the role of Player 2, and remained in the assigned role throughout the experiment. Each round, players were randomly rematched with a different player of the opposite role. In all rounds, no subject knew the identity of the player they were paired with. The order in which subject participated in each of the ten games was randomized across sessions.

The experiment instructions and the game tree that was displayed to the subjects are provided in Appendix B. In each round, Player 1 moves first by selecting one of three options. Option J corresponds to low investment level by Player 1, option T corresponds to high investment, and option N corresponds to Player's 1 decision to stay out of the contract in which case the game ends. Player 2 moves after options J or T have been selected. She has to select one of two options. Option A corresponds

to accepting the existing contract between Player 1 and Player 2, and option B corresponds to renegotiating it. Once Player 2 has made the decision, the game ends.

## 2.4 Predictions

The main goal of our study is to experimentally investigate the question whether particular levels of the fixed cancellation payment can lead to socially optimal outcomes, standard or reverse hold-up problems. We conducted five main treatments. Five additional treatments were performed in order to explore whether making the principal's and the agent's payoffs from certain strategies equitable affects their decisions. If participants are subject to fairness concerns, we expect to see lower frequency of subgame perfect equilibrium plays.

We are going to derive predictions on how the behavior by the principal and by the agent changes across treatments. The values of the parameters of the model used in our main treatments are provided in Table 2.1. Given the parameters, all treatments correspond to the case when  $2\alpha c_H - V_H > 2\alpha c_L - V_L$ . Thus, both high or low levels of investment can be optimal.

*Base No Entry.* In this treatment, the amount of fixed cancellation payment is set equal to \$0. The principal will renegotiate a contract with any level of investment since  $K < 2\alpha c_L - V_L$ . Knowing that, the agent will choose to stay out of the implicit contract and get her outside option of \$7 (Table 2.2). In this case her payoff is maximized. Given the parameters in this treatment, high level of investment is socially optimal, thus a standard hold-up problem exists.

*Base Standard Hold-up.* Given  $K = \$9$ , the principal's strategy will be to accept low-investment contracts and to renegotiate high-investment contracts since  $2\alpha c_H - V_H > K \geq 2\alpha c_L - V_L$ . Knowing that, the agent will choose low level of investment because it maximizes her payoff. She gets \$8 under  $e_L$  compared to \$7 under  $e_H$ . However, the social optimum is high investment, and a standard hold-up problem arises.

**Table 2.1** Parameters of the model used in the experiment

Treatment	$c_L$	$c_H$	$V_L$	$V_H$	$\eta$	K	SPE
Base No Entry	20	30	50	65	7	0	(N, B)
Base Reverse Hold-up	20	40	50	65	7	35	(T, B)
Base Low Optimal	20	40	50	65	7	20	(J, A)
Base High Optimal	20	30	50	65	7	35	(T, A)
Base Standard Hold-up	20	30	50	65	7	9	(J, A)

**Table 2.2** Payoffs and equilibrium predictions

Treatment	No Entry	Low, Accept	Low, Renegotiate	High, Accept	High, Renegotiate
Base No Entry	<b>(7,7)</b>	(8,22)	(5,25)	(12,23)	(2.5,32.5)
Base Reverse Hold-up	(7,7)	(8,22)	(22.7,7.5)	(16,9)	<b>(10,15)</b>
Base Low Optimal	(7,7)	<b>(8,22)</b>	(15,15)	(16,9)	(2.5,22.5)
Base High Optimal	(7,7)	(8,22)	(22.5,7.5)	<b>(12,23)</b>	(20,15)
Base Standard Hold-up	(7,7)	<b>(8,22)</b>	(9.5,20.5)	(12,23)	(7,28)
Fair No Entry	<b>(14,14)</b>	(15,15)	(12,18)	(19,16)	(10,25)
Fair Reverse Hold-up	(14,14)	(15,15)	(25,5)	(21,4)	<b>(17,8)</b>
Fair Low Optimal	(14,14)	<b>(15,15)</b>	(22,8)	(21, 4)	(9,16)
Fair High Optimal	(14,14)	(15,15)	(25, 5)	<b>(19,16)</b>	(27,8)
Fair Standard Hold-up	(14,14)	<b>(15,15)</b>	(17,13)	(19,16)	(14,21)

Note: Cell entries are payoffs for both Player1 (agent) and Player 2 (principal) at the corresponding terminal node of play. For each treatment, the subgame perfect payoffs are in bold.

In both treatments above, the amount of cancellation payment is sufficiently low to make the principal want to renegotiate high-investment contracts which are socially optimal. For the agent, the cancellation payment received when high investments are made is not high enough to make her invest efficiently.

**Prediction 1.** *Cancellation payment set too low can lead to standard hold-up problem; i.e., in Base No Entry treatment it is more likely for Player 1 to choose N and in Base Standard Hold-up treatment it is more likely for Player 1 to choose J.*

*Base Low Optimal.* If the agent enters the implicit contract with  $K = \$20$ , the principal will accept it only if the investment is low. Anticipating the principal's behavior, the agent chooses  $e_L$ , because then her payoff is \$8, while it would be \$2.5 under  $e_H$ . In this treatment,  $V_H - V_L < c_H - c_L$ . Hence, socially optimal level of investment is made.

*Base High Optimal.* When  $K = \$35$ , the principal will accept both kinds of contracts. This happens because now the cancellation payment paid out in the case of renegotiation is sufficiently high ( $K \geq 2\alpha c_H - V_H$ ). By accepting any contract, the principal is able to avoid this payment. This implies that if the agent is better off with the contract, she will always choose high investment. She receives \$12 under  $e_H$  compared to \$8 under  $e_L$ . Since  $V_H - V_L > c_H - c_L$  given the parameters of the treatment, the first-best outcome is achieved. Notice that this treatment differs from the first two in the level of cancellation payment. Thus, compared to no or low cancellation payment, setting it sufficiently high can enhance agent's incentive to invest and can solve hold-up problem.

**Prediction 2.** *Cancellation payments can be used to promote socially optimal outcomes; i.e., in Base Low Optimal treatment it is more likely for Player 1 to choose J and in Base High Optimal treatment it is more likely for Player 1 to choose T.*

*Base Reverse Hold-up.* The fixed cancellation payment to the agent is \$35 which means that the principal will accept low-investment contracts and she will renegotiate

high-investment contracts (the strategy is different from *Base High Optimal* treatment due to increased cost of high investment). Notice that the difference of this treatment from the *Base Low Optimal* is the level of  $K$ . Anticipating the principal's decisions, the agent will enter an implicit contract regardless of her choice of investment level because the payoffs with a contract are greater than the outside option. Since the cancellation payment is now sufficiently high, the agent will choose high investment in which case her payoff is maximized at \$10 versus \$8 under low investment. However, low investment is socially optimal. Privately optimal high level of investment by the agent results in reverse hold-up problem.

**Prediction 3.** *Cancellation payments set too high can lead to reverse hold-up problem; i.e., in Base Reverse Hold-up treatment it is more likely for Player 1 to choose T.*

We also conduct variants of five treatments described above. We use prefix Fair to distinguish them from Base treatments. In each of five additional treatments, we make the payoffs to Players 1 and 2 equal not only if option N is selected, but also when option J is selected by Player 1 and option A is selected by Player 2. The subgame perfect equilibria are unchanged. We expect this modification can cause the equatable option to be chosen more frequently and thus subgame perfect equilibrium to be reached less often if subjects have fairness concerns. The frequency of subgame perfect equilibrium play should be the same as in *Base* treatments though if subjects are rational money-maximizers.

**Prediction 4.** *The frequency of subgame perfect equilibrium play should not be greater in Base treatments than in Fair treatments.*

The goal of this experimental study is to test whether our predictions are supported by the data.



## 2.5 Results

We start describing the results of our experiment with providing the frequencies of each strategy for each of ten treatments across rounds in Table 2.3. A casual look at the data suggests that subjects follow subgame perfect equilibrium play predicted by the theory. Figures 2.1 and 2.2 offer a closer look at the data. Figure 2.1 shows the frequency of equilibrium choices by Players 1 and 2 and the frequency of subgame perfect equilibrium for each of five base treatments. Figure 2.2 provides same information for each of five Fair treatments. In all treatments except Base Standard Hold-up and Fair No Entry, equilibrium decisions are made more than 70% of the time. In Base Standard Hold-up treatment, these frequencies are above 40%, and in Fair No Entry treatment, they are above 60%.

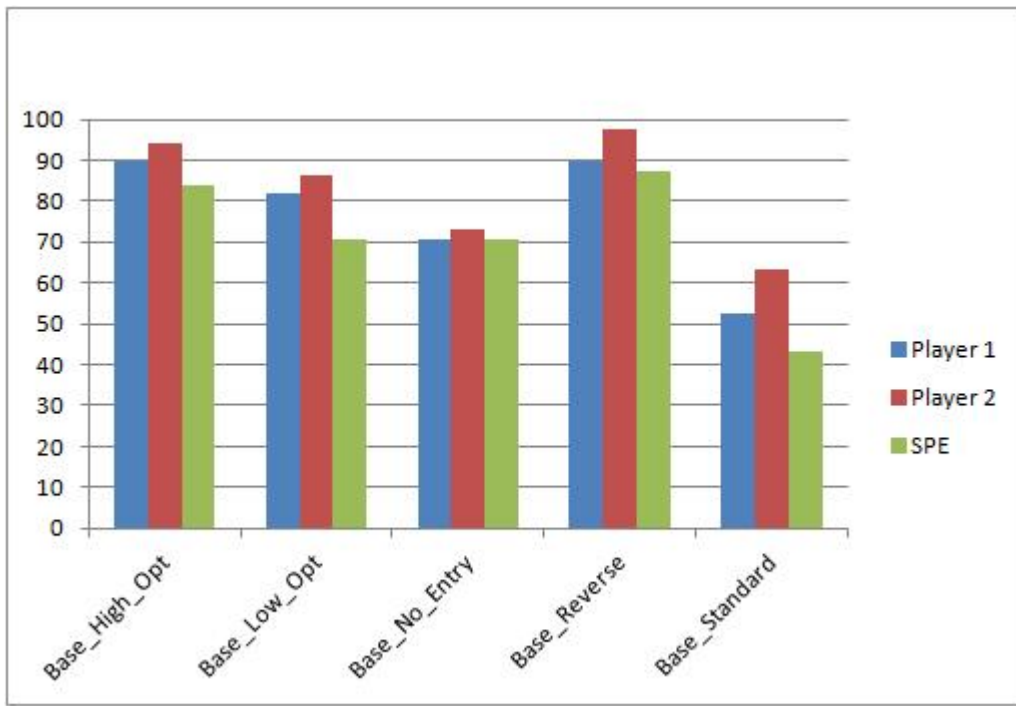
With regard to Base No Entry treatment, we find that the contract was rejected by Player 1 in 70.45% of the cases. Socially optimal high investment was selected in 23.86% of the cases. Also, whenever Player 1 entered the contract, it was renegotiated 73% of the time. In Base Standard Hold-up treatment, low investment was chosen in 52.27% of the cases. Socially optimal high investment was observed 25% of the time. This supports our first prediction that low levels of cancellation payment do not mitigate the hold-up problem with inefficiently low levels of investments. This is consistent with the standard contract-theoretic literature on hold-up stating that fear to be held-up by Player 2 stops Player 1 from entering the contract.

To test our Prediction 1, we compare the frequency of low-investment (no entry) choices by player 1 in Standard Hold-up (No Entry) treatment where cancellation payment is set too low to the frequency of low-investment choices in High Optimal and Reverse Hold-up treatments where cancellation fee is set high (significance levels are reported in Tables 2.4 and 2.5). We find that, in accordance with Prediction 1, decisions leading to the standard hold-up problem are selected significantly more often under low cancellation fee in Standard Hold-up and No Entry treatments.

**Table 2.3** Observed frequency of play

Treatment	No Entry	Low, Accept	Low, Renegotiate	High Accept	High Renegotiate
Base No Entry	<b>70.45</b> <b>(12.5)</b>	2.27 (12.5)	3.4 (12.5)	5.68 (12.5)	18.18 (50)
Base Reverse Hold-up	1.13 (0)	9.09 (40)	0 (0)	2.27 (10)	<b>87.5</b> <b>(50)</b>
Base Low Optimal	15.9 (12.5)	<b>70.45</b> <b>(25)</b>	11.36 (62.5)	0 (0)	2.27 (0)
Base High Optimal	4.54 (0)	5.68 (33.33)	0 (0)	<b>84.09</b> <b>(44.44)</b>	5.68 (22.22)
Base Standard Hold-up	22.72 (30)	<b>43.18</b> <b>(20)</b>	9.09 (10)	19.31 (20)	5.68 (20)
Fair No Entry	<b>65.9</b> <b>(77.77)</b>	4.54 (0)	19.31 (22.22)	1.13 (0)	9.09 (0)
Fair Reverse Hold-up	6.81 (22.22)	18.18 (55.55)	1.13 (0)	1.13 (11.11)	<b>72.72</b> <b>(11.11)</b>
Fair Low Optimal	11.36 (11.11)	<b>78.4</b> <b>(55.55)</b>	3.4 (11.11)	0 (0)	6.81 (22.22)
Fair High Optimal	4.54 (28.57)	6.81 (14.28)	0 (0)	<b>87.5</b> <b>(42.85)</b>	1.13 (14.28)
Fair Standard Hold-up	3.4 (0)	<b>77.27</b> <b>(44.44)</b>	2.27 (0)	1.13 (11.11)	15.9 (44.44)

Note: Cell entries are the observed frequency of play for each terminal node pooled over ten periods. The frequency of play for the given treatment in round 1 is given in parentheses. For each treatment, the subgame perfect predictions are in bold.



**Figure 2.1:** Base Equilibrium Play

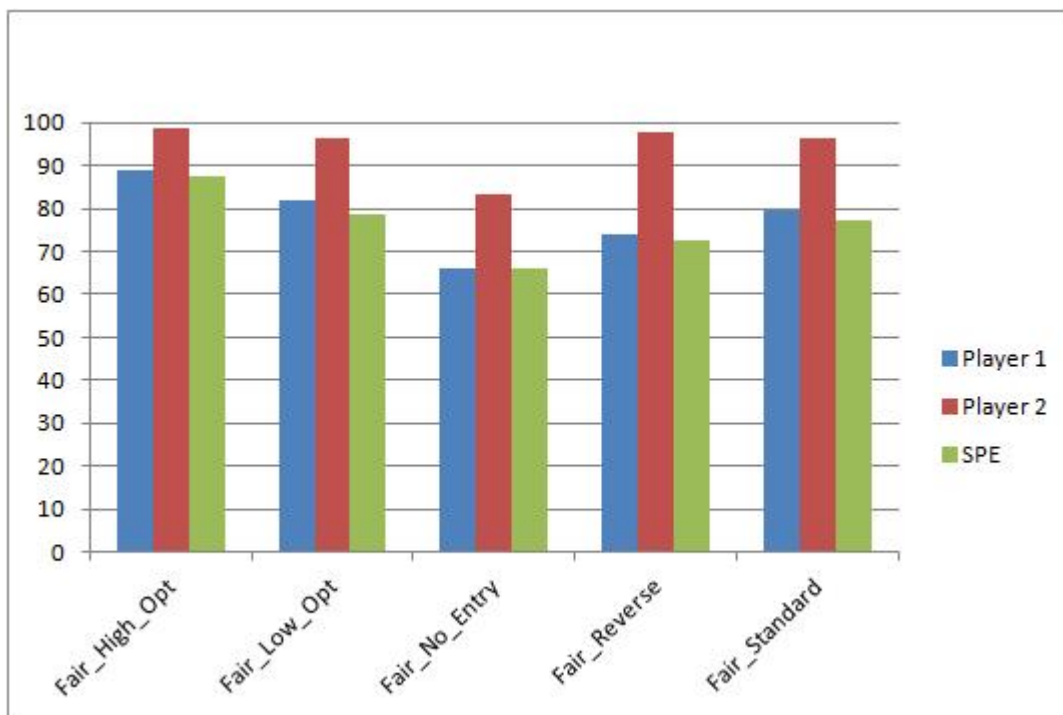


Figure 2.2: Fair Equilibrium Play

**Table 2.4** Significance levels for pairwise comparisons of L (low investment) choice by Player 1 between treatments.

	Standard Hold-up vs. Reverse Hold-up	Standard Hold-up vs. High Optimal
Base	<0.0001	<0.0001
Fair	<0.0001	<0.0001

**Table 2.5** Significance levels for pairwise comparisons of N (no entry) choice by Player 1 between treatments.

	No Entry vs. Reverse Hold-up	No Entry vs. High Optimal
Base	<0.0001	<0.0001
Fair	<0.0001	<0.0001

Consider now Base Low Optimal and Base High Optimal treatments. We observe Player 1 selecting low investment 81.81% of the time in Base Low Optimal treatment. High investment is observed 89.77% of all choices in Base High Optimal treatment. This is in line with our second prediction that it is possible to provide the incentives for any socially optimal level of investment by changing the amount of cancellation payment. Indeed, after increasing just the amount of cancellation payment from \$9 to \$35, the number of high investment choices went from 44 in Base Standard Entry to 158 in Base High Optimal treatments. We perform two-sided tests on the equity of the frequencies of socially optimal decisions by player 1 between treatments where cancellation payment is set optimally and treatments where it is not set optimally. Significance levels are reported in Table 2.6. The results suggest that socially optimal level of investment is selected in Low Optimal and High Optimal treatments significantly more frequent compared to No Entry, Standard Hold-up, and Reverse Hold-up treatments, which supports our Prediction 2.

In our Base Reverse Hold-up treatment, low investment was socially optimal, but high level of investment was selected 89.77% of the time. When high investment was made, the contract was renegotiated 97.46% of the time allowing Player 1 to receive high cancellation payment from Player 2. Low investments were made only 9.09% of the time. Notice, that the difference between this treatment and Base Low Optimal treatment is increased level of cancellation payment from \$20 to \$35. The number of high investments went from 4 in Base Low Optimal treatment to 158 in Base Reverse Hold-up. This is in accordance with our third prediction that inefficiently high levels of investment take place when cancellation payment is set too high. Mansi et al. (2013) find empirical evidence that CEO severance agreements are associated with some negative effects on a firm's performance including an increase in firm risk. Our experiment establishes a causal impact of large cancellation payments which play a role of severance agreement on the agent's effort.

**Table 2.6** Significance levels for pairwise comparisons of socially optimal choices by Player 1 between treatments.

	Low Optimal vs. No Entry	Low Optimal vs. Standard Hold-up	Low Optimal vs. Reverse Hold-up	High Optimal vs. No Entry	High Optimal vs. Standard Hold-up	High Optimal vs. Reverse Hold-up
Base	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fair	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001



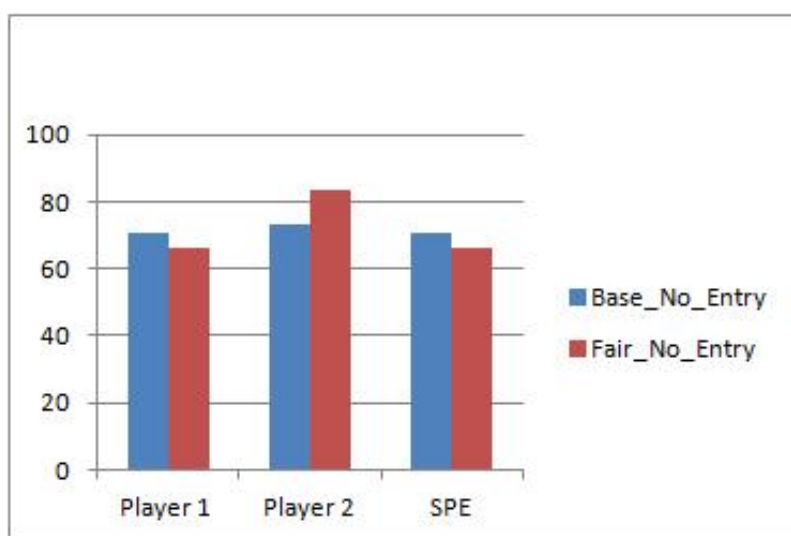
We test the equality of the frequencies of high-investment choice by player 1 in Reverse Hold-up treatment where cancellation payment is set too high and in Low Optimal and Standard Hold-up treatments where cancellation fee is set low (significance levels are reported in Table 2.7). Along with Prediction 3, our subjects picked high investments leading to the reverse hold-up problem significantly more often under high cancellation fee in Reverse Hold-up treatment.

In all Base treatments the subjects act like rational money maximizers. To allow for the possibility of fairness concerns, we constructed Fair treatments making strategy (J, A) result in equitable outcomes. If subjects have preferences for fair outcomes, we should observe less frequent subgame perfect equilibrium play in our Fair treatments. Analyzing the data from five Fair treatments, we find patterns similar to Base treatments. In Fair No Entry treatment, Player 1 chooses to stay out of the contract 65.9% of the time. High investment is socially optimal and is selected only 10.22% of the time. In Fair Standard Entry treatment, low investments were made in 79.54% of the cases, and socially optimal high investments were made in 17.04% of the cases. This corresponds to the standard hold-up problem. We observe high frequency of socially optimal investments in both Fair High Optimal and Fair Low Optimal treatments. In particular, low investments were selected 81.81% of the time in Fair Low Optimal, and high investments were selected 88.63% of the time in Fair High Optimal. Finally, in Fair Reverse Hold-up treatment, socially inefficient high investments are made 73.86% of the time.

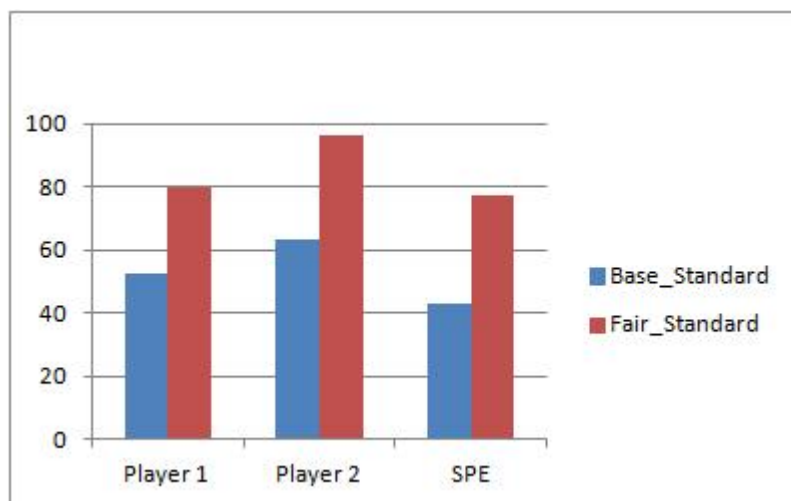
The comparison of frequencies of equilibrium choices between Base and Fair treatments is provided in Figures 2.3 - 2.7. We perform two-sided tests on the equity of the frequencies of subgame perfect equilibrium and of equilibrium decisions by both players between corresponding treatments. Significance levels are reported in Table 2.8.

**Table 2.7** Significance levels for pairwise comparisons of T (high investment) choice by Player 1 between treatments.

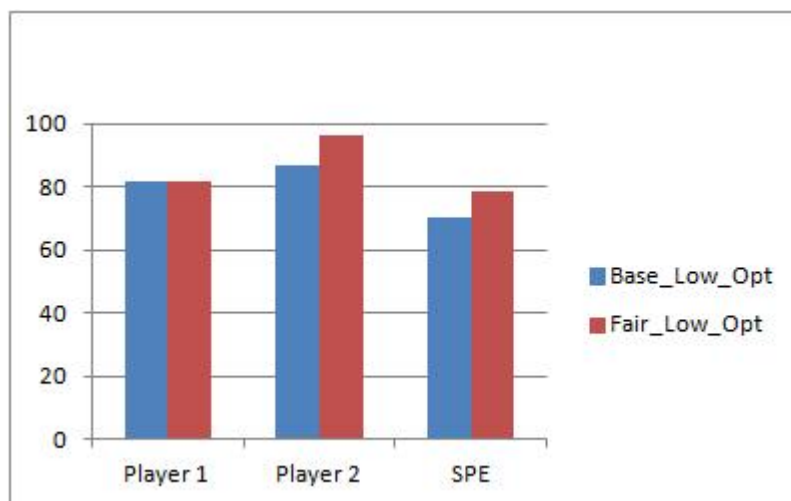
	Reverse Hold-up vs. Standard Hold-up	Reverse Hold-up vs. Low Optimal
Base	<0.0001	<0.0001
Fair	<0.0001	<0.0001



**Figure 2.3:** No Entry



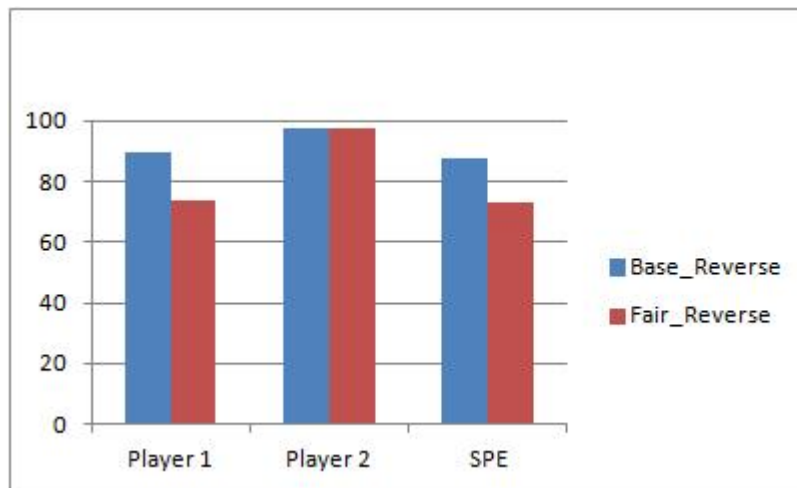
**Figure 2.4:** Standard Hold-up



**Figure 2.5:** Low Optimal



**Figure 2.6:** High Optimal



**Figure 2.7:** Reverse Hold-up

**Table 2.8** Significance levels for pairwise comparisons of equilibrium choices by Player 1 and Player 2 and of subgame perfect equilibrium between treatments.

	No Entry Base vs. Fair	Standard Hold-up Base vs. Fair	Low Optimal Base vs. Fair	High Optimal Base vs. Fair	Reverse Hold-up Base vs. Fair
Player 1	0.5174	0.0001	1	0.8081	0.0062
Player 2	0.2963	<0.0001	0.0419	0.2652	0.1195
SPE	0.5174	<0.0001	0.2265	0.5171	0.0141



In line with Prediction 4, we find that social preferences have no effect in No Entry, High Optimal treatments, and Low Optimal treatments with exception of Player 2's equilibrium play in Fair Low Optimal treatment. Making acceptance of a low-investment contract result in equal payoffs to both players enhances her equilibrium play as well as all equilibrium plays in Fair Standard Entry treatment. Also, in Fair Standard Entry treatment not only we observe significantly more subjects choosing option J, but significantly fewer subjects are choosing option N which was the only choice with equitable payoffs in the Base Standard Entry treatment. Possible reason for such redistribution of plays might be due to preferences for equality. Even though the equilibrium strategy in Fair No Entry treatment is played approximately as often as in the Base No Entry treatment, option J resulting in equitable payoffs is played significantly more frequent in Fair No Entry treatment <sup>7</sup>. This trend might be observed due to Players 1 either having concerns for equality or hoping that Players 2 act reciprocally and choose option A.

In Fair Reverse Hold-up treatment, the subgame perfect equilibrium is the most common outcome, however it is reached significantly less often compared to the Base treatment. Also, Player1's equilibrium choice is statistically less frequent in Fair Reverse Hold-up compared to Base Reverse Hold-up treatment. These differences are due to the first player choosing equitable option (low investment) more often in Fair Reverse Hold-up<sup>8</sup>, thus we observe some effect of social preferences, potentially inequality aversion, in this case.

To summarize, all four predictions are supported by the data. We find strong evidence that varying the levels of cancellation payment has effect on the hold-up problem: it arises when  $K$  is too low, it can be mitigated when  $K$  is sufficiently high, and it can be reversed when  $K$  is too high. This effect remains when one of the

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<sup>7</sup>Two-sided tests on the equity of proportions of low-investment decisions by Player 1 in Base No Entry and Fair No Entry treatments:  $H_0$ :  $\text{Prop}(\text{Base}) = \text{Prop}(\text{Fair})$  with P-value = 0.0007.

<sup>8</sup>Two-sided tests on the equity of proportions of low-investment decisions by Player 1 in Base Reverse Hold-up and Fair Reverse Hold-up treatments:  $H_0$ :  $\text{Prop}(\text{Base}) = \text{Prop}(\text{Fair})$  with P-value = 0.052.

strategies leads to equal payoffs to both players, however, we observe some evidence of social preferences in three out of five Fair treatments. This evidence is not as prominent as the results of other experiments aimed to study the hold-up problem. The scope of our experiment does not allow us to deeper understand the drivers of subjects' choices, and it is the area of further investigation.

## 2.6 Conclusion

This paper analyzes the effects of varying the levels of fixed cancellation payment in the cost-plus type contract on the hold-up problem. In particular, we are interested in the situation when high enough cancellation payment leads to the reverse hold-up problem, a case when inefficiently high investments intended to enhance a good's valuation are made. We report the results of the laboratory experiment that tests our theoretical predictions. The observed frequencies of subgame perfect equilibrium play in our five main treatments support the predictions.

Assuming that the observed play may be a result of the subjects' fairness concerns, we conduct additional treatments. We change the payoff structure slightly to make certain strategies result in equitable payoffs. No changes to the strategy space or equilibrium path were made. However, we still find that subjects follow the equilibrium strategy most of the time. We conclude that most of the time our subjects were not driven by social preferences when making their decisions. We observe some evidence of fairness concerns, potentially inequality aversion, in three out of five additional treatments when the option leading to the equitable outcome is picked more frequently by the first player relative to the corresponding Base treatment. Future investigation of the reasons driving the subjects' decisions, and particularly preferences for fairness, is of main interest.

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# Appendix



## A Now, Tomorrow, or Never: The Optimality of Delaying Quality Tests

Here we describe the early adopter's and the follower's purchasing decisions. The early adopter purchases the product after receiving a high signal  $s_H$  if

$$\frac{\alpha\gamma}{\alpha\gamma + (1-\alpha)(1-\gamma)}(1-p) - \frac{(1-\alpha)(1-\gamma)}{\alpha\gamma + (1-\alpha)(1-\gamma)}p \geq 0,$$

or

$$p \leq \frac{\alpha\gamma}{\alpha\gamma + (1-\alpha)(1-\gamma)} (\equiv D).$$

She buys the product after observing a low signal  $s_L$  if

$$\frac{\alpha(1-\gamma)}{\alpha(1-\gamma) + (1-\alpha)\gamma}(1-p) - \frac{(1-\alpha)\gamma}{\alpha(1-\gamma) + (1-\alpha)\gamma}p > 0,$$

or

$$p < \frac{\alpha(1-\gamma)}{\alpha(1-\gamma) + (1-\alpha)\gamma} (\equiv B).$$

Note that  $D > B$ , thus for sufficiently low prices ( $p < B$ ) the early adopter buys the product even if her signal is low, and for sufficiently high prices ( $p > D$ ) she abstains from buying even if her signal is high. Such decisions provide no additional information to the follower, and she finds herself in the position of the early adopter with only one signal. When  $p \in [B, D]$ , the early adopter follows her signal.

We now discuss the purchasing decisions by the follower. If there are two high signals, the follower purchases the product if

$$\frac{\alpha\gamma^2}{\alpha\gamma^2 + (1-\alpha)(1-\gamma)^2}(1-p) - \frac{(1-\alpha)(1-\gamma)^2}{\alpha\gamma^2 + (1-\alpha)(1-\gamma)^2}p \geq 0,$$

or

$$p \leq \frac{\alpha\gamma^2}{\alpha\gamma^2 + (1-\alpha)(1-\gamma)^2} (\equiv E).$$

The follower buys the product after two low signals if

$$\frac{\alpha(1-\gamma)^2}{\alpha(1-\gamma)^2 + (1-\alpha)\gamma^2}(1-p) - \frac{(1-\alpha)\gamma^2}{\alpha(1-\gamma)^2 + (1-\alpha)\gamma^2}p > 0,$$

or

$$p < \frac{\alpha(1-\gamma)^2}{\alpha(1-\gamma)^2 + (1-\alpha)\gamma^2} (\equiv E).$$

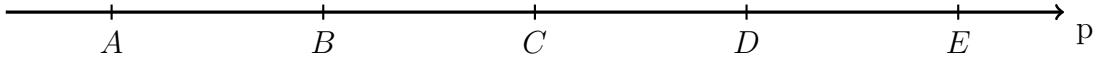
The follower's buying decision after two opposite signals is determined by

$$\frac{\alpha\gamma(1-\gamma)}{\alpha\gamma(1-\gamma) + (1-\alpha)\gamma(1-\gamma)}(1-p) - \frac{(1-\alpha)\gamma(1-\gamma)}{\alpha\gamma(1-\gamma) + (1-\alpha)\gamma(1-\gamma)}p \geq 0,$$

or

$$p \leq \alpha (\equiv C).$$

Note, that  $E > D$ , thus for  $p \in (D, E)$  (see Figure A.1) the follower still does not purchase because she acts as if she was the early adopter. Also,  $A < B$ , thus for  $p \in [A, B)$  the follower still buys the product because the early adopter's action is not informative. For  $p \in [B, C]$  the early adopter follows her signal and the follower purchases after two high signals or two opposite signals, and she abstains from buying after two low signals. For  $p \in (C, D]$  the early adopter follows her signal as well, and the follower now buys only after two high signals and abstains from buying after conflicting signals and two low signals.



**Figure A.1:** Price ranges

*Proof of Lemma 1.3.* We first are going to derive the condition on price for which the range of costs  $(\underline{s}_{1B}, \bar{s}_{1B})$  exists. It has to be that  $\underline{s}_{1B} < \bar{s}_{1B}$ , or

$$\frac{(1-\gamma)[2\alpha(1-p) + (1-\alpha)p]}{Y} < \frac{(1-\gamma)[\alpha\gamma(1-p) + (1-\alpha)(1-\gamma)p]}{1-Y},$$

which holds for  $p < \tilde{p}_{1B}$ .

Prices that satisfy the condition  $p < \tilde{p}_{1B}$  have to be in the range of  $(\alpha, \frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)})]$  for the pessimistic case. If  $\tilde{p}_{1B}$  is less than the lower bound  $\alpha$ , then no value of price exists in the pessimistic scenario for which  $\underline{s}_{1B} < \bar{s}_{1B}$ . Thus,  $\tilde{p}_{1B}$  has to be greater than the lower bound  $\alpha$ , which it holds when

$$\alpha < \frac{3-4\gamma}{4-8\gamma}. \quad (2)$$

Since  $\alpha \in (0,1)$ , there exists a value of  $\alpha$  which satisfies condition (2) when  $\gamma > 0.75$ .

Whether  $\tilde{p}_{1B}$  is greater or less than the upper bound  $\frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}$  depends on the level of prior probability  $\alpha$ . In particular, the value of  $\tilde{p}_{1B}$  is greater, and thus condition  $p < \tilde{p}_{1B}$  is binding, when  $\alpha > \frac{2\gamma^3-\gamma^2-3\gamma+2}{(1-2\gamma)(-2\gamma^2+\gamma+2)}$ <sup>9</sup>. Latter condition on  $\alpha$  together with condition (2) limit the range of values that  $\alpha$  can take, and together with price range and condition on  $\gamma$  establish the first set of conditions for the range of costs  $(\underline{s}_{1B}, \bar{s}_{1B})$  to exist.

The value of lower bound is greater than  $\tilde{p}_{1B}$  and thus is binding when  $\alpha < \frac{2\gamma^3-\gamma^2-3\gamma+2}{(1-2\gamma)(-2\gamma^2+\gamma+2)}$ . This condition on  $\alpha$  is stricter than condition (2), and it can be satisfied only when  $\gamma$  is greater than 0.781<sup>10</sup>. This results in the second set of conditions for the range of costs  $(\underline{s}_{1B}, \bar{s}_{1B})$  to exist.

We now are going to show that for  $c \in (\underline{s}_{1B}, \bar{s}_{1B})$  the regulator performs a test if and only if the first consumer buys the product. It has to be that  $OP^{1B} > OP^{1NB}$

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<sup>9</sup>Note, that  $\frac{2\gamma^3-\gamma^2-3\gamma+2}{(1-2\gamma)(-2\gamma^2+\gamma+2)} < \frac{3-4\gamma}{4-8\gamma}$  for  $\gamma > 0.75$ .

<sup>10</sup>When  $\gamma \leq 0.781$ , the condition on  $\alpha$  is not satisfied because  $\frac{\gamma^2(2\gamma-3)}{(1-2\gamma)(-2\gamma^2+\gamma+2)} \leq 0$ .

for testing after 1B to be the optimal strategy. This holds when

$$c > c'. \quad (3)$$

Note that  $p > \alpha$  since this is the pessimistic case, thus the numerator of  $c'$  is greater than zero. Also,  $\alpha < \frac{1-4\gamma}{4-8\gamma} < \frac{1}{2}$ , thus the denominator of  $c'$  is negative. Condition (3) holds for any  $c$ , and testing after 1B is the best strategy

□

*Proof of Lemma 1.4.* We first are going to derive the condition on price for which the range of costs  $(\underline{s}_{1NB}, \bar{s}_{1NB})$  exists. It has to be that  $\underline{s}_{1NB} < \bar{s}_{1NB}$ , or

$$\frac{(1-\gamma)[\alpha(1+\gamma)(1-p) + (1-\alpha)(2-\gamma)p]}{1-Y} < \frac{(1-\gamma)\alpha(1-p)}{Y},$$

which holds for  $p < \tilde{p}_{1NB}$ .

Since this is the pessimistic case which is defined for the range of prices  $(\alpha, \frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)})$ , it has to be the case that  $\tilde{p}_{1NB}$  is greater than the lower bound  $\alpha$ . This is satisfied when  $\alpha > \frac{1-4\gamma}{4-8\gamma}$ . Since  $\alpha \in (0, 1)$ , there exists a value of  $\alpha$  that satisfies the latter inequality when  $\gamma > \frac{3}{4}$ .

Also,  $\tilde{p}_{1NB}$  is less than the upper bound  $\frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}$ <sup>11</sup>, and thus  $p < \tilde{p}_{1NB}$  is binding condition on price.

We now are going to show that for  $c \in (\underline{s}_{1NB}, \bar{s}_{1NB})$  the regulator performs a test if and only if the first consumer abstains from buying the product. It has to be that  $OP^{1NB} > OP^{1B}$  for testing after 1NB to be the optimal strategy. This holds when

$$c > c'. \quad (4)$$

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<sup>11</sup>  $\tilde{p}_{1NB} < \frac{\alpha\gamma}{\alpha\gamma+(1-\alpha)(1-\gamma)}$  for  $\alpha < \frac{2\gamma^3-\gamma^2-3\gamma+1}{(1-2\gamma)(-2\gamma^2+\gamma+2)}$  which always holds because the right-hand side of the latter inequality is greater than one.

Note that  $c' < \underline{s}_{1NB}$  when

$$p < \frac{\alpha(1+\gamma)(1-2Y) + \alpha(1-\gamma)(1-Y)}{(1-\gamma)(1-Y) + (1-2Y)(\alpha(1+\gamma) - (1-\alpha)(2-\gamma))}, \quad (5)$$

which is always satisfied because the right-hand side of (5) is greater than one when conditions (1.11), (1.13), and (1.14) hold. Also note that  $\tilde{p}_{1NB} < 1$ . Thus, when  $(\underline{s}_{1NB}, \bar{s}_{1NB})$  exists and  $c$  belongs to that range, condition (4) is satisfied and testing after 1NB is the best strategy.

□

## B Cancellation Payments and the Hold-up Problem

*Proof of Lemma 2.1.* We start the proof with the first equilibrium prediction. Since the principal accepts a contract when the payoff from accepting it is at least as high as her payoff from renegotiation according to condition (2.1), then for  $K \geq 2\alpha c_H - V_H \geq 2\alpha c_L - V_L$  accepting any contract is her best strategy. Suppose that  $\eta > (\alpha - 1)c_H$ , then  $\eta > (\alpha - 1)c_L$ , and staying out of the contract is the best strategy for the agent since her payoff is maximized in this case. Suppose that  $\eta \leq (\alpha - 1)c_H$ , then high investment is the agent's best strategy since her payoff is solely determined by her cost and  $c_H > c_L$ .

When  $2\alpha c_H - V_H > K \geq 2\alpha c_L - V_L$ , the principal accepts low-investment contracts according to condition (2.1). She renegotiates high-investment contracts since her payoff from renegotiating is higher than her payoff from accepting it:  $\frac{1}{2}[V_H - K] > V_H - \alpha c_H$ . When the principal accepts low-investment contracts and rejects high-investment contracts, conditional on entering the agent chooses  $e_H$  if the fixed cancellation payment is sufficiently high such that her payoff is maximized:

$$K \geq 2(\alpha - 1)c_L + 2c_H - V_H. \quad (6)$$

The lower bound on  $K$  for the agent to choose  $e_H$  in (6) is not greater than the lower bound on  $K$  for the principal to accept low-investment contracts when  $(V_H - V_L) \geq 2(c_H - c_L)$ . Then condition (6) is nonbinding and the agent chooses high investment as long as the value resulted from the investment is high enough.

When the opposite is true and  $V_H - V_L < 2(c_H - c_L)$ , then condition (6) becomes binding and the agent exerts  $e_H$  if  $2\alpha c_H - V_H > K \geq 2(\alpha - 1)c_L + 2c_H - V_H$ , and she exerts  $e_L$  if  $2(\alpha - 1)c_L + 2c_H - V_H > K \geq 2\alpha c_L - V_L$ . Thus, knowing the principal's strategy, the agent induces renegotiation if the cancellation payment to her is larger enough, otherwise, she prefers the contract to be accepted. The agent chooses to not

enter such contracts if the outside option value is sufficiently high:  $\eta > (\alpha - 1)c_L$  for low-investment contract and  $\eta > \frac{1}{2}(V_H + K) - c_H$  for high-investment contract.

When  $K < 2\alpha c_L - V_L$ , then it is also the case that  $K < 2\alpha c_H - V_H$ , and according to condition (2.1) the principal will renegotiate any contract. The agent chooses high investment if her payoff from doing so is at least as high than the payoff from choosing low investment:  $\frac{1}{2}(V_H + K) - c_H \geq \frac{1}{2}(V_L + K) - c_L$ ; she chooses low investment otherwise. Her decision is independent of the level of cancelation payment, and is determined by the value resulting from her investment. High investment is made when  $V_H \geq V_L + 2(c_H - c_L)$ , and low investment is made otherwise. When high-investment contract with renegotiation dominates low-investment contract with renegotiation, the agent enters if the value of his outside option is sufficiently low:

$$\eta \leq \frac{1}{2}(V_H + K) - c_H,$$

and she stays out otherwise. She enters a low-investment contract if  $\eta \leq \frac{1}{2}(V_L + K) - c_L$ , she stays out otherwise.

When  $2\alpha c_H - V_H < 2\alpha c_L - V_L$  and  $2\alpha c_L - V_L > K \geq 2\alpha c_H - V_H$ , then according to (2.1) the principal accepts high-investment contracts. She renegotiates low investment contracts since her payoff from doing so exceeds the payoff from accepting them:  $\frac{1}{2}[V_L - K] > V_L - \alpha c_L$ . Conditional on entering the contract, the agent chooses  $e_H$  if the fixed cancellation payment is sufficiently low:

$$K \leq 2(\alpha - 1)c_H + 2c_L - V_L. \quad (7)$$

Since the principal's decision to accept only high-investment contracts is determined by  $2\alpha c_L - V_L > K \geq 2\alpha c_H - V_H$ , and the upper bound in (7)  $2(\alpha - 1)c_H + 2c_L - V_L > 2\alpha c_L - V_L$ , then condition (7) is non-binding. Conditional on entering the contract, exerting  $e_H$  is always privately optimal. The agent enters the contract if  $\eta \leq (\alpha - 1)c_H$ . Otherwise, she prefers to stay out.

## Instructions

Thank you for participating in this experiment on decision-making behavior. You will be paid for your participation in cash at the end of the experiment. Your earnings for today's experiment will depend partly on your decisions and partly on the decisions of the player with whom you are matched.

It is important that you strictly follow the rules of this experiment. If you disobey the rules, you will be asked to leave the experiment. If you have a question at any time during the experiment, please raise your hand and a monitor will come over to your desk and answer it in private.

### *Description of the task*

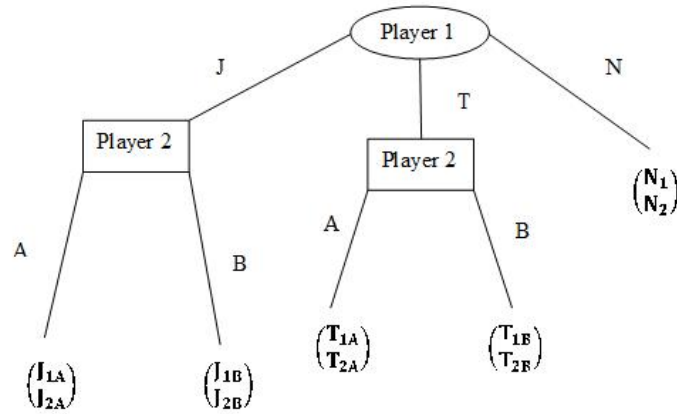
You will be participating in a simple game. The game requires 2 players, one of whom will be called Player 1 and the other Player 2. Prior to the start of the session, you will be randomly assigned the role of either Player 1 or Player 2 and will remain in this role throughout the experiment.

The experiment consists of 10 games. In each game you are matched with a different player of the opposite type. That is, if you are Player 1 you will be matched with a different Player 2 for each subsequent game. Importantly, you will not know the identity of the players with whom you will be matched, nor will the person with whom you are matched know your identity.

Below is a pictorial representation of the game.

Player 1 will move first by selecting one of three branches – Branch J, Branch T, or Branch N. If Player 1 selects Branch N, the game will end. If either Branch J or Branch T is selected, Player 2 will select one of two branches – Branch A or Branch B. Once Player 2 has made this decision, the game will end.





The terminal brackets contain the payoff information. The game will end at one of the five terminal brackets. The top number in each bracket gives the payoff in \$'s for Player 1. The bottom number in each bracket gives the payoff in \$'s for Player 2.

### ***Procedure for Playing the Game***

Player 1 will move first by selecting one of three branches – Branch J, Branch T, or Branch N. The procedure for playing the game that follows from each of these branches is detailed below.

#### **Branch J:**

If Player 1 selects **Branch J**, Player 2 will select one of two branches – Branch A or Branch B. Once Player 2 selects a branch, payoffs are realized as follows:

If Player 2 selects **Branch A**:

- Player 1 receives a payoff of  $J_{1A}$
- Player 2 receives a payoff of  $J_{2A}$

If Player 2 selects **Branch B**:

- Player 1 receives a payoff of  $J_{1B}$
- Player 2 receives a payoff of  $J_{2B}$

This will be the end of the game.

**Branch T:**

If Player 1 selects **Branch T**, Player 2 will select one of two branches – Branch A or Branch B. Once Player 2 selects a branch, payoffs are realized as follows:

If Player 2 selects **Branch A**:

- Player 1 receives a payoff of T1A
- Player 2 receives a payoff of T2A

If Player 2 selects **Branch B**:

- Player 1 receives a payoff of T1B
- Player 2 receives a payoff of T2B

This will be the end of the game.

**Branch N:**

If Player 1 selects **Branch N**, the game will end and payoffs are realized as follows:

- Player 1 receives a payoff of  $N_1$
- Player 2 receives a payoff of  $N_2$

This will be the end of the game.

***Final Payoffs***

You will only be paid your earnings for one of the ten games you will play during today's session. After all ten games have been completed, we will randomly select one of the games by selecting an index card that is numbered from 1 to 10. The number on the card which is selected will determine which game will determine your earnings for today's session.

Even though you will make ten decisions, only one of these will end up affecting your earnings. You will not know in advance which decision will hold, but each decision has an equal chance of being selected.

# Vita

Natalia Gritsko was born in Krasnoyarsk, Russia. Natalia graduated with honors from school 41 in 2002. She got her undergraduate degree in Economics from the Siberian Federal University in Krasnoyarsk, Russia. In 2008 Natalia started her graduate studies at the University of Tennessee in Knoxville. Natalia obtained a Master of Arts and a Doctor of Philosophy degrees from UT.