Product quality and third-party certification in potential lemons markets

Dong Yan, Christian A. Vossler and Scott M. Gilpatric

December 2020

WORKING PAPER #2020-04

WORKING PAPER SERIES
DEPARTMENT OF ECONOMICS
HASLAM COLLEGE OF BUSINESS
https://haslam.utk.edu/economics

HASLAM COLLEGE OF BUSINESS
THE UNIVERSITY OF TENNESSEE, KNOXVILLE

Product quality and third-party certification in potential lemons markets

Dong Yan
Department of Environment and Resource Economics, Renmin University of China, Beijing

Christian A. Vossler and Scott M. Gilpatric
Department of Economics, University of Tennessee, Knoxville

Correspondence should be directed to Christian Vossler, Department of Economics, 527F Stokely Management Center, The University of Tennessee, Knoxville, TN 37996-0550. E-mail: cvossler@utk.edu. Telephone: 865-974-1699. Fax: 865-974-4601. We thank seminar participants at the 2019 North American ESA Meeting and the University of Tennessee for helpful comments and suggestions. This paper reports research involving the collection of data on human subjects. Approval from the University of Tennessee Institutional Review Board was obtained, as protocol UTK IRB-19-05210-XM.

Product quality and third-party certification in potential lemons markets

Abstract: This paper examines a seller's incentives for investing in product quality when buyers have incomplete information on quality, and either the seller or the buyer can purchase quality certification from a credible third party. When the seller invests in quality before the certifier sets a price, we find that both seller effort and social welfare are higher in a setting where certification is available to the buyer relative to one where it is available to the seller. When the certifier instead moves first in the game, buyer certification continues to incentivize relatively more seller effort, although social welfare is not necessarily higher. In a complementary lab experiment, we find empirical support for some basic implications of the theory: certification improves market outcomes relative to when certification is not available, decreasing the price of certification increases its uptake, and making the certification process error-prone decreases seller effort and social welfare. Comparisons of seller and buyer certification settings suggest that differences are smaller than predicted by theory, which may be explained by behavioral factors that motivate buyers to over- or under-utilize certification. Our results also suggest that seller certification is a more robust tool for improving market efficiency.

JEL Classifications: C91, D82, D83, L15

Keywords: Market transparency, Certification, Information and product quality, Asymmetric information, Endogenous quality, Experiments

1. Introduction

An extensive literature has explored consequences, such as adverse selection, that arise in markets characterized by asymmetric information between parties engaged in potential transactions. One way to mitigate the information problem is for a certifier to enter the market and provide credible information to the less knowledgeable agent. That both buyers and sellers demand certification is evident from existing markets. For instance, in product markets where sellers have better information on product quality than buyers do, food companies certify their products as organic, consumers pay a business such as Lemon Busters to inspect a used car prior to purchase, and firms engage with credit rating agencies to attract buyers for their bonds. In this paper we focus on the seller's incentives to invest in product quality when a certification service is available. We are specifically interested in comparing markets where the seller has the option to purchase certification, a setting we will refer to as seller certification, with otherwise identical markets where instead buyer certification is available. While prior theory work examines investment in product quality in the case of seller certification, ours is the first paper to focus on the buyer certification case, and to make comparisons between otherwise equivalent buyer and seller certification markets. we test the validity of the new theory with a laboratory experiment.

As discussed by Stahl and Strausz (2017), there are fundamental differences between seller and buyer certification settings. Seller certification acts as a signaling device, and leads to transparency as it conveys information to the buyer about quality even when it is not used. In fact, certification is the only credible signal of quality, as the price set by the seller contains no meaningful information absent certification. In the buyer certification case, certification acts as an inspection tool. Here, the seller's price does provide a quality signal, albeit an imperfect one, as the seller is exposed to the possibility that the buyer will pay for certification and then forego the purchase if the product is not high quality. The certifier is incentivized to price the service in a way that minimizes market transparency, as this decreases the value of the seller's price signal and, in turn, maximizes the demand for certification.

In this study we show theoretically that, despite the decrease in market transparency, buyer certification provides a stronger motivation for sellers to invest in product quality. In fact, for the seller-certification case, product quality is fully revealed in the market, but the certifier captures the value of effort expended toward increased quality, leaving the seller with little incentive to create value through higher quality. Conversely, in the buyer-certification setting where the certifier provides the service at a lower cost to decrease transparency and increase demand for certification, the seller invests more in quality since he captures a higher return on investment.

Our analysis complements prior work on seller certification, which also demonstrates that introducing a certifier can improve upon market outcomes, but that the seller's incentive to invest in product quality is nevertheless below the first-best case. This literature dates back to Biglaiser (1993), who demonstrates how an information intermediary (e.g., a certifier) affects market efficiency. Albano and Lizzeri (2001) generalize the model of Lizzeri (1999) to allow for endogenous effort, and find that seller certification increases market efficiency; however, an inefficiency still remains as the certifier will always charge a positive price for the information and reduce the seller's incentive to invest in quality improvement. As another example, Biglaiser and Li (2018) show that when the seller certification process is perfectly revealing, this information mechanism crowds out any imperfect signal, and yields the certifier significant market power. In the extreme case, buyers have perfect information on quality, but sellers have absolutely no incentive to invest in quality. Board and Meyer-ter-Vehn (2013) and Marinovic, Skrzypacz, and Varas (2017) focus on the relationship between certification and reputation. In their model, they assume the firm can both build a reputation and use certification to signal product quality. A certification trap occurs in that environment as low reputation firms have no incentive to invest in quality as the certifier will take all their surplus.

Our research also contributes to the understanding of tradeoffs between seller and buyer certification. On this note, while there is a sizable literature focused on seller certification (see Dranove and Jin, 2010), only a few papers have compared the two types of processes. Importantly, these studies abstract from the seller's quality investment choice. Durbin (1999) first illustrates that the role of certification depends on the trading party and focuses on how a certifier can maximize profit through the choice of whether to engage with the buyer or seller. Fasten and Hofmann (2010) allow the certifier to trade with both parties, but the focus is on the profit-maximization problem of the certifier. Most relevant to our work, Stahl and Strauz (2017) allow for strategic interaction between the certifier and engagement party but assume product quality is exogenously determined. In their model, seller certification is more beneficial as it leads to a higher market transparency and social welfare.

Our model considers the case with one potential buyer, one seller, and one certifier. In our baseline model, the seller first makes a costly choice of effort to probabilistically determine the quality of the product, and then presents a take-it-or-leave-it offer to the buyer. Using a similar structure, we consider cases where the seller or buyer has the option to purchase certification. In the seller certification scenario, consistent with Biglaiser and Li (2018), the certifier sets the price of her service after quality is determined (that is, the certifier cannot commit to a price prior to the seller choosing effort). In this case, a profit-maximizing certifier will set the price of the service equal to difference in the buyer's willingness-to-pay for high and low quality items, leaving a seller no better off when they have a high-quality item to sell. In the buyer certification scenario, knowing that the low-quality seller has an incentive to mislead the buyer, a buyer will purchase certification with a probability less than one. With a lower certification price, the buyer's random inspection mechanism yields the seller an expected positive benefit for producing a high-quality product, thus motivating effort to increase quality.

We further consider a setting where the certifier moves first by committing to a price. While this has no effect on buyer certification, in the case of seller certification changing the order of the game does motivate the certifier to lower her price to incentivize seller effort which in turn increases demand for certification. Nevertheless, buyer certification continues to better motivate investment into product quality. From a social welfare perspective, the advantage of buyer certification is the additional effort towards quality improvement, while the disadvantage is the loss that occurs when a misleading low-type seller is caught and the product goes unsold. We show that buyer certification unambiguously increases social welfare when the certifier moves second in the game. Whether this is true in the case where the certifier moves first depends on the value of a low-quality product to buyers.

We consider two additional extensions. First, we assume the certification price is set competitively, rather than by a monopolistic certifier. In this case, seller certification leads to relatively higher product quality, as the certifier's rent-seeking behavior becomes limited while the advantage of market transparency still exists. Second, we introduce a probability that the certifier may classify a low-quality item as high-quality, and vice versa. The presence of errors in the certification process lowers both the price of certification and the seller's effort choice. However, we find the magnitudes of these effects differ across buyer and seller certification, leading to ambiguity in terms of which leads to more desirable market outcomes.

The theoretical model yields several testable hypotheses regarding investment in quality under varying market and institutional conditions, some of which we test in a complementary laboratory experiment. The experimental investigation contributes to an experimental literature on information provision in “lemons” markets, which has examined the effects of seller certification, information disclosure, cheap-talk communication, and reputation building (Forsythe, Isaac, and Palfrey, 1989; Cason and Gangadharan, 2002; List, 2006; Benndorf, Kübler, and Normann, 2015; Siegenthaler, 2017). Most directly related to our experiment is Cason and Gangadharan (2002), who examine whether (costly) seller-chosen certification improves market efficiency, and find that certification is a more reliable approach for improving market efficiency when compared to cheap talk and reputation building mechanisms. Parallel to the theory, our experiment adds to the literature an examination of the effects of buyer certification, and a comparison between buyer and seller certification mechanisms, in a setting where quality is endogenously determined. In the experiment, we compare settings where seller certification is predicted to be superior in terms of product quality and/or social welfare with others where buyer certification carries these potential advantages. We further investigate the effects of introducing errors in the certification process, and the effects of varying the price of certification.

The experimental results serve to both confirm and challenge the theoretical model. We find support for some primary hypotheses, including that certification improves market outcomes relative to when certification is not available, decreasing the price of certification increases its uptake, and introducing errors decreases both seller effort and social welfare. However, comparisons of parallel seller and buyer certification settings suggest that differences are smaller than predicted by theory, which may in part be explained by unanticipated drivers underlying the demand for buyer certification services. Additional details of our results are described later.

2. Theoretical model

In our model, there are three players in the market: one seller, one buyer and one certifier. We define player roles below.

Seller: the seller produces one unit of a product at some cost. The quality of the output θ is determined by the seller's effort, and is either high or low (discrete), $\theta \in \{L, H\}$. Define e as the probability that the item is high quality, and $c(e)$ as the cost function. We assume $c(e)$ is twice differentiable, strictly increasing and convex on the unit interval, $e \epsilon [0,1]$. Also, we assume $c'(0) = 0$, which guarantees an interior solution. Absent any certification cost, if the seller exerts effort e and the good is sold at price P, firm profits equal $P - c(e)$.

Buyer: the buyer neither observes the seller's effort nor the quality of the good prior to purchasing the item. However, the buyer has a prior belief about the seller's effort level, $\tilde{e}$, and updates his belief based on the price, and any information provided by a certifier. The buyer's utility depends on the quality of the product. Define $v = v_h$ if the product is high quality and $v = v_l$ if the product is low quality. Then, absent any certification cost, the buyer's expected payoff from purchasing the item is $E(v|P, \tilde{e}) - P$. If a purchase is made, the buyer knows with certainty the quality of the good.

Certifier: the certifier only benefits from selling its services. The certifier has an inspection technology, which is costless and possibly prone to errors. The certifier makes a "take-it-or-leave-it" price offer, P_c, for the service and provides a product certification only when the quality is determined to be high. The certifier either offers the service directly to the buyer or the seller, depending on the setting.

In the analysis that follows, we first define the benchmark model as the case without any certifier. Next, under the assumption that the certification service is perfectly-revealing, we compare seller certification and buyer certification when the certifier moves after the seller to illustrate the difference between the two mechanisms. We then consider the case where the certifier moves first and demonstrate the advantage of buyer certification remains. Last, we extend the certification models to consider a competitive certification market, and an error-prone certification process.

2.1 Benchmark case

In his classic article, Akerlof (1970) argues that information asymmetry over product quality can result in a market where only low-quality products ("lemons") are sold, and eventually all high-quality products are priced out of the market. As it is not obvious that a similar result will hold in a setting where sellers can expend costly effort to improve product quality, we first analyze a simple product market without a certifier. The game has three stages:

1. The seller chooses effort e and then learns product quality θ.
2. The seller makes a "take-it-or-leave-it" offer to the buyer at price P.
3. Observing price P, the buyer updates his belief about product quality and decides whether to purchase the product.

Our model is of a sequential game with incomplete information, and we rely on the Perfect Bayesian Equilibrium (PBE) equilibrium concept. Allowing for a mixed strategy, let $\sigma_\theta(P)$ denote the probability that a seller with quality θ offers the item at price P, and it satisfies the condition that:

(1) $\int_{v_l}^{v_h} \sigma_\theta(P) = 1, for\ \theta \in \{L, H\}$,

where we assume the reasonable range of prices to span the buyer's valuations of the high- and low-quality product.

The buyer updates her belief after observing the price signal using Bayes' rule. Since the only signal that a buyer has is the price, we define $\mu(P)$ as the buyer's belief that the item is high quality as follows:

(2) $\mu(P) = \frac{\tilde{e}\sigma_h(P)}{\tilde{e}\sigma_h(P)+(1-\tilde{e})\sigma_l(P)}$

In other words, when offered P, the buyer will form her belief based on the prior and the chance that a seller will offer a low (high) quality product at a price P. With the updated belief, the buyer will take the offer if $P \le \mu(P)v_h + (1-\mu(P))v_l$, and reject it if $P > \mu(P)v_h + (1-\mu(P))v_l$.

Knowing that the buyer has a belief about the expected value based on the price signal, the seller decides the optimal price based on the actual quality. Though we allow the seller to use a mixed strategy, it turns out that offering the good at $P^* = E(v) = \mu(P)v_h + (1-\mu(P))v_l$ dominants any other price for a high-quality seller. Any price higher than this will deter the buyer while any price lower than this will not maximize profit. For a low-type seller, he follows the same strategy as the high type seller, and offers the item at $P^* = E(v)$, since a different action will reveal his type to the buyer. Thus, we have $\sigma_h(P^*) = \sigma_l(P^*) = 1$, $\mu(P^*) = \tilde{e}$, and $E(v) = \tilde{e}v_h + (1-\tilde{e})v_l$. Notice here the optimal selling price does not depend on the effort choice of seller. Thus, the seller will set the price just equal to $\tilde{e}v_h + (1-\tilde{e})v_l$ and then choose effort in order to maximize profit

(3) $\max_{e\in[0,1]} P^* - c(e).$

Substituting in the value of P^*, the equivalent problem is

(3') $\max_{e\in[0,1]} \tilde{e}v_h + (1-\tilde{e})v_l - c(e).$

Clearly, the solution to this problem is for the seller to exert minimal effort, which minimizes cost. In equilibrium, the buyer's belief $\tilde{e}$ is correct and $\tilde{e} = 0$ indicates no high-quality item is produced. Conditional on the assumptions made, the solution for the problem is unique.

Lemma 1 When there is no certifier in the market, the optimal effort choice by the seller is $e^* = 0$, i.e. the seller chooses minimum effort, and only low-quality items are produced and traded.

2.2 Seller certification

Now we allow the certifier to enter the market and interact with the seller, which provides the seller an opportunity to signal product quality. We assume that certification perfectly reveals quality. If certification is purchased, a high-quality item will be certified whereas a low-quality item will not. With this additional interaction, the seller certification game has five stages:

1. The seller decides his effort level e, and then quality θ is revealed
2. The certifier determines the certification price P_c.
3. The seller decides whether to purchase certification. If the service is purchased, an item with high quality will convey a certification as a perfect quality signal to the buyer.
4. The seller sets the price P and makes a "take-it-or-leave-it" offer to the buyer.
5. Observing price P and whether the product is certified, the buyer updates her belief about product quality and decides whether to purchase the product.

Define $\sigma_\theta^c(P)$ as the probability a seller offers a certified item at price P, and $\sigma_\theta^u(P)$ as the probability a seller offers an uncertified item at price P. The seller's strategy must satisfy the condition that for each type of seller, the joint probability between choosing a selling price and taking certification equals to one. After observing the seller's action, as we assume certification provides a perfect signal, the buyer will treat any item with certification as high quality, and thus the maximum acceptable price is $P_H = E^c(v) = v_h$. For any item without certification, the buyer will form the belief $\mu(P)$ as

(4) $\mu(P) = \frac{\tilde{e}\sigma_h^u(P)}{\tilde{e}\sigma_h^u(P)+(1-\tilde{e})\sigma_l^u(P)}$,

which implies $P_L = E^u(v) = \mu(P)v_h + (1-\mu(P))v_l$. We first assume the price of certification, P_c, is exogenously given and define the equilibrium as follows:

Lemma 2 With P_c exogenously determined, under seller certification we have that

1. For any $P_c \leq P_H - P_L$, a high type seller will always purchase certification, and a low type seller will not. A PBE exists for which the expected profit for the certifier is $P_c e$ and the product is purchased with certainty.
2. For any $P_c > P_H - P_L$ neither the high type nor low type seller purchases certification. The equilibrium is the same as in the benchmark case.

Knowing the buyer takes the certification as a perfect signal and high type seller will always purchase certification when $P_c \leq P_H - P_L$, the certifier needs to solve their profit maximization problem. To maximize profit while incentivizing the seller to purchase certification, the certifier will set the price P_c such that the profit of the seller is the same regardless of the quality of the item, which implies $P_c = P_H - P_L$. Under this price we have $\sigma_h^u(P) = 0$, since it is always optimal for the high-type seller to purchase the certification. We also know that a low-type seller will never purchase certification since the inspection is perfect, $\sigma_l^u(P) = 1$. Thus,

(4') $\mu(P) = \frac{\tilde{e}\sigma_h^u(P)}{\tilde{e}\sigma_h^u(P)+(1-\tilde{e})\sigma_l^u(P)} = 0$,

(5) $P_L = E^u(q) = \mu(P)v_h + (1-\mu(P))v_l = v_l$,

and

(6) $P_c = P_H - P_L = v_h - v_l$.

With these conditions, the profit-maximizing problem for the seller becomes

(7) $\max_{e\in[0,1]} e(P_H - P_c) + (1-e)P_L - c(e).$

After substituting in the optimal P_c, the problem above is equivalent to

(7') $\max_{e\in[0,1]} v_l - c(e).$

Based on our assumptions, the unique solution for this problem is $e^* = 0$, as in the benchmark case. We summarize our first result in the following proposition.

Proposition 1 The market with available seller certification has a unique equilibrium. The high-quality seller certifies with certainty, and the low-quality seller does not certify. The buyer purchases a certified product at price v_h and an uncertified item at price v_l. The certifier sets the price of certification to be $P_c = v_h - v_l$, and the seller devotes minimal effort to improving the quality. The product is traded with certainty.

Intuitively, although the existence of the certifier provides the market with perfect information, the rent seeking nature of the certifier will also reduce the incentive for the seller to devote additional effort. Note here that the equilibrium for the seller certification case is fundamentally different from the benchmark case in the sense that the equilibrium is a perfect sorting equilibrium and a high-quality product is recognized by the market. While this distinction may seem trivial, consider a slight modification where we instead assume that expending minimal effort, $e = 0$, yields a high-quality item with a probability greater than zero. Thus, a high-quality product can arise, and when produced the seller will purchase certification. This, in turn, will increase social welfare relative to the benchmark case.

2.3 Buyer certification

As with the case of seller certification, the buyer certification has five stages:

1. The seller decides his effort level e and learns the quality θ following production.
2. The certifier determines the certification price P_c.
3. The seller sets a product price P and makes a "take-it-or-leave-it" offer to the buyer.
4. Based on the price of certification and the product price, the buyer decides whether to purchase a certification service. If certification is purchased, the buyer knows the quality for sure.
5. The buyer decides whether to purchase the product.

Allowing for a mixed strategy, we define $\sigma_\theta(P)$ as the probability that a seller with quality θ offers the item with price P, and $\sigma_\theta(P)$ satisfies the condition that

(8) $\int_{v_l}^{v_h} \sigma_\theta(P) = 1, for\ \theta \in \{L, H\}$.

In the absence of certification, the only signal available to the buyer is the offered price. We define $\mu(P)$ as the buyer's belief that the quality of the item is high based on the price signal. Using Bayes' rule, faced with P, the buyer will first consider the probability that a seller with type θ will sell the item at the given price, yielding the belief

(9) $\mu(P) = \frac{\tilde{e}\sigma_h(P)}{\tilde{e}\sigma_h(P)+(1-\tilde{e})\sigma_l(P)}$.

With the price and belief, the buyer has three possible actions:

1. Action s_b: the buyer does not purchase certification, and buys the item directly. The expected payoff is $U(s_b|P,\mu)$= $\mu(P)v_h + \left(1-\mu(P)\right)v_l - P$.
2. Action s_n: the buyer does not purchase certification, and does not buy the item.
3. Action s_h: the buyer purchases certification and purchases the product only if it is high quality. The expected payoff is $(s_h|P,\mu)$= $\mu(P)(v_h - P) - P_c$.

There are three other possible actions: paying for the certification service and purchasing the item if the quality is low; buying certification but never purchasing the item; and, paying for certification and always buy the item. Since these actions are payoff dominated, we can safely exclude them from consideration. We can calculate the range of values for $P, \mu,$ and P_c that allows one action to yield a higher payoff than the others. The action s_n is optimal when

(10) $\mathrm{P} > \mu(P)v_h + \big(1-\mu(P)\big)v_l$ and $P_c > \mu(P)(v_h - P)$.

Following the same logic, s_b is optimal when

(11) $\mathrm{P} \leq \mu(P)v_h + \big(1-\mu(P)\big)v_l$ and $P_c \geq (1-\mu)(P-v_l)$.

And last, s_h is optimal when

(12) $P_c \leq \mu(P)(v_h - P)$ and $P_c \leq (1-\mu)(P-v_l)$.

To fully characterize the equilibrium, we will divide the discussion into three parts. First, assuming a mixed strategy equilibrium, we identify the optimal action set for each player in the PBE. Second, conditional on consistency in beliefs we identify the probability of each action. Last, given the mixed strategy PBE, we will show that there is no meaningful pure strategy PBE in this game.[1] These three steps are sufficient to demonstrate that the equilibrium satisfies the requirement for a PBE.

In a mixed strategy equilibrium, a buyer must be indifferent among s_n, s_b and s_h, which implies:

(13) $P_c = \mu(P)(v_h - P)$,

(14) $P_c = (1-\mu)(P-v_l)$, and

(15) $P = \mu(P)v_h + \big(1-\mu(P)\big)v_l$.

Solving the system yields

(16) $\tilde{P} \equiv \frac{\left(v_h + v_l + \sqrt{\Delta v(\Delta v - 4P_c)}\right)}{2}$ and $\tilde{\mu} \equiv \frac{\left(1+\sqrt{1-4P_c/\Delta v}\right)}{2}$,

[1] There is a pure strategy equilibrium in which the seller choses e = 0 and buyer buys as the low-quality price. We ignore this self-fulfilling case in the following analysis.

where Δv is the difference in buyer valuations for high and low-quality items. If the seller sets the price at $\tilde{P}$ and the buyer has the belief $\tilde{\mu}$, then the buyer will be indifferent among these three actions. As the certifier wants to maximize profit, they will always set the certification price such that the buyer purchases it. As long as $P_c \leq \Delta v/4$, the buyer will have a demand for certification.

To fully characterize the equilibrium, we need to calculate the optimal strategy of the seller conditional on the realized quality. When $P = \tilde{P}$ and $\mu = \tilde{\mu}$, a high type seller will set $P = \tilde{P}$, since any higher price will result in the buyer not purchasing the item. Any lower price is not optimal since it would only decrease profit while not changing the purchase probability. For a low-type seller, he will face a semi-inspection game. If he offers a price other than $\tilde{P}$, he will be recognized as a low type under an updated belief from the buyer. Thus, if he does not ask for $\tilde{P}$, the maximum price he can ask is v_l. If he asks for $\tilde{P}$ he then will receive 0 when the buyer chooses certification, or $\tilde{P}$ if the buyer chooses not to. Defining $\sigma^*(s_h)$ as the probability a buyer will check the quality when facing $\tilde{P}$, and $\sigma_l^*(\tilde{P})$ as the probability that a low type seller attempts to mislead the buyer into thinking his product is high quality, we state Lemma 2 as follows:

Lemma 2 For a given P_c, under buyer certification we have that

1) For any $P_c \leq \Delta v/4$, a high type seller always offers the product at $\tilde{P}$. A low type seller offers $\tilde{P}$ with probability $\sigma_l^*(\tilde{P})$, and $P = v_l$ with probability $1 - \sigma_l^*(\tilde{P})$. Faced with $P = \tilde{P}$, the buyer purchases certification with probability $\sigma^*(s_h)$. When $P = v_l$, the buyer never purchases certification.
2) For any $P_c > \Delta v/4$, the buyer never purchases certification. The equilibrium is the same as the benchmark case.

For the buyer, $\sigma^*(s_h)$ makes the low type seller indifferent between offering to sell at $\tilde{P}$ or $P = v_l$. After some manipulations, we have that

(17) $\sigma^*(s_h) = \frac{\tilde{P} - v_l}{\tilde{P}}$.

For $\sigma_l^*(\tilde{P})$, knowing the high type seller always offers $\tilde{P}$, it follows that

(18) $\mu(\tilde{P}) = \frac{\tilde{e}\sigma_h(\tilde{P})}{\tilde{e}\sigma_h(\tilde{P}) + (1-\tilde{e})\sigma_l(\tilde{P})} = \frac{\tilde{e}}{\tilde{e} + (1-\tilde{e})\sigma_l(\tilde{P})}$.

We also have

(19) $\mu(\tilde{P}) = \tilde{\mu}$.

In order for the beliefs to be consistent we must have

(20) $\sigma_l^*(\tilde{P}) = \frac{\tilde{e}(1-\tilde{\mu})}{\tilde{\mu}(1-\tilde{e})}$,

where $\sigma_l^*(\tilde{P})$ is the probability that a low type seller offers the item at $\tilde{P}$.

Based on the derivations above, the seller's profit-maximization problem is

(21) $\max_{e \in [0,1]} e\tilde{P} + (1-e)\sigma_l^*(\tilde{P})(1-\sigma^*(s_h))\tilde{P} + (1-e)(1-\sigma_l^*(\tilde{P}))v_l - c(e)$,

which can be simplified by substituting in the expression of $\sigma_l^*(\tilde{P})$ and $\sigma^*(s_h)$ to yield

(21') $\max_{e \in [0,1]} e\tilde{P} + (1-e)v_l - c(e)$.

In equilibrium, a high-type seller will always offer $\tilde{P}$ and successfully sell the product. The expected profit for a low-type seller is v_l, as the frequency at which the buyer purchases certification makes the seller indifferent between attempting to mislead the buyer by offering $\tilde{P}$ (in which case the product is not purchased when checked) or offering $P = v_l$.

Taking the derivative of the revenue and cost functions with respect to e, we have

(22) $MB = \tilde{P} - v_l$ and $MC = c'(e)$.

Combining this result with our assumptions about the cost function, we can easily show that there exists an optimal effort e^* that is strictly positive and solves the maximization problem above. The intuition here is that, when a seller knows that the buyer might purchase certification, he puts more effort into product development since quality has a higher chance of being recognized. Compared with the seller certification case, clearly a market with available buyer certification leads to a greater investment in quality.

Though this result may seem counterintuitive, there is a clear story here. For the seller certification case, the only incentive compatible way to reveal quality is through certification. At the same time, any price claim without the reinforcement of certification is not credible. Such a mechanism provides the certifier with complete market power and allows the certifier to extract all the value from their service, leaving the seller with no benefit from investment in quality. On the other hand, in the buyer certification case, the action to offer $\tilde{P}$ also serves as an information device. When a seller self-claims to be a high type, he sends the market a signal, because he incurs an opportunity cost in expectation if his product is, in fact, low quality. The existence of the second source of information limits the rent-seeking ability of the certifier, which in turn increases the seller's incentive to invest in quality improvement.

When the quality of product is exogenously given, Stahl and Strausz (2017) find that a market with available seller certification yields a higher social welfare as the product is always sold. With endogenous quality, we find seller certification is still trade promoting compared with buyer certification, but the overall social welfare may become ambiguous as the effort level decreases. Here we show the social welfare is always higher under buyer certification when the seller moves first in the game. The advantage of buyer certification is the additional effort towards quality improvement, while the loss is the untraded item when a misleading low-type seller is caught. We can express the comparison as follows

(23) $e_b \Delta v - \sigma_l^*(\tilde{P}) \sigma^*(s_h) v_l,$

where e_b is the equilibrium effort level in the case of buyer certification. Substitute in the value of each term, and in equilibrium the expression above reduces to:

(24) $e_b \Delta v[1 - \frac{(1-\mu)}{\tilde{P}} v_l]$,

which is strictly positive as $\tilde{P} > v_l$ and $\mu < 1$.

Proposition 2: If the certification price is set after the seller observes product quality, a market where certification is available to the buyer increases both the seller's investment into product quality and social welfare when compared with a market where instead certification is available to the seller. The probability a product is traded is strictly less than 1.

2.4 Certification when the certifier moves first

In this section, we focus on a case where the certifier sets their price prior to when the seller chooses effort. With seller certification available, knowing that the seller will make his effort choice after observing the certification price, the certifier has the incentive to reduce the certification price to incentivize seller investment, which increases the chance that certification is purchased. On the other hand, the buyer's optimization problem when buyer certification is available is unaltered by the order of the game; therefore, the certification price and seller's optimal effort are the same as before.

To facilitate a cardinal comparison across certification mechanisms, we assume a flexible form for the cost of effort function; in particular, we assume this has the exponential form, $c(e) = e^{\lambda}$, where $\lambda > 1$ is a parameter that characterizes the convexity of the cost function. For the seller certification case, using backward induction, the optimal certification price and marginal benefit of effort are as follows

(25) $P_c = \frac{(\lambda-1)\Delta v}{\lambda}$ and $MB_s = \Delta v - P_c = \frac{\Delta v}{\lambda}$.

With buyer certification, based on the discussion in section 2.3, we can write the certifier's profit maximization problem as

(26) $\max_{P_c} \; [e_b(P_c) + (1 - e_b(P_c))\sigma_l^*(\tilde{P}(P_c))]\sigma^*(s_h(P_c))P_c.$

By choosing P_c, the certifier simultaneously influences many aspects of behavior. A higher price of certification makes the certification less favorable for the seller. However, if the chance the buyer purchases certification falls, this also increases the chance that a low-type seller may distort his price in an attempt to mislead the buyer. The solution to (26) is

(27) $P_c^* = -\frac{\Delta v(-2n\lambda-\lambda+n+1)\sqrt{(n+1)(\frac{1}{4}+n(\lambda-\frac{1}{2})^2)}+(n+1)(\lambda^2-(4n+1)\lambda+n+1)}{2\lambda^2},$

where $n = \frac{v_l}{\Delta v}$, represents the relative value of a low-quality product. The difference between the marginal benefit of effort in the buyer and seller certification cases is equal to

(28) $MB_b - MB_s = \frac{\Delta v}{2} + \frac{\sqrt{\Delta v(\Delta v - 4P_c^*)}}{2} - \frac{\Delta v}{\lambda},$

which is always positive, and increases with n. Intuitively, when the relative value of the low-quality item increases, the value of the price signal in the buyer certification case increases as well, which in turn leads to a lower certification cost and higher seller effort. Here, we provide our third proposition, a detailed proof of which is provided in the appendix.

Proposition 3: With the cost function $c(e) = e^{\lambda}$ and $\lambda > 1$, the seller's effort is higher in a market with available buyer certification relative to a market with available seller certification. The difference in effort across the certification mechanisms increases with the relative value of the low-quality product, $\frac{v_l}{v_l+v_h}$.

Whether buyer or seller certification leads to higher social welfare is ambiguous. As discussed in Section 2.3, the social welfare differences depend on whether the expected value of the additional effort induced by buyer certification outweighs the expected loss that occurs when a misleading low-type seller is caught, and the product is not sold. When the value of a low-quality product is sufficiently low, the additional effort induced by buyer certification is no longer large enough to offset the expected losses from misleading sellers.

2.5 Extension 1: Competitive certification market

In the previous sections we focused on a monopolistic certifier. At the other extreme, the certification market may be either competitive or under some regulation, and be one where the certifier charges the same price regardless of the engaging party. In this case, we can easily show that seller certification leads to higher seller effort. As the cost function and the price of the low-quality item are the same in the two cases, we compare the two mechanisms based on the expected price of the high-quality item. To set up the comparison we have

$$(29)\quad (P_H - P_C) - \tilde{P} = v_h - P_C - \frac{\left(v_h + v_l + \sqrt{\Delta v(\Delta v - 4P_C)}\right)}{2},$$

which equals zero when $P_C = 0$, and is strictly increasing in P_C. Intuitively, the constraint on the certification price limits the certifier's ability to obtain rents in both cases. However, the transparency advantage of seller certification provides the seller a higher incentive to devote effort, as a seller of a high-quality item can extract all available surplus without providing the buyer any compensation for potentially misleading behavior.

2.6 Extension 2: Imperfect certification process

Last, we consider the case where the certification process is error prone. Let τ denote the accuracy rate, or the probability that a high (low) quality product will be correctly deemed by the certifier to be of high (low) quality. We assume that errors are symmetric, in the sense there is a $1 - \tau$ probability that a low-quality item is certified to be high quality, and a $1 - \tau$ probability that a high-quality is determined to be low quality. We assume the probability is common knowledge. When the certifier sets the price after the seller chooses effort, regardless of whether the inspection is perfect or not, the certifier will always price so that they capture all seller surplus, leaving the seller with zero incentive to improve the quality. Therefore, Proposition 2 applies.

When the certifier sets their price before the seller chooses effort, it turns out that when the error rate, $1-\tau$, together with value of the low-quality item becomes large, the seller certification mechanism will lead to higher effort. This is because under buyer certification, when a high-quality product is certified to be low quality, the seller faces an additional opportunity cost as he is not able to sell the item. On the other hand, under seller certification, when the high-quality product is certified to be low quality, the seller can still sell it at the price of a low-quality item. Support for these claims can be found in the Appendix.

3. Experimental design

The theory models motivate several testable hypotheses. As a starting point for understanding whether the models are good approximations for actual behavior, we use a lab experiment with human subjects to test a subset of them. While mathematically tractable, a sophisticated game with three players introduces considerable complexities. To reduce this complexity, we simplify the experimental design by automating the role of the certifier. Specifically, we hold fixed certification prices within treatments. As such, the experimental game conceptually captures a setting where either the certifier moves first, or otherwise one where the certification market is competitive or regulated. One additional advantage of this design choice is that it allows us to compare otherwise identical buyer and seller certification markets while holding the price of certification fixed, a case described in Section 2.5.

The experimental treatments are summarized in Table 1, and Table 2 presents theoretical predictions for outcomes of interest.[2] The experimental design varies as between-subject treatment variables whether seller or buyer certification is available, and whether the certification process perfectly or imperfectly reveals product quality. As a within-subject treatment variable we vary whether the certification price, P_c, is the theoretically optimal certification price derived from the model in Section 2.4 or instead an alternative price. This randomization is implemented within-session, with half of participants facing the optimal (alternative) price at the start of the session, and then switching to the alternative (optimal) price for the remainder. The alternative price in the case of seller (buyer) certification is the optimal price for the parallel buyer (seller) certification treatment. We introduce as a control a standard lemons market, a market where certification is not available. We now provide details of the experimental game.

The experimental game involves a single seller and a single buyer. The seller chooses effort, e, by selecting an integer from 0 and 10, and this translates linearly into the probability the product will be of high quality – each additional unit of effort increases this chance by 10 percentage points and 10 units of effort guarantees the product is high quality. The cost of effort function is $c(e) = e^2$, and costs range from 0 to 100 lab dollars. The buyer has valuations of $v_l = 250$ and $v_h = 500$ lab dollars, respectively, for a low-quality and a high-quality item. The seller makes a take-it-or-leave it price offer to the buyer, and there is no outside opportunity to sell the product.

When seller certification is available, the seller has the option to purchase certification, at a known price, after product quality is revealed. The outcome from the certification process is known to the seller prior to making a price offer. When buyer certification is available, the buyer

[2] For convenience, we will refer to treatments using acronyms constructed by the type of certification available (B=buyer, S=seller), whether the certification process is perfect (P) or imperfect (I), whether the monopolistic (M) or an alternative (A) certification price is used certification price. As an example, BPA(125) refers to available buyer certification, a perfect certification process, and an alternative certification price of 125.

has the option to purchase certification, at a known price, after receiving the seller's price offer. In either certification setting, when a product is certified to be of high quality, this information is revealed to the buyer before he is asked to make a purchase decision.

The certification process can be perfect or imperfect. Under perfect certification, there is a 100% chance that a high-quality product, and a 0% chance that a low-quality product, will be certified as high quality to the buyer. Under imperfect certification, we set $\tau = 0.7$, and these percentages change to 70% and 30% respectively; i.e., there is now a 30% error rate. With seller certification, unless the product is certified to be high quality, no information about quality is made explicit to the buyer. To be clear, the buyer does not know for sure whether the seller simply elected not to purchase certification or instead whether certification was purchased but the outcome was unfavorable. Under buyer certification, the buyer learns the outcome from the certification process. In any case, the error rates are known to both buyers and sellers.

A seller's earnings are equal to the sales price (if any) minus production cost and any certification cost. A buyer's earnings are the difference between the product's valuation and sales price (if a purchase is made), less any certification cost. In addition, both the buyer and the seller receive 100 lab dollars in fixed income in each decision period. This fixed income helps to make earnings positive over the course of the experiment, given that losses are possible; e.g., a buyer may mistakenly overpay for a low-quality product.

3.1 Testable hypotheses and power analysis

Our design allows for tests of several hypotheses related to seller effort, the probability certification is purchased, and social welfare. For ease of interpretation we express social welfare (i.e., the sum of seller, buyer, and certifier profits) in terms of the percentage of possible welfare achieved; i.e., as an efficiency measure. Maximum social welfare equals 400, and is attained when the seller chooses the maximal effort of 10 (which guarantees a high-quality product, and costs 100), and the product is successfully sold to the buyer (who values it at 500). Note that any revenue collected by the (simulated) certifier does not alter welfare calculations, as this represents a transfer between parties. Below we summarize as hypotheses key predictions from the theory:

> **Hypothesis 1**: With the exception of buyer certification under the alternative certification price, both effort and social welfare are higher when certification is available relative to the no certification setting.
>
> **Hypothesis 2**: Under perfect inspection and the monopolistic certification price, buyer certification leads to higher seller effort relative to the seller certification case.
>
> **Hypothesis 3**: Under imperfect inspection and the monopolistic certification price, seller certification leads to higher seller effort relative to the buyer certification case.
>
> **Hypothesis 4**: Under perfect inspection and holding constant the certification price, seller certification will lead to higher seller effort relative to the buyer certification case.
>
> **Hypothesis 5**: Seller effort and social welfare are lower when the certification process is imperfect (i.e., subject to error).

Hypothesis 1 is the key prediction that certification induces higher seller effort and leads to a higher social welfare relative to the standard lemons market. As we have devised scenarios, for comparison purposes, that price the certifier out of the market, in a few treatments the expectation is instead that the market with certification does no better than our control setting. Hypothesis 2 compares the two treatments with perfect inspection and a monopolistic certification price, and this prediction follows directly from Proposition 3. Hypothesis 3 and 5 follow from the analysis in Section 2.6, where we consider imperfect inspection. Hypothesis 4 compares buyer and seller certification while holding fixed the certification price. Based on our model, when applying the alternative price into the seller certification model, the seller will maximize profit by choosing the highest effort level since the marginal profit is always higher than the marginal cost. When faced with the alternative price, the buyer will never purchase certification as the price is higher than the potential loss from overpaying for a low-quality product. With the exception of Hypothesis 3, these predictions are not specific to the parameters chosen in the experiment.

To determine sample sizes, we conducted a paid pilot experiment with 22 participants. During the pilot, participants first encountered the control condition for ten rounds and then switched to the buyer certification with perfect inspection treatment for another ten rounds. Each set of 10 rounds was preceded by two practice rounds. Aside from the fact that two between-subjects treatments were included in the same session, the procedures followed those described in Section 3.2. In our power calculations, we assume that the estimated within and between-subject variances from the pilot session are representative of all treatments.[3] Moreover, we assume that tests are based on a linear regression model with standard errors clustered at the participant-level. With these assumptions in mind, we settled on sample sizes of about 35 for each of the five between-subject treatments. This allows us to detect a minimum effect size of 1.5 effort units for a between-subjects test at 80% power, using a 5% significance level. To place this into perspective, considering all cases where treatment effects are expected to arise, the smallest predicted treatment effect is 2 units of effort. The minimum detectable effect size is 14 percentage points for both the certification purchase probability and social welfare measures, which also implies that we are well-powered to detect differences that are smaller than those predicted by theory for these variables.

3.2 Participants and procedures

One hundred and seventy-six undergraduate students participated in experiment sessions conducted in the UT Experimental Economics Laboratory during the Summer and Fall of 2019. Participants were drawn from a large pool of University of Tennessee students registered as

[3] Interestingly, both the within and between-subjects variances of the effort and market efficiency variables were virtually identical across the two treatments. This suggest that estimated variances from the pilot serve as a reasonable proxy for the remaining treatments, as assumed in the power calculations.

potential participants in economics experiments. The pool resembles the general population of students with respect to gender, age, and academic college. Overall, there are 10 sessions with 16 to 22 participants in each. Experiment sessions lasted approximately 90 minutes and individual earnings averaged $23.

Decisions were made via networked computers using a program coded with the software z-Tree (Fischbacher, 2007). The software collected all decisions and made all earnings calculations. Written instructions were provided to each participant, which were read aloud by the same moderator in each session. Prior to the certification experiment, participants faced a risk elicitation procedure modelled after Holt and Laury (2002). In the certification experiment, there were two practice rounds that gave participants experience in both the buyer and seller roles. This was followed by 20 rounds, and participants were paid based on the outcomes in each round. Earnings from the certification experiment were converted at the rate of 200 lab dollars to 1 US dollar. At the conclusion of the experiment, participants completed a short questionnaire which elicited basic demographics and further included the 10-item Big-Five personality instrument of Gosling, Rentfrow, and Swann (2003). Participants were paid privately and in cash at the end of the session. Representative instructions and computer screenshots are provided in the Appendix.

In each decision round, players are anonymously and randomly matched into groups of two, with one player in a group assuming the seller role and the other player the buyer role. Participants are re-matched in each period; i.e., we use a "strangers" design. To facilitate learning and to minimize cognitive burden, a player maintains a particular role (buyer or seller) for five consecutive rounds before switching to the alternative role.[4] In treatments with certification, there are two possible certification prices which vary within session. Specifically, at the beginning of

[4] To help reduce order effects due to the within-session price variation, within a session, half of the participants first face the monopolistic certification price while the other face the alternative certification price.

the experiment half of the participants are assigned the monopolistic price, and the other half are assigned the alternative price. These prices stay in effect for ten rounds, and then prices are switched for the remaining ten rounds. This way, when a participant assumes the role of seller (buyer), he faces each of the two certification prices exactly half of the time.

4. Results

Table 3 provides descriptive statistics for variables used in the data analysis. In terms of participant characteristics, the risk elicitation task suggests that 51% can be classified as risk-averse, 43% are female, 62% have participated in a prior (unrelated) experiment, and about 39% of participants have experience in sales. On average, across all treatment settings and decision rounds, the seller chooses 3.7 units of effort and sells the product 66% of the time. Conditional on the certification service being available, certification is purchased 39% of the time. On average, social welfare is 51%.

Table 4 presents estimates from a set of linear regression models associated with several outcome measures of interest: seller effort, whether certification was purchased, whether the product was sold, and social welfare. The regressions include indicators for all certification treatments, the coefficients on which measure (unconditional) mean differences in the outcome relative to the control condition. The control variables summarized in Table 3 are included to adjust estimates for unintended sampling differences across treatments.[5] These controls are demeaned, which allows the estimated intercept to be interpreted as the mean outcome for the control. Cluster-robust standard errors are presented for all regressions.

[5] The conclusions we draw are robust to the inclusion/exclusion of these control variables. Table C1 in the Appendix presents estimation results with control variables excluded.

Overall, a casual examination of the regression results in comparison to the theoretical point predictions in Table 2 suggests that differences in experimental outcomes are not as dramatic as theory predicts. In general, differences in effort are less stark across treatments, certification is not purchased as often as predicted, too many products go unsold, and both social welfare and market efficiency are less than predicted. Many of the basic, directional hypotheses are nevertheless supported by the experimental data.

4.1 Effort

Based on the parameters of the experimental design, point predictions of seller effort span the full range of the choice set. Theory predicts zero effort in the control and some certification treatments with alternative prices, and high levels of effort in the monopolistic certifier treatments with a perfect certification process. As illustrated in model (1) in Table 4, mean effort in the control lemons market is 2.6 units, which is much higher than predicted. This could stem from other-regarding preferences, or otherwise attempts to produce a high-quality product mostly by "luck" in the hopes of being able to sell it for a reasonable profit. Consistent with theory, effort in the BPA(125) and BIA(90) treatments are not statistically different from the control. Also in support of Hypothesis 1, for the five of the six treatments where certification is predicted to increase effort, effort is in fact statistically higher than the control. The lone exception is SIM(90).

Tests of other hypotheses are presented in Table 5, based on t-tests of the estimated coefficients presented in Table 4. Hypothesis 2 predicts that under perfect certification and monopolistic certifier pricing, buyer certification markets yield higher effort than markets with available seller certification. Hypothesis 3 states that under imperfect certification, seller certification will lead to a higher effort level under the selected parameter values due to the additional opportunity cost of delivering the high-quality item in the buyer-side mechanism.

Neither of these claims are supported by the data, and the point estimates of the differences are small in magnitude. The direction of the estimated effect is consistent with theory, but is small in magnitude and not statistically significant. We will explore possible reasons for these results later.

Hypothesis 4 predicts that if we hold the certification price fixed, seller certification leads to a higher effort relative to buyer certification. The experiment reveals that the seller side mechanism motivates an extra 1.8 units of effort under the higher certification price, and an extra 1.1 units under the low certification price. Both of these effects are statistically significant, and in the expected direction. Under Hypothesis 5, making the certification process error prone reduces seller effort. This hypothesis is confirmed for both buyer and seller certification markets. In particular, the change in certification quality decreases effort by 1.7 units under seller certification and 1.2 units for buyer certification markets.

The regressions also show that the market responds to a change in certification price, and in the expected direction. We find a significant decrease in effort when the certification process is perfectly revealing and the higher certification price is in effect. When certification is error-prone, though the direction of change is consistent with theory, we fail to find a significant difference.

4.2 Certification uptake

A treatment effects regression of the certification purchase decision is presented as model (2) in Table 4. As certification is not available in the control, the intercept is excluded from the regression such that the coefficients measure the mean purchase frequencies for each treatment. The rank-ordering of observed certification purchase probabilities is roughly consistent with theoretical predictions, with the main exception that certification is highest in SIA(20), rather than SPA(60). As theory predicts that certification purchases should be based on other available information, in Table 6 we summarize conditional certification purchase frequencies. In markets where certification is available to the seller, we display the purchase frequencies conditional on the quality of the item. Theory predicts that the seller always certifies a high-quality item and never certifies a low-quality one. Although there are some differences from these stark predictions, the experimental results are rather close to predictions in the perfect inspection cases. When certification is perfectly-revealing and the product is high quality, the service is purchased 92% and 98% of the time, respectively, under monopolistic and alternative pricing. When the product is low quality, certification is purchased just 1% and 7% of the time with these prices, respectively.

When the certification becomes error-prone, we see a significant drop in the usage of the certification service when product quality is high, and an increase in uptake when quality is low. Under monopolistic pricing, the usage is 74% (high quality) and 18% (low quality). Under alternative pricing, these figures are 90% and 60%. Especially in the latter case, where the certification price is rather low, there is clear evidence that sellers with a low-quality product attempt to mispresent their product quality by purchasing the service and hoping that there is an error in their favor. Albano and Lizzeri (2001) argue that a monopolistic certifier might have the incentive to increase the certification error rate in order to attract more consumers for their service, which is supported by our lab result.

In the bottom panel of Table 6, we present buyer certification purchase frequencies conditional on the product price offered by the seller. According to the theory, the buyer checks quality only if the price is higher than the value of the low-quality item. Though some participants still purchase certification when the price is lower than 250, the data are, generally speaking, consistent with theoretical predictions. We also notice that the frequency of certification purchases significantly decreases when the price of the service is high, which also aligns with theory. From the data, we notice that buyers underutilize certification when the process is error prone and the seller's price offer exceeds 250, which might explain our earlier findings with respect to seller effort under monopolistic certification pricing. A lower chance of certification means a lower chance that a high-quality product is misclassified as low, and thus, the opportunity cost of effort in the buyer certification setting is much lower than what theory predicts. We also notice that buyers overuse the certification service when the process is perfectly revealing, which contrasts the finding in the imperfect inspection case. One explanation is that some participants select certification only in cases where it maximizes their lowest possible earnings. With a perfect certification process, purchasing certification serves as insurance, which increases the potential lowest payoff to the price of certification. On the other hand, under imperfect inspection, certification lowers the potential lowest possible payoff as the chance of being misled is still positive after inspection. Thus, a participant may not purchase certification as it reduces the payoff under the worst-case scenario.

4.3 Product sales and social welfare

Model (3) and (4) in Table 4 coincide with the product sold and social welfare measures, respectively. For the control group, there is a 60% chance that a transaction occurs, and social welfare is 42%. Our theory, as well as Stahl and Strausz (2017), predicts that seller certification is trade-promoting relative to the buyer certification setting. The data lend qualified support of this assertion. Sales are the highest in two seller certification treatments with perfect inspection. For these treatments the sales frequencies are approximately 20 percentage points higher than in the control. Of the remaining treatments, only the BPM(60) treatment yields a (marginally) significant increase in the purchase frequency.

Paralleling the product purchase behavior, social welfare is only significantly higher than the control in the SPA(60), SPA(125), and BPM(60) treatments. These parallel results make intuitive sense, as social welfare is heavily dependent upon a transaction taking place.

4.4 Seller misrepresentation

To gain additional insight into market behavior, we further analyze seller quality misrepresentation, which we define as any case where the seller offers a low-quality item at a price higher than 250 (i.e., the buyer's induced valuation for a low-quality item). It is logical to interpret such behavior as an attempt to mislead the buyer into thinking the product is high quality. Table 7 summarizes by treatment the percentage of cases where sellers misrepresented quality through their price offers, along with average price offers for high- and low-quality items. Certification treatments have lower misrepresentation frequencies when compared to the control, even for treatments where theory predicts certification will never actually be purchased.[6] When certification perfectly reveals quality, seller certification significantly reduces the misrepresentation behavior compared with the buyer certification treatments, from about 24% to 4%. The direction of this effect is consistent with the theoretical prediction. However, when comparing misrepresentation across seller and buyer certification treatments when certification is error-prone, there are no statistical differences. Making the process error-prone does increase quality misrepresentation for seller certification. We fail to reject the hypothesis that the misrepresentation probability is the same across all buyer certification treatments.

4.5 Additional findings

The regressions include control variables, and reveal a few associations with experiment outcomes. People who had participated in a prior economics experiment, and those with prior sales

---

[6] These and other conclusions are based on hypotheses tests from a treatment effects regression where the dependent variable is *Quality Misrepresentation*.

experience (outside the lab) invested less into product quality. Risk averse persons are less likely to purchase certification, and this result is robust to whether certification is the choice of the seller or buyer. In theory, risk aversion decreases seller effort, which in turn decreases the chance he optimally purchases certification. With available buyer certification, it is less risky if one only purchases when the price is less than or equal to her valuation for a low-quality item. Otherwise, the buyer faces risk by pursuing a purchase when the seller's price signals high quality, as the seller may be attempting to mislead the buyer. Using results from the Big-5 personality survey, people with a higher "openness" measure devote more effort when in the seller role. Those more "agreeable" are less likely to make a product purchase when in the buyer role, although the magnitude of the effect is small.

To further explore welfare implications, we include model (5) in Table 4, using as the outcome variable an alternative measure of market efficiency. In particular, this measure is identical to our social welfare measure but excludes any certifier profits. This measure thus provides insight into the question of whether the *introduction* of a certifier to an existing lemons market is desirable from the vantage point of existing buyers and sellers. Although subtracting the costs of certification, as expected, lowers efficiency in all treatments, the main result is that those same three treatments that enhance social welfare also increase product market efficiency.

Last, we explored whether results are robust to learning by restricting the data to include observations from the last half of the experiment. These results are presented in Table C2 in the Appendix. Aside from BIM(20), making a certification service available statistically increases effort relative to the control in all treatments; further, when compared to those based on all decision rounds, the point estimates of the treatment effects are noticeably larger as well. While this increased effort does not coincide with either a higher frequency of certification purchases or product sales, social welfare is increased by about 50% in SPA(60), and increases about three-fold for both seller certification treatments with error-prone inspection technology. The latter two treatments now increase welfare relative to the control. It stands to reason that learning is more challenging with an imperfect certification service, which is perhaps why these treatments have little impact on either seller effort or social welfare when data from the entire experiment is considered. On the other hand, whereas BPM(60) increases social welfare on average across the entire experiment, it does decrease with market learning and is no better than the lemons market over the second half of the experiment.

5. Conclusion

In this study, we use theory to examine a seller's incentives for investing in product quality when buyers have incomplete information on quality, and either the seller or the buyer can purchase quality certification from a credible third party. While prior work examines investment in product quality in the case of seller certification, ours is the first paper to focus on the buyer certification case, and to make comparisons between otherwise equivalent buyer and seller certification markets. When the certification process perfectly-reveals quality, and the certification market is monopolistic, the buyer certification mechanism leads to higher quality. Under the seller mechanism, where the seller has the option to purchase quality certification from a third party, the existence of a perfect certification service crowds out the value of information provided by the seller's imperfect quality signal (i.e., price), thus yielding the certifier significant bargaining power (Biglaiser and Li, 2018). In contrast, under buyer certification, where the buyer has the option to purchase certification, there is no information crowding-out effect. Due to this difference, the seller mechanism leads to a much higher price for the certification service, which in turn decreases the seller's incentive to devote resources to quality improvement. Similar to Stahl and Strausz (2017), our model also shows that buyer certification brings less transparency to the market. However, with the advantage in quality improvement, we identify many cases where the buyer mechanism leads to higher social welfare, which contradicts the prior finding in the literature when quality is instead assumed to be exogenous.

We conduct a complementary lab experiment to test implications of the theory. For both buyer and seller certification, we confirm that making certification available to either the buyer or seller increases seller effort. Increasing the certification price decreases seller investment into product quality, as does making the certification process error prone. However, when comparing buyer and seller certification mechanisms, empirical differences in seller effort are smaller than theory predicts, and are statistically insignificant in two of four comparisons. We offer some possible explanations for these unexpected results below.

When deciding whether to purchase certification when it is available, buyers have to form beliefs about the probability the product is high quality based on the seller's price offer. We find that when the inspection service is perfectly-revealing and a seller signals high quality through his price signal, buyers purchase certification more frequently than what theory predicts. As a possible motivation, some buyers may experience disutility from being deceived, especially in a situation where this can be avoided by verifying quality. In the model, the overuse of certification increases the expected certification cost to the buyer, thus lowering the acceptable price on a high-quality item and in turn decreasing seller effort. This possibly explains why buyer certification does not motivate more effort than seller certification when a monopolistic certifier has a perfect inspection technology.

When inspection is error-prone, buyers purchase certification less often than predicted by theory. The lower usage of certification decreases the chance that a high-quality item is misclassified as low, thus reducing the expected cost of seller effort. This incentivizes seller effort, and may explain why seller certification did not induce more effort in the case of a monopolistic certifier with an imperfect inspection technology. We speculate that the under-use of certification is driven by an objective to maximize the lowest payoff. Under imperfect inspection, purchasing certification lowers the potential lowest possible payoff as the chance of being misled is still positive after inspection. Thus, a participant may not purchase certification as it reduces the payoff under the worst-case scenario.

While our experimental evidence supports the notion that making certification available can increase seller effort, and further that there is revealed demand for certification by both sellers and buyers, this does not necessarily lead to increases in social welfare. Nevertheless, a perfectly-revealing seller certification service appears to be a robust mechanism for enhancing welfare. Our evidence also suggests that this can also be true for an error-prone seller certification service, at least after participants gain experience with the mechanism.

In the experiment, in order to compare buyer and seller certification mechanisms while holding prices fixed, we simplified the decision setting by exogenously setting certification prices. Extending the design to have participants in the role of certifiers may lead to interesting behavioral insights, and has not been explored in prior lemons market experiments. For instance, the collapse of AAA-rated structured financial products during the years 2007 and 2008 has brought attention again to the certifier moral hazard issue. Bolton, Freixas, and Shapiro (2012) show the problems of the current credit rating system not only include the agency's conflict of understating risk to attract business, but also the fact that firms can “window shop” for the most favorable rating. Our design can easily include (multiple) certifiers to explore the validity of these results.

As the first step to incorporate quality investment in the buyer-seller certification comparison, our model is limited in many aspects. In particular, as with most prior work on certification, we assume a three-person game. Of course, markets are typically characterized by multiple buyers and sellers, and possibly also competition among certifiers. Whether competition among sellers and perhaps certifiers fosters greater investments in product quality is an important but challenging question. A valuable extension would be to consider heterogeneity among buyers in their valuations for a higher quality product. In that setting, if a seller also has market power, certification may interact with price discrimination because demand for a certified product could indicate a higher willingness-to-pay by the consumer.

References

Akerlof, George A. (1970). The market for lemons: Quality and the market mechanism. *Quarterly Journal Economics*, 84, 488-500.

Albano, Gian L., & Lizzeri, Alessandro. (2001). Strategic certification and provision of quality. *International Economic Review*, 42(1), 267-283.

Benndorf, Volker, Kubler, Dorothea, & Normann, Hans-Theo. (2015). Privacy concerns, voluntary disclosure of information, and unraveling: An experiment. *European Economic Review*, 75, 43-59.

Biglaiser, Gary. (1993). Middlemen as experts. *The RAND Journal of Economics*, 24(2), 212-223.

Biglaiser, Gary, & Li, Fei. (2018). Middlemen: the good, the bad, and the ugly. *The RAND Journal of Economics*, 49(1), 3-22.

Board, Simon, & Meyer-ter-Vehn, Moritz. (2013). Reputation for quality. *Econometrica*, 81(6), 2381-2462.

Bolton, Patrick, Freixas, Xavier, & Shapiro, Joel. (2012). The credit ratings game. *The Journal of Finance*, 67(1), 85-111.

Cason, Timothy N., & Gangadharan, Lata. (2002). Environmental labeling and incomplete consumer information in laboratory markets. *Journal of Environmental Economics and Management*, 43(1), 113-134.

Dranove, David, & Jin, Ginger Z. (2010). Quality disclosure and certification: Theory and practice. *Journal of Economic Literature*, 48(4), 935-63.

Durbin, Erik. (1999). McDonald's or the Michelin Guide? Revealing Quality through Private-Sector Certification. Mimeo, Olin School of Business, Washington University.

Fasten, Erik. R., & Hofmann, Dirk. (2010). Two-sided certification: The market for rating agencies (No. 338). SFB/TR 15 Discussion Paper.

Fischbacher, U. (2007). z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics*, 10(2), 171-178.

Forsythe, Robert, Isaac, R. Mark, & Palfrey, Thomas R. (1989). Theories and tests of "blind bidding" in sealed-bid auctions. *The RAND Journal of Economics*, 20(2), 214-238.

Gosling, Samuel D., Rentfrow, Peter J., & Swann, William B. (2003). A very brief measure of the Big-Five personality domains. *Journal of Research in Personality*, 37(6), 504-528.

Holt, Charles A., & Laury, Susan K. (2002). Risk aversion and incentive effects. *American Economic Review*, 92(5), 1644-1655.

List, John A. 2006. The behavioralist meets the market: Measuring social preferences and reputation effects in actual transactions. *Journal of Political Economy*, 114(1), 1-37.

Lizzeri, Alessandro. (1999). Information revelation and certification intermediaries. *The RAND Journal of Economics*, 30(2), 214-231.

Marinovic, Iván, Skrzypacz, Andrzej, & Varas, Felipe. (2018). Dynamic certification and reputation for quality. *American Economic Journal: Microeconomics*, 10(2), 58-82.

Siegenthaler, Simon. (2017). Meet the lemons: An experiment on how cheap-talk overcomes adverse selection in decentralized markets. *Games and Economic Behavior*, 102, 147-161.

Spulber, Daniel F. (1996). Market microstructure and intermediation. *Journal of Economic Perspectives*, 10(3), 135-152.

Stahl, Konrad, & Strausz, Roland. (2017). Certification and market transparency. *The Review of Economic Studies*, 84(4), 1842-1868.

Table 1. Experiment treatments

Treatment	Available Certification	Certification process	Certification price
Control	N/A	N/A	N/A
SPA(60)	Seller	Perfect	Alternative – 60
SPM(125)	Seller	Perfect	Monopolistic – 125
BPA(125)	Buyer	Perfect	Alternative – 125
BPM(60)	Buyer	Perfect	Monopolistic – 60
SIA(20)	Seller	Imperfect	Alternative – 20
SIM(90)	Seller	Imperfect	Monopolistic – 90
BIA(90)	Buyer	Imperfect	Alternative – 90
BIM(20)	Buyer	Imperfect	Monopolistic - 20

Note: Under an imperfect certification process, there is a 70% chance that a high-quality item will be certified as high quality and a 30% chance that a low-quality item will be certified as high quality. Monopolistic prices are those derived directly from the theory. The alternative price for seller (buyer) certification is the monopolistic price from the comparable buyer (seller) certification treatment.

Table 2. Theoretical predictions

Treatment	Seller effort (probability of high-quality product)	Probability certification purchased	Social welfare (efficiency)
Control	0 (0%)	N/A	62.5%
SPA(60)	10 (100%)	100%	100%
SPM(125)	6 (60%)	60%	91%
BPA(125)	0 (0%)	0%	62.5%
BPM(60)	8 (80%)	33.86%	89.73%
SIA(20)	6 (40%)	60%	91%
SIM(90)	4 (40%)	40%	83.5%
BIA(90)	0 (0%)	0%	62.5%
BIM(20)	2 (20%)	18.70%	70.94%

Table 3. Data Description

Variable Name	Description	Mean	S.D.
Seller Effort	Seller's effort choice, 0 to 10	3.702	2.900
Certification Purchased	=1 if certification service purchased; missing if service unavailable	0.393	0.489
Product Sold	=1 if buyer purchased product	0.664	0.472
Social Welfare	Percentage of available surplus (buyer, seller, certifier) realized	50.854	46.010
Quality Misrepresentation	=1 if seller offers a price above 250 for a low-quality item	0.238	0.426
Price	Seller's price offer	304.591	95.872
Product Market Efficiency	Percentage of available surplus (buyer and seller only) realized	45.860	44.443
Control	=1 if control condition	0.227	0.419
SPA(60)	=1 if seller perfect certification with alternative price treatment	0.097	0.295
SPM(125)	=1 if seller perfect certification with monopolistic price treatment	0.097	0.295
BPA(125)	=1 if buyer perfect certification with alternative price treatment	0.097	0.296
BPM(60)	=1 if buyer perfect certification with monopolistic price treatment	0.096	0.295
SIA(20)	=1 if seller imperfect certification with alternative price treatment	0.097	0.295
SIM(90)	=1 if seller imperfect certification with monopolistic price treatment	0.097	0.295
BIA(90)	=1 if buyer imperfect certification with alternative price treatment	0.097	0.295
BIM(20)	=1 if buyer imperfect certification with monopolistic price treatment	0.097	0.295
Risk Averse	=1 if participant selected the safe option at least six times in the risk elicitation task	0.512	0.500
Employed	=1 if participant is employed full or part-time	0.512	0.500
Female	=1 if participant is female	0.551	0.497
Prior Experiment	=1 if participated in a prior economics other experiment before	0.619	0.486
Sales Experience	=1 if participant has sales experience before	0.386	0.487
Extraversion	Measure of "extraversion", 1 to 7	4.531	1.441
Agreeableness	Measure of "agreeableness", 1 to 7	4.628	1.235
Conscientiousness	Measure of "extraversion", 1 to 7	5.614	1.225
Emotional Stability	Measure "emotional stability", 1 to 7	4.668	1.310
Openness	Measure "openness to experience", 1 to 7	5.278	1.082

Table 4. Treatment effects regressions

	(1) Seller Effort	(2) Certification Purchased	(3) Product Sold	(4) Social Welfare	(5) Product market efficiency
SPA(60)	3.159***	0.593***	0.191***	26.87***	17.75***
	(0.515)	(0.052)	(0.050)	(5.32)	(5.07)
SPM(125)	2.217***	0.487***	0.232***	28.82***	13.55***
	(0.504)	(0.056)	(0.044)	(3.86)	(3.59)
BPA(125)	0.460	0.154***	–0.003	3.17	−1.70
	(0.516)	(0.039)	(0.058)	(4.92)	(5.06)
BPM(60)	2.078***	0.430***	0.092*	17.00***	9.80*
	(0.598)	(0.045)	(0.054)	(5.76)	(5.77)
SIA(20)	0.985**	0.676***	0.067	4.84	1.52
	(0.489)	(0.053)	(0.050)	(4.52)	(4.49)
SIM(90)	0.538	0.359***	0.037	3.96	−4.20
	(0.538)	(0.049)	(0.047)	(4.95)	(4.87)
BIA(90)	0.692	0.156***	0.021	1.89	−1.65
	(0.524)	(0.031)	(0.056)	(5.64)	(5.50)
BIM(20)	0.950*	0.300***	0.045	5.11	3.58
	(0.554)	(0.040)	(0.052)	(4.65)	(4.63)
Constant	2.632***		0.598***	42.00***	42.13***
	(0.346)		(0.033)	(2.89)	(2.86)
Observations	1,760	1,360	1,760	1,760	1,760
R^2	0.147	0.489	0.037	0.056	0.030

Notes: *,**, and *** denote estimates that are statistically different from zero at the 10%, 5%, and 1% significance levels, respectively. Standard errors in (1) – (3) are clustered by participant. Standard errors in (4) and (5) are based on two-way clustering as the actions of two participants determine each social welfare and efficiency outcome. The control variables summarized in Table 3 are included in all regressions.

Table 5. Selected hypothesis tests

Hypothesis	Treatment 1	Treatment 2	Difference of means
		Seller versus buyer certification	
H2	Buyer Perfect Monopolistic	Seller Perfect Monopolistic	−0.140
H3	Seller Imperfect Monopolistic	Buyer Imperfect Monopolistic	−0.412
H4	Seller Perfect Monopolistic	Buyer Perfect Alternative	1.757^{***}
H4	Seller Perfect Alternative	Buyer Perfect Monopolistic	1.08^{*}
		Perfect versus imperfect certification	
H5	Seller Perfect Monopolistic	Seller Imperfect Monopolistic	1.679^{***}
H5	Buyer Perfect Monopolistic	Buyer Imperfect Monopolistic	1.127^{*}
		Changes in certification prices	
	Seller Perfect Alternative	Seller Perfect Monopolistic	0.941^{**}
	Buyer Perfect Monopolistic	Buyer Perfect Alternative	1.618^{***}
	Seller Imperfect Alternative	Seller Imperfect Monopolistic	0.447
	Buyer Imperfect Monopolistic	Buyer Imperfect Alternative	0.259

Notes: *,**, and *** denote estimates that are statistically different from zero at the 10%, 5%, and 1% significance levels, respectively. Test results based on regressions presented in Table 4.

Table 6. Conditional certification purchases

Seller Certification	Item Quality	Certification Purchased (%)
Perfect Monopolistic	High	91.9
Perfect Monopolistic	Low	1.2
Perfect Alternative	High	97.9
Perfect Alternative	Low	6.7
Imperfect Monopolistic	High	74.1
Imperfect Monopolistic	Low	17.8
Imperfect Alternative	High	89.5
Imperfect Alternative	Low	58.4
Buyer Certification	**Price**	**Certification Purchased (%)**
Perfect Monopolistic	>250	62.6
Perfect Monopolistic	≤250	9.6
Perfect Alternative	>250	22.1
Perfect Alternative	≤250	6.0
Imperfect Monopolistic	>250	36.7
Imperfect Monopolistic	≤250	20.5
Imperfect Alternative	>250	18.5
Imperfect Alternative	≤250	11.9

Table 7. Quality misrepresentation

	Quality misrepresentation (%)	P_H	P_L
Control	43.0	320.20	283.95
Seller Perfect Monopolistic	3.5	420.05	211.83
Seller Perfect Alternative	5.3	418.45	224.08
Buyer Perfect Monopolistic	22.3	382.35	276.16
Buyer Perfect Alternative	24.7	389.09	268.63
Seller Imperfect Monopolistic	22.3	365.29	251.07
Seller Imperfect Alternative	31.1	353.56	271.70
Buyer Imperfect Monopolistic	15.0	369.04	246.78
Buyer Imperfect Alternative	27.0	345.67	278.03

Notes: product quality misrepresentation is defined as a case where the actual product quality is low, and the seller offers a price that is higher than the buyer's reservation price for a low-quality item. The last two columns provide the average prices offered for all high and low-quality products, respectively.

Appendix A. Theory Derivations

Proof of Proposition 3:

Given the cost function $c(e) = e^{\lambda}$, under seller certification, the seller solves the profit-maximization problem

(A1) $\max_{e \in [0,1]} e(v_h - P_c) + (1 - e)E(v) - e^{\lambda}$,

and chooses effort based on

(A2) FOC: $\Delta v - P_c = \lambda e^{\lambda - 1}$,

which yields

(A3) $e_s(P_c, \Delta v) = (\frac{\Delta v - P_c}{\lambda})^{\frac{1}{\lambda - 1}}$,

where Δv denotes the difference in buyer valuations between a high- and low-quality item. Using backward induction, the certifier solves the profit-maximization problem

(A4) $\max_{P_c} e_s(P_c, \Delta v) P_c$.

Solving the system, we find the optimal price for certification equals

(A5) $P_c = \frac{(\lambda - 1)\Delta v}{\lambda}$,

which means the marginal benefit of additional effort in the seller certification equals

(A6) $MB_c = \frac{\Delta v}{\lambda}$.

For buyer certification, the certifier's problem is

(A7) $\max_{P_c} [e_b(P_c) + (1 - e_b(P_c))\sigma_l^*\big(\tilde{P}(P_c)\big)]\sigma^*(s_h(P_c))P_c$.

By substituting in the expression for the two probabilities, we reframe the problem as

(A8) $\max_{P_c} P_c \frac{e_b(P_c)(\tilde{P}(P_c) - v_l)}{\tilde{P}(P_c)\tilde{\mu}(P_c)}$.

Defining $v_l = n\Delta v$, and solving the system, we find the optimal price for certification to be

(A9) $P_c^* = -\frac{\Delta q(-2n\lambda-\lambda+n+1)\sqrt{(n+1)(\frac{1}{4}+n(\lambda-\frac{1}{2})^2)}+(n+1)(\lambda^2-(4n+1)\lambda+n+1)}{2\lambda^2}$.

Substituting P_c^* back into the FOC condition of the seller's profit maximization problem, and comparing the marginal benefit of effort between the buyer and seller mechanisms,, we have

(A10) $MB_b - MB_c = \frac{\Delta v}{2} + \frac{\sqrt{\Delta v(\Delta v - 4P_c^*)}}{2} - \frac{\Delta v}{\lambda}$.

Setting (A10) equal to zero we find that when $\lambda_1 = 1, \lambda_2 = \frac{2}{\frac{2n+1+\sqrt{5n^2+6n+1}}{n+2}+1}$ and $\lambda_3 = \frac{2}{\frac{-2n-1+\sqrt{5n^2+6n+1}}{n+2}+1}$, the two certification mechanisms will provide the same level of incentives. Clearly, since n is a non-negative number, λ_2 is less than 1, which is outside of the range of λ, while λ_3 is larger than 2. Since the above equation is continuous when $n > 0\ and\ \lambda > 1$, it follows that for any $\lambda \in [1, \lambda_3]$, (A10) conveys the same sign. When $\lambda = 2$, the equation above becomes

(A11) $\frac{\sqrt{1+(-3n-1)\sqrt{(n+1)(\frac{1}{4}+\frac{9}{4}n)}+2(n+1)(\frac{9}{4}n-\frac{1}{4})}}{2}$,

which is larger than

(A12) $\frac{\sqrt{1+(-3n-1)\sqrt{(n+1)(\frac{1}{4}+\frac{1}{4}n)}+2(n+1)(\frac{9}{4}n-\frac{1}{4})}}{2} = \frac{\sqrt{3n^2+2n}}{2} \geq 0$.

We could also notice that when $\lambda > 2$, (A10) is always positive. Thus, buyer certification incentivizes more effort from the seller for any $\lambda \in (1, +\infty]$ and for any value of the low-quality item. Also, we observe that the difference between mechanisms becomes larger as value of low-quality item increases.

Proof of Extension 2:

Under seller certification, the seller's profit maximization problem is

(A13) $\max_{e \in [0,1]} \tau e(P_h - P_c) + e(1-\tau)(P_L - P_c) + (1-e)P_L - c(e),$

with first-order condition

(A14) $FOC\text{: } \tau(P_h - v_L) - P_c = c'(e)\,,$

and optimal $P_c = \frac{(\lambda-1)(P_h - v_L)}{\lambda}$. At the same time, the problem needs to satisfy one participation constraint that eliminates the seller's incentive to cheat:

(A15) $\pi^* \geq (1-\tau)P_h + \tau v_l - P_c.$

When the constraint is satisfied, $P_h = \tau\Delta v + v_l$ and $P_L = e(1-\tau)\Delta v + v_l.$

On the other hand, for buyer imperfect certification, we keep all our assumptions in the buyer perfect certification case except we allow errors in the certification process. Thus, the seller still determines the price in order to make the buyer indifferent among s_b, s_h and s_n. Receiving the price signal, the buyer will be indifferent among the three actions only if the following three equations hold:

(A16) $P_c = \tau\mu(P)(v_h - P) + (1-\tau)(1-\mu)(v_l - P),$

(A17) $P_c = \tau(1-\mu)(P - v_l) + (1-\tau)\mu(P - v_h)$, and

(A18) $P_c = \mu(P)v_h + \big(1-\mu(P)\big)v_l.$

Recall that τ denotes the probability that the certification (correctly) indicates the item is high quality item while $1-\tau$ represents the error rate. Solving the equations, we have

(A19) $\tilde{P}' \equiv \frac{\left(v_h + v_l + \sqrt{\Delta v\left(\Delta v - \frac{4P_c}{2\tau-1}\right)}\right)}{2}$ and $\tilde{\mu}' \equiv \frac{1+\sqrt{1-\frac{4P_c}{\Delta v(2\tau-1)}}}{2},$

which indicates a lower equilibrium price for the high-quality item and a smaller price range for certification[7]. Following the same logic as the buyer perfect certification case, the buyer uses certification with probability $\sigma'^{*}(s_h)$ in order to make the low-type seller indifferent between offering price $\tilde{P}'$ for v_l, and

(A20) $\sigma'^{*}(s_h) = \frac{\tilde{P}' - v_l}{\tilde{P}'\tau}$.

Also, based on the consistency of belief, we have

(A21) $\sigma_l'^{*}(\tilde{P}) = \frac{\tilde{e}(1-\tilde{\mu}')}{\tilde{\mu}'(1-\tilde{e})}$.

Substituting all the terms back into the seller's problem, we have

(A22) $\max_{e\in[0,1]} \tau e\tilde{P} + (1-e)v_l - c(e)$, and

(A23) $FOC\colon\ \tau(\tilde{P} - v_l) - (1-\tau)v_l = c'(e)$.

From the profit-maximization condition, notice that when the product of the error rate and value of low-quality item increases, the seller's effort in the buyer certification case will decrease even further when compared with seller certification. This is because under buyer certification, a high-type seller will be punished with an additional opportunity cost, which is the inability to sell the item at any price if the item is certified as low quality. Seller certification can dominate buyer certification as the additional opportunity cost increases. For example, based on numerical calculations, when $v_h = 2v_l$ and $\tau = 0.7$, seller certification leads to higher effort.

[7] Intuitively, the potential certification errors decrease the buyer's maximum willingness to pay for the service. Mathematically, P_c must guarantee that the term under the square root is positive, and thus a smaller τ limits the range of P_c.

Appendix B: Experiment Instructions and Computer Screenshots

Instructions for seller imperfect certification treatment

Thank you for participating in today's study. Please follow the instructions carefully. At any time, please feel free to raise your hand if you have a question.

You have been randomly assigned an ID number for this session. You will make decisions using a computer. You will never be asked to reveal your identity to anyone. Your name will never be associated with any of your decisions. In order to keep your decisions private, please do not reveal your choices or otherwise communicate with any other participant. Importantly, please refrain from verbally reacting to events that occur.

Today's session has three parts: Experiment 1, Experiment 2, and a short questionnaire. You will have the opportunity to earn money in both experiments based on your decisions. You will be paid your earnings privately, and in cash, at the end of the experiment session. **We will proceed through the written materials together. Please do not enter any decisions on the computer until instructed to do so.**

Instructions for Experiment 1

Please refer to your computer screen while we read the instructions.

We would like you to make a decision for each of 10 scenarios. Each scenario involves a choice between playing a lottery that pays either \$4 or \$0 according to specified chances (Option A) or receiving \$2 for sure (Option B).

You will notice that the only differences across scenarios are the chances of receiving the high or low prize for the lottery. At the end of the today's session, ONE of the 10 scenarios will be selected at random and you will be paid according to your decision for this selected scenario ONLY. Each scenario has an equal chance of being selected.

Please consider your choice for each scenario carefully. Since you do not know which scenario will be played out, it is in your best interest to treat each scenario as if it will be the one used to determine your earnings.

Before making decisions, are there any questions?

Please proceed to entering decisions on your computer. Once you are ready to submit your decisions, please click the "Submit" button.

Instructions for Experiment 2

In this experiment, you will be randomly placed into a two-person group to form a trading market. One member of your group will be a seller and the other will be a buyer.

There will be many decision rounds in the experiment. You will not know the number of rounds until the experiment has been completed. Each decision round is separate from the other rounds, in the sense that the decisions you make in one round will not affect the outcome or earnings of any other round.

In this experiment, all money amounts are denominated in lab dollars, and will be exchanged at a rate of 200 lab dollars to 1 US dollar at the end of the experiment. There are five parts to each decision period:

- The seller decides how much effort to put into "product" quality. Increasing effort improves the chance that the product is of "high" rather than "low" quality.
- Product quality (high or low) is revealed to the seller. The seller then has the option to purchase a certification service. If a product is certified to be of high quality, this information is made known to the buyer. Otherwise, the buyer does not know product quality when making a purchase decision.
- The seller makes a take-it-or-leave-it price offer to the buyer.
- The buyer chooses whether to accept the offer.
- The computer calculates earnings.

We will now go through the details of the seller and buyer tasks in each decision round.

Information for Sellers:

The seller produces and offers to sell one unit of a "product". The product may be of "low" or "high" quality. Buyers are willing to pay more for a high quality product, but producing a high quality product can be more costly.

The seller first makes an effort choice. Production cost increases with effort, but higher effort increases the chance that the product is high quality. The relationship between effort, product quality, and production cost is presented in the following table.

Effort choice	Chance of high product quality	Production cost
0	0%	0
1	10%	1
2	20%	4
3	30%	9
4	40%	16
5	50%	25
6	60%	36
7	70%	49
8	80%	64
9	90%	81
10	100%	100

For example, if the seller selects an effort of 0, production cost will be 0 lab dollars and there will be a 0% chance that the product is high quality. As another example, if the seller selects an effort of 10, production cost will be 100 lab dollars and there will be a 100% chance the product is high quality.

After the effort choice is made, product quality will be revealed to the seller, but it will not be known to the buyer. The seller can purchase a certification service at a known cost. However, the certification is error prone. If the service is purchased, and the actual quality is High, the service has a 70% chance of revealing to the buyer that the product quality is High; If the actual quality is Low, the service has a 30% chance of revealing to the buyer that the product is High. If the service is purchased, and the service determines the product is low quality, this information will not be revealed to the buyer.

The seller next makes a take-it-or-leave-it price offer to the buyer. This is the only opportunity to sell the product.

In each round, the seller will receive 100 lab dollars in fixed income. This amount does not depend on any decisions made. If the buyer accepts the offer, seller earnings are equal to the fixed income plus price received, minus any production cost. If the buyer rejects the offer, seller earnings are equal to fixed income minus any production cost. To summarize,

If the buyer accepts the offer:

Seller earnings = Fixed income + Price received – Production cost – Certification Cost (if any)

If the buyer rejects the offer:

Seller earnings = Fixed income – Production cost – Certification Cost (if any)

Information for Buyers:
The value of the product to the buyer depends on whether it is high or low quality. If the buyer purchases a high-quality product, they will receive 500 lab dollars. If the buyer purchases a low-quality product, the buyer will instead receive 250 lab dollars. If the seller purchases the certification service and the product is certified to be high quality, this information will be revealed to the buyer. Otherwise, the quality of product is not known to the buyer when making a purchase decision.

The buyer can accept any price offer they choose. There is no budget constraining this purchase.

In each round, the buyer will receive 100 lab dollars in fixed income. This amount does not depend on any decisions made. If the buyer accepts the seller's offer, the buyer's earnings are equal to the fixed income plus the value of the product (which depends on actual quality), minus the price paid. If the buyer rejects the offer, buyer earnings are equal to the fixed income. To summarize,

If the buyer accepts the offer:
Buyer earnings = Fixed Income + Value of product – Price Paid

If the buyer rejects the offer:
Buyer earnings = Fixed Income

Proceeding through the experiment:

Prior to each new decision round, you will be randomly matched with a different person in the room. The computer is programmed such that, when you are a seller, you will not be matched with the buyer from the previous round. Similarly, when you are a buyer, you will not be matched with the seller from the previous round. The decisions you made in prior rounds will not be known to your trading partner.

Your role in the experiment (buyer or seller) and the cost of the certification service may change from one round to the next. Please look carefully at the information on your computer screen before making any decisions.

We will begin with two training rounds to help you understand the procedures. In one training round you will play the role of a buyer and in the other you will be a seller.

Aside from decisions in the training rounds, you will be paid based on the outcome of each decision round. This means that it is very important to consider each decision prior to making it. Before we continue, do you have any questions?

SCENARIO	LOTTERY	CERTAIN AMOUNT	YOUR CHOICE
	Choice A	Choice B	
1	10% chance of $4 and 90% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
2	20% chance of $4 and 80% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
3	30% chance of $4 and 70% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
4	40% chance of $4 and 60% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
5	50% chance of $4 and 50% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
6	60% chance of $4 and 40% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
7	70% chance of $4 and 30% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
8	80% chance of $4 and 20% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
9	90% chance of $4 and 10% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B
10	100% chance of $4 and 0% chance of $0	$2 for sure	Choice A ◯ ◯ Choice B

On the left are 10 scenarios which ask you to select between a lottery and a sure amount of money, $2.00.

Please choose either A or B for each scenario.

At the end of the experiment the computer will randomly select ONE of these 10 scenarios.

If you selected the lottery, Choice A, for the randomly selected scenario, the computer will determine the outcome based on the chances associated with the selected scenario.

If you select Choice B for the randomly selected scenario, you will for sure receive $2.00.

Submit

Figure 1. Subject screen for risk elicitation task

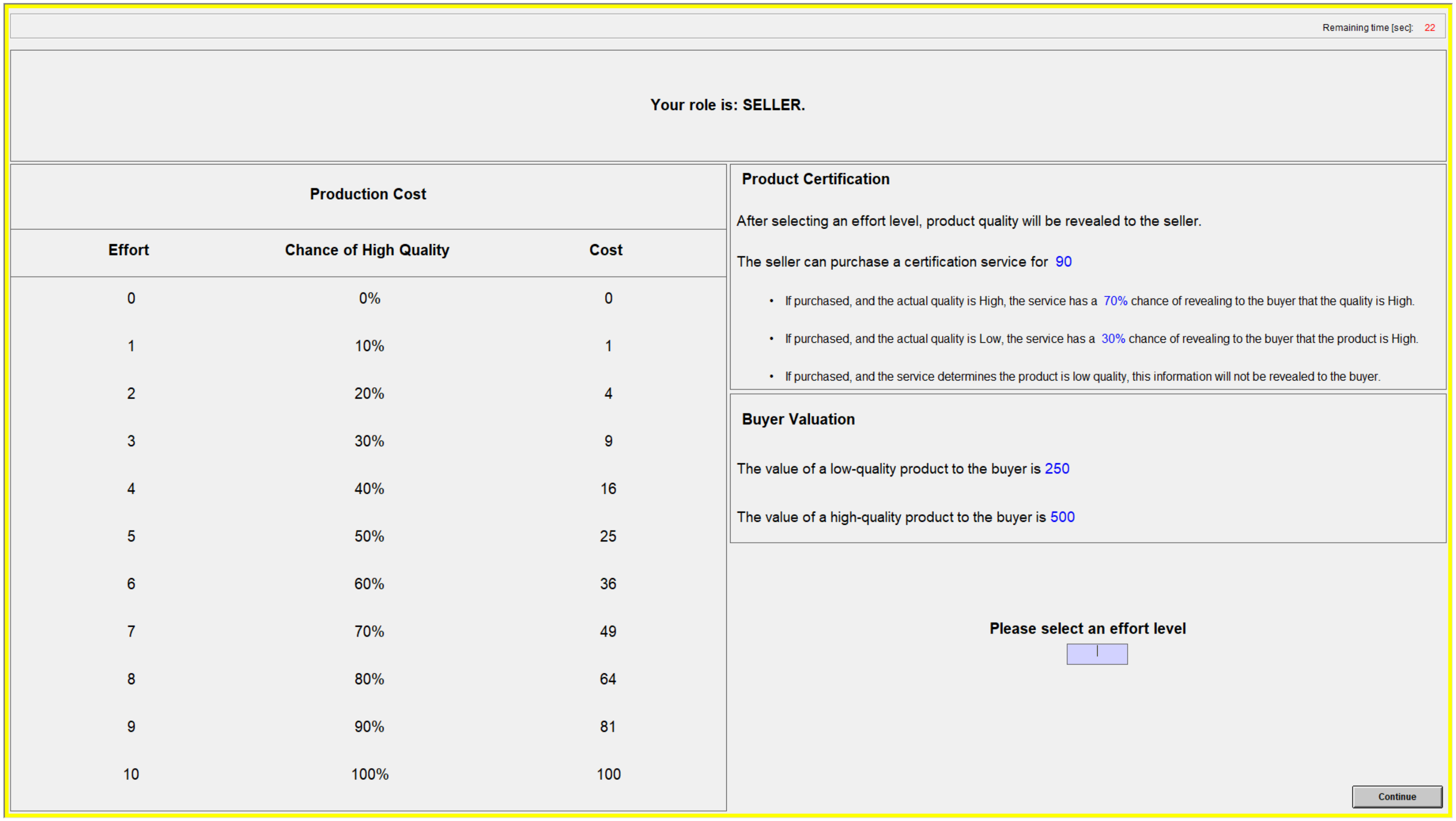


Figure 2. Subject screen for seller's effort choice

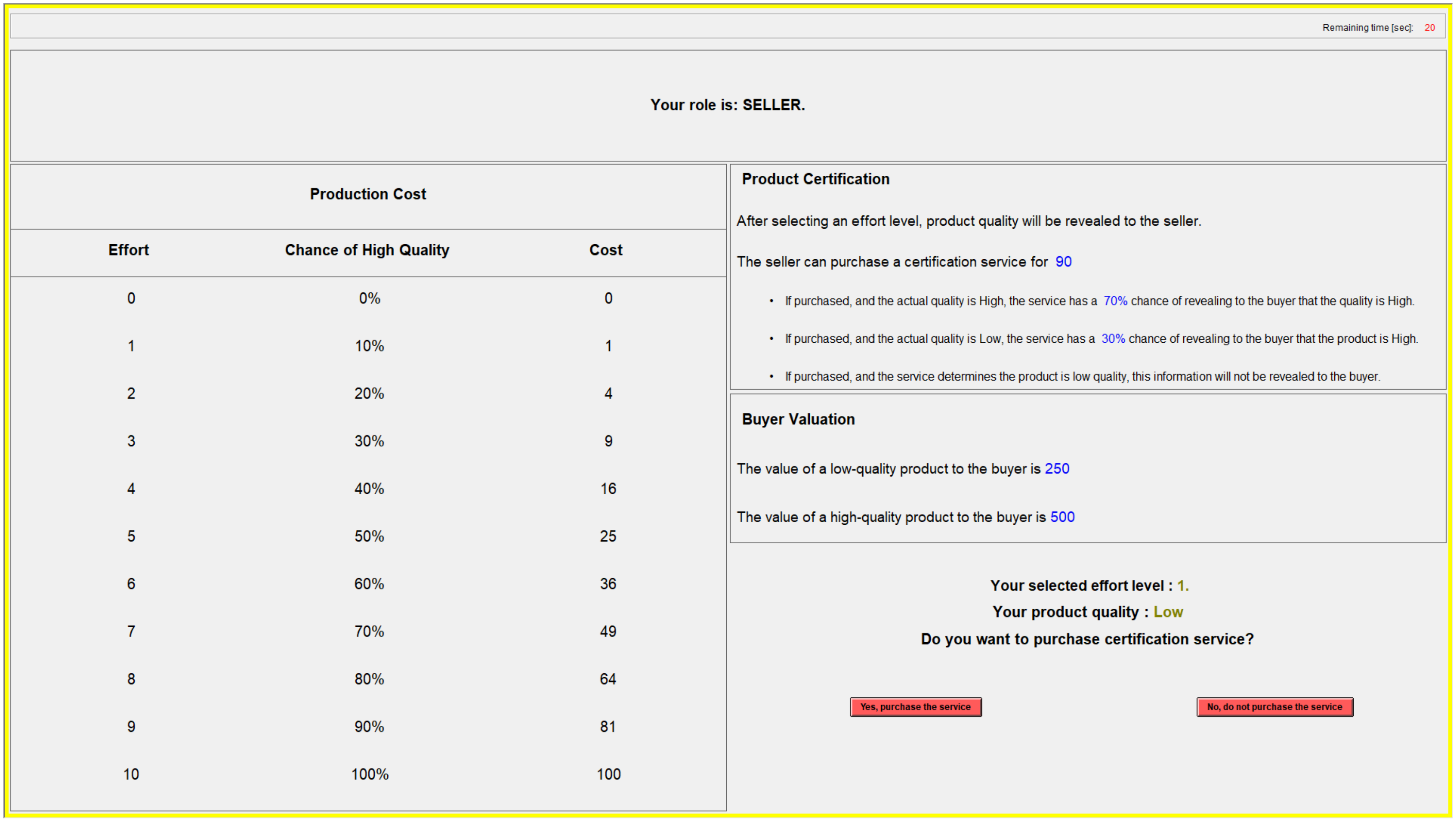
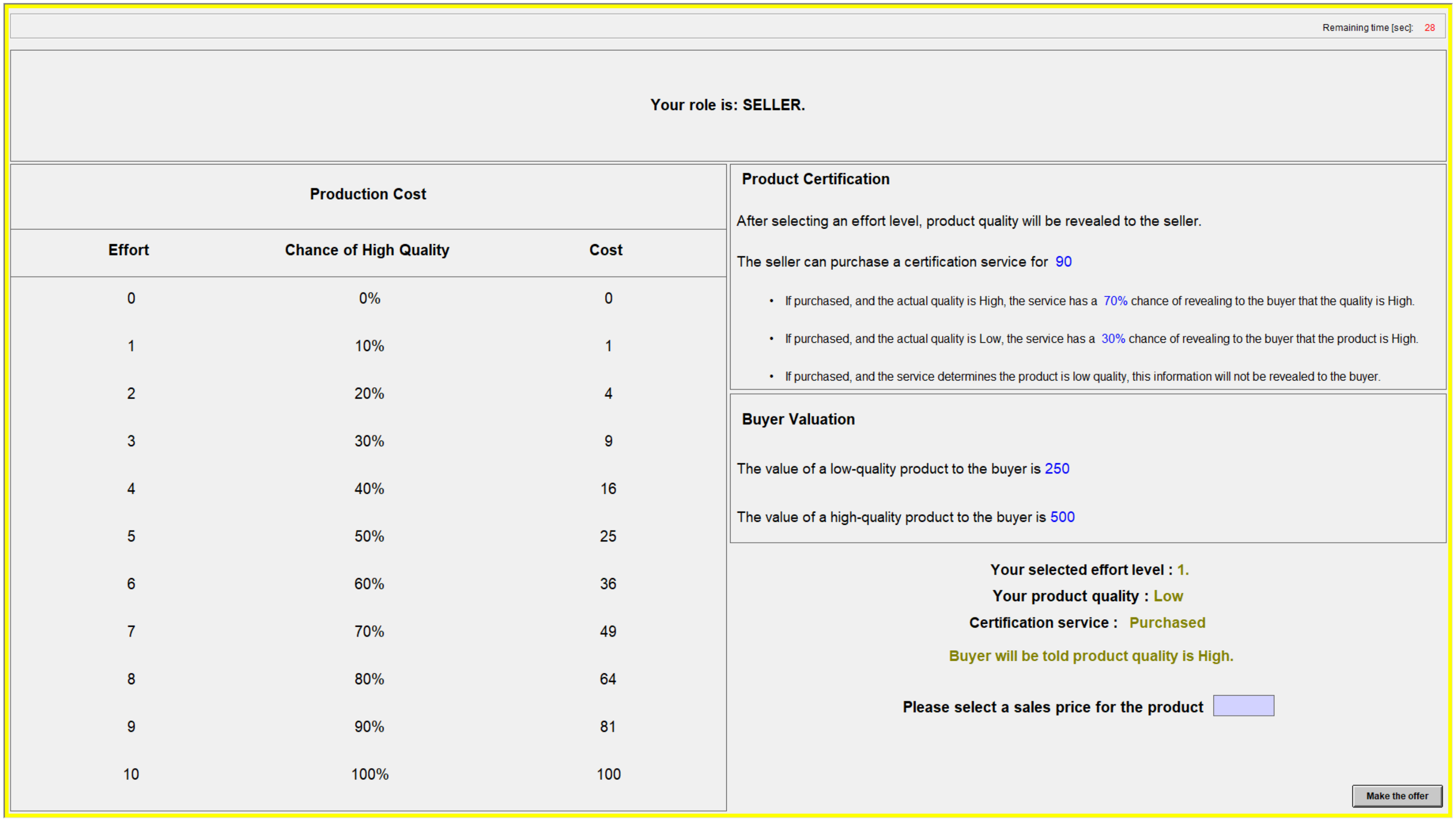


Figure 3. Subject screen for seller's certification decision


Remaining time [sec]: 28

Your role is: SELLER.

Production Cost

Effort	Chance of High Quality	Cost
0	0%	0
1	10%	1
2	20%	4
3	30%	9
4	40%	16
5	50%	25
6	60%	36
7	70%	49
8	80%	64
9	90%	81
10	100%	100

Product Certification

After selecting an effort level, product quality will be revealed to the seller.

The seller can purchase a certification service for 90

- If purchased, and the actual quality is High, the service has a 70% chance of revealing to the buyer that the quality is High.
- If purchased, and the actual quality is Low, the service has a 30% chance of revealing to the buyer that the product is High.
- If purchased, and the service determines the product is low quality, this information will not be revealed to the buyer.

Buyer Valuation

The value of a low-quality product to the buyer is 250

The value of a high-quality product to the buyer is 500

Your selected effort level : 1.
Your product quality : Low
Certification service : Purchased

Buyer will be told product quality is High.

Please select a sales price for the product

Make the offer

Figure 4. Subject screen for seller's price offer

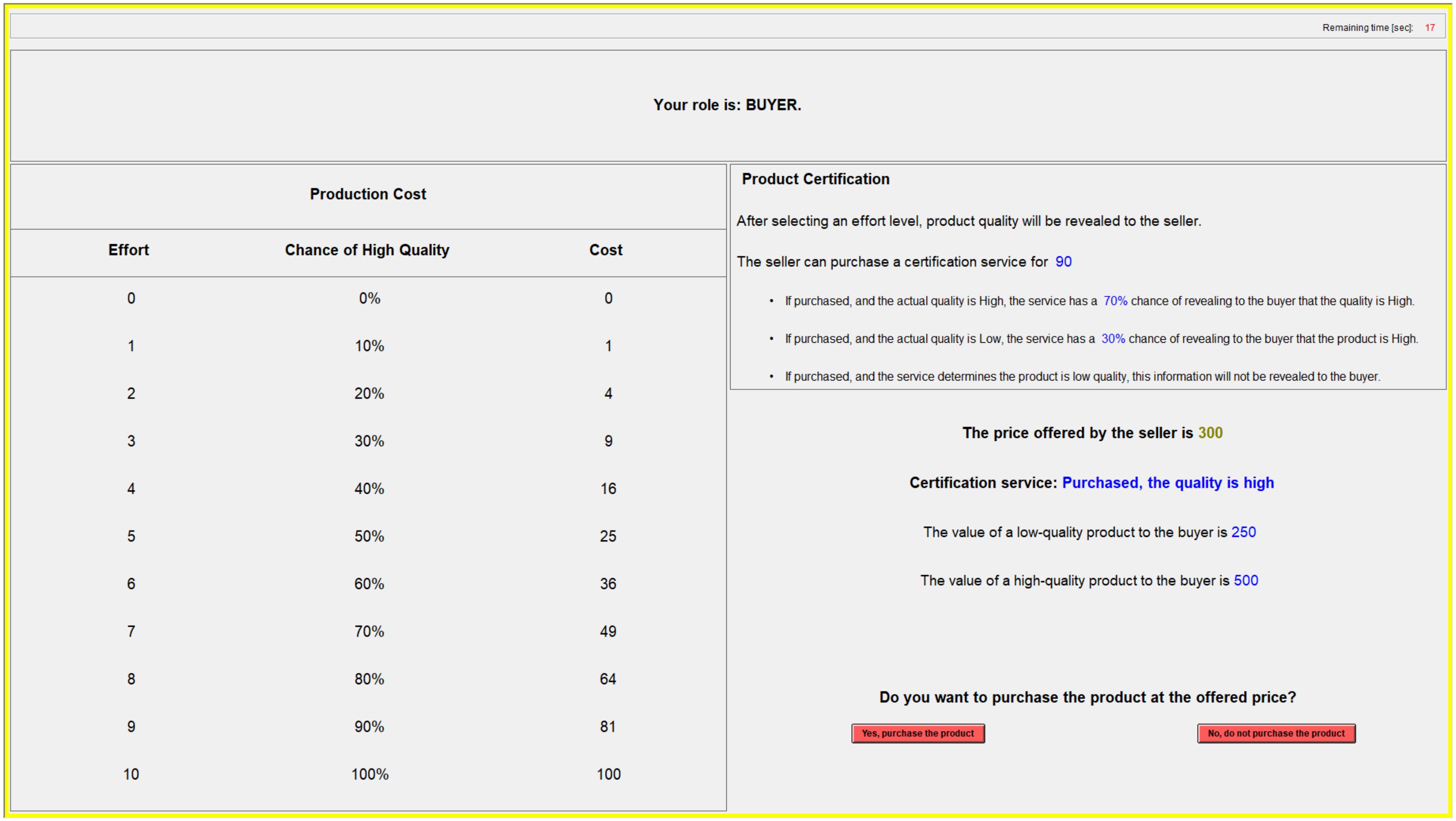


Figure 5. Subject screen for buyer's purchase decision

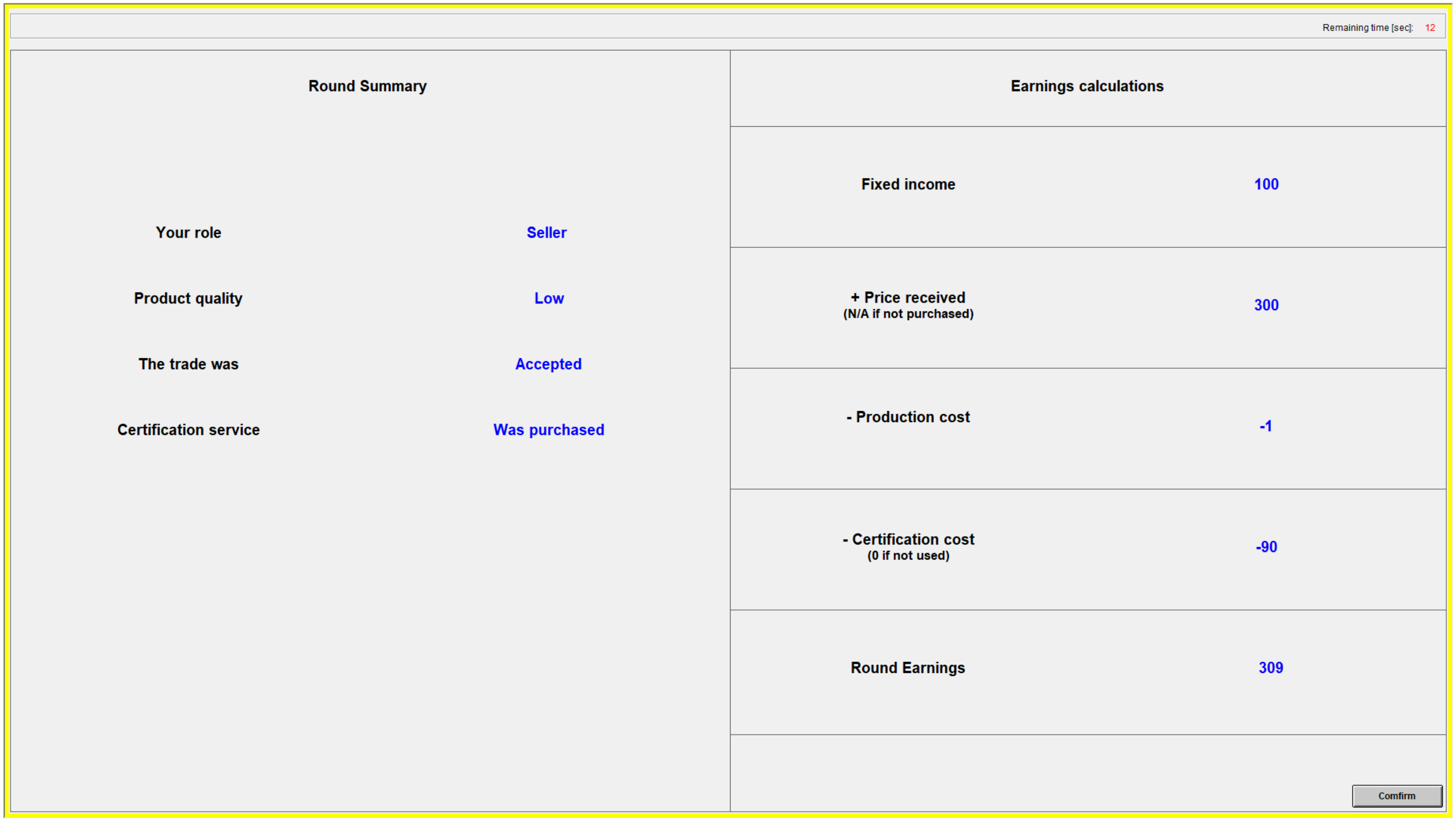


Figure 6. Subject screen for seller's round summary

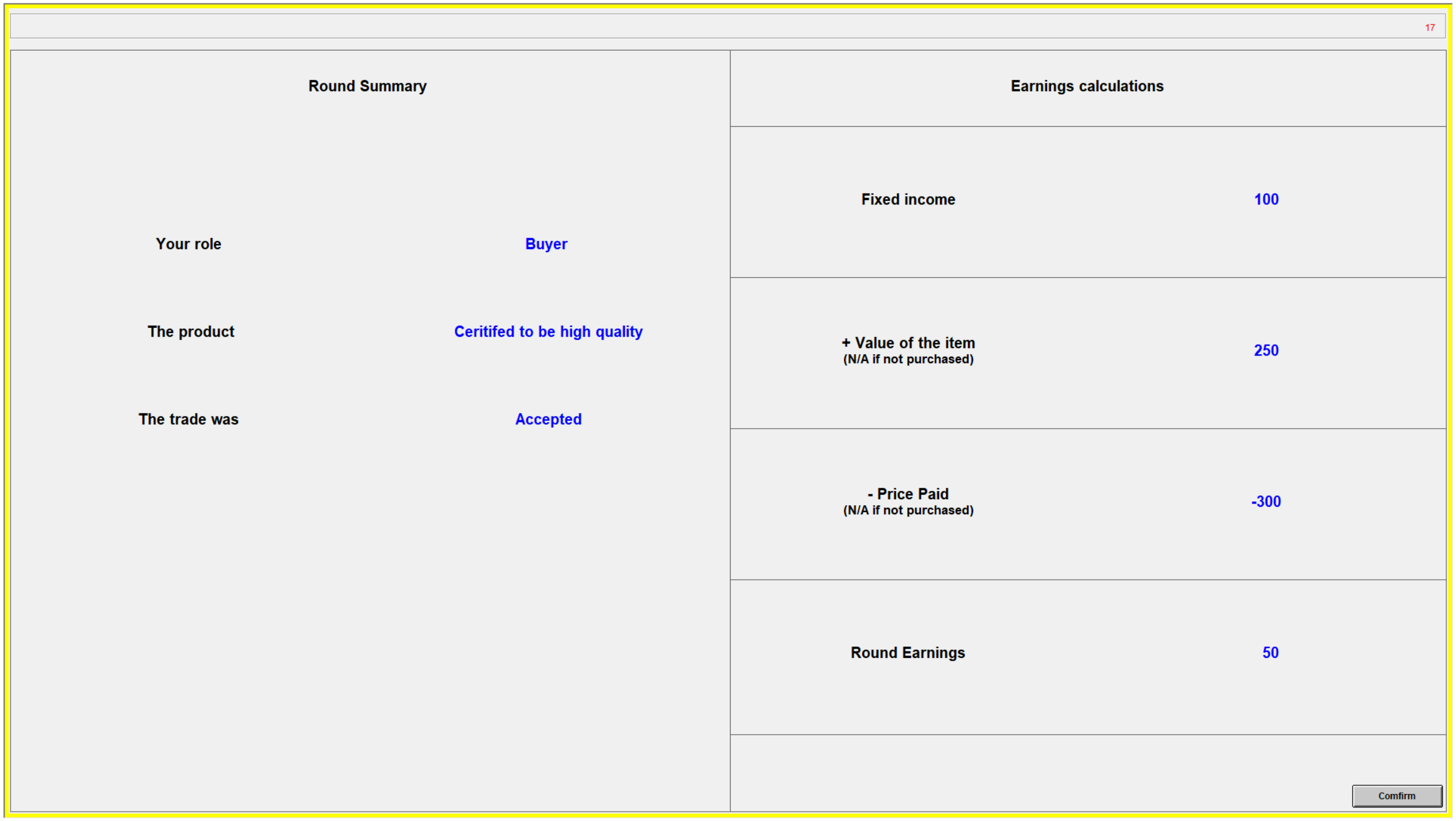


Figure 7. Subject screen for buyer's round summary

Appendix C. Supplemental econometric analyses

Table C1. Treatment effects regressions, with control variables excluded

	(1) Seller Effort	(2) Certification Purchased	(3) Product Sold	(4) Social Welfare	(5) Product market efficiency
SPA(60)	2.969***	0.582***	0.196***	27.60***	18.87***
	(0.505)	(0.054)	(0.053)	(5.46)	(5.20)
SPM(125)	2.028***	0.476***	0.237***	29.56***	14.67***
	(0.515)	(0.057)	(0.044)	(3.99)	(3.75)
BPA(125)	0.563	0.158***	–0.008	2.06	−2.53
	(0.489)	(0.030)	(0.057)	(4.65)	(4.75)
BPM(60)	2.180***	0.432***	0.082	15.55***	8.65
	(0.567)	(0.042)	(0.051)	(5.51)	(5.56)
SIA(20)	1.016**	0.688***	0.084*	8.02*	4.58
	(0.472)	(0.056)	(0.050)	(4.24)	(4.22)
SIM(90)	0.569	0.371***	0.060	7.35	−0.98
	(0.534)	(0.055)	(0.046)	(4.85)	(4.67)
BIA(90)	0.539	0.153***	0.031	3.72	0.28
	(0.540)	(0.028)	(0.056)	(5.55)	(5.44)
BIM(20)	0.798	0.282***	0.055	7.04	5.62
	(0.561)	(0.044)	(0.054)	(4.82)	(4.81)
Constant	2.673***		0.593***	41.11***	41.11***
	(0.340)		(0.034)	(2.95)	(2.95)
Observations	1,760	1,360	1,760	1,760	1,760
R^2	0.107	0.475	0.028	0.049	0.023

Notes: *,**, and *** denote estimates that are statistically different from zero at the 10%, 5%, and 1% significance levels, respectively. Standard errors in (1) – (3) are clustered by participant. Standard errors in (4) and (5) are based on two-way clustering as the actions of two participants determine each social welfare and efficiency outcome.

Table C2. Treatment effects regressions, data restricted to last half of experiment

	(1) Seller Effort	(2) Certification Purchased	(3) Product Sold	(4) Social Welfare	(5) Product market efficiency
SPA(60)	4.112***	0.619***	0.230***	33.91***	24.62***
	(0.697)	(0.078)	(0.067)	(6.77)	(6.42)
SPM(125)	2.872***	0.537***	0.170***	26.87***	9.69***
	(0.542)	(0.075)	(0.060)	(5.28)	(5.68)
BPA(125)	1.104*	0.122***	–0.003	2.45	−1.71
	(0.610)	(0.045)	(0.075)	(6.81)	(7.11)
BPM(60)	2.137**	0.395***	0.052	12.81	5.66
	(0.899)	(0.059)	(0.065)	(7.89)	(8.07)
SIA(20)	1.352**	0.678***	0.140**	13.12**	9.68
	(0.585)	(0.085)	(0.065)	(5.29)	(5.36)
SIM(90)	1.182**	0.472***	0.089	12.36*	1.44
	(0.589)	(0.076)	(0.060)	(7.07)	(7.20)
BIA(90)	1.547**	0.164***	0.079	11.51	7.49
	(0.721)	(0.042)	(0.075)	(7.32)	(7.19)
BIM(20)	0.836	0.248***	−0.004	−0.05	−1.09
	(0.631)	(0.048)	(0.073)	(6.51)	(6.53)
Constant	1.812***		0.608***	41.18***	41.49***
	(0.362)		(0.041)	(3.62)	(3.63)
Observations	880	680	880	880	880
R^2	0.209	0.510	0.048	0.074	0.042

Notes: *,**, and *** denote estimates that are statistically different from zero at the 10%, 5%, and 1% significance levels, respectively. Standard errors in (1) – (3) are clustered by participant. Standard errors in (4) and (5) are based on two-way clustering as the actions of two participants determine each social welfare and efficiency outcome. The control variables summarized in Table 3 are included in all regressions.