Product Ratings and Externalities (Preliminary version, please do not disseminate)

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Abstract

We investigate how information regarding production externalities (e.g. ecolabels) can be presented to create market pressure on firms to reduce them. Specifically and novelly, we ask whether integrating information regarding externalities *and* consumer product ratings into one rating, can result in firms feeling pressure to reduce externalities from all consumers, not just 'green/activist' consumers. Theoretically we show that a reputation equilibrium exists where producers invest in both high product quality and low negative product externalty. However, we show that with separate ratings, this equilibrium requires a high share of 'green' consumers who only wish to purchase products with low production externalities, whereas with combined ratings it does not. Experimentally we confirm the prediction that while both separate and combined ratings help overcome the asymmetric information problem, investments in externality reduction were substantially higher in the combined rating treatment.

1 Introduction

Markets providing products that come with possible negative production externalities is a longstanding problem in economics. Since Pigou (1920), one main suggestion by economists is to use taxation to internalize negative externalities otherwise not taken into account by producers and consumers. In reality, Pigouvian-style taxation is not often and only mildly applied. Furthermore, there are situation in which Pigouvian-style taxation may not be able to restore first-best, e.g. when the exact source of harm is unobserved by regulating authorities.

As an alternative to taxation, a trend has emerged to provide products with labels and certificates, indicating the relation to possible negative effects on environment or health. Green labels have become a prevalent feature of consumer information. However the effectiveness of for example 'green' labels to internalize is unclear (Carlsson et al., 2021). One drawback of the way information on product externalities is disseminated is that it often features unclear information. A wildernis of different labels allows producers who's production methods are not amongst the low-externality ones, to 'greenwash' their reputation by simply also presenting their products with a green label of their own. Even if the noisiness of the information provision regarding product externalities would be solved (for example by a more unified and salient labeling system), another fundamental problem remains. Using green labels to encourage producers to reduce production externalities, works for markets where a sufficient share of consumers actively value products to be 'green', but would not have much effect in markets where consumers do not focus on externality labeling but rather only on the direct consumption value of the products.

While the effects of green labels to encourage more low-externality consumption are in question, the introduction of consumer rating systems to facilitate the markets for different experience goods has proven to be a potent mechanism. Specifically, evidence suggests that consumer rating systems have been effective in terms of mitigating problems of moral hazard and adverse selection by proving incentives for producers to provide high quality products and services.[1] A vast and mature theoretical literature suggests that sharing sellers´ history with buyers, e.g. through consumer ratings, will help markets overcome problems related to asymmetric information by inducing *reputational concerns*.[2] The empirical relevance of reputational concerns has been well established.[3,4]

In this paper we introduce a new informational mechanism to internalize externalities in markets for experience goods where the market is aided by product ratings. The mechanism bundles information regarding the quality of a good (consumer ratings) with information regarding a producer´s externality reducing efforts (a green label). We evaluate our informational mechanism in a theoretical model and with an incentivised laboratory market experiment.

[1]See Tadelis (2016) and Sun (2012) and Liu et al. (2021).

[2]See Fudenberg and Levine (1989, 1992); Mailath and Samuelson (2001); Board and Meyer-ter Vehn (2013); Liu (2011); Liu and Skrzypacz (2014).

[3]See Cabral and Li (2015) and Tadelis (2016) for an overview of the empirical literature and Liu et al. (2021) for a more recent contribution.

[4]Several experiments also highlight the relevance of reputational concerns. See Camerer and Weigelt (1988), Neral and Ochs (1992), Brandts and Figueras (2003), Bohnet and Huck (2004), Bolton et al. (2003), List (2006), Grosskopf and Sarin (2010), Huck et al. (2012), and Bartling et al. (2018).

The theoretical model extends a simplified version of the canonical reputation models of Fudenberg and Levine (1989, 1992) to a context where the long-lived side of the market (the producer) can build and maintain a reputation along two dimensions: Product quality and damage reduction. In the model, the producer can invest in product quality, which increases the value of the good to all consumers, and in damage reduction, which reduces a negative externality and affect the value of the good to *some* consumers. Consumers observe the producer´s ratings, which are noisy averages of the producer´s historical investments in product quality and damage reduction. In line with the type-based approach pioneered by Kreps et al. (1982), there are commitment types corresponding to each combination of actions available to the producer (investment decisions). We show that the damage reduction rating (the green label) on it´s own only provides producers with incentives to reduce externalities if a high share of consumers care about reducing externalities. On the other hand, bundling the green label with a consumer rating may provide producers with incentives to reduce externalizes regardless of the share of consumers who care about reducing externalities.

In the incentizived experiment, we create a market environment akin to the theoretical setting. Participants play either the role of producer or consumer, who are randomly matched. Producers decide whether to invest in product quality and/or "damage reduction", and consumers decide whether to buy the offered product (at a given constant price) or not. Consumers are not aware what investment decisions the producer has made and only derive consumption value from products with quality investment. Lack of damage reduction investment creates a negative externality for everyone in the market.

To allow reputation effects to form, the experiment has a multi periods format, with an indefinite horizon, including a number of restarts resulting in 4 supergames.[5] Consumers, before making their purchasing decisions, get to observe the ratings of the matched producer. These rating reflects an average of the investment decisions in past periods.

We compare two treatments. In the "Separate ratings" treatment, a consumer observes two ratings, one reflecting the average past investment in product quality, and the other in damage reduction. In the "Combined ratings" treatment the consumer observes one rating which is an average of the product quality and damage reduction ratings.

We find a significant 15 percent point increase in the investment in damage reduction in the Combined ratings treatment. This effect remains stable over the different periods in the experiment. At the same time we do not see a significant difference in the investment in product quality between the treatments. Both rating systems overcome the asymmetric

[5]See for a discussion of repeated game designs Fréchette and Yuksel (2017).

information problem regarding quality investment to a large degree. This means that, importantly and in line with our theoretical analysis, the bundeling of information into one reputation rating has not undermined the power of the rating system to overcome the moral hazard problem in the market. We see moreover, in line with a key premise of the theory, that most consumers only condition their choices on the quality rating and not on the damage reduction rating in the Separate ratings treatment. In the combined rating treatment these same non-green consumers do reward damage reduction investment as their purchase decisions now depend on a rating which incorporates this investment.

Our paper contributes by introducing a novel information mechanism to tackle negative market externalities, that is especially suited for the consumer rating 'driven' market platforms we have seen becoming popular in the last 10 years. The information intervention we propose is somewhat in line with the idea of Bayesian persuasion (Kamenica and Gentzkow (2011); Kamenica (2019)) where the a central idea is to consider what type of information revealed to players in a game yields desirable outcomes. Our paper also connects to several literatures focusing on the experimental testing of different market equilibria. We add to the experiments focusing on markets with moral hazard problems and reputational concerns (Bohnet and Huck, 2004; List, 2006; Huck et al., 2016), and we add to the literature focusing on markets with negative externalities (Bartling et al., 2015, 2019; Fernandes and Valente, 2021). To our knowledge we are the first to run an experimental test of a market that exhibits both an asymmetric information problem and a negative production externality simultaneously. Yet we think that this duo feature is likely relevant for many markets. The combined ratings mechanism utilizes the product quality ratings created to overcome the moral hazard problem, and uses this channel to simultaneously address a negative externality issue.

The main implication of our results is that platforms who want to support vendors/producers who score well on reducing the negative externalities connected to their products, should perhaps not facilitate the separate advertising of for example environmental friendly performance, but incorporate this as part of the main salient rating consumers use to compare products on their market platform.

The rest of this article is organized as follows: We introduce the model and derive our key equilibrium properties in section 2, section 3 describes the experimental design and section 4 reports the results of the experiment. Section 5 discusses the findings and concludes.

2 A model of reputation and production externalities

2.1 Model

Stage game: In each period $t \in \{0, 1, 2, ...\}$, the producer is matched with a new consumer. The producer then makes two investment decisions. Investing in product quality ($I_{PQ} = 1$) yields high product quality with certainty and lack of investment ($I_{PQ} = 0$) yields low product quality with certainty. Investing in damage reduction ($I_{DR} = 1$) mitigates all negative production externalities with certainty and lack of investment ($I_{DR} = 0$) yields an external cost with certainty. Consumers have a unit demand and chose whether to purchase ($b = 1$) or not purchase ($b = 0$) the product offered by the producer at an exogenously fixed price of p without observing the producer´s decisions.

Payoffs: The cost of investing in product quality is $c_{PQ} > 0$ and the cost of investing in damage reduction is $c_{DR} > 0$. The external cost associated with lack of investment in damage reduction is denoted by e.[6] We assume that it is socially optimal to invest in damage reduction ($e > c_{DR}$).[7] The producer's payoff is then $p - c_{PQ}I_{PQ} + c_{DR}I_{DR}$. The seller discounts future payoffs with a discount factor $\delta \in (0, 1)$. We make the following assumption about δ, relative to the other parameters:

A1: $\delta p > c_{PQ} + c_{DR}$

Assumption **A1** insures that the producer has incentives to build and maintain a reputation.[8]

All consumers value product quality and have a reservation price of 1 for high product quality and 0 for low product quality. A share of consumers, $\lambda \in [0, 1]$, also value damage reduction. Consumers who value damage reduction experience a disutility $d > 0$ when buying from a producer who has not invested in damage reduction.[9] We will refer to consumers who value damage reduction as *green consumers* and consumers who do not value damage reduction as *regular consumers*. The consumer type is private information. The outside option of the consumer is normalized to zero. When choosing to purchase, the payoff to a

[6]While our focus is on environmental externalities, our results extend to other production externalities as well.

[7]e is the total damage experienced by all affected parties. We assume that damage experienced by any single party is negligible and therefor ignore it in what follows.

[8]Note that this assumption will not be sufficient to insure that the producer always invests in both product quality and damge reduction in our framework.

[9]We can think of d as the "warm glow" experienced by green consumers when purchasing from a producer who invests in damage reduction.

regular consumer is $I_{PQ} - p$, and the payoff to a green consumer is $I_{PQ} - d(1 - I_{DR}) - p$. We make the following assumption regarding the parameters p and d:

A2: $1 > p > 1 - d$

Assumption **A2** implies that a consumer who cares about damage reduction will not purchase the product if he believes that the producer has invested in product quality only.

Producer types: There are four commitment types corresponding to the potential actions of the producer, and a strategic type. The producer type is private information and priors are denoted by $\mu_{i,0}$ for types $i \in \{Full, PQ, DR, No, S\}$. $Full$ is committed to high product quality and damage reduction, PQ to high product quality and now damage reduction, DR to damage reduction and low product quality, and No is committed to low product and no damage reduction. S denotes the strategic type. We let $\boldsymbol{\mu}_0$ denote the set of priors. We impose two assumptions on prior beliefs:

A3: $\mu_{i,0} > 0$ for all $i \in \{Full, PQ, DR, No, S\}$
A4: $\mu_{S,0} > p$

Assumption **A3** implies that consumers initially assign a positive belief on all types. Assumption **A4** insures that our results are driven by the behavior of the strategic type. Specifically, **A4** implies that both consumer types, given their prior, will purchase if they believe that the strategic producer invests in product quality and damage reduction.

The strategic type is the focus of the analysis, and any references to "the producer" in what follows refers to the strategic type.

Ratings: Prior to making their purchasing decisions consumers observe the producer´s *ratings*. The producer's ratings in period t are determined by the investment decision made in periods $t' < t$. We let R^t_{PQ} denote the rating for product quality and R^t_{DR} denote the rating for damage reduction.[10] R^t_{PQ} and R^t_{DR} are the averages of *reported* product quality and damage reduction for each period, r^t_{PQ} and r^t_{DR}:

[10] The rating of product quality can be thought of as coming from consumers, while the rating of damage reduction can be thought of as coming from some organization or government agency.

$$R^t_{PQ} = \frac{1}{t}\sum_{t'=0}^{t-1} r^{t'}_{PQ} \tag{1}$$

$$R^t_{DR} = \frac{1}{t}\sum_{t'=0}^{t-1} r^{t'}_{DR} \tag{2}$$

Reporting of quality is assumed to be biased. Specifically, we assume that investing in high product quality or damage reduction leads to an accurate report with certainty while not inventing in product quality or damage reduction may still result in a report of high quality. We let $\varepsilon \in (0,1)$ denote the probability that not inventing in quality still results in a report of high quality. In addition, the consumer observes a third rating, R^t, which is average of the two ratings: $R^t = \frac{R^t_{PQ}+R^t_{DR}}{2}$.

2.2 Discussion and key predictions

The focus of the analysis is on the producer's incentives to invest in product quality and damage reduction depending on what the consumers observe: R^t_{PQ} and R^t_{DR}, or R^t only. Specifically, we focus on the existence of equilibria where the producer always invests in both product quality and damage reduction on the equilibrium path, and where both consumer types purchase, depending on which ratings consumers observe. In what follows, we refer to this as a *full investment equilibrium*.[11] The purpose of our analysis is to derive the conditions under which full investment equilibria exists when consumers observe R^t_{PQ} and R^t_{DR} and when consumers observe R^t only. We refer to the case where consumers observe both R^t_{PQ} and R^t_{DR} as the separate rating case, and the case where consumers observe only R^t as the combined rating case. Our main result is summarized in Proposition 1.[12]

Proposition 1. *Fix some parameters* $(\delta, p, c_{PQ}, c_{DR}, \lambda, \varepsilon)$*, a set of priors* $\boldsymbol{\mu}_0$ *and define* $\underline{\lambda} := \frac{c_{DR}(1-\delta\varepsilon)}{\delta p(1-\varepsilon)}$.

[Separate ratings] A full investment equilibrium exists iff $\lambda \geq \underline{\lambda}$.

[Combined rating] A full investment equilibrium may exist for any $\lambda \in [0,1]$.

What drives our main result is the set of (rational) posterior beliefs consumers may hold in

[11] The formal analysis is contained in appendix A.

[12] The proof may be found in appendix A.

an equilibrium where the producer always invests in product quality and damage reduction. As it turn out, these beliefs are very different depending on which ratings consumers observe. We elaborate on this below.

Consider first the case in which consumers observe R^t_{PQ} and R^t_{DR}, and fix an equilibrium candidate in which the strategic producer always invests in product quality and damage reduction. For some period t, and if the producer has invested in product quality and damage reduction in all $t' < t$, the producer´s ratings will be $R^t_{PQ} = 1$ and $R^t_{DR} = 1$. Due to the bias in reported quality (ε), these ratings are consistent with all producer types. However, since $R^t_{PQ} = 1$ and $R^t_{DR} = 1$ is unlikely to materialize for producer types who invest only in one type of quality (PQ and DR types), or neither (the No type), posterior beliefs must be highest for the strategic producer and the $Full$ type.[13] Consider next what would happen if the strategic producer were to deviate and only invest in product quality. In the subsequent period, if the damage reduction is reported correctly, the producer´s ratings are $R^t_{PQ} = 1$ and $R^t_{DR} < 1$. Under the assumptions of the equilibrium candidate, these ratings are only consistent with the PQ-type and the No-type. However, since $R^t_{PQ} = 1$ and $R^t_{DR} < 1$ is unlikely to materialize for the No-type, posterior beliefs must be highest for the PQ-type. In particular, the posterior belief on the PQ-type following such a deviations will come arbitrarily close to 1 as $t \to \infty$ and/or $\varepsilon \to 0$. Thus, regardless of priors, there will always be a period after which the strategic producer can deviate and only invest in product quality and then (in the continuation) serve only regular consumers. Whether or not such a deviation is optimal depends on the distribution of consumer types. If the share of green consumers is sufficiently high ($\lambda \geq \underline{\lambda}$), the producer cannot increase payoffs by deviating. If, however, this share is low ($\lambda < \underline{\lambda}$), the producer can increase payoffs by deviating. If this is the case, a full investment equilibrium cannot exist. Thus, when consumers observe R^t_{PQ} and R^t_{DR}, the existence of a full investment equilibrium depends crucially on there being enough consumers who value damage reduction.

Consider next the case in which consumers observe only R^t, and fix an equilibrium candidate in which the strategic producer always invests in product quality and damage reduction. For some period t, and if the producer has invested in product quality and damage reduction in all $t' < t$, the producer´s rating will be $R^t = 1$. Due to the bias in reported quality (ε), these ratings are consistent with all producer types. However, since $R^t = 1$ is unlikely to materialize for producer types who invest only in one type of quality (PQ and DR types), or neither (the No type), posterior beliefs must be highest for the

[13] In fact, posterior beliefs on the producer being either one of these tow types following $R^t_{PQ} = 1$ and $R^t_{DR} = 1$ will converge to 1 as $t \to \infty$.

strategic producer and the *Full* type. Consider next what would happen if the strategic producer were to deviate and invest only in product quality or neither.[14] In the subsequent period, quality is reported correctly, the producer´s rating is $R^t < 1$. Under the assumptions of the equilibrium candidate, this rating is consistent with the PQ-type, the DR-type and the No-type. However, since a rating close to 1 is unlikely to materialize for the No-type, posterior beliefs must be highest for the PQ-type and the DR-type. In particular, the posterior belief on the PQ-type following such a deviations will come arbitrarily close to $\frac{\mu_{PQ}}{\mu_{PQ}+\mu_{DR}} < 1$ as $t \to \infty$ and/or $\varepsilon \to 0$. Thus, unlike case with two ratings, there may not be a period after which the strategic producer can deviate and serve only regular consumers in the continuation. This implies that a full investment equilibrium may exists regardless of the share of green consumers (λ). Thus, by bundling the ratings, ratings below 1 become ambiguous which in turn may incentives the producer to maintain a rating of 1, which it can only do by always investing in both environmental and product quality regardless of the share of green consumers.

While the model does not provide unambiguous predictions, it points to environments in which one should expect the combined rating to outperform the separate ratings in terms of reducing externalities. Specifically, in an environment where λ is low, the model predicts that investments in damage reduction should be higher if consumers only observe a combined rating, compared to observing both. As we explain in the following section (3.2), we believe that the lab offers such an environment.

3 Experimental Design

3.1 Design and treatments

In the experiment participants are randomly assigned the roles of producers and consumers and divided in matching groups of 6 (3 producers, 3 consumers). The experiment consists of a number of periods. In each period, producers are randomly matched with consumer within their matching groups. Each producer then chooses whether to invest in high product quality at a cost of 15 points and whether to invest in production damage reduction at a cost of 10 points. Each consumer chooses whether to buy the offered product in a period at a price of 60 points or not without observing the investment decisions of the producer. Over the course of one session participants are randomly matched within their matching groups

[14] Note that when consumers only observe R^t, producers who have failed to invest a certain number of times will be indistinguishable from each other regardless of how they have failed to invest.

approximately 48 periods.

Consumers receive 100 points if they purchase a high-quality product 0 points if they purchase a low-quality product. Furthermore, consumers (and producers) lose 0.25 points for each percent of producers that did not invest in damage-reduction. While these decisions are not observed by the consumer, the consumer observes the producer´s ratings. Ratings are calculated as the average of past investment decisions from the matched producer.[15] These ratings are reset at three random times during the experiment.

The three resets mean that there are four stretches of periods (supergames) where the reputations are accumulating over. These supergames are always a minimum of five periods long and after period five have a 87.5% of continuation of another period. This leads to an expected 12 number of periods for each stretch and a total of 48 periods average over the experiment. The number of periods in each supergame is drawn before a session.

There are two treatments and treatments are randomized also within an experimental session. The treatments vary with respect to which ratings consumers observe. In one treatment the consumers will observe two separate ratings, one summarizing the past relative frequency of quality investment (R^t_{PQ}) and the other the past relative frequency of damage reduction investments (R^t_{DR}). In a second treatment the consumers only observe one rating for each matched producer which will be the weighted sum of the past relative frequency of investment for both kinds of investment (R^t).

3.2 Discussion of Design Choices

A key element of the experimental design that makes it a suitable setting to test our theoretical predictions is the heterogeneity of consumer attitudes towards the externality. In the model we exogenously define the population to exist of a share (λ) of green consumers who are willing to pay (or forgo the option to purchase) to have a green product over a non green one, and of a remaining share who do not care about the damage reduction choices of the product producer.

In the experiment we implement the existence of a matching-group specific externality which targets every participant in the matching group. Given past heterogeneous results on participant's willingness to take externalities into account (Bartling et al., 2015, 2019; Fernandes and Valente, 2021), we believe this setup will just like in the theory, implement a setup where some consumers care for the producer's choice to invest in damage reduction and are willing to forgo a purchase by a producer who imposed a negative externality, but where

[15]See equations 3 and 4.

also a large part of the consumers are not willing to actively take the externality dimension of producer behavior into account when deciding on whether to purchase the good.[16]

In this way we think that our experimental design captures the required consumer heterogeneity of attitudes towards the damage reduction well and in a way that provides the participants with a natural market/(consumer choice) tradeoff.

4 Results

The experimental data was collected at the BI Research Lab at BI Norwegian Business School in Oslo in the fall of 2022 and was run using zTree software Fischbacher (2007). In total 240 participants participated in experiment sessions lasting on average 75 minutes and earning on average 351 NOK. The participants were randomly designed into 40 matching groups of six participants. Matching groups were assigned to one of two treatments, a "Separate" ratings treatment or a "Combined" rating treatment. A single session would contain matching groups assigned to different treatments.

In subsections 4.1 and 4.2 we will first report our main results by providing an overview of the choices made by the participants in the roles of producer and consumer. After this we will have a closer look at the dynamics of the choices in the experiments over the periods in subsection 4.4. To give a preview of our main results, Table 1 below reports the result of the regressions of the product quality and damage reduction investments, and purchase decisions, on the Combined rating treatment dummy. We observe a significant 15 percentage point treatment increase in damage reduction investment, while we record no significantly different rate of product quality investment and purchase decisions by consumers.

Table 1: Regression

	PQ investment	DR investment	Purchase share
Combined treatment	-0.0593 (0.0504)	0.1531 (0.0610)	0.0027 (0.0407)
p-value treatment	0.246	0.016	0.947
N	5346	5346	5346

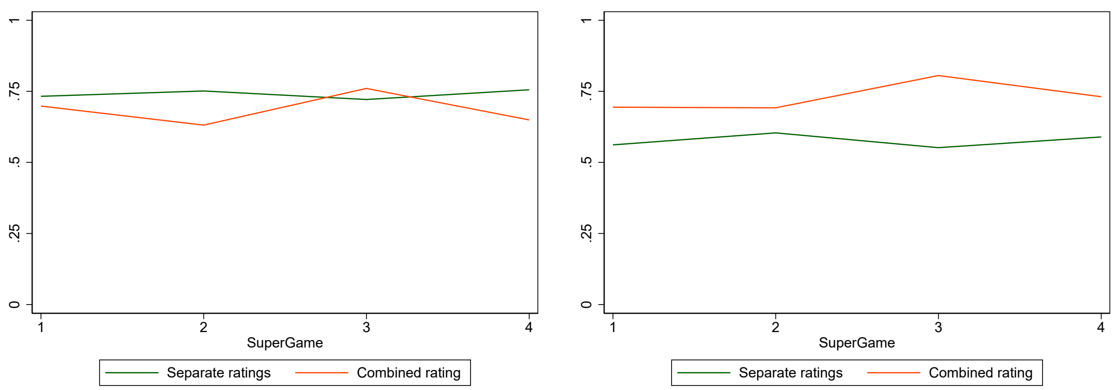
Standard errors are clustered at the matching group level.

[16] The use of homegrown values, rather than induced ones, has been common in the experimental literature on externalities. See Fernandes and Valente (2021) for an overview.

4.1 Producer decisions

Our main preregistered prediction for this experiment was that in a market where consumers observe the investment reputations of the matched producer as one integrated rating, producers would substantially increase their investment in damage reduction, without substantially reducing their investment in product quality, compared to the market with separate reputation ratings. The results from the experiment confirm this hypothesis. Figure 1 and Tables 2 and 3 below show the main results including a view of how the results evolved over the four supergames that participants got to play.

Figure 1: Producer investment decisions



(a) Product quality (b) Damage reduction

Table 2: Investment in Product Quality

	Separate	Combined	Mann-Whitney p	t-test p
All supergames	74.09%	68.16%	0.3653	0.2262
Supergame 1	73.25%	69.82%	0.1470	0.1636
Supergame 2	75.13%	63.12%	0.1220	0.0785
Supergame 3	72.13%	76.02%	0.6440	0.5803
Supergame 4	75.55%	64.95%	0.2181	0.1624
N=240	20 matching groups	20 matching groups		

Table 3: Investment in Damage Reduction

	Separate	Combined	Mann-Whitney p	t-test p
All supergames	57.86%	73.16%	0.0093	0.0121
Supergame 1	56.17%	69.43%	0.1157	0.1700
Supergame 2	60.38%	69.20%	0.1294	0.0943
Supergame 3	55.18%	80.56%	0.0034	0.0036
Supergame 4	58.95%	73.10%	0.0297	0.0252
N=240	20 matching groups	20 matching groups		

Comparing the level of product quality investment between the treatments, we see that on average producers invested 74.28% of the time in the Separate treatment and 68.03% in the Combined treatment, summarizing over all periods played in the experiment. This difference is not significant (Mann-Whitney p=0.3653, t-test p=0.2262). When looking at the damage reduction investments however, we see this is on average 57.27% in the Separate treatment and 73.45% in the Combined treatment. This 16 percent point treatment difference in externality-reduction investment is significant (Mann-Whitney p=0.0093, t-test p=0.0121). Moreover, as we can observe in Figure 1 and in Table 3, this difference in the damage reduction investment appears not to be simply the product of first supergame ”trial, error and learning” dynamics. In fact the damage reduction investment treatment difference is largest in the later supergames.

4.2 Consumer decisions

In the market we study, producer and consumer choice behavior is interdependent. This means that to understand our main result regarding producer investment behavior across the two treatments, looking consumer behavior helps us interpret the producer behavior. Moreover our theoretical equilibrium predictions also include predictions on consumer purchase behavior. Specifically our main prediction is, that consumer purchase decisions should not diminish in our Combined treatment compared to the Separate treatment. Figure 2 and Table 4 below confirm this prediction.

Figure 2: Consumer purchase decisions

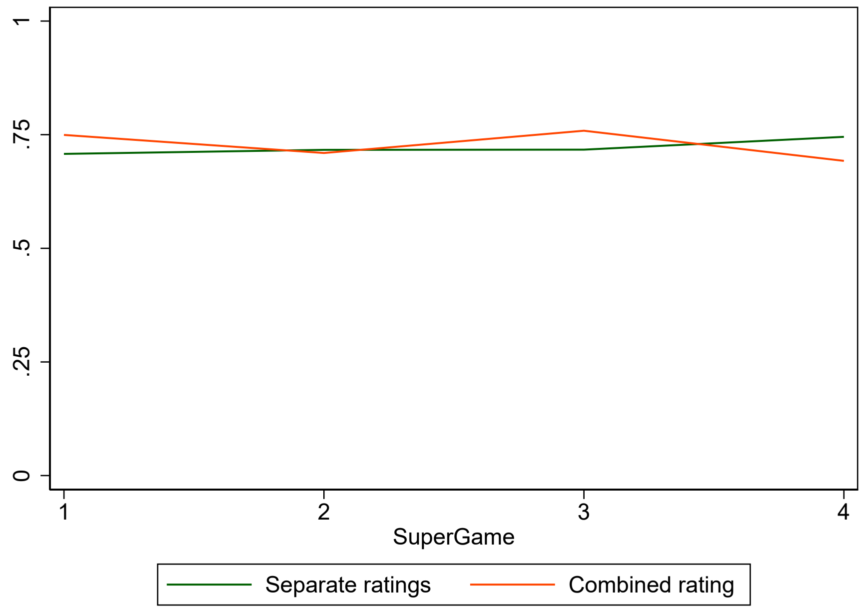


Table 4: Purchases

	Separate	Combined	Mann-Whitney p	T-test p
All supergames	72.25%	72.53%	0.9307	0.9937
Supergame 1	70.78%	74.95%	0.9626	0.7224
Supergame 2	71.67%	70.98%	0.8566	0.9268
Supergame 3	71.71%	75.88%	0.8881	0.9762
Supergame 4	74.53%	69.24%	0.5782	0.4931
N=240	20 matching groups	20 matching groups		

Comparing the level of consumer purchases between the treatments, we see that on average consumers purchased 72.48% of the time in the Separate treatment and 72.52% in the Combined treatment, summarizing over all periods played in the experiment. This difference is clearly not significant (Mann-Whitney p=0.9307, t-test p=0.9937).

An important question to investigate, in order to interpret producer investment behavior, is how consumers let their purchasing decisions depend on the rating information they received about the matched producer from that period. The regression in Table 5 and the purchase likelihood in Figure 3 below show that the consumers purchasing decisions in the Separate rating treatment clearly depend on the product quality rating they observe from their matched producer. However there seems to be no effect of the damage reduction rating on the likelihood of a purchase decision. This result makes it clear that we can indeed view our experiment as testing a market environment where there are no or only few consumers who voluntarily let information regarding production externalities influence their purchase decisions.

When focusing on the Combined ratings treatment, the second regression in Table 5 and Figure 4 show that again the likelihood of a consumer purchase strongly correlates with the observed rating before the purchase decision. In both treatments though, this relation between producer ratings and puchases is more gradual than the Full Investment equilibria described in section 2.

Table 5: Regression

	Purchases (Separate)	Purchases (Combined)
Rating PQ	0.8283 (0.0491)	
Rating DR	-0.0510 (0.0279)	
Rating C		0.6360 (0.0934)
N	2667	2679

Standard errors are clustered at the matching group level.

Figure 3: Purchase likelihood, Separate ratings

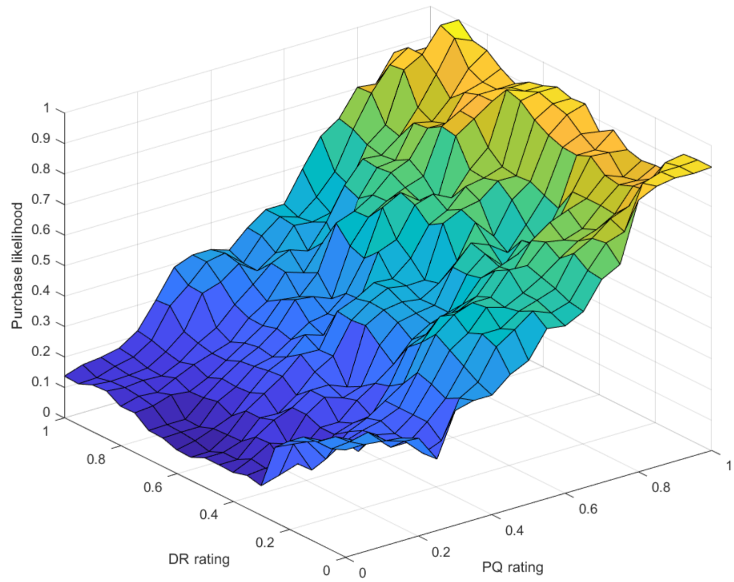


Figure 3 shows the approximate likelihood of consumer purchase for different combinations of product quality and damage reduction ratings. For each point on the 2-dimensional grid in the PQ-rating, DR-rating space, datapoints from the nearest 50 (or more in case of ties) observations from the experiment are selected and the purchasing likelihood set equal to the average over these selected observations.

Figure 4: Purchase likelihood, Combined rating

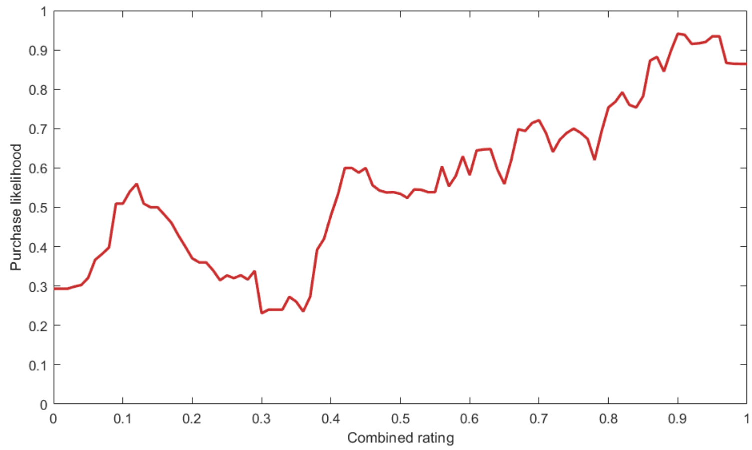


Figure 4 shows the approximate likelihood of consumer purchase for different levels of the Combined rating. For each point on the grid of the Combined rating, datapoints from the nearest 50 (or more in case of ties) observations from the experiment are selected and the purchasing likelihood set equal to the average over these selected observations.

4.3 Treatment welfare comparison

Looking at the average payoff in points the participants earned, the 'welfare', we see no significant difference between the two treatments with an average of 20.67 points in the Separate ratings treatment and an average of 23.24 points in the combined treatment (Mann-Whitney p=0.7994, t-test p=0.7089)

In our setup, the welfare gain of a combined investment in quality and purchase is 85 points, whereas the welfare gain of an investment in damage reduction is 40 points. We have seen that there is a clear increase in damage reduction investment, an nearly identical purchasing rate, and a slightly smaller though insignificantly different investment rate in product quality. Next to this we also find that the correlation between the purchase and product quality investment decision is slightly lower in the Combined rating treatment.

In our current setting it seems these factors balance each other out and leave the level of total welfare created in the market the same, although with more externality investment in the Combined rating treatment. Our current design limited the externality spillover of the damage reduction investment to 6 persons. Taking the investment behavior as given the welfare calculations would change if the externalities had wider consequences.

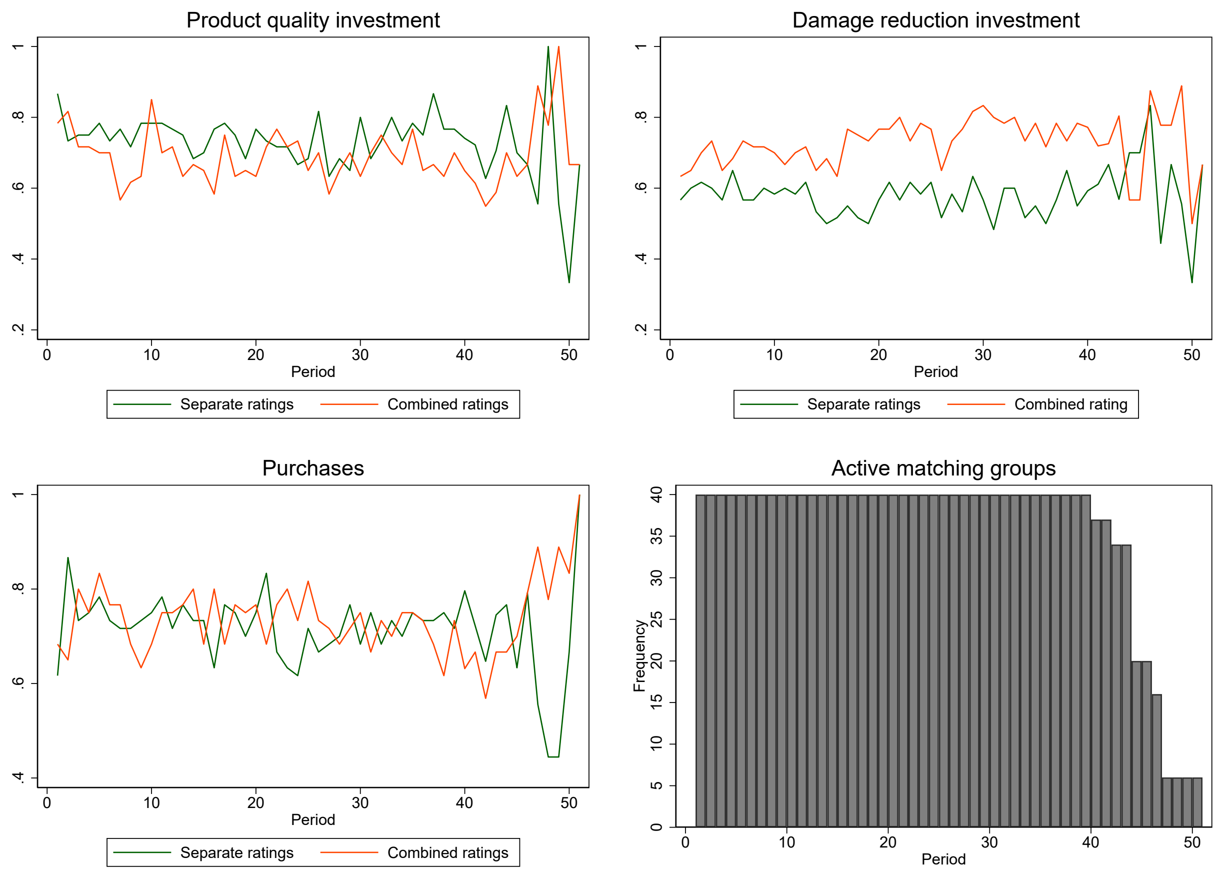
4.4 Investment and purchase dynamics

Figure 5 below shows that investment behavior for both product quality and damage reduction remains relatively stable over the different periods in our experiment. This holds as well for Purchases, which are essentially indistinguishable between treatments.

Note that only 6 matching groups have played more than 46 periods, so the increased fluctuation in the last periods can possibly be attributed to that.

Apart from the fluctuations after period 45, there is not much clear evidence for endgame effects between supergames, which suggests that the stochastic horizon setting worked well enough to have participants build and keep reputations.

Figure 5: Investment and purchase dynamics



5 Discussion of the results

Both our theoretical and experiment results suggest that adjusting vendor reputation ratings to incorporate information on production externalities has the potential to help guide consumers to more 'concerned' purchasing choices and persuade vendors to offer products with lower negative externalities.

Furthermore, the experimental results show that the combining of the ratings clearly did not undermine the effectiveness of the rating system to help overcome the experience-good asymmetric information problem. Product quality investments were nearly the same and consumer purchases nearly identical.

We think our experiment provided a good first test setting for the potential of combining ratings. Crucially, as Table 5 and Figure 3 highlighted, there were not many consumer's in the Separate rating treatment who were willing to base their purchasing decision on information on past Damage reduction investments. This absence of 'green' consumers is precisely what our presented model points to as what makes the combined rating likely provide a stronger reputation push for externality reducing investments than separate ratings.

There is however one feature of the results that deserves some discussion. This is the 57.86% average investment in Damage reduction in the Separate ratings treatment. As mentioned above the consumers in the Separate ratings treatment really did not reward the producers for better Damage reduction ratings, so this investment must be either the product of mis-estimating the importance of the DR investment, or reflect a genuine altruistic (including possible 'warm glow pride') consideration on the part of the investors. If the second reason is driving this result then its also interesting to reflect on the fact that the consumer's definitely not chose to be 'indirectly' altruistic by avoiding low DR rating producers, but producers did to a degree respond to the chance of making a 'direct' altruistic contribution to reduce a matching group externality.

Nonetheless even despite the high level of Separate rating externality reducing investment, we identify a clear and significant treatment effect of the combining of the ratings. But it could be that the 15 percentage points we estimated is actually somewhat deflated due to producer generosity, and the effect could be larger in the face of more profit-optimizing producers.

Our promising results suggest several future steps. One is to see how the ratings combining would work in markets with more direct producer competition. Potentially the interaction of the combined rating and more competitive choice for consumers, could make the effect persuading producers to score better on externalities even stronger. Another question is to see how consumers would use the opportunity, at an (effort) cost, to acquire information about the rating composition. This would be a robustness check for the mechanism. Beyond this it would be very interesting to test the Combined rating mechanism on an actual market platform selling consumer experience goods that have different levels of production externalities.

References

Bartling, B., E. Fehr, D. Huffman, and N. Netzer (2018): "The causal effect of trust," ECON - Working Papers 304, Department of Economics - University of Zurich.

Bartling, B., V. Valero, and R. Weber (2019): "On the scope of externalities in experimental markets," *Experimental Economics*, 22, 610–624.

Bartling, B., R. A. Weber, and L. Yao (2015): "DO MARKETS ERODE SOCIAL RESPONSIBILITY?" *The Quarterly Journal of Economics*, 130, 219–266.

Board, S. and M. Meyer-ter Vehn (2013): "Reputation for Quality," *Econometrica*, 81, 2381–2462.

Bohnet, I. and S. Huck (2004): "Repetition and Reputation: Implications for Trust and Trustworthiness When Institutions Change," *American Economic Review*, 94, 362–366.

Bolton, G. E., E. Katok, and A. Ockenfels (2003): "How Effective are Electronic Reputation Mechanisms? An Experimental Investigation," Working Paper Series in Economics 3, University of Cologne, Department of Economics.

Brandts, J. and N. Figueras (2003): "An exploration of reputation formation in experimental games," *Journal of Economic Behavior & Organization*, 50, 89–115.

Cabral, L. and L. I. Li (2015): "A Dollar for Your Thoughts: Feedback-Conditional Rebates on eBay," *Management Science*, 61, 2052–2063.

Camerer, C. and K. Weigelt (1988): "Experimental Tests of a Sequential Equilibrium Reputation Model," *Econometrica*, 56, 1–36.

Carlsson, F., C. Gravert, O. Johansson-Stenman, and V. Kurz (2021): "The use of green nudges as an environmental policy instrument," *Review of Environmental Economics and Policy*, 15, 216–237.

Fernandes, M. E. and M. Valente (2021): "What you get is not what you paid for: New evidence from a lab experiment on negative externalities and information asymmetries," *Journal of Behavioral and Experimental Economics*, 93, 101712.

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

Fréchette, G. R. and S. Yuksel (2017): "Infinitely repeated games in the laboratory: Four perspectives on discounting and random termination," *Experimental Economics*, 20, 279–308.

Fudenberg, D. and D. K. Levine (1989): "Reputation and Equilibrium Selection in Games with a Patient Player," *Econometrica*, 57, 759–778.

——— (1992): "Maintaining a Reputation when Strategies are Imperfectly Observed," *The Review of Economic Studies*, 59, 561–579.

Grosskopf, B. and R. Sarin (2010): "Is Reputation Good or Bad? An Experiment," *American Economic Review*, 100, 2187–2204.

Huck, S., G. K. Lünser, and J. Tyran (2016): "Price competition and reputation in markets for experience goods: an experimental study," *The RAND Journal of Economics*, 47, 99–117.

Huck, S., G. K. Lünser, and J.-R. Tyran (2012): "Competition fosters trust," *Games and Economic Behavior*, 76, 195 – 209.

Kamenica, E. (2019): "Bayesian persuasion and information design," *Annual Review of Economics*, 11, 249–272.

Kamenica, E. and M. Gentzkow (2011): "Bayesian persuasion," *American Economic Review*, 101, 2590–2615.

Kreps, D. M., P. Milgrom, J. Roberts, and R. Wilson (1982): "Rational cooperation in the finitely repeated prisoners' dilemma," *Journal of Economic Theory*, 27, 245 – 252.

List, J. A. (2006): "The Behavioralist Meets the Market: Measuring Social Preferences and Reputation Effects in Actual Transactions," *Journal of Political Economy*, 114, 1–37.

Liu, M., E. Brynjolfsson, and J. Dowlatabadi (2021): "Do Digital Platforms Reduce Moral Hazard? The Case of Uber and Taxis," *Management Science*, 67, 4665–4685.

Liu, Q. (2011): "Information Acquisition and Reputation Dynamics," *The Review of Economic Studies*, 78, 1400–1425.

Liu, Q. and A. Skrzypacz (2014): "Limited records and reputation bubbles," *Journal of Economic Theory*, 151, 2 – 29.

Mailath, G. J. and L. Samuelson (2001): "Who Wants a Good Reputation?" *The Review of Economic Studies*, 68, 415–441.

Neral, J. and J. Ochs (1992): "The Sequential Equilibrium Theory of Reputation Building: A Further Test," *Econometrica*, 60, 1151–1169.

Sun, M. (2012): "How does the variance of product ratings matter?" *Management Science*, 58, 696–707.

Tadelis, S. (2016): "Reputation and Feedback Systems in Online Platform Markets," *Annual Review of Economics*, 8, 321–340.

A Equilibrium analysis

In the following section we derive the conditions for the existence of equilibria where the producer always invests in both product quality and damage reduction.

A.1 Strategies, equilibrium and beliefs

The focus of the analysis is on Perfect Bayesian Equilibria in which players use stationary Markov strategies with posterior beliefs on the different producer types (reputation) as the state variable. Thus, the strategy of the producer specifies probabilities of investing in product quality and damage reduction as functions of the producer´s reputation, while consumer strategies specify probabilities of purchasing as a function of the firm´s reputation. Furthermore, we restrict our attention to the existence of equilibria where the producer always invests in both product quality and damage reduction on the equilibrium path, and where both consumer types purchase. In what follows, we refer to this as a *full investment equilibrium*. We derive conditions for the existence of such equilibrium. When doing so, we consider the producer´s incentives to deviate after many periods of play when incentives to deviate will be strongest.

The focus of the analysis is on the producer's incentives to invest in product quality and damage reduction depending on what the consumers observe: R^t_{PQ} and R^t_{DR}, or R^t only. We refer to the environment in which consumers observe both ratings as the *separate rating* case, and the environment in which consumers only observe R^t as the *combined rating* case. We let $\mu^{SEP}_{i,t}$ denote posterior beliefs when consumers observe both ratings, and $\mu^{COMB}_{i,t}$ denote posterior beliefs when consumers observe R^t only, where $i \in \{Full, PQ, DR, No, S\}$. Finally, we let $\boldsymbol{\mu}^{SEP}_t$ and $\boldsymbol{\mu}^{COMB}_t$ denote the vectors of posterior beliefs in the two cases.

When consumers observe R^t_{PQ} and R^t_{PQ}, and in an equilibrium where the strategic producer always invests in product quality and damage reduction, posterior beliefs are as follows:

$$\mu^{SEP}_{Full,t} = \frac{\mu_{Full,0}\mathbf{1}\{R^t_{PQ} = R^t_{DR} = 1\}}{P^{SEP}(R^t_{PQ}, R^t_{DR})}$$

$$\mu^{SEP}_{S,t} = \frac{\mu_{S,0}\mathbf{1}\{R^t_{PQ} = R^t_{DR} = 1\}}{P^{SEP}(R^t_{PQ}, R^t_{DR})}$$

$$\mu^{SEP}_{PQ,t} = \frac{\mu_{PQ,0}\mathbf{1}\{R^t_{PQ} = 1\}\varepsilon^{t\cdot R^t_{DR}}}{P^{SEP}(R^t_{PQ}, R^t_{DR})}$$

$$\mu^{SEP}_{DR,t} = \frac{\mu_{DR,0}\mathbf{1}\{R^t_{DR} = 1\}\varepsilon^{t\cdot R^t_{PQ}}}{P^{SEP}(R^t_{PQ}, R^t_{DR})}$$

$$\mu^{SEP}_{No,t} = \frac{\mu_{No,0}\varepsilon^{t\cdot(R^t_{PQ}+R^t_{DR})}}{P^{SEP}(R^t_{PQ}, R^t_{DR})}$$

where $\mathbf{1}\{...\}$ are indicator functions and $P^{SEP}(R^t_{PQ}, R^t_{DR})$ is defined as:

$$\begin{aligned} P^{SEP}(R^t_{PQ}, R^t_{DR}) =& (\mu_{Full,0} + \mu_{S,0})\mathbf{1}\{R^t_{PQ} = R^t_{DR} = 1\} + \mu_{PQ,0}\mathbf{1}\{R^t_{PQ} = 1\}\varepsilon^{t\cdot R^t_{DR}} \\ &+ \mu_{DR,0}\mathbf{1}\{R^t_{DR} = 1\}\varepsilon^{t\cdot R^t_{PQ}} + \mu_{No,0}\varepsilon^{t\cdot(R^t_{PQ}+R^t_{DR})} \end{aligned}$$

Given the posterior beliefs, the probability of high product quality and damage reduction is given by $\mu^{SEP}_{Full,t} + \mu^{SEP}_{S,t}$, which converges to 1 as $\varepsilon \to 0$ or $t \to \infty$ on the equilibrium path. Furthermore, $\mu^{SEP}_{Full,t}$ and $\mu^{SEP}_{S,t}$ drop to zero immediately if $R^t_{DR} < 1$ since ratings below 1 are incompatible with $Full$ and the strategy of the producer. Posterior beliefs on PQ, however, will still remain strictly positive as long as $R^t_{DR} = 1$. Specifically, assuming that $R^t_{DR} < 1$ and $R^t_{PQ} = 1$,

$$\mu^{SEP}_{PQ,t} = \frac{\mu_{PQ,0}}{\mu_{PQ,0} + \mu_{No,0}\varepsilon^t}. \tag{3}$$

which converges to 1 as $\varepsilon \to 0$ or $t \to \infty$.

Next, we consider beliefs when consumers observe R only. When consumers observe R only, and in an equilibrium where the producer always invests in product quality and damage reduction, posterior beliefs are defined as follows:

$$
\begin{aligned}
\mu^{COMB}_{Full,t} &= \frac{\mu_{Full,0}\mathbf{1}\{R^t = 1\}}{P^{COMB}(R^t)} \\
\mu^{COMB}_{S,t} &= \frac{\mu_{S,0}\mathbf{1}\{R^t = 1\}}{P^{COMB}(R^t)} \\
\mu^{COMB}_{PQ,t} &= \frac{\mu_{PQ,0}\mathbf{1}\{0.5 \leq R^t \leq 1\}\varepsilon^{t \cdot R^t}}{P^{COMB}(R^t)} \\
\mu^{COMB}_{DR,t} &= \frac{\mu_{DR,0}\mathbf{1}\{0.5 \leq R^t \leq 1\}\varepsilon^{t \cdot R^t}}{P^{COMB}(R^t)} \\
\mu^{COMB}_{No,t} &= \frac{\mu_{No,0}\varepsilon^{t \cdot 2 \cdot R^t}}{P^{COMB}(R^t)}
\end{aligned}
$$

where $\mathbf{1}\{...\}$ are indicator functions $P^{COMB}(R^t)$ is defined as:

$$
\begin{aligned}
P^{COMB}(R^t) =& (\mu_{Full,0} + \mu_{S,0})\mathbf{1}\{R^t = 1\} + \mu_{PQ,0}\mathbf{1}\{0.5 \leq R^t \leq 1\}\varepsilon^{t \cdot R^t} \\
&+ \mu_{DR,0}\mathbf{1}\{0.5 \leq R^t \leq 1\}\varepsilon^{t \cdot R^t} + \mu_{No,0}\varepsilon^{t \cdot 2 \cdot R^t}
\end{aligned}
$$

Given the posterior beliefs, the probability of high product quality and damage reduction is given by $\mu^{COMB}_{Full,t} + \mu^{COMB}_{S,t}$, which converges to 1 as $\varepsilon \to 0$ or $t \to \infty$ on the equilibrium path. Furthermore, $\mu^{COMB}_{Full,t}$ and $\mu^{COMB}_{S,t}$ drop to zero immediately if $R^t < 1$ since ratings below 1 are incompatible with $Full$ and the strategy of the producer. Posterior beliefs on PQ and DR, however, will still remain strictly positive as long as $R^t \geq 0.5$. Specifically, assuming that $0.5 \leq R^t < 1$,

$$
\mu^{COMB}_{PQ,t} = \frac{\mu_{PQ,0}}{\mu_{DR,0} + \mu_{PQ,0} + \mu_{No,0}\varepsilon^{t \cdot R^t}}. \tag{4}
$$

The difference between equations 3 and 4 is one of the keys to understanding the impact of the combined rating. When consumers observe R^t_{PQ} and R^t_{DR}, they can distinguish between PQ-producers and DR-producers. As such, a producer can cherry pick among potential candidates for what reputation to build. When consumers observe R^t only, this is no longer the case as PQ-producers and DR-producers will be pooled together. This ambiguity is what may increase incentives to invest in damage reduction.

A.2 Full investment equilibrium with separate ratings

We consider first the case in which consumers observe R^t_{PQ} and R^t_{DR}. We let ${}^{+}\boldsymbol{\mu}^{SEP}_t$ denote a vector of beliefs in which $\mu^{SEP}_{Full,t} > 0$ and $\mu^{SEP}_{S,t} > 0$, and ${}^{-}\boldsymbol{\mu}^{SEP}_t$ denote a vector of beliefs in which $\mu^{SEP}_{Full,t} = 0$ and $\mu^{SEP}_{S,t} = 0$, where posteriors are calculated under the assumption that the producer invests in both product quality and damage reduction.

Consider first the consumers. Under assumption **A4**, given a vector ${}^{+}\boldsymbol{\mu}^{SEP}_t$ and in an equilibrium where the strategic producer invests in product quality and damage reduction, purchasing is a best response for both consumer types. Next, given a vector ${}^{-}\boldsymbol{\mu}^{SEP}_t$ and in an equilibrium where the strategic producer invests in product quality and damage reduction, purchasing is a best response for regular consumers if $\frac{\mu_{PQ,0}}{\mu_{PQ,0}+\mu_{No,0}\varepsilon^t} - p \geq 0$, where $\frac{\mu_{PQ,0}}{\mu_{PQ,0}+\mu_{No,0}\varepsilon^t}$ is the posterior belief on the PQ type when $R^t_{PQ} = 1$ and $R^t_{DR} < 1$. Note that by assumption **A2** consumers green consumers will never purchase given ${}^{-}\boldsymbol{\mu}^{SEP}_t$.

Next, consider the producer. We let $V(\boldsymbol{\mu}^{SEP}_t)$ denote the producer´s value function:[17]

$$V({}^{+}\boldsymbol{\mu}^{SEP}_t) = \max\big\{p - c_{PQ} - c_{DR} + \delta V({}^{+}\boldsymbol{\mu}^{SEP}_{t+1}), \\ p - c_{PQ} + \delta\left((1-\varepsilon)V({}^{-}\boldsymbol{\mu}^{SEP}_{t+1}) + \varepsilon V({}^{+}\boldsymbol{\mu}^{SEP}_{t+1})\right)\big\} \tag{5}$$

Note that we here assume that $\frac{\mu_{PQ,0}}{\mu_{PQ,0}+\mu_{No,0}\varepsilon^t} - p \geq 0$. Since $\varepsilon < 1$, this must be true for some t and subsequently all $t' > t$.

If investing in both environmental and product quality is an equilibrium strategy, $V({}^{+}\boldsymbol{\mu}^{SEP}_t) = p - c_{PQ} - c_{DR} + \delta V({}^{+}\boldsymbol{\mu}^{SEP}_{t+1})$, which hold if

$$\delta(1-\varepsilon)\big(V({}^{+}\boldsymbol{\mu}^{SEP}_{t+1}) - V({}^{-}\boldsymbol{\mu}^{SEP}_{t+1})\big) \geq c_{DR}. \tag{6}$$

Since the producer cannot re-build its reputation following a one-time deviation, it follows that

$$V({}^{-}\boldsymbol{\mu}^{SEP}_t) = (1-\lambda)p - c_{PQ} + \delta V({}^{-}\boldsymbol{\mu}^{SEP}_{t+1}) \tag{7}$$

Using equations 8, 9 and 10, we can provide the following result.

[17] Note that assumption **A1** rules out investing in neither as an optimal deviation from investing in both. Consequently, we need not consider such a deviation.

Lemma 1. ***Full investment equilibrium with separate ratings:*** *Assume that consumers observe R^t_{PQ} and R^t_{DR}. Then, iff*

$$\delta \geq \delta_{SEP} := \frac{c_{DR}}{\lambda p + \varepsilon(c_{DR} - \lambda p)},$$

a full investment equilibrium exists.

Proof. Note first that if $\frac{\mu_{PQ,0}}{\mu_{PQ,0}+\mu_{No,0}\varepsilon^t} - p \geq 0$ for some $\boldsymbol{\mu}_t^{SEP}$, then $\frac{\mu_{PQ,0}}{\mu_{PQ,0}+\mu_{No,0}\varepsilon^{t'}} - p \geq 0$ for all $\boldsymbol{\mu}_{t'}^{SEP}$ where $t' > t$. Consequently, $V(^-\boldsymbol{\mu}_t^{SEP}) = V(^-\boldsymbol{\mu}_t{}^{SEP})$, and equation 10 pins down the continuation payoffs following a deviation

$$V(^-\boldsymbol{\mu}_t^{SEP}) = \frac{(1-\lambda)p - c_{PQ}}{1-\delta}.$$

Next, it must be the case that $V(^+\boldsymbol{\mu}_t^{SEP}) = V(^+\boldsymbol{\mu}_t{}^{SEP})$. Thus, the continuation value of investing in both is

$$V(^+\boldsymbol{\mu}_t^{SEP}) = \frac{p - c_{PQ} - c_{DR}}{1-\delta}.$$

Thus, the condition in equation 9 becomes:

$$\delta(1-\varepsilon)\left(\frac{p - c_{PQ} - c_{DR}}{1-\delta} - \frac{(1-\lambda)p - c_{PQ}}{1-\delta}\right) \geq c_{DR}$$

which we can re-arrange to obtain

$$\delta \geq \frac{c_{DR}}{\lambda p + \varepsilon(c_{DR} - \lambda p)},$$

This completes the proof. □

Note that δ_{SEP} is decreasing in λ. Consequently, an equilibrium where the producer invests in both types of quality can only exists if λ is sufficiently high. If λ is small, the producer prefers to deviate and build a reputation as a PQ type instead.

A.3 Full investment equilibrium with combined rating

Next, we consider the case in which consumers observe R only. We let ${}^{+}\boldsymbol{\mu}_t^{COMB}$ denote a vector of beliefs in which $\mu_{Full,t}^{COMB} > 0$ and $\mu_{S,t}^{COMB} > 0$, and ${}^{-}\boldsymbol{\mu}_t^{COMB}$ denote a vector of beliefs in which $\mu_{Full,t}^{COMB} = 0$ and $\mu_{S,t}^{COMB} = 0$, where posteriors are calculated under the assumption that the producer invests in both product quality and damage reduction.

Consider first the consumers. Under assumption **A4**, given a vector ${}^{+}\boldsymbol{\mu}_t^{COMB}$ and in an equilibrium where the strategic producer invests in product quality and damage reduction, purchasing is a best response for both consumer types. Next, given a vector ${}^{-}\boldsymbol{\mu}_t^{COMB}$ and in an equilibrium where the strategic producer invests in product quality and damage reduction, purchasing is a best response for regular consumers if $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}+\mu_{No,0}\varepsilon^{t \cdot R^t}} - p \geq 0$, where $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}+\mu_{No,0}\varepsilon^{t \cdot R^t}}$ is the posterior belief on the PQ type when $R^t < 1$. Note that by assumption **A2** green consumers will never purchase given ${}^{-}\boldsymbol{\mu}_t^{COMB}$. Furthermore, regular consumers will purchase given ${}^{-}\boldsymbol{\mu}_t^{COMB}$ only if the prior on the PQ type is sufficiently large as compared to the prior on the DR type.

Next, consider the producer. We let $V(\boldsymbol{\mu}_t^{COMB})$ denote the producer´s value function:

$$V({}^{+}\boldsymbol{\mu}_t^{COMB}) = \max \big\{ p - c_{PQ} - c_{DR} + \delta V({}^{+}\boldsymbol{\mu}_{t+1}^{COMB}), \\ p + \delta \left((1-\varepsilon^2) V({}^{-}\boldsymbol{\mu}_{t+1}^{COMB}) + \varepsilon^2 V({}^{+}\boldsymbol{\mu}_{t+1}^{COMB}) \right) \big\} \tag{8}$$

Note that we here consider a deviation in which the producer invests in neither. The reason is as follows: With the combined rating, any $R^t \in [0.5, 1)$ will be interpreted by consumers as coming a PQ-type or a DR-type. Thus, unlike the case with separate ratings, there is no reason for the producer, if it deviates, to continue investing in product quality unless R^{t+1} will fall below 0.5 if it does not.

If investing in both environmental and product quality is an equilibrium strategy, $V({}^{+}\boldsymbol{\mu}_t^{COMB}) = p - c_{PQ} - c_{DR} + \delta V({}^{+}\boldsymbol{\mu}_{t+1}^{COMB})$, which hold if

$$\delta(1-\varepsilon^2)\big(V({}^{+}\boldsymbol{\mu}_{t+1}^{COMB}) - V({}^{-}\boldsymbol{\mu}_{t+1}^{COMB})\big) \geq c_{PQ} + c_{DR}. \tag{9}$$

The continuation payoffs following a one-time deviation depends crucially on prior beliefs on PQ-types and DR-types. That is, if $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}+\mu_{No,0}\varepsilon^{t \cdot R^t}} \geq p$ the producer can keep serving regular consumers, if $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}+\mu_{No,0}\varepsilon^{t \cdot R^t}} < p$ the producer can serve neither consumer type.

Furthermore, if $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} - p \geq 0$, then $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}+\mu_{No,0}\varepsilon^{t \cdot R^t}} - p \geq 0$ for some t and all other $t' > t$. This implies that after a number of periods where the producer has invested in both, it can deviate and still serve regular if $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} - p \geq 0$. In the opposite case, if $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} - p < 0$, the producer can serve neither consumer type after a deviation regardless of the n umber of periods the producer has invested in both product quality and damage reduction. Since the producer cannot re-build its reputation following a one-time deviation, we can use this property to define an upper bound on continuation payoffs following a one-time deviation:

$$\overline{V}(^{-}\boldsymbol{\mu}_t^{COMB}) = \begin{cases} \frac{(1-\lambda)p}{1-\delta} & \frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} \geq p \\ 0 & \frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} < p \end{cases} \tag{10}$$

Using equations 8, 9 and 10, we can provide the following result.

Lemma 2. ***Full investment equilibrium with a combined rating:*** *Assume that consumers observe R^t. Then, if*

1. $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} < p$ *and* $\delta \geq \delta_{COMB1} := \frac{c_{PQ}+c_{DR}}{p+\varepsilon^2(c_{PQ}+c_{DR}-p)}$, *or*
2. $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} \geq p$ *and* $\delta \geq \delta_{COMB2} := \frac{c_{PQ}+c_{DR}}{\lambda p+\varepsilon^2(c_{PQ}+c_{DR}-p)}$

a full investment equilibrium exists.

Proof. If $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} < p$ we use equation 10 to replace $V(^{-}\boldsymbol{\mu}_{t+1}^{COMB})$ in equation 9 with 0. By doing so, we find that a full investment equilibrium exists if

$$\delta \geq \frac{c_{PQ}+c_{DR}}{p+\varepsilon^2(c_{PQ}+c_{DR}-p)}.$$

Next, If $\frac{\mu_{PQ,0}}{\mu_{DR,0}+\mu_{PQ,0}} \geq p$ we use equation 10 to replace $V(^{-}\boldsymbol{\mu}_{t+1}^{COMB})$ in equation 9 with $frac(1-\lambda)p1-\delta$. By doing so, we find that a full investment equilibrium exists if

$$\delta \geq \frac{c_{PQ}+c_{DR}}{\lambda p+\varepsilon^2(c_{PQ}+c_{DR}-p)}.$$

This completes the proof. □

The key difference between the two cases is that when consumers observe the combined rating only, a full investment equilibrium can exist independently of λ and e.

A.4 Proof of Proposition 1

The results follow from Lemmas 1 and 2.

[Separate ratings] By re-arranging the condition on δ from Lemma 1 we find that a full investment equilibrium exists iff $\lambda \geq \frac{c_{DR}(1-\delta\varepsilon)}{\delta p(1-\varepsilon)}$.

[Combined rating] The result follows directly from part 1 of Lemma 2.