Cover-Up of Vehicle Defects: The Role of Regulator Investigation Announcements

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Automakers such as Toyota and GM were recently caught by the U.S. regulator for deliberately hiding product defects in an attempt to avoid massive recalls. Interestingly, regulators in the U.S. and U.K. employ different policies in informing consumers about potential defects: The U.S. regulator publicly announces all on-going investigations of potential defects to provide consumers with early information, whereas the U.K. regulator does not. To understand how these different announcement policies may affect cover-up decisions of automakers, we model the strategic interaction between a manufacturer and a regulator. We find that, under both countries' policies, the manufacturer has an incentive to cover up a potential defect when there is a high chance that the defect indeed exists and it may inflict only moderate harm. However, if there is only a moderate chance that the defect exists, only under the U.S. policy does the manufacturer have an incentive to cover up a potential defect with *significant* harm. We show that the U.S policy generates higher social welfare only for very serious issues for which both the expected harm and recall cost are very high and the defect is likely to exist. We make four policy recommendations that could help mitigate manufacturers' cover-ups, including a hybrid policy in which the regulator conducts a confidential investigation of a potential defect *only when* it may inflict significant harm.

Key words: Product recalls, automotive industry, socially responsible operations, public policy

1. Introduction

> "A new car built by my company leaves somewhere traveling at 60 mph. The rear differential locks up. The car crashes and burns with everyone trapped inside. Now, should we initiate a recall? Take the number of vehicles in the field, A, multiply by the probable rate of failure, B, multiply by the average out-of-court settlement, C. A times B times C equals X. If X is less than the cost of a recall, we don't do one."
> From the movie *Fight Club*.

In 2009 and 2010, Toyota recalled more than eight million vehicles due to a sudden unintended acceleration defect that resulted in 89 deaths and 57 injuries (McCurry 2010, CBS News 2010). Although this was a serious defect, Toyota was criticized mainly for attempting to *cover up* the defect. Specifically, the United States (U.S.) government accused Toyota of deliberately hiding the evidence of defects from the regulatory agency, National Highway Traffic Safety Administration

(NHTSA), and delaying the recall (Mitchell and Linebaugh 2010). The company denied the accusation, and blamed drivers by stating that "most of the 48 deaths ... involved drivers who were elderly, had medical issues, were distracted or navigating slippery roads" (Searcey 2010). However, in 2014, four years of criminal probe by the Department of Justice revealed that Toyota knew of the problem in 2007, but decided not to report it to NHTSA. As a result, Toyota agreed to pay $1.2 billion to settle the criminal charge (Levinson et al. 2014).

Toyota is not alone in covering up safety issues. In 2014, General Motors (GM) recalled 2.6 million vehicles because of a faulty ignition switch that could shut off engines while driving and prevent airbags from deploying. By August 2015, this defect was linked to 124 deaths and 275 injuries, and GM set aside $625 million to settle damages (The Wall Street Journal 2015). Similar to the Toyota case, the U.S. government found that GM was aware of this defect as early as 2004, but GM decided to neither report this problem to NHTSA nor recall the affected vehicles (Bennett 2014). An alarming fact is that NHTSA considered opening a formal investigation into this defect twice in 2007 and 2010 following multiple consumer reports, but they decided not to pursue it because they concluded that there was no discernible trend and that the investigation would have taken too long and cost too much (White et al. 2014). In the end, GM was criminally charged by the Department of Justice for deliberately hiding the product defect, and GM agreed to pay $900 million to settle the charge (Spector and Matthews 2015).

These examples demonstrate that automakers can (and do) deliberately hide potential product safety hazards if they believe they can get away with these issues without being caught by the regulator. This is possible because manufacturers know their products better and have more resources than the regulator to investigate safety problems. In addition, manufacturers receive warranty claims directly from consumers, and a disproportionate number of warranty claims on a particular component provides a good indication of a product defect. Although the regulator does not have direct access to those warranty claims, the regulator receives complaints on potential defects directly from consumers and can voluntarily initiate an investigation. However, the regulator cannot investigate all alleged problems due to limited resources and costly inspection. Therefore, the regulator often has to rely on the manufacturers to share detailed information about potential defects. For example, The Wall Street Journal reports "it's common for NHTSA to work cooperatively with all auto-makers [to identify potential hazards]... Its Office of Defects Investigation has only 57 employees to deal with some 35,000 complaints a year" (Linebaugh et al. 2010).

Interestingly, regulators in the U.S. and the United Kingdom (U.K.) employ different policies in informing consumers about alleged product defects. In the U.S., following the Firestone tire controversy in 2000, Congress passed the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act, which mandates manufacturers to submit Early Warning Reporting

(EWR) data. These data include death, injury, and property damage claims, as well as warranty claims and consumer complaints to manufacturers. In case NHTSA opens an investigation into an alleged defect based on EWR data, NHTSA announces on its website the on-going investigation and detailed information about the alleged defect to consumers.

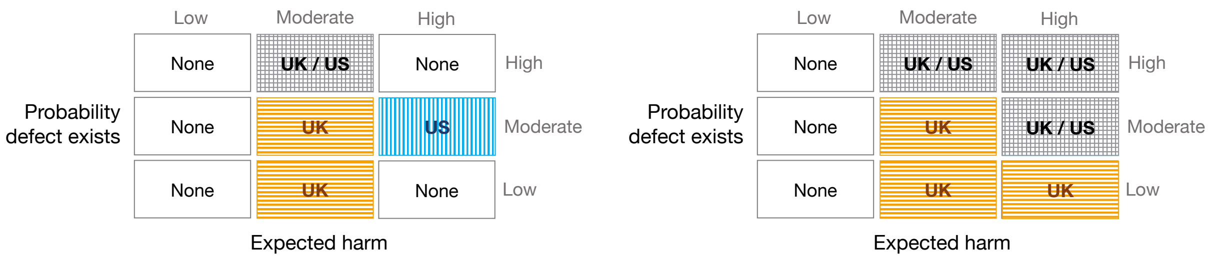
By contrast, our conversations with the U.K. regulator, Driver & Vehicle Standards Agency (DVSA), revealed that DVSA also collects detailed information on potential defects from manufacturers, but does not announce this information to consumers unless DVSA opens a formal investigation *and* concludes that there is a defect. The rationale behind this approach is that DVSA believes manufacturers will be more cooperative if DVSA does not announce to consumers every single alleged safety issue that may turn out to be a false allegation.

Motivated by the contrasting policies in these two countries, we explore two research questions. First, how does the regulator's policy on investigation announcement affect manufacturers' propensity to cover up potential vehicle defects? Second, how does the announcement policy affect the regulator's willingness to investigate potential defects and ultimately social welfare? To address these research questions, we develop a game-theoretic model that captures the strategic interactions between a regulator ("he") and a manufacturer ("she"). In the model, the manufacturer receives a private signal, which may not be completely reliable, about whether her product is defective or not. If the signal indicates a defect, then the manufacturer decides whether to report a potential defect to the regulator in order to maximize her expected profit. If the manufacturer reports the potential defect, then the regulator decides whether to immediately investigate the potential defect in order to maximize social welfare. If the manufacturer decides to cover up the potential defect, then the regulator still receives complaints directly from consumers and may initiate a voluntary investigation at a later time.

Our main findings are summarized in Figure 1. As for our first research question, we find that both countries' policies induce manufacturers to cover up a potential defect when the suspected defect is highly likely to exist but could inflict only relatively moderate harm (upper middle box in Figure 1(a)). This is because in this case there is a good chance that the manufacturer may get away with the cover-up under both countries' policies. This means neither policy is perfect.

However, the major difference is that the U.S. policy is more likely to induce manufacturers to cover up potential defects with significant harm than the U.K. policy. Specifically, manufacturers under the U.S. policy have an incentive to cover up a potential defect with significant harm if there is only a moderate chance that the defect may actually exist (right middle box in Figure 1(a)). This is because, under the U.S. policy, revealing an alleged defect with significant harm could substantially reduce consumer demand and thus the manufacturer's profit, whereas this is not the case under the U.K. policy. Although a cover-up could potentially increase the manufacturer's recall

Figure 1 Cover-up and Investigation Decisions



(a) Countries in Which Manufacturers Cover Up (b) Countries in Which Regulator Investigates Immediately

and liability costs if caught by the regulator at a later time, this does not concern the manufacturer much if there is only a moderate chance the defect exists. This finding is in line with the anecdotal evidence that most recent high-profile cover-ups, such as GM's cover-up of the ignition switch defect and Toyota's sudden acceleration scandal discussed above, have been discovered in the U.S. but not in the U.K.

As for our second research question, we find that the U.S. regulator is more reluctant to investigate a potential defect than its U.K. counterpart (see Figure 1(b)). Moreover, the U.S. policy generates higher social welfare only when the suspected defect is very harmful and highly likely to exist, and its expected recall cost is high. The intuition for both results is as follows. For the U.S. regulator, investigation announcements reduce consumer demand, thereby having a negative impact on both consumer surplus and manufacturer's profit. Although reduced consumer demand also has the benefits of reducing potential consumer harm and recall costs, these benefits exceed the aforementioned downside only when the expected harm, recall cost, and reliability of the signal are all sufficiently high. The fact that the U.S. policy provides higher social welfare only for serious issues is rather counterintuitive, because consumers are better informed of alleged defects under the U.S. policy.

In summary, our analysis shows that the U.S. policy may make the regulator reluctant to investigate alleged defects and discourage manufacturers from reporting potential defects with significant harm, as compared to the U.K. policy, and may produce higher social welfare only for rather extreme cases. To better understand our results from a practical perspective, we illustrate all of our results using realistic parameter values that represent Toyota's sudden unintended acceleration recalls.

Based on our findings, we provide four policy recommendations to better prevent cover-up of potential defects. The first two recommendations apply to the case with full investigation announcements (as in the current U.S. policy) and the last two recommendations apply to the case with only partial investigation announcements. Our first policy recommendation is that the regulator could allocate more resources to the investigation of potential defects with significant harm so as to shorten the investigation lead time, while announcing all investigations. This would mitigate the impact of investigation announcements on consumer demand. Second, the regulator could improve his communication approach so that consumers correctly understand and interpret the probability the defect exists, while announcing all investigations. For instance, the regulator could use a color-coding scheme, in which red corresponds to highest probability of defect, orange to intermediate, and yellow to low. This would help consumers not to overreact to investigation announcements. Third, the regulator could employ a hybrid policy in which he conducts a confidential investigation *only when* the potential defect could inflict significant harm. This hybrid policy is essentially a combination of what works best in each country's policy. Finally, the regulator could conduct a two-phase investigation and only announce the second phase. The U.S. regulator currently conducts a two-phase investigation, in which the first phase (preliminary analysis) determines whether a thorough investigation in the second phase (engineering analysis) is warranted. Although the U.S. regulator announces both phases, announcing only the investigations that proceed to the second phase would both reduce the number of investigations announced and shorten the announcement time period, thereby mitigating the overall impact of announcements on consumer demand.

2. Literature Review

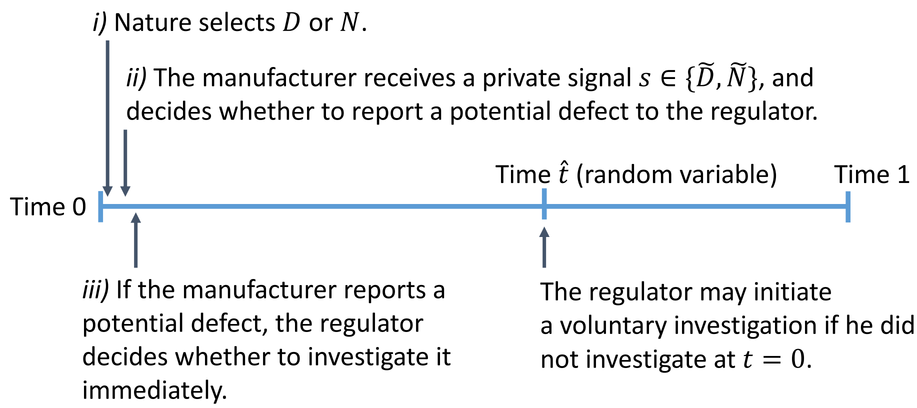
Three streams of literature are related to our paper. The first and second streams of literature are analytical and empirical work on product recalls, respectively. The third stream has a broader scope and studies the effect of regulatory policies on firm behavior in sustainable operations management.

The first stream of literature is analytical work on product risks and related recall decisions. A majority of the work examines the effect of different liability rules and regulatory policies on firms' incentives to make socially optimal decisions. For example, Hua (2011) studies how a firm's incentive to recall depends on different liability rules once it has found safety hazards, and finds that the firm does not necessarily make a socially optimal number of recalls even if the firm bears no liability after recall. Spier (2011) studies the effects of different liability rules on a firm's recall decisions, when the firm offers monetary compensation to consumers to "buy back" the product. Sezer and Haksöz (2012) study the timing of recall as an optimal stopping problem, when the product may have a fault that affects the distribution of the expiration time of the product. Polinsky and Shavell (2012) examine whether a firm should be mandated to disclose product risks when the firm can learn about such risks at a cost, and compare the effects of mandatory and voluntary disclosure of product risks. Although this stream of literature, especially Polinsky and Shavell (2012), is related to our work, the main difference is that these papers do not consider firms' deliberate hiding of product risks and the regulator's voluntary investigations that could reveal such cover-ups, nor do they study the effects of the regulator's investigation announcements.

The second stream of literature is empirical work on product recalls. This literature examines the impact of various operational and strategic factors on product recalls. For example, Hora et al. (2011) empirically find that the time to recall is longer if the recall is "preventive" rather than "reactive," the recall is due to a design flaw rather than a manufacturing defect, and the proximity of the supply chain entity to the end customer is lower. Shah et al. (2017) study drivers of vehicle recalls at the plant and product levels, and find that manufacturing-related recalls are positively associated with product variety and plant utilization. Colak and Bray (2019) study the drivers of vehicle recalls from a more strategic perspective, and find that auto manufacturers initiate recalls to avoid consumer complaints rather than to avoid government ordered recalls. In addition, studies find that severe automobile recalls could have a significant short-term impact on demand (Grafton et al. 1981, Reilly and Hoffer 1983, Rubel et al. 2011, Kalaignanam et al. 2013), although their impacts on stock prices are unclear (Jarrell and Peltzman 1985, Hoffer et al. 1988, Thirumalai and Sinha 2011). Similar to these empirical findings, our model assumes that the public announcement of an on-going investigation of a potential defect has a negative impact on consumer demand. Furthermore, we model a short-term demand drop after a recall in §C.3 in the online appendix and find that our main insights are robust. Our work complements the empirical literature by providing insights into firms' decisions, prior to product recalls, on whether to reveal the existence of a potential defect in the first place. For more comprehensive review of the literature on product safety and recalls, see Marucheck et al. (2011).

Finally, our paper is broadly related to sustainable operations management in that we explore how regulators can induce socially optimal behavior from firms. In particular, our work is related to those that study the impact of regulatory policies and information disclosure on firm behavior. For example, Kim (2015) examines how the interplay between inspections performed by a regulator and noncompliance disclosure by a production firm affects environmental performance. Cho et al. (2019) study the effect of information disclosure and penalty schemes in combating child labor. Kalkanci and Plambeck (2018) examine how mandating disclosure of information about social and environmental impacts in a supply chain affects a firm's valuation by investors. Kraft et al. (2018) experimentally investigate when firms benefit from greater supply chain visibility and transparency. Kraft et al. (2019) analytically study how a manufacturer should invest in a supplier's social responsibility practices when such practices are not perfectly observable. Chen et al. (2019) study the impact of supply chain transparency on supply chain sustainability and the role of NGOs. Wang et al. (2019) develop a global game model in which competing firms decide on developing or adopting a green technology when the probability of a stricter standard on a pollutant increases with an industry's voluntary adoption level. Plambeck and Taylor (2016) study the situation in which buyers, rather than regulators, inspect their own suppliers who can exert effort to hide their

Figure 2 Sequence of Events



noncompliance with social and environmental standards. We contribute to this stream of literature by analyzing how the regulatory policies in the U.S. and in the U.K., which differ in whether or not to disclose information about ongoing investigation, affect auto manufacturers' incentives to cover up potential defects.

3. Model

A manufacturer sells a product with finite life cycle, at selling price p, and, for simplicity, zero production cost. The true state of the product may be defective (denoted by D) or non-defective (N). Let $h \in (0, \bar{h}]$ represent the expected harm of a defective product to consumers, defined as the impact of the harm times the probability of the defect causing harm conditional on the product being defective; e.g., Online Appendix B estimates the expected harm of Toyota's sudden unintended acceleration defect to be \$125. The prior probability of the product being defective, $Pr(D)$, and its expected harm, h, are exogenously determined and common knowledge.

A continuum of consumers arrive at a constant rate of one for time $t \in [0,1]$; that is, we standardize the length of product life cycle to one. A consumer's product valuation, v, is a uniform random variable in $[0, \bar{v}]$ with density $f(v) = 1/\bar{v}$ and cumulative distribution function $F(v)$. Only consumers with $v \geq p$ purchase the product and thus the consumer *demand rate* is $d(p) = 1 - F(p) = 1 - p/\bar{v}$.

Figure 2 depicts the sequence of events. At time $t = 0$, the following events occur sequentially with negligible time intervals. First, Nature chooses the true state to be D with probability $Pr(D)$ and N with probability $1 - Pr(D)$; that is, the prior is unbiased. Second, the manufacturer receives a private signal $s \in \{\tilde{D}, \tilde{N}\}$, where $\tilde{D}$ indicates defective and $\tilde{N}$ non-defective. The signal may come from the manufacturer's internal inspections or consumer complaints. The manufacturer uses her private signal to calculate her posterior probability of defect and optimally chooses whether to report a potential defect to the regulator (denoted by R) or not (NR) in order to maximize her expected profit. If the private signal indicates a defect ($s = \tilde{D}$), the regulator mandates the manufacturer to report a potential defect.[1] Hence, if the manufacturer does not report (NR), we say that the manufacturer *covers up* the potential defect. If the private signal is $s = \tilde{N}$, we assume that the manufacturer does not report (NR). Third, if the manufacturer reports a potential defect, the regulator decides whether to investigate immediately (denoted by I) or not (NI) in order to maximize social welfare. There is a fixed cost C (> 0) of carrying out an investigation and the lead time of an investigation is a random variable defined on support $[0,1]$ with mean $l \in (0,1)$.[2] The only difference between the U.S. and the U.K. policies is that the U.S. regulator announces the investigation during this l period, whereas the U.K. regulator does not.

If the regulator did not investigate at time $t = 0$ (either because the manufacturer did not report a potential defect or the regulator decided not to investigate immediately), then the regulator may initiate a *voluntary* investigation at a later time. Whether the regulator initiates such an investigation depends on the true state of the product being defective or non-defective. If the true state is D, then consumer complaints may trigger the regulator's voluntary investigation at some random time $\hat{t}$. We assume that an investigation is more likely to happen if the expected harm h is higher and that the timing of the investigation $\hat{t}$ is uniformly distributed on the interval $[0, 1-l]$.[3] For notational convenience, we define $\hat{t} = 1$ to represent the event that the regulator does not carry out a voluntary investigation. Then, $\hat{t}$ is a random variable that is a mix of a uniform distribution with density $g(\hat{t} \mid D) = h/((1-l)\bar{h})$ for $\hat{t} \in [0, 1-l]$ and a probability mass at $\hat{t} = 1$ with $Pr(\hat{t} = 1 \mid D) = 1 - h/\bar{h}$. If the true state is N, the regulator may still receive some consumer complaints, but we assume that they are not significant enough to trigger a voluntary investigation; that is, $Pr(\hat{t} = 1 \mid N) = 1$.

A *product recall* takes place right after any regulator's investigation (immediate or voluntary) that concludes that the product is defective. The manufacturer must recall all products sold up to

[1] The U.S. mandates manufacturers by law to report all information related to deaths, injuries, warranty claims, consumer complaints, internal testing results, and other safety related data (Transportation Recall Enhancement, Accountability, and Documentation Act 2000). The U.K. also mandates manufacturers by law to report any data that could suggest a potential defect (Driver & Vehicle Standards Agency 2014, The General Product Safety Regulations 2005).

[2] We assume that the cost C and lead time l of an investigation are independent of the expected harm h, because investigating a defect with more significant harm does not necessarily cost more and take longer. For instance, the investigations of the accelerator malfunction of 2012-2013 Navistar Prostar vehicles and the brake malfunction of 2013-2014 Dodge Dart vehicles of Fiat Chrysler Automobiles took less than 8 months (National Highway Traffic Safety Administration 2015a,b). Meanwhile, the investigation of spontaneous sunroof breakage of 2011-2013 Kia Sorento, which could be considered less harmful than an accelerator or brake pedal malfunction, has taken more than 5 years and is still on-going as of July 2019 (National Highway Traffic Safety Administration 2014).

[3] We assume that $\hat{t} \leq 1 - l$ for tractability, but this assumption also implies that if the regulator receives consumer complaints, he is likely to initiate an investigation not too late. For instance, Toyota introduces a new generation of Corolla approximately every 5 years by changing design and components, and NHTSA's typical investigation duration is approximately one year. This results in $l = 0.2$ and $\hat{t} \in [0, 0.8]$. This assumption greatly simplifies our analysis without altering the main insights.

that point, incurring the unit recall cost $r \in (0,p)$.[4] The manufacturer is liable for any harm suffered by consumers until the recall, and thus has to fully compensate consumers for their harm. This full compensation may be carried out through consumers' lawsuits or through the manufacturer's voluntary compensation without such lawsuits. In addition, if the manufacturer did not report a potential defect, the regulator's voluntary investigation may discover the manufacturer's cover-up with probability $\theta \in [0,1]$. In this case, the manufacturer pays a penalty to the regulator of $K_1 h + K_2$, where $K_1, K_2 \geq 0$. Note that K_1 is the variable penalty per unit of expected harm and K_2 is the fixed penalty for the manufacturer's cover-up. This penalty models, for instance, \$1.2 billion that Toyota had to pay to settle the criminal charge for covering up the sudden unintended acceleration defect. If the true state is D but the regulator never investigates, then consumers may still sue the manufacturer for compensation. In this case, we define $\alpha \in [0,1]$ as (probability of consumers filing and winning a lawsuit) $\times$ (fraction of the harm for which the manufacturer is liable).

In the U.S., the regulator announces any investigation to consumers, who become aware of the potential harm from using the product, h. Therefore, while the product is under investigation, consumers' valuation temporarily decreases from v to $v-h$, and thus consumers buy the product only if their decreased valuation $v-h$ exceeds the price p. As a result, the consumer demand rate changes from $d(p)$ to $d(p,h) = 1 - F(p+h)$ during the investigation period. By contrast, consumers in the U.K. are not informed of any investigation, and thus the consumer demand rate remains unaffected.

We model the manufacturer's private signal following the approach in Chen et al. (2001) and Iyer et al. (2007). We assume the signal is unbiased; i.e., $Pr(\tilde{D}) = Pr(D)$ and $Pr(\tilde{N}) = Pr(N)$. Let T be the probability that the signal is correct; i.e., $T = Pr(\tilde{D}|D) \cdot Pr(D) + Pr(\tilde{N}|N) \cdot Pr(N)$. When the signal is perfectly reliable, we have that $Pr(\tilde{D}|D) = 1$ and $Pr(\tilde{N}|N) = 1$, and thus $T = T_{max} = 1$. When the signal is completely unreliable, it does not provide any information beyond the prior distribution, and thus $Pr(\tilde{D}|D) = Pr(D)$ and $Pr(\tilde{N}|N) = Pr(N)$. In this case, $T = T_{min} = Pr(D)^2 + Pr(N)^2$. To simplify notation, we define the reliability parameter $\rho = (T - T_{min})/(T_{max} - T_{min}) \in [0,1]$. Then, the manufacturer's posterior distribution can be written as:

$$Pr(D|\tilde{D}) = \rho + (1-\rho)Pr(D), \quad Pr(N|\tilde{D}) = (1-\rho)Pr(N).$$

[4] The assumption that the manufacturer recalls all products sold up to the point of recall is consistent with Toyota's recall in 2009-2010 due to the unintended acceleration defect. Toyota recalled vehicles manufactured as early as 2004 to those manufactured in 2009-2010 (Vlasic and Bunkley 2009, Bunkley 2010). Note that we assume that the unit recall cost r is independent of the expected harm h, because a defect with significant harm does not necessarily result in a high recall cost. For instance, GM could fix the faulty ignition switch that led to 124 deaths and 275 injuries, and eventually led to a recall of 2.6 million vehicles in 2014, for only 57 cents per vehicle (Isidore 2014).

Table 1 Summary of Notation

Symbols	Description
$t, \hat{t} \in [0,1]$	Time variable (t) and time of voluntary investigation ($\hat{t}$)
$v \in [0, \bar{v}]$	Consumer valuation of the product (random variable)
$f(v), F(v)$	Density and cumulative distribution function of consumer valuation v
$g(\hat{t})$	Density of the time of voluntary investigation $\hat{t}$
p	Unit price of the product
$d(p)$	Consumer demand rate without investigation announcement
$d(p,h)$	Consumer demand rate during investigation with public announcement
$\{D, N\}$	True state of the product: D means defective and N means non-defective
$s \in \{\tilde{D}, \tilde{N}\}$	Manufacturer's private signal: $\tilde{D}$ means defective and $\tilde{N}$ means non-defective
$\rho \in [0,1]$	Reliability of the signal s
$h \in (0, \bar{h}]$	Expected harm per product (probability of occurrence $\times$ impact)
r	Recall cost for each unit of product
$K_1 h + K_2$	Penalty for a cover-up, where $K_1, K_2 \geq 0$
$\theta \in [0,1]$	Probability that regulator finds manufacturer's cover-up from voluntary investigation
$\alpha \in [0,1]$	When the regulator never investigates: (The probability of consumers filing and winning a lawsuit) $\times$ (The fraction of the harm for which the manufacturer is held liable)
$\{R, NR\}$	The manufacturer's action space: R represents reporting, and NR not reporting
$\{I, NI\}$	The regulator's action space: I represents immediate investigation and NI no immediate investigation
$C\ (>0)$	Regulator's cost of investigation
$l \in (0,1)$	Expected duration of the regulator's investigation

Before presenting the manufacturer's expected profit and the regulator's objective function in §3.1 and §3.2 respectively, we remark on our assumptions. First, we assume that there is positive demand during the investigation period (i.e., $\bar{v} > p + \bar{h}$), and that all consumers take into account the expected harm h when making purchase decisions during this period. In general, negative rumors or publicity (e.g., investigation announcements, product recalls, negative reviews) tend to reduce consumers' valuation and hence sales (Tybout et al. 1981, Berger et al. 2010, Grafton et al. 1981). It is easy to extend our analysis to the case where only a fraction of consumers take into account such investigation. Second, our demand model assumes that no consumers arrive before $t = 0$. Relaxing this assumption would influence both countries' policies in the same way, and thus it would not affect our qualitative insights. Table 1 summarizes the notation.

3.1. Manufacturer's Expected Profit

We focus on the case where the manufacturer receives a private signal of defect, $s = \tilde{D}$, because when the manufacturer receives $s = \tilde{N}$, there is nothing for the manufacturer to report. We examine three scenarios for each of the two countries: (i) the manufacturer reports a potential defect and the regulator immediately investigates, (ii) the manufacturer reports a potential defect but the regulator does not immediately investigate, and (iii) the manufacturer does not report. We use superscripts US and UK to denote the country and subscripts (R, I), (R, NI), and (NR) to denote the scenarios (i), (ii), and (iii), respectively.

Under scenario (i) and U.S. policy, the manufacturer's expected profit is

$$\pi^{US}_{(R,I)} = p[ld(p,h) + (1-l)d(p)] - Pr(D \mid \tilde{D}) \cdot (r+h)ld(p,h). \tag{1}$$

The first term in (1) is the manufacturer's sales revenue. The demand rate is $d(p,h)$ for l period during the regulator's investigation and $d(p)$ for the remaining $(1-l)$ period. The second term is the expected recall and liability cost. The manufacturer's posterior probability of defect is $Pr(D \mid \tilde{D})$. If the product is found defective, the manufacturer incurs the unit recall cost r and has to fully compensate consumers for the expected harm, h, they suffer from defective products sold. Note that, in (1), we take an expectation of the manufacturer's profit over the investigation lead time after taking all other expectations. Since all resulting expressions are linear in the lead time, we just use the mean lead time $l \in (0,1)$. Under the U.K. policy, the manufacturer's expected profit is the same except that the demand rate $d(p)$ is unaffected by the investigation and hence,

$$\pi^{UK}_{(R,I)} = p \cdot d(p) - Pr(D \mid \tilde{D}) \cdot (r+h)ld(p). \tag{2}$$

Under scenario (ii) and U.S. policy, the manufacturer's expected profit is

$$\begin{aligned}\pi^{US}_{(R,NI)} = p \cdot d(p) - Pr(D \mid \tilde{D}) \Bigg[& \int_0^{1-l} lp(d(p) - d(p,h)) g(\hat{t} \mid D) d\hat{t} \\ & + \int_0^{1-l} (r+h)(d(p)\hat{t} + d(p,h)l) g(\hat{t} \mid D) d\hat{t} + \alpha h \cdot d(p) Pr(\hat{t} = 1 \mid D) \Bigg]. \end{aligned} \tag{3}$$

In (3), the first term is the expected revenue when there is no defect, and the second term is the expected loss when there exists a defect. Inside the square bracket, the first term is the expected revenue loss due to demand decrease during the regulator's voluntary investigation, the second term is the expected recall and liability costs when the regulator investigates, and the last term is the expected liability cost when the regulator never investigates. Under U.K. policy, the manufacturer's expected revenue is unaffected by the investigation and hence,

$$\pi^{UK}_{(R,NI)} = p \cdot d(p) - Pr(D \mid \tilde{D}) \left[\int_0^{1-l} (r+h)(\hat{t} + l) d(p) g(\hat{t} \mid D) d\hat{t} + \alpha h \cdot d(p) Pr(\hat{t} = 1 \mid D) \right]. \tag{4}$$

Under scenario (iii), for both the U.S. and U.K., the manufacturer's expected profit is the same as in scenario (ii), $\pi_{(R,NI)}$, except that the manufacturer has to pay a penalty to the regulator if he finds out that the manufacturer covered up a defect signal; that is,

$$\pi^{j}_{(NR)} = \pi^{j}_{(R,NI)} - Pr(D \mid \tilde{D}) \cdot \theta(K_1 h + K_2) \int_0^{1-l} g(\hat{t} \mid D) d\hat{t}, \quad \text{for } j = \text{US or UK}. \tag{5}$$

Note that the manufacturer fully compensates consumer harm whenever the regulator's investigation (either immediate or voluntary) discovers a defect in any scenario, but pays a penalty to the regulator only when the regulator discovers the manufacturer's cover-up in scenario (iii).

3.2. Regulator's Objective Function

We assume the regulator's objective is to maximize the social welfare $W = \pi + S - \Gamma$, where π is the manufacturer's expected profit, S is the expected consumer surplus, and Γ is the regulator's expected cost. We now derive social welfare for scenarios (i), (ii), and (iii) introduced in §3.1.

Under scenario (i) and U.S. policy, the expected consumer surplus is

$$S^{US}_{(R,I)} = l\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv + (1-l)\int_{p}^{\bar{v}}(v-p)f(v)dv, \tag{6}$$

where the first and second terms correspond to the consumer surplus during and after the regulator's investigation, respectively. In the first term, consumer surplus is obtained from comparing the temporarily decreased valuation $v-h$ and the price p. As before, we use the mean lead time l due to linearity. Note that the consumer harm does not affect consumer surplus under scenario (i) because consumers are fully compensated by the manufacturer. Instead, consumer harm appears in the manufacturer's expected profit as a cost; see the second term of the manufacturer's expected profit in (1). Under U.K. policy, the expected consumer surplus is the same except that the demand rate $d(p)$ is unaffected by the investigation; that is, $S^{UK}_{(R,I)} = \int_p^{\bar{v}}(v-p)f(v)dv$. Under both countries' policies, the regulator's expected cost is $\Gamma^{US}_{(R,I)} = \Gamma^{UK}_{(R,I)} = C$.

Under scenario (ii) and U.S. policy, the expected consumer surplus is

$$\begin{aligned} S^{US}_{(R,NI)} = Pr(D \mid \tilde{D})\left[\int_0^{1-l} g(\hat{t} \mid D)d\hat{t}\left((1-l)\int_p^{\bar{v}}(v-p)f(v)dv + l\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv\right)\right. \\ \left. + Pr(\hat{t}=1 \mid D)\left(\int_p^{\bar{v}}(v-p)f(v)dv - (1-\alpha)hd(p)\right)\right] + Pr(N \mid \tilde{D})\int_p^{\bar{v}}(v-p)f(v)dv. \end{aligned} \tag{7}$$

The first and second terms give the expected consumer surplus when the product is defective and non-defective, respectively. Inside the square bracket, the first term corresponds to the case when the regulator voluntarily investigates at a later time, and the second term the case when the regulator never investigates. In the former case, consumers get fully compensated for the harm by the manufacturer, and thus consumer surplus is unaffected by the actual harm. In the latter case, consumers get compensated for only a fraction α of the harm, and hence the consumer surplus decreases by a fraction $(1-\alpha)$ of the expected harm consumers suffer, while the rest of the harm appears as a cost to the manufacturer; see the last term inside the square bracket in (3). Under U.K. policy, the demand rate $d(p)$ is unaffected by investigation and hence,

$$S^{UK}_{(R,NI)} = \int_p^{\bar{v}}(v-p)f(v)dv - Pr(D \mid \tilde{D}) \cdot Pr(\hat{t}=1 \mid D) \cdot (1-\alpha)hd(p). \tag{8}$$

Under both countries' policies, the regulator's expected cost is $\Gamma^{US}_{(R,NI)} = \Gamma^{UK}_{(R,NI)} = Pr(D \mid \tilde{D}) \cdot \int_0^{1-l} g(\hat{t} \mid D)d\hat{t} \cdot C$, where the cost of investigation, C, is multiplied by the probability that the regulator will conduct a voluntary investigation later.

Under scenario (iii), the expected social welfare coincides with that under scenario (ii). The only difference between these two scenarios is the penalty payment, which is a a transfer payment from the manufacturer to the regulator, and thus cancels out in the social welfare calculation.

Finally, it is important to notice that our formulation of social welfare *accounts for consumer harm at face value* through either the manufacturer's profit or a combination of the manufacturer's profit and the consumer surplus, depending on whether the manufacturer compensates the consumer harm fully or only partially.

In §4, we characterize the regulator's best response to the manufacturer who reports a potential defect. In §5, using the result in §4, we derive subgame perfect Nash equilibrium for the manufacturer's decision on whether to report a potential defect.

4. The Regulator's Investigation Decision

When the manufacturer reports a potential defect, the regulator investigates immediately if doing so generates higher social welfare; i.e., if $W_{(R,I)} \geq W_{(R,NI)}$. We assume that the regulator chooses to investigate immediately when he is indifferent between the two options. The following proposition characterizes the regulator's best response in both countries.

PROPOSITION 1. *Suppose the manufacturer reported a potential defect. There exist real numbers $h_I^{US}, h_I^{UK} \in (0, \bar{h})$ and functions $\rho_I^{US}(h) : [h_I^{US}, \bar{h}] \to [0,1]$ and $\rho_I^{UK}(h) : [h_I^{UK}, \bar{h}] \to [0,1]$ (where $\rho_I^{US}(h_I^{US}) = 1$ and $\rho_I^{UK}(h_I^{UK}) = 1$) such that:*

(i) When $h \geq h_I^{US}$ ($h \geq h_I^{UK}$), the regulator investigates immediately if and only if $\rho \geq \rho_I^{US}(h)$ ($\rho \geq \rho_I^{UK}(h)$) in the U.S. (U.K.)

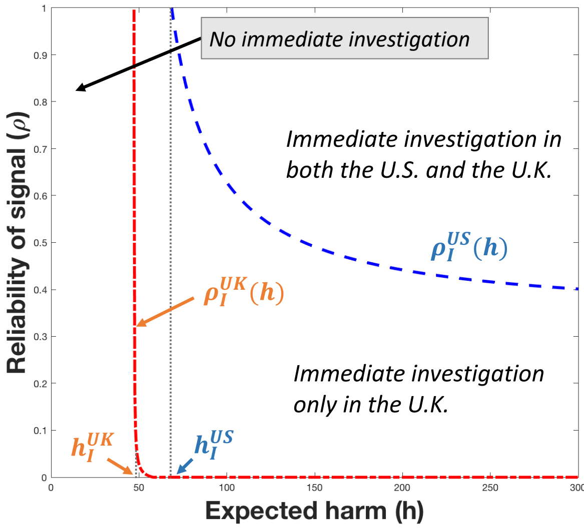
(ii) When $h < h_I^{US}$ ($h < h_I^{UK}$), the regulator does not investigate immediately in the U.S. (U.K.)

Figure 3 illustrates the thresholds h_I^{US} and h_I^{UK} and threshold functions $\rho_I^{US}(h)$ and $\rho_I^{UK}(h)$ characterized in Proposition 1. The parameter values in all figures are those estimated for Toyota's sudden unintended acceleration defect in Online Appendix B. The U.S. and U.K. regulators find it socially optimal to investigate immediately only on the upper right side of the threshold functions, $\rho_I^{US}(h)$ and $\rho_I^{UK}(h)$, respectively. Therefore, in both countries, the regulator investigates the alleged defect only if the expected harm h and the reliability of the signal ρ are sufficiently high. Figure 3 suggests that the U.S. regulator is more reluctant to investigate immediately than the U.K. regulator. We analytically establish this result under some sufficient conditions.[5]

COROLLARY 1. *Suppose the manufacturer reported a potential defect. If $r \leq \bar{v} - \frac{3}{2}\bar{h}$, then the following holds: If the U.S. regulator finds it optimal to investigate immediately, i.e., $W_{(R,I)}^{US} \geq W_{(R,NI)}^{US}$, then so does the U.K. regulator, i.e., $W_{(R,I)}^{UK} \geq W_{(R,NI)}^{UK}$.*

[5] Note that the condition in Corollary 1, $r \leq \bar{v} - \frac{3}{2}\bar{h}$, is only a sufficient condition and is likely to hold for a wide range of parameters, because $r < p < \bar{v} - \bar{h}$ by assumption (see §3). For instance, this condition holds under the parameter values we estimated for Toyota's sudden unintended acceleration defect in Online Appendix B.

Figure 3 The Regulator's Decision in Response to the Manufacturer's Reporting

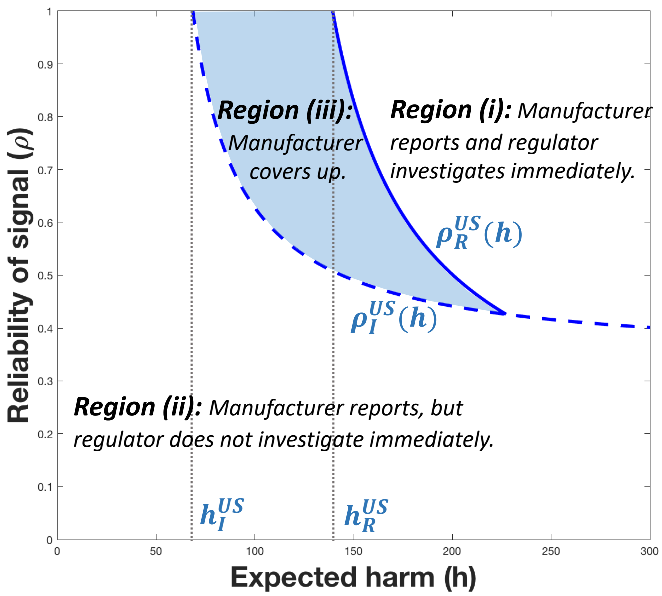


Note. All figures in this paper use the following parameter values: $p = 2,000$, $\bar{v} = 4,000$, $h = 125$, $\bar{h} = 500$, $r = 250$, $K_1 = 0.3$, $K_2 = 37.5$, $C = 0.056$, $l = 0.2$, $\theta = 0.2$, $\alpha = 0.2$, and $Pr(D) = 0.01$.

We now discuss the intuition for the U.K. regulator's decision characterized in Proposition 1. For small expected harm h, the U.K. regulator finds it socially optimal not to investigate immediately in order to avoid the investigation cost as well as the recall cost if the defect exists, knowing that the potential harm to consumers would be small and that he is unlikely to investigate at a later time a potential defect with such small expected harm. In addition, when the reliability ρ is small, the U.K. regulator is reticent to investigate immediately in order to avoid the fixed cost of an investigation given that the posterior probability of defect is small. Note, however, that the effect of reliability ρ on the U.K. threshold function is very small for the Toyota example; i.e., the threshold function $\rho_I^{UK}(h)$ is almost vertical around h_I^{UK}. This is because the investigation cost is very small compared to the recall cost and expected harm.

The U.S. regulator is more reluctant to investigate immediately than the U.K. regulator, as shown in Corollary 1, because in the U.S. the public announcement of an on-going investigation reduces consumers' demand, thereby having a negative impact on consumer surplus and manufacturer's profit, whereas this is not the case in the U.K. Although the public announcement has benefits of reducing consumer harm and potential recall costs, these benefits exceed the aforementioned downside only when the expected harm h, recall cost r, and reliability of the signal ρ are all sufficiently high. Therefore, although the U.S. regulator makes public announcements with good intentions to reduce potential consumer harm and recall cost, these announcements make the U.S. regulator more cautious than the U.K. counterpart in initiating an investigation, especially when the recall cost r is low (as stated in Corollary 1) and when the expected harm h or the reliability of the signal ρ is low (as stated in Proposition 1).

Figure 4 Equilibrium Outcomes in the U.S.



5. The Manufacturer's Cover-Up Decision

Anticipating the best response of the regulator characterized in §4, the manufacturer decides whether to report a potential defect to the regulator or not in order to maximize her expected profit. When the manufacturer is indifferent between the two options, we assume that she reports a potential defect. We first characterize the subgame perfect Nash equilibrium under the U.S. policy.

Proposition 2. *In the U.S., there exist a real number* $h_R^{US} \in (0, \bar{h})$ *and a function* $\rho_R^{US}(h)$: $[h_R^{US}, \bar{h}] \to [0,1]$ *(where* $\rho_R^{US}(h_R^{US}) = 1$*) such that the unique equilibrium outcomes are as follows:*

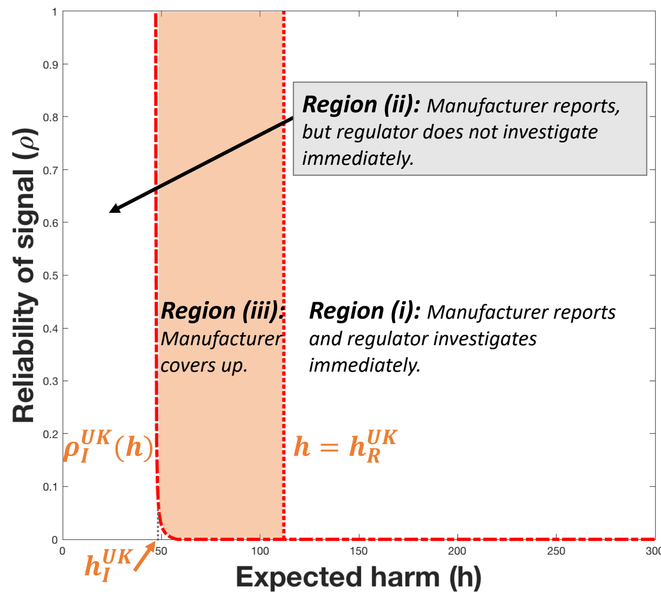
(i) If $h \geq \max\{h_I^{US}, h_R^{US}\}$ *and* $\rho \geq \max\{\rho_I^{US}(h), \rho_R^{US}(h)\}$*, then the manufacturer reports a potential defect and the regulator investigates it immediately.*

(ii) If $h < h_I^{US}$ *or* $\{h \geq h_I^{US}$ *and* $\rho < \rho_I^{US}(h)\}$*, then the manufacturer reports a potential defect but the regulator does not investigate it immediately.*

(iii) If $\{h_I^{US} \leq h < h_R^{US}$ *and* $\rho \geq \rho_I^{US}(h)\}$ *or* $\{h \geq h_R^{US}$ *and* $\rho_I^{US}(h) \leq \rho < \rho_R^{US}(h)\}$*, then the manufacturer does not report and therefore the regulator does not investigate immediately.*

We discuss Proposition 2 using Figure 4. In Region (ii), we know from Proposition 1 that the regulator's best response is not to investigate immediately even if the manufacturer reports a potential defect. Anticipating this, the manufacturer always reports a potential defect because, by doing so, she can avoid the penalty levied if the regulator's voluntary investigation at a later time finds the manufacturer's cover-up. In both Regions (i) and (iii), the regulator's best response is to investigate immediately upon receiving a report on a potential defect. Anticipating this, in Region (iii), in which either the expected harm h (for a fixed ρ) or the reliability of the signal ρ (for

Figure 5 Equilibrium Outcomes in the U.K.



a fixed h) is lower than in Region (i), the manufacturer decides to cover up the potential defect. This is because of two main reasons. First, when the expected harm h is lower, there is a lower risk that the regulator will conduct a voluntary investigation at a later time. Therefore, there is a higher chance that the manufacturer can get away with the cover-up. Second, when the reliability of the signal ρ is lower, it is less certain that the defect actually exists and thus the manufacturer chooses not to report a potential defect to avoid the impact of the regulator's investigation announcement on consumer demand and thus on the manufacturer's profit.

We now characterize the subgame perfect Nash equilibrium for the U.K.

PROPOSITION 3. *In the U.K., there exists a real number $h_R^{UK} \in (0, \bar{h})$ such that the unique equilibrium outcomes are as follows:*

(i) If $h \geq \max\{h_I^{UK}, h_R^{UK}\}$ and $\rho \geq \rho_I^{UK}(h)$, then the manufacturer reports a potential defect and the regulator investigates it immediately.

(ii) If $h < h_I^{UK}$ or $\{h \geq h_I^{UK}$ and $\rho < \rho_I^{UK}(h)\}$, then the manufacturer reports a potential defect but the regulator does not investigate it immediately.

(iii) If $h_I^{UK} \leq h < h_R^{UK}$ and $\rho \geq \rho_I^{UK}(h)$, then the manufacturer does not report and therefore the regulator does not investigate immediately.

We discuss Proposition 3 using Figure 5, which employs the same notation for Regions (i), (ii), and (iii) as Figure 4 for the U.S case. The main difference from the U.S. case is that Regions (i) and (iii) in the U.K. equilibrium are separated by a *vertical* line, $h = h_R^{UK}$; that is, the U.K. manufacturer's decision to cover up depends *only* on the expected harm and not on the reliability of the private signal. The intuition is that in the U.K., all investigations are confidential and hence do not have an impact on consumer demand. Consequently, the manufacturer in the U.K. is not concerned about the reliability of the information when making a decision whether to cover up or not.[6] By contrast, the manufacturer in the U.S. is less inclined to report a potential defect when the reliability of her private signal is lower, in order to avoid a demand drop.

We next compare the equilibrium outcomes of the two countries in Figure 6, which we obtain by overlapping Figures 4 and 5. We observe that the manufacturer covers up a potential defect in both countries in Region I. Therefore, in this region, neither of the two countries' policies is effective in inducing the manufacturer to report a potential defect. In Regions II and III, however, the two countries' policies lead to different outcomes: In Region II only the U.S. manufacturer covers up, whereas in Region III only the U.K. manufacturer covers up.[7] Note that, in Region III, although the manufacturer in the U.K. covers up the potential defect to avoid the regulator's immediate investigation, the U.S. regulator would not have initiated an immediate investigation even if the manufacturer had reported the potential defect. By contrast, in Region II the manufacturer in the U.S. covers up a potential defect that both the U.S. and the U.K. regulators would have investigated immediately. Therefore, Region II poses a more serious concern than Region III.

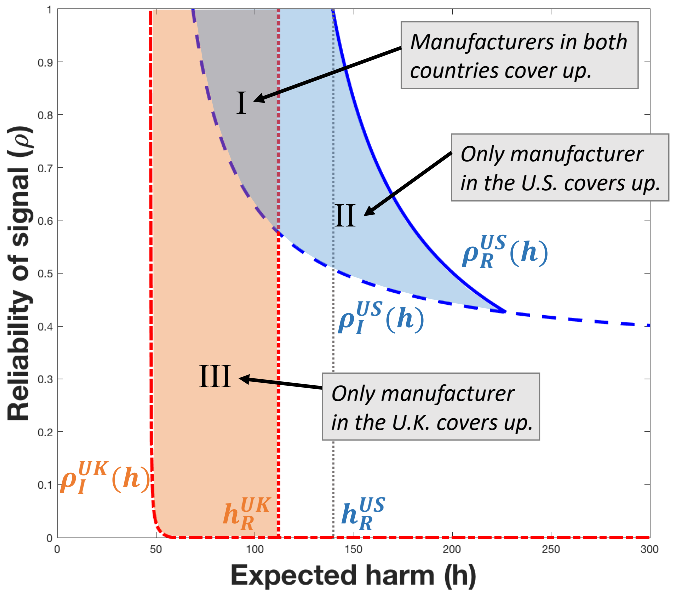
Overall, our results suggest that the U.S. policy induces fewer investigations and more cover-ups of potential defects with significant harm than the U.K. policy. This directly goes against the original purpose of the U.S. policy: The public announcements of ongoing investigations are intended to provide early information to the public so that consumers can avoid harm. However, our analysis reveals that these announcements have unintended consequences by making the regulator reluctant to initiate investigations (as per Corollary 1) and inducing the manufacturer to cover up potential defects with significant harm (as in Region II of Figure 6).[8]

[6] A more detailed intuition is as follows. Ex post, there are two cases. The first case is when the defect does exist. This case happens with the posterior probability $Pr(D \mid \tilde{D})$, which increases with the reliability of signal ρ. In this case, if the U.K. manufacturer chose to cover up a potential defect, she may incur a penalty cost; or if the U.K. manufacturer chose to report it to the regulator, she incurs the recall and liability cost. The second case is when the defect does not exist. This case happens with probability $(1 - Pr(D \mid \tilde{D}))$. In this case, regardless of whether the manufacturer chose to cover it up or report it to the regulator, the U.K. manufacturer does not incur any penalty or recall/liability costs. Taken together, under either option, the U.K. manufacturer's expected profit depends on ρ through $Pr(D \mid \tilde{D}) \times (\text{cost})$. Therefore, when determining which option leads to a higher expected profit, ρ does not play a role.

[7] Technically, if $h_R^{UK} > h_R^{US}$, there exists an additional small region (defined by $h_R^{US} \le h < h_R^{UK}$ and $\rho \ge \rho_R^{US}(h)$) in which the U.K. policy induces a cover-up, while the U.S. policy induces the manufacturer to report a potential defect followed by a regulator's immediate investigation. We can characterize a sufficient condition under which this region exists, and interpret this region similarly.

[8] Note that the manufacturer in the U.S. may reduce her price following an investigation announcement to compensate for the drop in consumer demand. While this would alleviate the negative impact of an investigation announcement on both social welfare and manufacturer's profit, it is clear that this impact will continue to be negative in the U.S. By contrast, investigations are *not* announced in the U.K. Because our focus is on the comparison between the two countries' policies, the manufacturer's ability to adjust her price will not change our main insights.

Figure 6 Comparison of Equilibrium Outcomes in the U.S. and the U.K.



In this section, we have compared the two countries' policies in terms of incidence of manufacturer cover-ups. We now turn to social welfare.

6. Social Welfare

We first compare social welfare in the two cases where both countries' policies lead to the same decisions in equilibrium.

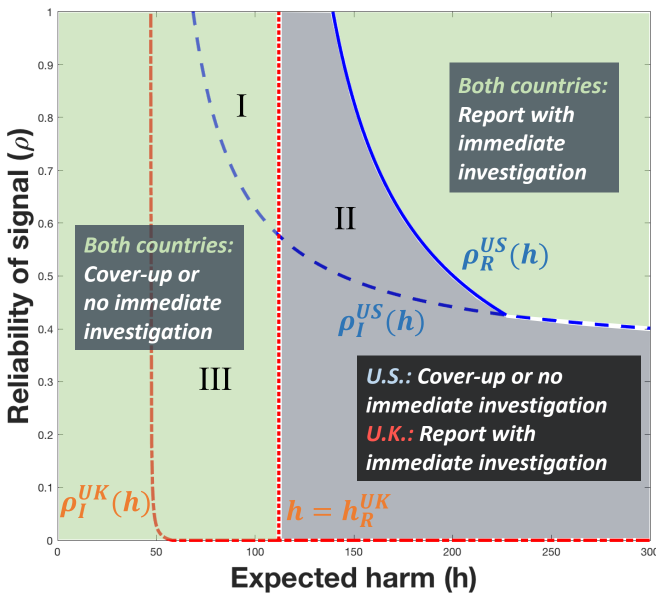
PROPOSITION 4. *The social welfare under the U.S. and U.K. policies satisfy the following:*

(i) Suppose that, in both countries, the manufacturer does not report a potential defect or the regulator does not investigate immediately even if the manufacturer reported. Then, social welfare is higher under the U.S. policy if and only if $r + (3/2)h > \bar{v}$.

(ii) Suppose that, in both countries, the manufacturer reports a potential defect and the regulator investigates it immediately. Then, social welfare is higher under the U.S. policy if and only if $(1/2)h + Pr(D \mid \tilde{D})(r + h) > \bar{v}$.

Proposition 4(i) implies that when the manufacturer does not report a potential defect (scenario (NR)) or the regulator does not investigate immediately upon receiving a report (scenario (R, NI)) (leftmost light-green region in Figure 7), social welfare is higher in the U.S. if and only if the expected harm level h and the recall cost r are sufficiently high. To gain intuition about this result, it suffices to study scenario (NR) because the social welfare for scenarios (NR) and (R, NI) is identical as explained in §3.2. Note also that the regulator's expected cost $\Gamma_{(NR)}$ is identical under both countries' policies. Consequently, we need to compare only the expected consumer surplus $S_{(NR)}$ and the manufacturer's expected profit $\pi_{(NR)}$ under each country's policy in scenario (NR).

Figure 7 **Regions in Which Both Countries' Policies Have the Same or Different Effects**



First, the expected consumer surplus $S_{(NR)}$ is always higher in the U.K. because consumer demand is unaffected by the regulator's investigation unlike in the U.S.[9] Note that even if the manufacturer covers up a potential defect, the regulator may initiate a voluntary investigation at a later time, triggering a reduction in consumer demand. Consequently, as h increases, the difference between the two countries' expected consumer surplus, $S_{(NR)}^{UK} - S_{(NR)}^{US}$, increases. Second, it is possible to show that the manufacturer's expected profit $\pi_{(NR)}$ is higher in the U.S. if both the expected harm h and recall cost r are sufficiently high. Unlike in the U.K., in the U.S. the demand drop during a *voluntary* investigation reduces the manufacturer's revenue, but this demand drop also reduces the manufacturer's recall and liability costs because there are fewer products to recall on the market. When both h and r are sufficiently high, the savings in recall and liability costs compensate the reduction in revenue, and the manufacturer's expected profit is higher in the U.S. Combining consumer surplus and manufacturer profit, we find that, if both h and r are sufficiently high, then the U.S. policy leads to a higher social welfare than the U.K. policy by compensating a lower consumer surplus with a higher manufacturer's profit.

Proposition 4(ii) implies that when the manufacturer reports and the regulator investigates immediately (scenario (R, I), upper-right light-green region in Figure 7), the social welfare is higher in the U.S. if and only if the posterior probability of defect $Pr(D \mid \tilde{D})$ as well as h and r is sufficiently

[9] We can ignore consumer harm when comparing consumer surplus, because consumer harm affects both countries' consumer surplus in the same way. Suppose the true state is D. If the regulator initiates an investigation and finds a defect, then the manufacturer will be required to compensate consumers for all the harm they suffered. Thus, consumer surplus is unaffected by the harm. If the regulator does not investigate at all, under both countries policies, the same number of consumers buy the product, sue the firm, and get compensated for α fraction of the harm.

high. (Note that this condition in Proposition 4(ii) is the same as that in Proposition 4(i) when $Pr(D \mid \tilde{D}) = 1$.) The rationale behind this result is the same as that for scenario (NR) except the following. In the U.S., under scenario (R, I), the consumer demand and manufacturer's revenue drop with certainty, unlike under scenario (NR) in which they drop only if the regulator initiates a voluntary investigation. Yet, the manufacturer incurs the recall and liability costs only when the defect actually exists, i.e., with probability $Pr(D \mid \tilde{D})$. Therefore, the savings in recall and liability costs compensate the reduction in revenue only when $Pr(D \mid \tilde{D})$ as well as h and r is sufficiently high.[10]

These results highlight that even if the two countries' policies lead to the same decisions in equilibrium, their implications for social welfare may differ. In particular, the U.S. policy achieves higher social welfare than the U.K. policy for serious defects, i.e., when the expected harm h, the recall cost r, and the likelihood of having a defect, $Pr(D \mid \tilde{D})$, are all high. Otherwise, the U.K. policy achieves higher social welfare. To gauge how likely the U.S. policy is to result in higher social welfare, we consider the parameter values estimated for the Toyota example in Online Appendix B. We find that the conditions in Proposition 4 do not hold for these parameter values because we have $r + (3/2)h = 437.5 \ngtr \bar{v} = 4,000$. Considering that Toyota's sudden unintended acceleration defect was such a serious issue, one may infer that the two conditions in Proposition 4 are unlikely to hold for most defects in reality.

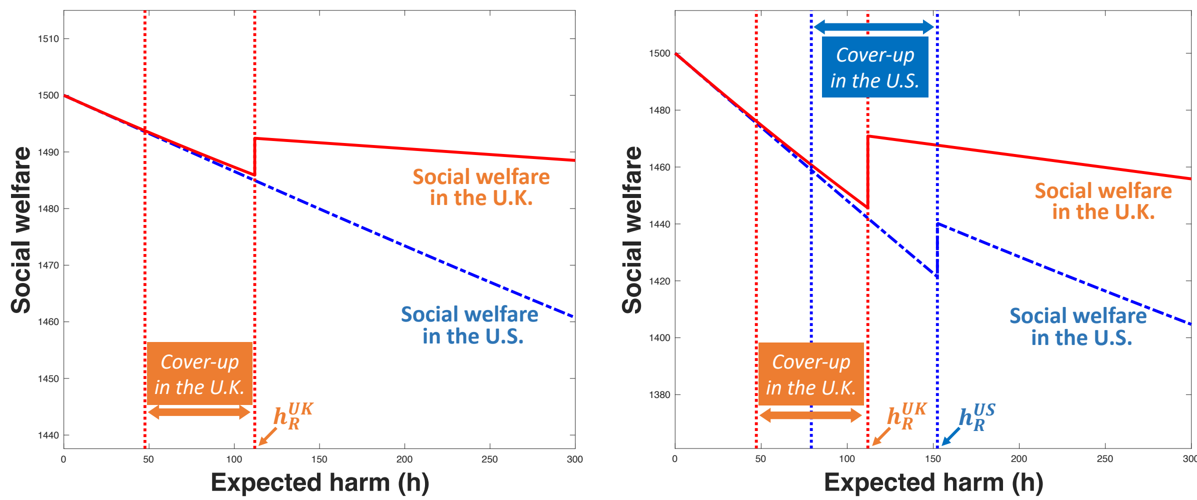
Finally, we compare the social welfare when the two countries' policies lead to different outcomes in equilibrium.

PROPOSITION 5. *Suppose that we are in the middle dark-gray region in Figure 7. That is, in the U.K., the manufacturer reports a potential defect and the regulator investigates it immediately, while in the U.S. the manufacturer does not report a potential defect, or even if she does, the regulator does not investigate it immediately. Then, there exists a function* $\rho_W^{UK}(h) : [h_R^{UK}, \bar{h}] \to \mathbb{R}$ *such that the U.K. social welfare is higher than the U.S. social welfare if and only if the reliability of the signal satisfies* $\rho > \rho_W^{UK}(h)$.

We numerically observe that $\rho_W^{UK}(h)$ is close to the investigation threshold $\rho_I^{UK}(h)$ for a broad range of parameters. Because the reliability in this region is bounded below by $\rho_I^{UK}(h)$, we infer that social welfare is likely to be higher under the U.K. policy in this entire region. For instance, for the parameter values estimated for the Toyota example in Figure 7, we have that $\rho_W^{UK}(h) < 0$ and $\rho_I^{UK}(h) = 0$, implying that social welfare is indeed higher under the U.K. policy in this entire region.

[10] To see why the condition in Proposition 4(i) does not depend on $Pr(D|\tilde{D})$, note that the regulator initiates a voluntary investigation only if a defect exists. Therefore, the social welfare under the two countries' policies differs only if the defect actually exists; that is, with probability $Pr(D|\tilde{D})$. If a defect does exist, then the only difference between the two countries' policies is the impact of investigation announcement, which is independent of $Pr(D|\tilde{D})$. As a result, the difference in *expected welfare* does not depend on $Pr(D|\tilde{D})$.

Figure 8 Social Welfare Comparison



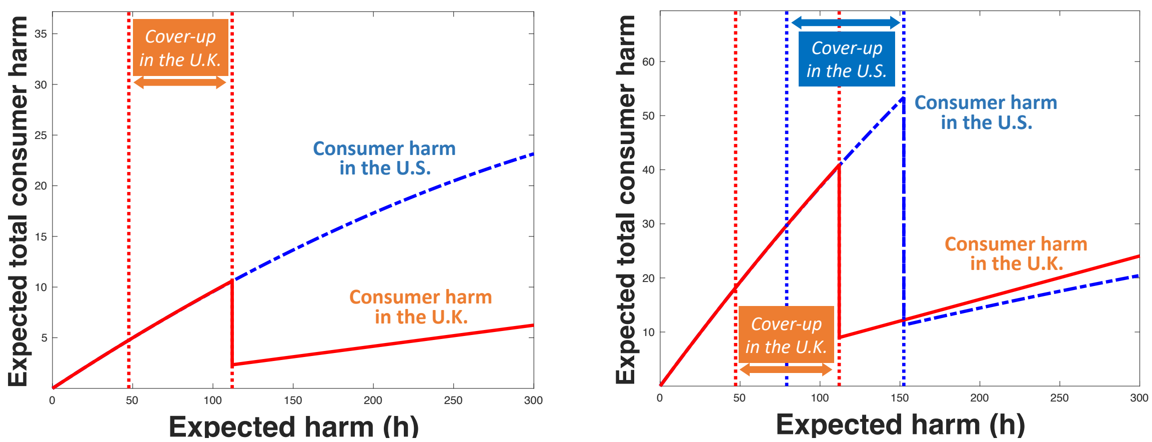
(a) Social Welfare When $\rho = 0.2$

(b) Social Welfare When $\rho = 0.8$

In summary, the U.K. policy generally induces higher social welfare than the U.S. policy, except for defects that may cause very serious harm to consumers and with very high product recall costs. To get a better sense of how likely it is for the U.K. policy to achieve higher social welfare than the U.S. policy, we illustrate social welfare under the two countries' policies for the parameter values estimated for the Toyota example in Figures 8. In Figure 8(a), the private signal has a low reliability ($\rho = 0.2$), and cover-ups could occur only in the U.K., whereas in Figure 8(b), the private signal has a high reliability ($\rho = 0.8$), and cover-ups could occur in both countries (as can also be seen in Figure 6). In both figures, the U.K. social welfare is higher than the U.S. social welfare irrespective of the reliability of signal ρ and the expected harm h. In fact, the U.K. social welfare is very similar to the U.S. social welfare for $h \le h_R^{UK} = 112$, but the U.K. social welfare becomes increasingly larger than the U.S. social welfare as h increases, for $h > h_R^{UK} = 112$.[11] Although Proposition 4 indicates that the U.S. policy generates higher social welfare for serious issues with high expected harm h and high recall cost r, we observe that both h and r should be significantly higher than the Toyota example, in order for the U.S. social welfare to be higher. For instance, in the Toyota example, if we change $\bar{h} = 500$ to $2,000$ and $r = 250$ to $1,900$, while keeping all other parameter values fixed, then the U.S. social welfare is higher when $\rho = 0.8$ and $h \ge 1,902$. In this case, the U.S. social welfare initially decreases with h as in Figure 8(b), but eventually starts increasing with h when $h \ge 1,567$ and exceeds the U.K. social welfare when $h \ge 1,902$.

[11] Kinks exist at $h = h_R^{UK}$ and h_R^{US}, for which the manufacturer is indifferent between covering up and reporting a potential defect. Thus, at these points, the manufacturer's expected profit is continuous, but social welfare is not.

Figure 9 Consumer Harm Comparison



(a) Consumer Harm When $\rho = 0.2$

(b) Consumer Harm When $\rho = 0.8$

A cautionary note is that although the U.K. policy generally achieves higher social welfare, either the U.K. or the U.S. policy may induce lower expected consumer harm depending on the equilibrium outcome. Figures 9(a) and 9(b) illustrate the expected consumer harm with the parameter values of Figures 8(a) and 8(b), respectively (see Online Appendix D.5 for the formulation of consumer harm). In both Figures 9(a) and 9(b), the expected consumer harm in the U.K. is slightly higher than that in the U.S. for the expected harm $h \leq h_R^{UK} = 112$ (although the difference is not clearly noticeable). When $h > h_R^{UK} = 112$, the consumer harm in the U.K. is still higher than that in the U.S. except two cases: i) when the U.K. regulator investigates a reported potential defect immediately while the U.S. regulator does not (i.e., $h > h_R^{UK} = 112$ in Figure 9(a)) and ii) when only the manufacturer in the U.S. covers up a potential defect (i.e., $112 < h < 152$ in Figure 9(b)).

7. Extensions

In Online Appendix C, we explore various extensions of our model to examine the robustness of our main insights. Overall, although each extension affects our results in different ways, we verify that our main insight continues to hold: In the U.S., the regulator remains less likely to investigate and the manufacturer remains more likely to cover up defects with significant harm than in the U.K. We provide a brief summary of these extensions, while referring the readers to Online Appendix C for more details.

We enrich our model of consumers as follows. In §C.1, we consider an extension where consumers are sophisticated enough to correctly assess the posterior probability of the existence of a defect, $Pr(D \mid \tilde{D})$, and thus their decreased valuation during the U.S. regulator's investigation is $v - Pr(D \mid \tilde{D}) \cdot h$ instead of $v - h$. In this extension, the cover-up decision of the manufacturer in the U.S. becomes less sensitive to the reliability of signal ρ than in the base model. In §C.2, we model consumers' risk aversion in perceiving potential harm. In this extension, in the U.S., the regulator becomes more reluctant to investigate and the manufacturer covers up significant defects with higher likelihood of existence than in the base model.

We also extend our analysis by considering various scenarios for consumer demand. As discussed in §2, there is empirical evidence that manufacturers experience a short-term drop in consumer demand after a product recall. In §C.3, we analyze this case, and find that manufacturers in both countries cover up potential defects with more significant harm and regulators become more reluctant to immediately investigate a potential defect than in the base model. In §C.4, we consider the case in which consumer demand drops temporarily after a cover-up is revealed. We find that manufacturers in both countries become less likely to cover up potential defects than in the base model. In §C.5, we consider another plausible scenario under which consumers may be able to purchase a substitute product during investigation in the U.S. In this extension, the U.S. regulator becomes more willing to immediately investigate a potential defect than in the base model.

As for the regulator, in §C.6, we consider an alternative objective function in which the regulator puts more emphasis on reducing consumer harm than maximizing social welfare. In this case, in both countries, regulators become more likely to investigate a potential defect immediately, but manufacturers cover up more potential defects than in the base model. In our base model, we assume the regulator's voluntary investigation timing, $\hat{t}$, is uniformly distributed. In §C.7, we extend our analysis to a linearly increasing (or decreasing) distribution which represents the case where a defect has a lower probability of causing harm but with a larger impact of the harm than the uniform case. We find that such an increasing distribution reduces the overall amount of cover-ups in both countries.

Finally, in §C.8 we analyze the case in which the manufacturer may conduct her own internal investigation after deciding to cover up her potential defect or after observing the regulator's decision not to investigate. In this extension, the manufacturer in the U.S. tends to cover up more potential defects with even more significant harm than in the base model.

8. Policy Recommendations and Conclusion

Our analysis demonstrates that the U.S. policy offers advantages and disadvantages compared to the U.K. policy. An advantage of the U.S policy is that it provides early information about potential defects to consumers, so that consumers can take this information into consideration when making purchasing decisions. This could decrease the number of consumers who purchase the product and may suffer from the potential harm. One disadvantage, however, is that the U.S. policy makes the regulator reluctant to investigate and discourages the manufacturer from reporting a potential defect with significant harm, compared to the U.K. policy.

We make four policy recommendations to dissuade manufacturers from covering up potential defects with significant harm, while allowing for early information to be communicated to consumers. The first two recommendations provide full early information to consumers and the last two recommendations provide only partial early information to consumers.

First, the regulator could announce his investigations, providing full early information to consumers, and allocate more resources to the investigation of potential defects with significant harm. These additional resources would shorten the lead time l of the regulator's investigation, which would not only reduce the impact of investigation announcement on demand, but also reduce the number of products to recall if the defect actually exists. Both of these effects would encourage the manufacturer to report a potential defect rather than to cover it up.

Second, while announcing investigations, the regulator could improve his communication approach so that consumers correctly understand and interpret the probability that the defect exists. This would help consumers not to overreact to the investigation announcement and reduce manufacturers' incentives to cover up potential defects with significant harm. For the parameters we estimated for the Toyota recall, we find that if consumers took into account the true posterior probability of defect, the manufacturer would not cover up potential defects with expected harm above \$165, whereas for our base case the manufacturer covers up defects with expected harm of up to \$227 (see §C.1 in the online appendix). In practice, it is not possible to convey the exact probability of defect, but a simple color-coding scheme, where, for instance, red corresponds to highest probability of defect, orange to intermediate, and yellow to low, could be used to improve communications with consumers.

Third, the regulator could employ a hybrid policy in which he conducts a confidential investigation *only when* the potential defect could inflict significant harm; that is, providing only partial early information to consumers. For instance, referring to Figure 6 based on the parameters estimated for the Toyota recall, the regulator should keep confidential the investigation of the sudden unintended acceleration defect only if its expected harm is greater than $h_R^{UK} = \$112$. This would induce the manufacturers to report potential defects in Region II of Figure 6, thus preventing manufacturer cover-ups of defects with significant harm, which are the most worrying. This hybrid policy is also good in terms of social welfare. As we have seen in Figure 8, when the expected harm h is smaller than $h_R^{UK} = \$112$, an investigation announcement does not affect social welfare much, but when h is greater than $h_R^{UK} = \$112$, confidential investigations could generate significantly higher social welfare.

Our fourth recommendation builds on the current procedure of NHTSA, which conducts two-phase investigations on alleged defects. The first phase (preliminary evaluation) is "usually resolved within four months" and its goal is to gather detailed information and "determine whether further analysis is warranted." The second phase (engineering analysis) takes longer and "conducts a more detailed and complete analysis" (National Highway Traffic Safety Administration 2011). Currently, NHTSA announces his investigations at the beginning of the preliminary evaluation. Our recommendation is that the regulator makes the preliminary evaluation a *silent* phase and announces the investigation only at the beginning of the engineering analysis. This would induce manufacturers to report potential defects to the regulator in the knowledge that (i) the preliminary analysis phase does not have an impact on consumer demand and (ii) the regulator may not proceed with the engineering analysis phase if the preliminary analysis concludes that there is a low chance that the defect may exist or its expected harm is low.

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Appendix A: Proof of All Results

Proof of Proposition 1. We show this result for each country separately.

The U.S. Case. For the U.S., the social welfare is calculated as follows:

$$\begin{aligned}
W^{US}_{(R,I)} &= \pi^{US}_{(R,I)} + S^{US}_{(R,I)} - \Gamma^{US}_{(R,I)}\\
&= p\left(1-\frac{p}{\bar v}-\frac{lh}{\bar v}\right) - Pr(D\mid\tilde D)(r+h)l\left(1-\frac{p+h}{\bar v}\right)+\frac{l}{2\bar v}(\bar v-p-h)^2+\frac{(1-l)}{2\bar v}(\bar v-p)^2-C,\\
W^{US}_{(R,NI)} &= \pi^{US}_{(R,NI)} + S^{US}_{(R,NI)} - \Gamma^{US}_{(R,NI)}\\
&= \frac{\bar v^2-p^2}{2\bar v} - Pr(D\mid\tilde D)\left[\frac{lph^2}{\bar v\bar h}+\frac{h(r+h)((1+l)(\bar v-p)-2lh)}{2\bar v\bar h}+\frac{h^2 l(2\bar v-2p-h)}{2\bar v\bar h}\right.\\
&\qquad \left.+\frac{h(\bar h-h)(\bar v-p)}{\bar v\bar h}+\frac{h}{\bar h}C\right], \text{ so that}
\end{aligned}$$

$$W^{US}_{(R,I)} - W^{US}_{(R,NI)} = Pr(D\mid\tilde D)\chi_1(h) - \frac{lh}{\bar v}\left(\bar v-\frac{1}{2}h\right)-C, \tag{9}$$

$$\text{where}\quad \chi_1(h)=\frac{h}{\bar h}C+\frac{(r+h)}{2\bar v\bar h}\big((\bar v-p)(h(1+l)-2\bar h l)+2lh(\bar h-h)\big)+\frac{lh^2}{\bar v\bar h}\left(\bar v-\frac{h}{2}\right)+\frac{h(\bar h-h)(\bar v-p)}{\bar v\bar h}. \tag{10}$$

If $\chi_1(h) < \frac{lh}{\bar v}\left(\bar v-\frac{1}{2}h\right)+C$, or equivalently, $\widehat\chi_1(h)=\chi_1(h)-\frac{lh}{\bar v}\left(\bar v-\frac{1}{2}h\right)-C<0$, then $W^{US}_{(R,I)}-W^{US}_{(R,NI)}<0$ is always satisfied, because $Pr(D\mid\tilde D)\le 1$. If $\widehat\chi_1(h)\ge 0$, then $W^{US}_{(R,I)}-W^{US}_{(R,NI)}\ge 0$ if and only if

$$\rho \ge \rho' = \frac{\frac{lh(\bar v-h/2)/\bar v+C}{\chi_1(h)}-Pr(D)}{1-Pr(D)}, \tag{11}$$

since $Pr(D\mid\tilde D)=\rho+(1-\rho)Pr(D)$. It is easy to see that $\widehat\chi_1(h)$ is a cubic function of h, the coefficient of the cubic term is negative, $\widehat\chi_1(0)=\chi_1(0)-C=-\frac{rl}{\bar v}(\bar v-p)-C<0$, and $\widehat\chi_1(\bar h)=\frac{(r+\bar h)}{2\bar v}(\bar v-p)(1-l)>0$. Therefore, there exists $h^{US}_I\in(0,\bar h)$ such that $W^{US}_{(R,I)}-W^{US}_{(R,NI)}<0$ is satisfied regardless of ρ if and only if $h<h^{US}_I$, and $W^{US}_{(R,I)}-W^{US}_{(R,NI)}\ge 0$ is satisfied if and only if $h\ge h^{US}_I$ and $\rho\ge\rho^{US}_I(h)=\max\{\rho',0\}$, where $\rho^{US}_I(h)\in[0,1]$ is a function of h.

The U.K. Case. For the UK, the social welfare is calculated as follows:

$$W^{UK}_{(R,I)} = \pi^{UK}_{(R,I)} + S^{UK}_{(R,I)} - \Gamma^{UK}_{(R,I)}$$
$$= \frac{1}{2\bar{v}}(\bar{v}-p)^2 + (p - Pr(D \mid \tilde{D})(r+h)l) \cdot \left(1 - \frac{p}{\bar{v}}\right) - C,$$
$$W^{UK}_{(R,NI)} = \pi^{UK}_{(R,NI)} + S^{UK}_{(R,NI)} - \Gamma^{UK}_{(R,NI)}$$
$$= \frac{1}{2\bar{v}}(\bar{v}-p)^2 + p\left(1-\frac{p}{\bar{v}}\right) - Pr(D \mid \tilde{D})\left[h\left(1-\frac{h}{\bar{h}}\right)\left(1-\frac{p}{\bar{v}}\right) + \frac{(r+h)(\bar{v}-p)(1+l)h}{2\bar{v}\bar{h}} + \frac{h}{\bar{h}}C\right], \text{ so that}$$

$$W^{UK}_{(R,I)} - W^{UK}_{(R,NI)} = Pr(D \mid \tilde{D})\chi_2(h) - C, \tag{12}$$

$$\text{where} \quad \chi_2(h) = \frac{h}{\bar{h}}C + h\left(1-\frac{h}{\bar{h}}\right)\left(1-\frac{p}{\bar{v}}\right) + (r+h)\left(1-\frac{p}{\bar{v}}\right)\frac{h(1+l)-2\bar{h}l}{2\bar{h}}. \tag{13}$$

If $\chi_2(h) < C$, or equivalently, $\widehat{\chi}_2(h) = \chi_2(h) - C < 0$, then $W^{UK}_{(R,I)} - W^{UK}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\chi}_2(h) \ge 0$, then $W^{UK}_{(R,I)} - W^{UK}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho'' = \frac{\frac{C}{\chi_2(h)} - Pr(D)}{1 - Pr(D)}, \tag{14}$$

since $Pr(D \mid \tilde{D}) = \rho + (1-\rho)Pr(D)$. It is straightforward to see that $\widehat{\chi}_2(h)$ is a quadratic function of h, $\widehat{\chi}_2(0) = \chi_2(0) - C = -rl(1-\frac{p}{\bar{v}}) - C < 0$, and $\widehat{\chi}_2(\bar{h}) = (r+\bar{h})(1-\frac{p}{\bar{v}})\frac{1-l}{2} > 0$. Therefore, there exists $h^{UK}_I \in (0,\bar{h})$ such that $W^{UK}_{(R,I)} - W^{UK}_{(R,NI)} < 0$ is satisfied regardless of ρ if and only if $h < h^{UK}_I$, and $W^{UK}_{(R,I)} - W^{UK}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h^{UK}_I$ and $\rho \ge \rho^{UK}_I(h) = \max\{\rho'', 0\}$, where $\rho^{UK}_I(h) \in [0,1]$ is a function of h. □

Proof of Corollary 1. We show that if $r \le \bar{v} - 3\bar{h}/2$, then $(W^{UK}_{(R,I)} - W^{UK}_{(R,NI)}) - (W^{US}_{(R,I)} - W^{US}_{(R,NI)}) \ge 0$. Using the results in the proof of Proposition 1, we can obtain the following:

$$(W^{UK}_{(R,I)} - W^{UK}_{(R,NI)}) - (W^{US}_{(R,I)} - W^{US}_{(R,NI)}) = \frac{hl}{2\bar{h}\bar{v}}\left[\bar{h}(2\bar{v}-h) + Pr(D \mid \tilde{D})\chi_3(h)\right],$$

where

$$\chi_3(h) = 3h^2 - 2\bar{h}r - 2h(\bar{h} - r + \bar{v}).$$

Note that $\chi_3(0) = -2\bar{h}r < 0$ and $\chi_3(\bar{h}) = \bar{h}(\bar{h} - 2\bar{v}) < 0$. Since $\chi_3(h)$ is quadratic in h and the coefficient of the quadratic term is positive, we have that $\chi_3(h) < 0$ for all $h \in [0,\bar{h}]$. Therefore,

$$(W^{UK}_{(R,I)} - W^{UK}_{(R,NI)}) - (W^{US}_{(R,I)} - W^{US}_{(R,NI)}) \ge \frac{hl}{2\bar{h}\bar{v}}\left[\bar{h}(2\bar{v}-h) + \chi_3(h)\right] = \frac{hl}{2\bar{h}\bar{v}} \cdot \widehat{\chi}_3(h),$$

where

$$\widehat{\chi}_3(h) = 3h^2 - (3\bar{h} + 2(\bar{v}-r))h + 2\bar{h}(\bar{v}-r).$$

Note that $\widehat{\chi}_3(h)$ is a quadratic function achieving the minimum at $h = \bar{h}/2 + (\bar{v}-r)/3$. Furthermore, $\widehat{\chi}_3(0) = 2\bar{h}(\bar{v}-r) > 0$ and $\widehat{\chi}_3(\bar{h}) = 0$. It is straightforward to see that if $r \le \bar{v} - 3\bar{h}/2$, then $\widehat{\chi}_3(h)$ achieves its minimum at $h \ge \bar{h}$, and therefore $\widehat{\chi}_3(h) \ge 0$ for all $h \in [0,\bar{h}]$. Hence, if $r \le \bar{v} - 3\bar{h}/2$, then $(W^{UK}_{(R,I)} - W^{UK}_{(R,NI)}) - (W^{US}_{(R,I)} - W^{US}_{(R,NI)}) \ge 0$. □

Proof of Proposition 2. This proof consists of two steps. In Step 1, we define h_R^{US} and $\rho_R^{US}(h)$ in such a way that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h_R^{US}$ and $\rho \geq \rho_R^{US}(h)$. In Step 2, we characterize the subgame perfect Nash equilibrium.

Step 1. Defining $\mathbf{h_R^{US}}$ and $\boldsymbol{\rho_R^{US}(h)}$. Assume that the regulator always investigates immediately. By (1), the manufacturer's expected profit from reporting a potential defect is

$$\begin{aligned}\pi_{(R,I)}^{US} &= p[(1-l)d(p)+ld(p,h)] - Pr(D \mid \tilde{D}) \cdot (r+h)ld(p,h) \\ &= p\left(1-\frac{p}{\bar{v}}-\frac{lh}{\bar{v}}\right) - Pr(D \mid \tilde{D}) \cdot (r+h)l\left(1-\frac{p+h}{\bar{v}}\right).\end{aligned}$$

By (5), the manufacturer's expected profit from not reporting is

$$\begin{aligned}\pi_{(NR)}^{US} &= p \cdot d(p) - Pr(D \mid \tilde{D})\left[\int_0^{1-l} lp(d(p)-d(p,h))g(\hat{t} \mid D)d\hat{t}\right. \\ &\quad \left.+\int_0^{1-l}(r+h)(d(p)\hat{t}+d(p,h)l)g(\hat{t} \mid D)d\hat{t} + \theta(K_1h+K_2)\int_0^{1-l} g(\hat{t} \mid D)d\hat{t} + \alpha h \cdot d(p)Pr(\hat{t}=1 \mid D)\right]. \\ &= p\left(1-\frac{p}{\bar{v}}\right) - Pr(D \mid \tilde{D})\left[-\frac{lh^3}{\bar{h}\bar{v}}+(p-r)\frac{lh^2}{\bar{h}\bar{v}}\right. \\ &\quad \left.+\frac{(1+l-2\alpha)h^2+(r(1+l)+2\alpha\bar{h})h}{2\bar{h}}\left(1-\frac{p}{\bar{v}}\right)+\theta(K_1h+K_2)\frac{h}{\bar{h}}\right].\end{aligned}$$

Therefore,

$$\pi_{(R,I)}^{US} - \pi_{(NR)}^{US} = Pr(D \mid \tilde{D}) \cdot \Omega_1(h) - \frac{plh}{\bar{v}}, \tag{15}$$

where

$$\begin{aligned}\Omega_1(h) &= -\frac{l}{\bar{h}\bar{v}}h^3 + \left(\frac{K_1\theta}{\bar{h}} + \frac{(1-2\alpha+l)\left(1-\frac{p}{\bar{v}}\right)}{2\bar{h}} + \frac{l}{\bar{v}} + \frac{l(p-r)}{\bar{h}\bar{v}}\right)h^2 \\ &\quad + \left(\frac{K_2\theta}{\bar{h}} + \frac{(2\alpha\bar{h}+(1+l)r)\left(1-\frac{p}{\bar{v}}\right)}{2\bar{h}} + \frac{lr}{\bar{v}} - l\left(1-\frac{p}{\bar{v}}\right)\right)h - lr\left(1-\frac{p}{\bar{v}}\right).\end{aligned} \tag{16}$$

If $\Omega_1(h) < plh/\bar{v}$, or equivalently, $\widehat{\Omega}_1(h) = \Omega_1(h) - plh/\bar{v} < 0$, then $\pi_{(R,I)}^{US} - \pi_{(NR)}^{US} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. If $\widehat{\Omega}_1(h) \geq 0$, then $\pi_{(R,I)}^{US} - \pi_{(NR)}^{US} \geq 0$ if and only if

$$\rho \geq \rho_1 = \frac{1}{1-Pr(D)}\left(\frac{plh/\bar{v}}{\Omega_1(h)} - Pr(D)\right), \tag{17}$$

because $Pr(D \mid \tilde{D}) = \rho + (1-\rho)Pr(D)$. It is easy to see that $\widehat{\Omega}_1(h)$ is a cubic function of h and the coefficient of the cubic term is negative. Moreover, $\widehat{\Omega}_1(0) = \Omega_1(0) = -lr(1-p/\bar{v}) < 0$ and

$$\widehat{\Omega}_1(\bar{h}) = \frac{1}{2\bar{v}}\left[(1-l)(\bar{v}-p)r + 2K_2\theta\bar{v} + \bar{h}((1-l)(\bar{v}-p)+2K_1\theta\bar{v})\right] > 0. \tag{18}$$

Thus, there exists $h_R^{US} \in (0,\bar{h})$ such that $\widehat{\Omega}_1(h) \geq 0$ if and only if $h \geq h_R^{US}$. Then, $\pi_{(R,I)}^{US} - \pi_{(NR)}^{US} \geq 0$ if and only if $h \geq h_R^{US}$ and $\rho \geq \rho_R^{US}(h) = \max\{\rho_1, 0\}$, where $\rho_R^{US}(h) \in [0,1]$ is a function of h satisfying $\rho_R^{US}(h_R^{US}) = 1$.

Step 2. Characterizing subgame perfect Nash equilibrium. We use backward induction to characterize the subgame perfect Nash equilibrium. Let $A_1 \in \{R, NR\}$ denote the manufacturer's strategy, in which R denotes reporting a potential defect, and NR not reporting. Let (A_2, A_3) denote the regulator's strategy, in which $A_2 \in \{I, NI\}$ and $A_3 = NI$ are the regulator's actions when the manufacturer reports a potential defect and when the manufacturer does not report, respectively, where I denotes an immediate investigation and NI no immediate investigation. The equilibrium can be denoted by $(A_1, (A_2, A_3))$.

First, suppose $h < h_I^{US}$, or $h \geq h_I^{US}$ and $\rho < \rho_I^{US}(h)$. Then, by Proposition 1, the regulator's best response is not to investigate immediately even if the manufacturer reports a potential defect. By (5), we have $\pi_{(R,NI)}^{US} \geq \pi_{(NR)}^{US}$. Therefore, the manufacturer always reports a potential defect. Hence, the unique subgame perfect Nash equilibrium is $(R, (NI, NI))$.

Second, suppose $h_I^{US} \leq h < h_R^{US}$ and $\rho \geq \rho_I^{US}(h)$, or $h \geq h_R^{US}$ and $\rho_I^{US}(h) \leq \rho < \rho_R^{US}(h)$. Then, by Proposition 1, when the manufacturer reports a potential defect, the regulator's best response is to investigate immediately. However, anticipating this, the manufacturer does not report as we have shown in Step 1. Therefore, the unique subgame perfect Nash equilibrium is $(NR, (I, NI))$.

Finally, suppose $h \geq \max\{h_I^{US}, h_R^{US}\}$ and $\rho \geq \max\{\rho_I^{US}(h), \rho_R^{US}(h)\}$. By Proposition 1, when the manufacturer reports a potential defect, the regulator's best response is to investigate immediately. Also, by Step 1, the manufacturer reports a potential defect even if she anticipates the regulator's immediate investigation. Therefore, the unique subgame perfect Nash equilibrium is $(R, (I, NI))$. □

Proof of Proposition 3. This proof consists of two steps. In Step 1, we define h_R^{UK} in such a way that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h_R^{UK}$. In Step 2, we characterize the subgame perfect Nash equilibrium.

Step 1. Defining $\mathbf{h_R^{UK}}$. By (2), the manufacturer's expected profit from reporting a potential defect is

$$\pi_{(R,I)}^{UK} = p \cdot d(p) - Pr(D \mid \tilde{D}) \cdot (r+h) l d(p) = (p - Pr(D \mid \tilde{D}) \cdot (r+h) l) \left(1 - \frac{p}{\bar{v}}\right).$$

By (5), the manufacturer's expected profit from not reporting is

$$\begin{aligned}
\pi_{(NR)}^{UK} &= p \cdot d(p) - Pr(D \mid \tilde{D}) \left[\int_0^{1-l} (r+h)(\hat{t}+l) d(p) g(\hat{t} \mid D) d\hat{t} \right. \\
&\qquad \left. + \theta(K_1 h + K_2) \int_0^{1-l} g(\hat{t} \mid D) d\hat{t} + \alpha h \cdot d(p) Pr(\hat{t} = 1 \mid D) \right] \\
&= p\left(1 - \frac{p}{\bar{v}}\right) - Pr(D \mid \tilde{D}) \left[(r+h) \frac{(1+l)h}{2\bar{h}} \left(1 - \frac{p}{\bar{v}}\right) + \theta(K_1 h + K_2) \frac{h}{\bar{h}} + \alpha h \left(1 - \frac{h}{\bar{h}}\right)\left(1 - \frac{p}{\bar{v}}\right) \right].
\end{aligned}$$

Therefore,

$$\pi_{(R,I)}^{UK} - \pi_{(NR)}^{UK} = Pr(D \mid \tilde{D}) \cdot \Omega_2(h),$$

where

$$\Omega_2(h) = \left[\frac{\theta K_1}{\bar{h}} - \left(\frac{\alpha}{\bar{h}} - \frac{(1+l)}{2\bar{h}} \right)\left(1 - \frac{p}{\bar{v}}\right) \right] h^2 + \left[\frac{\theta K_2}{\bar{h}} - \left(l - \alpha - \frac{r(1+l)}{2\bar{h}} \right)\left(1 - \frac{p}{\bar{v}}\right) \right] h - rl\left(1 - \frac{p}{\bar{v}}\right). \quad (19)$$

Note that $\Omega_2(h)$ is a quadratic function of h, with $\Omega_2(0) = -rl(1 - p/\bar{v}) < 0$ and

$$\Omega_2(\bar{h}) = \frac{1}{2\bar{v}} \left[(1-l)(\bar{v} - p)(r + \bar{h}) + 2K_2\theta\bar{v} + 2K_1\theta\bar{v}\bar{h} \right] > 0. \quad (20)$$

Therefore, there exists $h_R^{UK} \in (0, \bar{h})$ such that $\pi_{(R,I)}^{UK} - \pi_{(NR)}^{UK} \geq 0$ if and only if $h \geq h_R^{UK}$. Note that h_R^{UK} is independent of the posterior probability $Pr(D \mid \tilde{D})$ or the reliability of the signal ρ.

Step 2. Characterizing subgame perfect Nash equilibrium. We characterize the subgame perfect Nash equilibrium following the same approach as Step 2 in the proof of Proposition 2.

First, suppose $h < h_I^{UK}$, or $h \geq h_I^{UK}$ and $\rho < \rho_I^{UK}(h)$. Then, by Proposition 1, the regulator's best response is not to investigate immediately even if the manufacturer reports a potential defect. By (5), we have $\pi_{(R,NI)}^{UK} \geq \pi_{(NR)}^{UK}$. Therefore, the manufacturer always reports a potential defect. Hence, the unique subgame perfect Nash equilibrium is $(R,(NI,NI))$.

Second, suppose $h_I^{UK} \leq h < h_R^{UK}$ and $\rho \geq \rho_I^{UK}(h)$. Then, by Proposition 1, when the manufacturer reports a potential defect, the regulator's best response is to investigate immediately. However, anticipating this, the manufacturer does not report as we have shown in Step 1. Therefore, the unique subgame perfect Nash equilibrium is $(NR,(I,NI))$.

Finally, suppose $h \geq \max\{h_I^{UK}, h_R^{UK}\}$ and $\rho \geq \rho_I^{UK}(h)$. By Proposition 1, when the manufacturer reports a potential defect, the regulator's best response is to investigate immediately. Also, by Step 1, the manufacturer reports a potential defect even if she anticipates the regulator's immediate investigation. Therefore, the unique subgame perfect Nash equilibrium is $(R,(I,NI))$. □

Proof of Proposition 4. When the manufacturer does not report a potential defect, we have that $W_{(NR)}^{US} = W_{(R,NI)}^{US}$ and $W_{(NR)}^{UK} = W_{(R,NI)}^{UK}$. Using $W_{(R,NI)}^{US}$ and $W_{(R,NI)}^{UK}$ obtained in the proof of Proposition 1,

$$W_{(NR)}^{US} - W_{(NR)}^{UK} = W_{(R,NI)}^{US} - W_{(R,NI)}^{UK} = -Pr(D \mid \tilde{D}) \cdot \frac{h^2 l}{2\bar{v}\bar{h}} \cdot (2\bar{v} - 2r - 3h).$$

Therefore, $W_{(NR)}^{US} > W_{(NR)}^{UK}$ if and only if $\bar{v} < r + \frac{3}{2}h$.

When the manufacturer reports a potential defect and the regulator investigates it immediately, using $W_{(R,I)}^{US}$ and $W_{(R,I)}^{UK}$ obtained in the proof of Proposition 1, we have that

$$W_{(R,I)}^{US} - W_{(R,I)}^{UK} = -\frac{lh}{\bar{v}}\left[\bar{v} - \frac{1}{2}h - Pr(D \mid \tilde{D})(r+h)\right].$$

Therefore, $W_{(R,I)}^{US} > W_{(R,I)}^{UK}$ if and only if $\bar{v} < \frac{1}{2}h + Pr(D \mid \tilde{D})(r+h)$. □

Proof of Proposition 5. Using $W_{(R,NI)}^{US}$ and $W_{(R,I)}^{UK}$ obtained in the proof of Proposition 1, we have that $W_{(R,I)}^{UK} - W_{(R,NI)}^{US} = Pr(D \mid \tilde{D})\chi_4(h) - C$, where

$$\chi_4(h) = \frac{1}{2\bar{v}\bar{h}}\left[-3lh^3 - ((1-3l)\bar{v} - (1-l)p + 2lr)h^2 + (2\bar{h}(1-l)(\bar{v}-p) + (2C + r + rl)\bar{v} - (1+l)pr)h - 2\bar{h}lr(\bar{v}-p)\right].$$

If $\widehat{\chi}_4(h) = \chi_4(h) - C < 0$, then $W_{(R,I)}^{UK} - W_{(R,NI)}^{US} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. In this case, we define $\rho_W^{UK}(h) = 1$. If $\widehat{\chi}_4(h) \geq 0$, then $W_{(R,I)}^{UK} - W_{(R,NI)}^{US} \geq 0$ if and only if

$$\rho \geq \frac{C/\chi_4(h) - Pr(D)}{1 - Pr(D)}.$$

In this case, we define $\rho_W^{UK}(h) = \frac{C/\chi_4(h) - Pr(D)}{1 - Pr(D)}$. □

Online Appendix

Appendix B: Parameter Values Used in Figures

All figures in the paper use the following parameter values: $p = 2,000$, $\bar{v} = 4,000$, $h = 125$, $\bar{h} = 500$, $r = 250$, $K_1 = 0.3$, $K_2 = 37.5$, $C = 0.056$, $l = 0.2$, $\theta = 0.2$, $\alpha = 0.2$, and $Pr(D) = 0.01$. These values are motivated by Toyota's sudden unintended acceleration recalls in 2009 and 2010. Toyota Corolla, one of the recalled models, sells for around \$20,000 (base model) in the U.S. We use $p = \$2,000$, because we assume zero production cost in our model and Toyota's net income has been around 5-10% of the revenue since 2014.[12] We set $\bar{v} = 2p = \$4,000$, which produces the price elasticity of demand of -1 in our model. This is in line with the findings of McCarthy (1996), who estimated that the price elasticity of demand for new vehicles was -0.87.

We use the settlement amounts in lawsuits to measure the expected harm h of Toyota's sudden unintended acceleration problem. CBS News (2010) reported that 89 people died and 57 got injured because of this defect. Although settlement sizes are difficult to estimate because most of them are confidential, Toyota settled one of the wrongful death claims with \$10 millions (CNBC 2013). Also, Miller Jr. (2015) reports that an average settlement amount for personal injuries in Pennsylvania is around \$1 million. Using these two numbers, we can roughly estimate the total settlement amount to be around $89 \times \$10\text{m} + 57 \times \$1\text{m} = \$947\text{m} \approx \$1$ billion. Since 8 million vehicles had to be recalled, the expected harm per vehicle is $h = \$1\text{b}/8\text{m}=\$125$. Conservatively, we use $\bar{h} = 4h = \$500$ for the maximum expected harm, but our results are not sensitive to different values of $\bar{h}$. Toyota spent \$2 billion to recall 8 million vehicles (McCurry 2010), and therefore we use the per-vehicle recall cost of $r = \$2\text{b}/8\text{m}=\$250$.

To estimate the penalty $K_1 h + K_2$ and the regulator's investigation cost C, we need to scale the real-world numbers to fit to our model. Specifically, Toyota recalled 8 million vehicles, but in our model, the manufacturer can only sell 0.5 vehicle in the entire selling season due to normalization assuming no demand drop (because $d(p) = 1 - p/\bar{v} = 1/2$ when $\bar{v} = 2p$). Roughly, 8 million vehicles in the Toyota case correspond to 0.5 vehicle in our model, and therefore we need to divide the real penalty and investigation costs by 8m/0.5. Toyota paid a penalty of \$1.2 billion for deliberately hiding the defect.[13] Therefore, this penalty corresponds to $\$1.2\text{b}/(8\text{m}/0.5) = \$75$. We assume that half of this penalty is a fixed penalty regardless of the expected harm. This results in $K_1 = 0.3$ and $K_2 = 37.5$.

As for the investigation cost C, for the 2017 budget, NHTSA requested \$47.5 million for its Office of Safety Defects Investigation (ODI), a department that has 28 employees, 16 of whom conduct formal investigation (National Highway Traffic Safety Administration 2016). Based on the announcements of on-going investigations, we found that NHTSA was conducting, on average, 31.7 investigations in any given month between

[12] Source: Nasdaq webpage (http://www.nasdaq.com).

[13] Note that this penalty was imposed by the Department of Justice for the criminal charge. NHTSA can also impose a fine on auto-makers for delaying recalls, but this is legally capped at \$32.4 million. Toyota indeed paid a fine of \$16.4 million to NHTSA in April 2010, and later in the year, paid an additional fine of \$32.4 million (Rushe 2010). However, the fines imposed by NHTSA are a negligible amount compared to \$1.2 billion and therefore are not considered in calculating the parameters.

August 2015 and January 2016.[14] According to NHTSA, most investigations last between 0.33 and 1.33 years. Therefore, assuming that there are 30 on-going investigations at any given time and an investigation lasts one year on average, we can estimate, by Little's law, that NHTSA conducts roughly 30 investigations a year. If we assume that the fraction of the ODI budget that is allocated to investigations is proportional to the number of employees who conduct those investigations (16 out of 28), an investigation costs \$47.5m $\times(16/28)/30 = \$0.9$m. This corresponds to $C = \$0.9\text{m}/(8\text{m}/0.5) \approx \$0.056$ in our model.

Toyota introduces a new generation of Corolla every 4 to 7 years by changing the vehicle design and components. Assuming that the life-cycle of one generation is 5 years, with the NHTSA's average investigation duration of one year, we use $l = 1/5 = 0.2$ as the average investigation duration in our model. Also, the prior probability that a new vehicle is defective is generally low (otherwise it would not have passed initial testings), and hence we set $Pr(D) = 0.01$; however, we find that our results are not sensitive to the prior and the shapes and qualitative properties of the figures remain the same with different priors.

Finally, we use $\theta = 0.2$ and $\alpha = 0.2$. In general, it is difficult to estimate the probability with which the regulator can find out whether the manufacturer covered up a potential defect, θ, and the fraction of the manufacturer's liability when the manufacturer does not recall the product, α. However, again, we find that the shapes and qualitative properties of the figures do not change much when we vary θ and α.

Appendix C: Extensions

We study the robustness of our main insights in Propositions 1-4 by considering: (1) consumers that use the posterior probability of defect when adjusting their demand for a product under investigation in the U.S., (2) consumer's risk aversion, (3) a short-term demand drop after a product recall, (4) demand drop after a cover-up revelation, (5) demand substitution, (6) alternative objective function of the regulator that places more emphasis on consumer harm, (7) alternative distributions of voluntary investigation timing, and (8) the manufacturer's internal investigation. Overall, we find that our main insights are robust to these extensions.

C.1. Consumers' Use of Posterior Distribution

In the base model, when the regulator announces the investigation of a potential defect, all consumers take into account its potential harm h and thus the demand rate is reduced from $1 - F(p)$ to $1 - F(p + h)$. As mentioned in §3, our main findings also hold for the case where only a fraction of consumers take into account the potential harm. Both of these models rely on the assumption that it is difficult for regulators to accurately convey to consumers the exact probability with which a defect exists (i.e., the posterior distribution), and that consumers have limited ability to interpret probabilities correctly and therefore overreact to the news of alleged existence of a defect. However, we could envision a situation in which consumers are fully rational and capable of assessing the exact posterior probability $Pr(D \mid \tilde{D})$ with which a defect exists. In such case, the demand rate would change to $1 - F(p + Pr(D \mid \tilde{D}) \times h)$, instead of $1 - F(p + h)$.

[14] NHTSA's investigation consists of two phases. The first phase is Preliminary Evaluation, in which ODI collects information from manufacturers and determines whether further analysis is warranted. The Preliminary Evaluation is generally resolved within four months. The second phase is Engineering Analysis, in which ODI conducts a more detailed analysis including inspection, testing, and surveys. This phase generally lasts one year, but it could last longer for complicated issues (National Highway Traffic Safety Administration 2011). We found that NHTSA was conducting, on average, 23.7 Preliminary Evaluations and 8 Engineering Analyses in any given month between August 2015 and January 2016.

Figure 10 Equilibrium Outcomes with Consumers' Use of Posterior Distribution

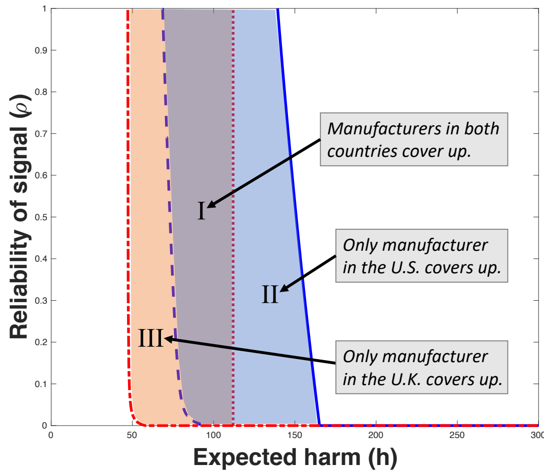


Figure 10 illustrates the equilibrium outcomes of this case, using the same parameter values as in previous figures. The three regions in this figure are separated mainly by the expected harm h, rather than by the reliability of signal ρ. When ρ is high, Figure 10 looks similar to Figure 6, because the posterior probability $Pr(D \mid \tilde{D})$ is high and thus the demand rate reduces almost to $1 - F(p+h)$ under the U.S. policy, similar to the base model. When ρ is low, however, the demand rate does not decrease much even if there is an on-going investigation, because $Pr(D \mid \tilde{D})$ is low. This makes the manufacturer less likely to cover up a potential defect than when ρ is high. This effect, however, is countervailed by the fact that low $Pr(D \mid \tilde{D})$ implies that there is a high chance that the defect actually does not exist, and this makes the manufacturer more likely to cover up than when ρ is high. As a result, the manufacturer's cover-up decision depends on the expected harm h in a similar way to the case when the reliability of signal ρ is high. Therefore, we observe that the manufacturer in the U.S. covers up more serious issues (i.e., potential defects with higher expected harm) than the manufacturer in the U.K., and this does not depend much on the reliability of signal.

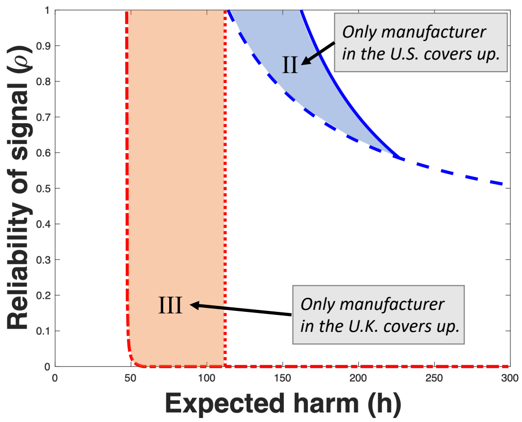
Note that Region II, in which only the manufacturer in the U.S. covers up a potential defect, has lower expected harm than Region II does in the base model. Specifically, in Figure 10, the maximum expected harm of a potential defect that the manufacturer is willing to cover up is \$165, whereas this was \$227 in the base model (see Figure 6).

C.2. Consumers' Risk Aversion

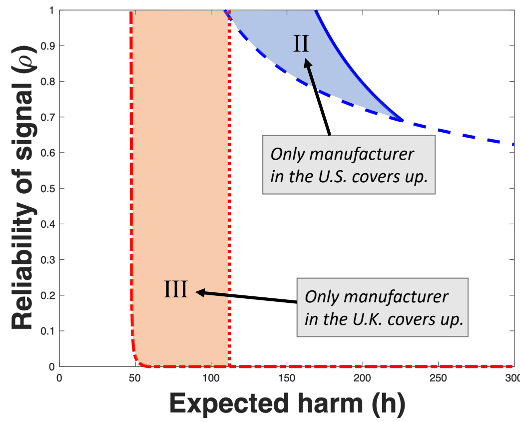
In our base model, we consider risk neutral consumers. We now study the robustness of our findings to the presence of risk-averse consumers. To model consumers' risk aversion, we use a mean-standard-deviation utility function. Specifically, a consumer's utility from purchase during investigation under the U.S. policy is $v - p - (h + \gamma\sigma)$, where σ is the standard deviation of the harm distribution and $\gamma \geq 0$ is the risk-aversion parameter. Then, the demand rate during investigation under the U.S. policy is $1 - F(p + h + \gamma\sigma)$, where we assume that $\gamma\sigma \leq \bar{v} - p - \bar{h}$ to ensure a positive demand rate.

We consider two cases depending on the relationship between the standard deviation σ and the mean h of the harm distribution. Specifically, we assume that σ is independent of h in the first case and σ is proportional

Figure 11 Equilibrium Outcomes with Consumers' Risk Aversion



(a) σ is independent of h: $\gamma \cdot \sigma$=125



(b) σ is proportional to h: β=2

to h in the second case. Note that, in the second case, the standard deviation can be represented by $\sigma = \tau h$, where $\tau > 0$.[15] Then, we have that $v - p - (h + \gamma\sigma) = v - p - (1 + \tau\gamma)h = v - p - \beta h$, where $\beta = 1 + \tau\gamma$, and thus the demand rate during investigation under the U.S. policy in the second case can be simplified to $1 - F(p + \beta h)$. We specify that $\beta \in [1, (\bar{v} - p)/\bar{h})$, where $\beta > 1$ means risk aversion and $\beta < (\bar{v} - p)/\bar{h}$ ensures that the positive demand rate assumption (i.e., $\gamma\sigma \leq \bar{v} - p - \bar{h}$) holds. Both cases collapse to the base model if we assume risk neutrality by setting $\gamma = 0$.

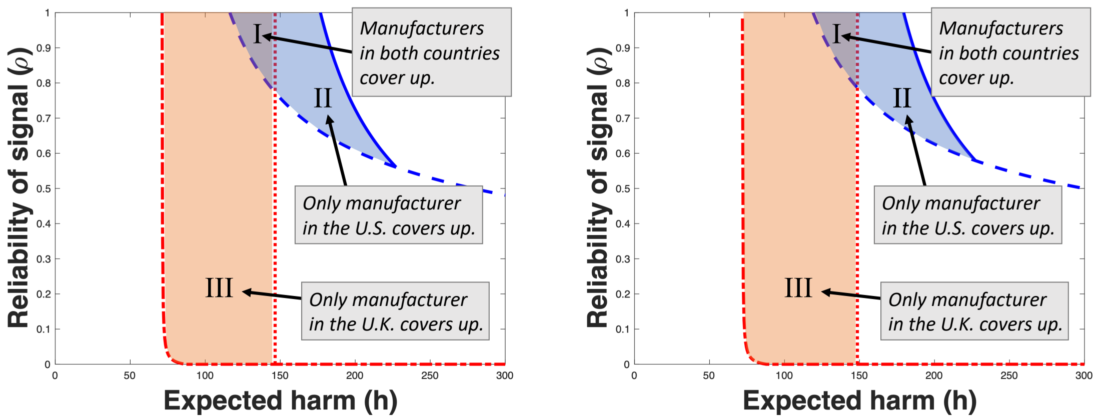
We observe that, in both cases, the overall structure of the equilibrium remains unaffected by considering risk-averse consumers. In particular, we verify that Propositions 1, 2, and 3 continue to hold in both cases, and Proposition 4 also continues to hold with a slight change of conditions (see Appendix D.1 for proofs).[16] Figure 11(a) illustrates the equilibrium outcomes when σ is independent of h, where $\gamma\sigma = 125$. Figure 11(b) illustrates the equilibrium outcomes when σ is proportional to h, where $\beta = 2$.[17] As consumers become more risk averse, the negative impact of the investigation announcement on demand becomes more significant. Therefore, in Figures 11(a) and 11(b), the regulator is more reluctant to investigate and the manufacturer tends to cover up significant defects with higher likelihood of existence than in the base model in Figure 6. Yet, the underlying intuition behind the regulator's investigation decision and the manufacturer's cover-up decision remains the same: Risk aversion only accentuates the impact of the investigation announcement in the U.S, while keeping all results under the U.K. policy unchanged. Finally, comparing the equilibria under the U.S. and U.K. policies, we observe that our main insight continues to hold: in the U.S. the regulator is less likely to investigate and the manufacturer is more likely to cover up defects with significant harm.

[15] This is satisfied, for instance, by the exponential distribution, in which case $\tau = 1$.

[16] When σ is independent of h, the condition is $\bar{v} < r + (3h + \gamma\sigma)/2$ for Proposition 4(i) and $\bar{v} < (h + \gamma\sigma)/2 + Pr(D \mid \tilde{D})(r + h)$ for Proposition 4(ii). When σ is proportional to h, the condition is $\bar{v} < r + ((2 + \beta)/2)h$ for Proposition 4(i) and $\bar{v} < (\beta/2)h + Pr(D \mid \tilde{D})(r + h)$ for Proposition 4(ii).

[17] Note that, using the parameter value of $h = \$125$ we estimated for the Toyota recalls in Online Appendix B, the parameter values of Figures 11(a) and 11(b) are comparable in the sense that $h + \gamma\sigma = \$250$ and $\beta h = \$250$.

Figure 12 Equilibrium Outcomes with Short-Term Demand Drop After a Recall



(a) Fixed impact (b) Time-dependent impact

C.3. Short-Term Demand Drop After a Product Recall

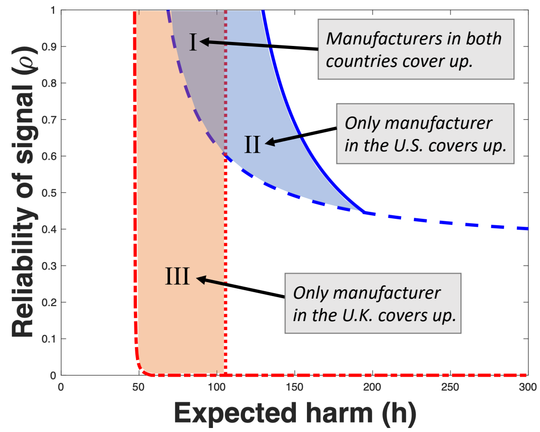
As discussed in §2, there is empirical evidence that manufacturers experience a short-term drop in consumer demand after a product recall. We can incorporate this effect by assuming that the demand rate drops to $1 - F(p + \delta h)$, where $\delta > 0$, after a product recall for $\epsilon \in (0, 1)$ time period. This assumption, however, raises the issue of what happens if a recall occurs after $t = 1 - \epsilon$, in which case the remaining time period is less than ϵ. We consider two cases with different assumptions to deal with this issue.

In the first case, we assume a fixed impact; that is, even if the recall occurs after $t = 1 - \epsilon$, the reductions in the manufacturer's expected profit and consumer surplus are the same as those in the case when the recall occurs before $t = 1 - \epsilon$. We find that the overall structure of the equilibrium is similar to that in the main body of the manuscript. Specifically, we verify that Propositions 1, 2, 3, and 4 continue to hold (see Appendix D.2 for proofs). Figure 12(a) depicts the equilibrium outcomes when $\delta = 1$ and $\epsilon = 0.2$.[18] We observe that the cover-up regions in the U.S. (Regions I and II) and in the U.K. (Regions I and III) moved to the right of those in the base model (see Figure 6). This is because the demand drop following a product recall decreases both the manufacturer's expected profit and the consumer surplus. Therefore, the manufacturers and regulators in both countries try to avoid product recalls; manufacturers attempt to cover up potential defects with more significant harm and regulators become more reluctant to immediately investigate a potential defect than in the base model. Yet, the underlying difference between the two countries' policies on investigation announcement remains the same. Therefore, the findings are similar to those in the main body of the manuscript.

In the second case, we assume a time-dependent impact; that is, if a recall occurs after $t = 1 - \epsilon$, the demand drops only until $t = 1$ and thus the demand drops for less than ϵ period. We numerically explore this second case in Figure 12(b) with the same parameter values as in the first case, and observe that the equilibrium outcomes remain very similar to those in the first case and in the main body of the manuscript.

[18] With these parameter values, the amount of demand drop is the same as that during the regulator's investigation under the U.S. policy.

Figure 13 Equilibrium Outcomes with Demand Drop After a Cover-Up Revelation



Overall, we find that our main findings are robust to short-term demand drop after a product recall: In the U.S. the regulator remains less likely to investigate and the manufacturer is more likely to cover up defects with significant harm compared to the U.K.

C.4. Demand Drop After a Cover-Up Revelation

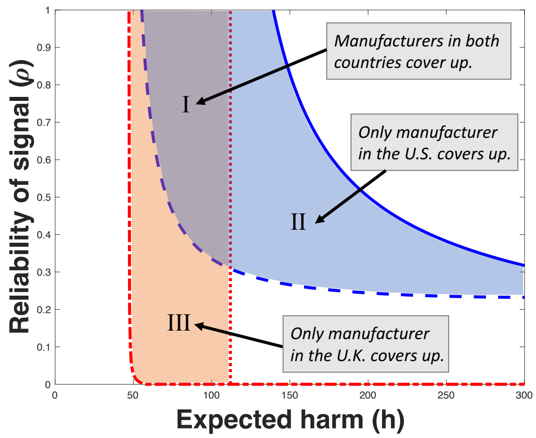
In our base model, we assume that consumer demand decreases only during the regulator's investigation under the U.S. policy. In this section, we consider the case where consumer demand also decreases temporarily after a cover-up is revealed by the regulator's voluntary investigation in both the U.S. and the U.K. This additional demand drop could occur because consumers may be wary of purchasing a product from a manufacturer that has recently covered up a defect. Similar to our approach in Appendix C.3, we assume that the demand rate drops to $1-F(p+\delta h)$, where $\delta > 0$, for $\epsilon \in (0,1)$ time period after a cover-up is revealed. As in the first case of Appendix C.3, to simplify the analysis, we assume that even if a cover-up is revealed after $t = 1-\epsilon$, the reductions in the manufacturer's expected profit and expected consumer surplus are the same as those in the case when a cover-up is revealed before $t = 1-\epsilon$.

We find that the overall structure of the equilibrium remains unaffected by considering demand drop after a cover-up revelation. In particular, we verify that Propositions 1, 2, 3, and 4 continue to hold (see Appendix D.3 for proofs). Figure 13 depicts the equilibrium outcomes when $\epsilon = 0.2$ and $\delta = 4$. Note that, with these parameter values, the amount of demand drop after a cover-up revelation is four times greater than the demand drop during the regulator's investigation under the U.S. policy.[19] Yet, we still find that the overall structure of the equilibrium in Figure 13 remains similar to that in Figure 6 of the base model.

As expected, demand drop after a cover-up revelation discourages the manufacturers to cover up a potential defect in both countries. Yet, the manufacturers still have an incentive to cover up a potential defect because there is a chance that the regulator may not initiate a voluntary investigation at a later time when the expected harm h is relatively low (Regions I and III) and that the defect may not actually exist when the

[19] Recall that all our figures are depicted with parameter values we estimated from the Toyota recalls in 2009-2010, in which the consumer demand drops to $1-F(p+h)$ during the regulator's investigation in the U.S. for, on average, $l = 0.2$ time period.

Figure 14 Equilibrium Outcomes under Demand Substitution



reliability of the signal ρ is moderate (Region II). Note that demand drop after a cover-up revelation does not affect the regulator's decision, because the regulator only decides whether to immediately investigate a potential defect reported by the manufacturer *when there is no cover-up*. Overall, our main findings are robust: In the U.S. the regulator remains less likely to conduct an immediate investigation and the manufacturer more likely to cover up defects with significant harm compared to the U.K.

C.5. Demand Substitution

In our base model, during investigation of the U.S. regulator, consumers assume the defect exists, and thus they purchase the product only if their valuation v is higher than the sum of the price and the expected harm of the defect, $p+h$. Consequently, consumer surplus decreases from $\int_p^{\bar{v}}(v-p)f(v)dv$ to $\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv$ during the investigation period; see equations (6) and (7). However, consumers may be able to purchase a similar product from a different manufacturer. In this scenario, their total surplus may not decrease as much as in our base model (while the manufacturer still suffers from decreased demand). We check the robustness of our results to this scenario, in which consumer surplus is unaffected by the investigation announcement.

Under the U.S. policy, different from the base model, demand substitution makes consumer surplus equal to that under the U.K. policy, i.e., $S^{US}=S^{UK}$. This is because the only difference between the two countries' policies, i.e., investigation announcement, no longer affects consumer surplus.[20] However, the manufacturer's expected profit in the U.S. remains unchanged from the base model by demand substitution because she still suffers from decreased demand as in the base model. Under the U.K. policy, demand substitution changes neither consumer surplus nor the manufacturer's expected profit, because the U.K. regulator does not announce the investigation anyway.

[20] Note that, if a defect exists, then the consumers in the U.S. who purchase the substitute product during an investigation period do not suffer from the harm, whereas all consumers in the U.K. suffer from the harm. However, we still have that $S^{US}=S^{UK}$ because of the following reasons. First, if there is an investigation, any consumer harm is accounted for in the manufacturers' expected profit as compensation, and thus is not accounted for in the consumer surplus. Second, if there is no investigation, then there is no investigation announcement either. Therefore, $S^{US}=S^{UK}$.

We verify that Propositions 1, 2, and 3 continue to hold. We observe that Proposition 4 also holds but under different conditions (see Appendix D.4 for proofs).[21] Overall, we find that the structure of the equilibrium is similar to that in the base model, as illustrated in Figure 14. The only difference from the equilibrium in the base model is that the U.S. regulator is now less reluctant to immediately investigate a potential defect. This is because, under demand substitution, the regulator's investigation announcement reduces only the manufacturer's expected profit, whereas in the base model it reduces both the manufacturer's expected profit and consumer surplus. Therefore, with demand substitution, the regulator's investigation announcement does not decrease social welfare as much as in the base model, and thus the regulator is less reluctant to immediately investigate. Nonetheless, comparing the U.S. and U.K. equilibria in Figure 14, we observe that our main insights continue to hold: In the U.S. the regulator is less likely to carry out an immediate investigation and the manufacturer is more likely to cover up defects with significant harm compared to the U.K.

C.6. Alternative Objective Function of the Regulator

In our base model, the regulator's objective is to maximize the social welfare $W = \pi + S - \Gamma$, where π is the manufacturer's profit, S is the consumer surplus, and Γ is the regulator's cost. Note that social welfare does account for consumer harm at its *face value* through either the manufacturer's profit or a combination of the manufacturer's profit and the consumer surplus, depending on whether the manufacturer compensates the consumer harm fully or only partially. In this section, we demonstrate the robustness of our main findings by considering an alternative objective function of the regulator that places more emphasis on consumer harm. Our approach to do this is inspired by the objective functions used in the sustainable OM literature such as Atasu et al. (2009) and Kraft et al. (2013). Specifically, we consider the following alternative objective function:

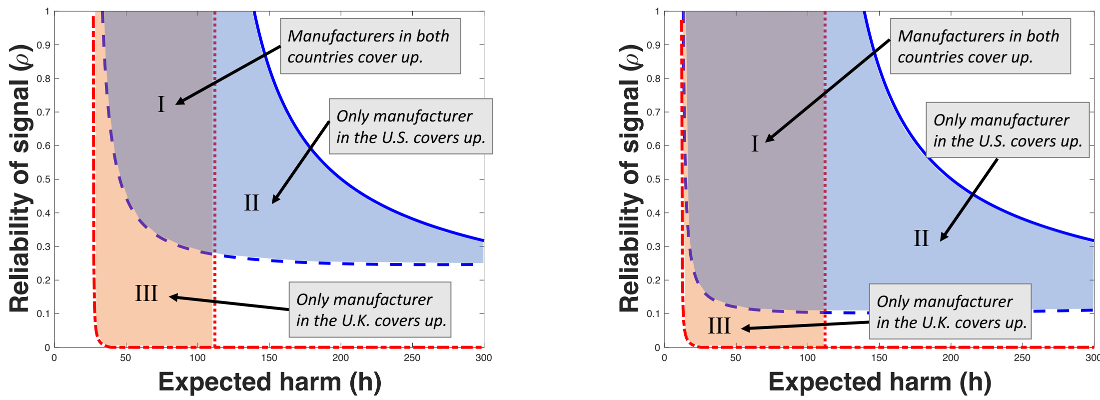
$$\widehat{W} = \phi(\pi + S) - (1-\phi)H - \Gamma, \tag{21}$$

where H is the expected consumer harm and $\phi \in [0,1]$ is a parameter that allows us to adjust the weight that the regulator assigns to consumer harm. For $\phi = 1$, this alternative objective function coincides with social welfare; i.e., $\widehat{W} = W$. For $\phi < 1$, $\widehat{W}$ assigns a higher weight to consumer harm than W. For $\phi = 0$, $\widehat{W}$ considers only consumer harm and the regulator's cost; i.e., $\widehat{W} = -H - \Gamma$.

We find that the overall structure of the equilibrium with this alternative objective is similar to that in the main body of the manuscript. In particular, we verify that Propositions 1, 2, and 3 continue to hold (see Appendix D.5 for proofs). Figures 15(a) and 15(b) depict the equilibrium outcomes for the cases with $\phi = 0.5$ and $\phi = 0.2$, respectively. As ϕ decreases, the regulator's willingness to investigate increases, because immediate investigation can reduce consumer harm. However, conditional on the regulator's investigation decision, the manufacturer's decision on cover-up remains unaffected. More importantly, these figures demonstrate that our findings are robust to this alternative objective: In the U.S., the regulator remains less likely

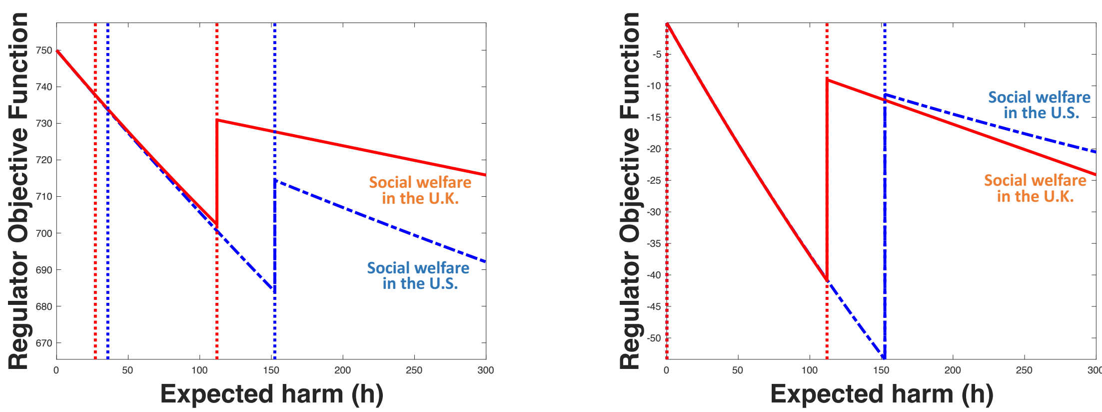
[21] The condition is $p < r + h$ for Proposition 4(i) and $p < Pr(D \mid \tilde{D})(r + h)$ for Proposition 4(ii). Under the parameter values we estimated for Toyota recalls in Online Appendix B, the U.K. social welfare is higher than the U.S. social welfare as in the base model.

Figure 15 Equilibrium Under the Alternative Objective Function of the Regulator



(a) Equilibrium When $\phi = 0.5$ (b) Equilibrium When $\phi = 0.2$

Figure 16 Values of the Alternative Objective Function of the Regulator



(a) Regulator's Objective When $\phi = 0.5$ and $\rho = 0.8$ (b) Regulator's Objective When $\phi = 0$ and $\rho = 0.8$

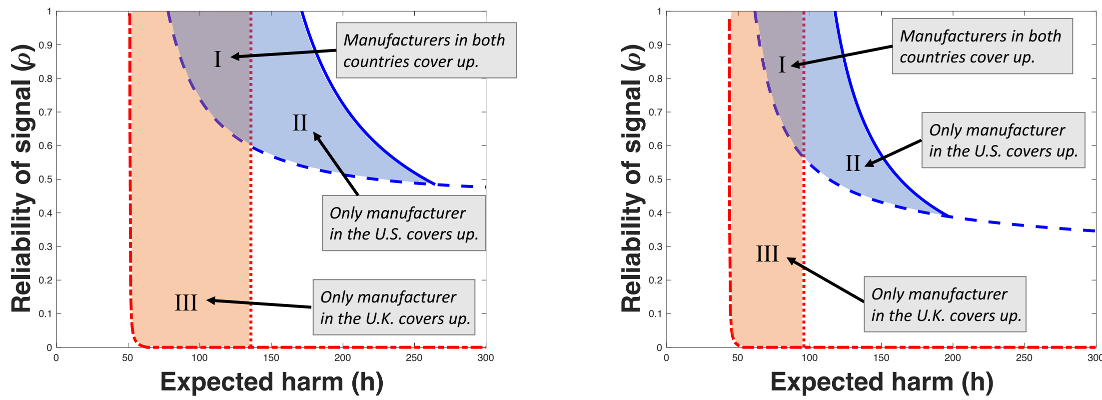
to investigate and the manufacturer is more likely to cover up defects with significant harm than in the U.K. Finally, Figure 16 shows how the value of this alternative objective function changes with the expected harm h. As in the main body of the paper, we find that the value of this alternative objective function is generally higher under the U.K. policy, except for the extreme case when ϕ is close to zero, as can be seen in Figure 16(b).

C.7. Alternative Distributions of Voluntary Investigation Timing

In the main body of the manuscript, we assume the regulator's voluntary investigation timing, $\hat{t}$, is uniformly distributed on $[0, 1-l]$. In this section, we relax this assumption to consider distributions that are either linearly increasing or decreasing in $\hat{t}$.

To understand our motivation to study these alternative distributions, consider two defects with the same expected harm, h, but one of the defects has a larger probability of causing harm coupled with a smaller impact of the harm. Then, one may expect that the regulator may receive a larger number of consumer

Figure 17 Equilibrium Outcomes under Nonuniform Distributions of $\hat{t}$



(a) $g(\hat{t} \mid D)$ is linearly decreasing in $\hat{t}$ (b) $g(\hat{t} \mid D)$ is linearly increasing in $\hat{t}$

complaints for the large-probability small-impact defect and this could advance the regulator's investigation timing. Thus, this type of defect could be modeled with a decreasing distribution of voluntary investigation timing. By contrast, the small-probability large-impact defect could be modeled with an increasing distribution.

We consider the following linearly decreasing and increasing distributions:

$$g(\hat{t} \mid D) = -\frac{2h}{(1-l)\bar{h}}\left(\frac{\hat{t}-(1-l)}{(1-l)}\right) \quad \text{and} \quad g(\hat{t} \mid D) = \frac{2h}{(1-l)^2\bar{h}}\hat{t}.$$

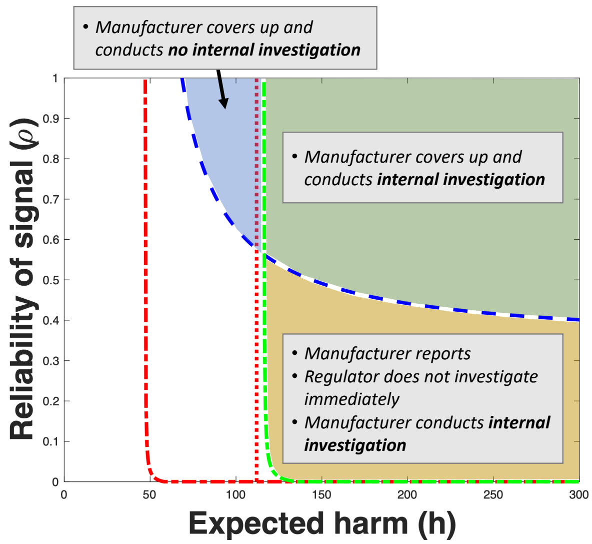
We have selected the slopes of these linear distributions to ensure a fair comparison among all three distributions by having the same probability that the regulator will initiate a voluntary investigation, which is $\int_0^{1-l} g(\hat{t} \mid D)d\hat{t} = h/\bar{h}$.

We find that the structure of the equilibrium is similar to that in the main body of the manuscript. In particular, we verify that Propositions 1, 2, 3, and 4 continue to hold (see Appendix D.6 for proofs). Figure 17 illustrates the equilibrium outcomes. The main effect of considering an increasing distribution is that the regulator is more likely to investigate immediately and the manufacturer is less likely to cover up potential defects. This is because with increasing distribution, voluntary investigations take place later, increasing potential recall costs and consumer harm, both in the U.K. and U.S. More importantly, comparing the equilibria for the U.S. and U.K, we observe that our main insight continues to hold: In the U.S. the regulator is less likely to investigate immediately and the manufacturer is more likely to cover up defects with significant harm for both alternative distributions.

C.8. Manufacturer's Internal Investigation

In our base model, the following two decisions are sequentially made: 1) the manufacturer decides whether to report a potential defect, and 2) if the manufacturer reports a potential defect, then the regulator decides whether to investigate it immediately. We can consider a situation where the manufacturer makes the following additional decision after the first two decisions are made: if the manufacturer covered up or the regulator did not investigate a report immediately, then the manufacturer decides whether to conduct an internal investigation. This results in a three-stage game.

Figure 18 U.S. Equilibrium Outcomes When the Manufacturer Carries Out an Internal Investigation



Unfortunately, it is not possible to characterize the equilibrium of this complex three-stage game under the assumptions in the main body of the manuscript. Thus, we characterize the equilibrium numerically under the following additional assumptions. First, the manufacturer's internal investigation has the same characteristics as the regulator's investigation, including the duration l and cost C. Second, the regulator does not initiate his voluntary investigation while the manufacturer's own internal investigation is underway. Third, if the manufacturer decides to cover up a potential defect, the expected penalty the manufacturer pays to the regulator is the same regardless of whether the manufacturer conducts an internal investigation or not. Finally, when the regulator decides whether to immediately investigate a potential defect in the second stage of the game, he ignores the possibility that the manufacturer may run a secret investigation internally. In fact, our interview with the U.K. regulator indicated no such consideration when deciding its investigation.

Under this model, for the U.S., we find that the manufacturer tends to cover up more potential defects with even more significant harm and instead conducts an internal investigation, as depicted in Figure 18. Specifically, the equilibrium outcomes differ from those in the base model in the two regions on the right of Figure 18. First, in the green region on the upper right side, the manufacturer covers up a potential defect and conducts an internal investigation. Compared with the equilibrium outcomes in the base model (see Figure 6), we observe that the manufacturer covers up even more defects, although she ends up conducting an internal investigation. Second, in the yellow region in the lower right side, the manufacturer reports a potential defect but the regulator does not investigate it immediately, and subsequently the manufacturer conducts an internal investigation. By contrast, for the U.K., we find that the manufacturer has no incentive to conduct an internal investigation. This is mainly because the manufacturer always prefers the regulator conducting the investigation instead of the manufacturer herself, since i) the regulator would not announce the investigation anyway and ii) the manufacturer does not need to incur the investigation cost C if the regulator does the investigation. Therefore, the equilibrium outcomes for the U.K. remain the same as in the base model depicted in Figure 5.

From these results, we observe that the manufacturer's internal investigation may set the two countries' policies even farther apart and induce more cover-ups under the U.S. policy, although it induces more internal investigations too.

Appendix D: Proofs of Results in Extensions

We provide the proofs of propositions for the extensions given in Appendix C. The proofs build on the proofs of the corresponding propositions under the base model, which are given in Appendix A. Thus, to conserve space, for each proposition, we refer to intermediate results provided in the proof of the corresponding proposition given in Appendix A. We denote the expected values of the manufacturer's profit, consumer surplus, regulator's cost, and social welfare in each extension by $\widehat{\pi}$, $\widehat{S}$, $\widehat{\Gamma}$, and $\widehat{W}$ respectively, while denoting those of the base model by π, S, Γ, and W.

D.1. Proofs for Appendix C.2: Consumers' Risk Aversion

Only the analysis of the U.S. policy is affected by this extension.

D.1.1. When σ is independent of h Let $d(p,h+\gamma\sigma)$ be the demand rate during investigation under the U.S. policy. We have that $\widehat{\Gamma}^{US}_{(R,I)} = \Gamma^{US}_{(R,I)}$ and $\widehat{\Gamma}^{US}_{(R,NI)} = \Gamma^{US}_{(R,NI)}$. Moreover,

$$\widehat{\pi}^{US}_{(R,I)} = \pi^{US}_{(R,I)} - pl\cdot(d(p,h) - d(p,h+\gamma\sigma)) + Pr(D\mid\tilde{D})(r+h)l\cdot(d(p,h)-d(p,h+\gamma\sigma)),$$
$$\widehat{\pi}^{US}_{(R,NI)} = \pi^{US}_{(R,NI)} - Pr(D\mid\tilde{D})\left[\int_0^{1-l} lp(d(p,h)-d(p,h+\gamma\sigma))g(\hat{t}\mid D)d\hat{t} - \int_0^{1-l}(r+h)l(d(p,h)-d(p,h+\gamma\sigma))g(\hat{t}\mid D)d\hat{t}\right],$$
$$\widehat{\pi}^{US}_{(NR)} = \widehat{\pi}^{US}_{(R,NI)} - Pr(D\mid\tilde{D})\cdot\theta(K_1h+K_2)\int_0^{1-l} g(\hat{t}\mid D)d\hat{t},$$
$$\widehat{S}^{US}_{(R,I)} = S^{US}_{(R,I)} - l\left[\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv - \int_{p+h+\gamma\sigma}^{\bar{v}}(v-p-h-\gamma\sigma)f(v)dv\right],$$
$$\widehat{S}^{US}_{(R,NI)} = S^{US}_{(R,NI)} - Pr(D\mid\tilde{D})\int_0^{1-l} g(\hat{t}\mid D)d\hat{t}\cdot l\left[\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv - \int_{p+h+\gamma\sigma}^{\bar{v}}(v-p-h-\gamma\sigma)f(v)dv\right].$$

Proof of Proposition 1. We have that

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} = Pr(D\mid\tilde{D})\xi_1(h) - \frac{lh}{\bar{v}}\left(\bar{v}-\frac{1}{2}h\right) - \frac{\gamma\sigma l}{\bar{v}}\left(\bar{v}-h-\frac{\gamma\sigma}{2}\right) - C,$$

where

$$\xi_1(h) = \chi_1(h) + \frac{\gamma\sigma l}{\bar{v}}\left(r+h+(p-r-h)\frac{h}{\bar{h}} + (2\bar{v}-2p-2h-\gamma\sigma)\frac{h}{2\bar{h}}\right),$$

using $\chi_1(h)$ defined in (10). If $\widehat{\xi}_1(h) = \xi_1(h) - \frac{lh}{\bar{v}}\left(\bar{v}-\frac{1}{2}h\right) - \frac{\gamma\sigma l}{\bar{v}}\left(\bar{v}-h-\frac{\gamma\sigma}{2}\right) - C < 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} < 0$ is always satisfied, because $Pr(D\mid\tilde{D}) \le 1$. If $\widehat{\xi}_1(h) \ge 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho_I^{US}(h) = \max\left\{\frac{\frac{(lh/\bar{v})(\bar{v}-h/2)+(\gamma\sigma l/\bar{v})(\bar{v}-h-\gamma\sigma/2)+C}{\xi_1(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_1(h)$ is a cubic function of h and the coefficient of the cubic term is negative. Also, $\widehat{\xi}_1(0) = -\frac{rl}{\bar{v}}(\bar{v}-p) - \frac{\gamma\sigma l}{\bar{v}}(\bar{v}-r-\frac{\gamma\sigma}{2}) - C < 0$, because $\bar{v}-r-\frac{\sigma\gamma}{2} \ge \bar{v}-r-\frac{1}{2}(\bar{v}-p-h) = \frac{1}{2}(\bar{v}+p+h-2r) > 0$ since $\gamma\sigma \le \bar{v}-p-h$ and $r<p<\bar{v}$. Moreover, $\widehat{\xi}_1(\bar{h}) = \frac{(r+\bar{h})}{2\bar{v}}(\bar{v}-p)(1-l) > 0$. Therefore, there exists $h_I^{US} \in (0,\bar{h})$

such that $\widehat{\xi}_1(h) \geq 0$ if and only if $h \geq h_I^{US}$. Thus, $\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,NI)}^{US} \geq 0$ is satisfied if and only if $h \geq h_I^{US}$ and $\rho \geq \rho_I^{US}(h)$, where $\rho_I^{US}(h) \in [0,1]$. □

Proof of Proposition 2. We show that there exist h_R^{US} and $\rho_R^{US}(h)$ such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h_R^{US}$ and $\rho \geq \rho_R^{US}(h)$. The rest of the proof is similar to the proof of Proposition 2 under the base model.

Using $\Omega_1(h)$ defined in (16), we have that

$$\widehat{\pi}_{(R,I)}^{US} - \widehat{\pi}_{(NR)}^{US} = Pr(D \mid \tilde{D})\psi_1(h) - \frac{pl(h+\gamma\sigma)}{\bar{v}}, \qquad \text{where } \psi_1(h) = \Omega_1(h) + \frac{\gamma\sigma l}{\bar{v}}\left(r + h + (p-r-h)\frac{h}{\bar{h}}\right).$$

If $\widehat{\psi}_1(h) = \psi_1(h) - \frac{pl(h+\gamma\sigma)}{\bar{v}} < 0$, then $\widehat{\pi}_{(R,I)}^{US} - \widehat{\pi}_{(NR)}^{US} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. If $\widehat{\psi}_1(h) \geq 0$, then $\widehat{\pi}_{(R,I)}^{US} - \widehat{\pi}_{(NR)}^{US} \geq 0$ if and only if

$$\rho \geq \rho_R^{US}(h) = \max\left\{\frac{\frac{pl(h+\gamma\sigma)/\bar{v}}{\psi_1(h)} - Pr(D)}{1 - Pr(D)}, 0\right\}. \tag{22}$$

We verify that $\widehat{\psi}_1(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\psi}_1(0) = -lr\left(1 - \frac{p}{\bar{v}}\right) - \frac{\gamma\sigma l}{\bar{v}}(p-r) < 0$ and $\widehat{\psi}_1(\bar{h}) = \widehat{\Omega}_1(\bar{h}) > 0$ by (18). Therefore, there exists $h_R^{US} \in (0, \bar{h})$ such that $\widehat{\psi}_1(h) \geq 0$ if and only if $h \geq h_R^{US}$. Thus, $\widehat{\pi}_{(R,I)}^{US} - \widehat{\pi}_{(NR)}^{US} \geq 0$ if and only if $h \geq h_R^{US}$ and $\rho \geq \rho_R^{US}(h)$, where $\rho_R^{US}(h) \in [0,1]$. □

Proof of Proposition 3. The proof is the same as in the base model. □

Proof of Proposition 4. We have that

$$\widehat{W}_{(NR)}^{US} - \widehat{W}_{(NR)}^{UK} = \widehat{W}_{(R,NI)}^{US} - \widehat{W}_{(R,NI)}^{UK} = -Pr(D \mid \tilde{D})\frac{hl(h+\gamma\sigma)}{\bar{v}\bar{h}}\left[\bar{v} - r - \frac{3h+\gamma\sigma}{2}\right].$$

Therefore, $\widehat{W}_{(NR)}^{US} - \widehat{W}_{(NR)}^{UK} > 0$ if and only if $\bar{v} < r + \frac{3h+\gamma\sigma}{2}$. Also,

$$\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,I)}^{UK} = -\frac{l(h+\gamma\sigma)}{\bar{v}}\left[\bar{v} - \frac{h+\gamma\sigma}{2} - Pr(D \mid \tilde{D})(r+h)\right].$$

Therefore, $\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,I)}^{UK} > 0$ if and only if $\bar{v} < \frac{h+\gamma\sigma}{2} + Pr(D \mid \tilde{D})(r+h)$. □

D.1.2. When σ is proportional to h Let $d(p, \beta h)$ be the demand rate during investigation under the U.S. policy. We have that $\widehat{\Gamma}_{(R,I)}^{US} = \Gamma_{(R,I)}^{US}$ and $\widehat{\Gamma}_{(R,NI)}^{US} = \Gamma_{(R,NI)}^{US}$. Moreover,

$$\widehat{\pi}_{(R,I)}^{US} = \pi_{(R,I)}^{US} - pl\cdot(d(p,h) - d(p,\beta h)) + Pr(D \mid \tilde{D})(r+h)l\cdot(d(p,h) - d(p,\beta h)),$$

$$\widehat{\pi}_{(R,NI)}^{US} = \pi_{(R,NI)}^{US} - Pr(D \mid \tilde{D})\left[\int_0^{1-l} lp(d(p,h) - d(p,\beta h))g(\hat{t} \mid D)d\hat{t} - \int_0^{1-l}(r+h)l(d(p,h) - d(p,\beta h))g(\hat{t} \mid D)d\hat{t}\right],$$

$$\widehat{\pi}_{(NR)}^{US} = \widehat{\pi}_{(R,NI)}^{US} - Pr(D \mid \tilde{D})\cdot\theta(K_1 h + K_2)\int_0^{1-l} g(\hat{t} \mid D)d\hat{t},$$

$$\widehat{S}_{(R,I)}^{US} = S_{(R,I)}^{US} - l\left[\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv - \int_{p+\beta h}^{\bar{v}}(v-p-\beta h)f(v)dv\right],$$

$$\widehat{S}_{(R,NI)}^{US} = S_{(R,NI)}^{US} - Pr(D \mid \tilde{D})\int_0^{1-l} g(\hat{t} \mid D)d\hat{t}\cdot l\left[\int_{p+h}^{\bar{v}}(v-p-h)f(v)dv - \int_{p+\beta h}^{\bar{v}}(v-p-\beta h)f(v)dv\right].$$

Proof of Proposition 1. We have that

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_2(h) - \frac{l\beta h}{\bar{v}}\left(\bar{v} - \frac{\beta h}{2}\right) - C,$$

where

$$\xi_2(h) = \frac{\beta l h^2}{\bar{v}\bar{h}}\left(\bar{v} - \frac{\beta h}{2}\right) + \frac{(r+h)}{2\bar{v}\bar{h}}\left((\bar{v}-p)((1+l)h - 2l\bar{h}) + 2h\beta l(\bar{h}-h)\right) + \frac{(\bar{v}-p)(\bar{h}-h)h}{\bar{v}\bar{h}} + \frac{h}{\bar{h}}C.$$

If $\widehat{\xi}_2(h) = \xi_2(h) - \frac{l\beta h}{\bar{v}}\left(\bar{v} - \frac{\beta h}{2}\right) - C < 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_2(h) \ge 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho^{US}_I(h) = \max\left\{\frac{\frac{l\beta h(\bar{v}-\beta h/2)/\bar{v}+C}{\xi_2(h)} - Pr(D)}{1 - Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_2(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\xi}_2(0) = -\frac{rl}{\bar{v}}(\bar{v}-p) - C < 0$ and $\widehat{\xi}_2(\bar{h}) = \frac{1}{2\bar{v}}(1-l)(r+\bar{h})(\bar{v}-p) > 0$. Therefore, there exists $h^{US}_I \in (0,\bar{h})$ such that $\widehat{\xi}_2(h) \ge 0$ if and only if $h \ge h^{US}_I$. Thus, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if $h \ge h^{US}_I$ and $\rho \ge \rho^{US}_I(h)$, where $\rho^{US}_I(h) \in [0,1]$. □

Proof of Proposition 2. We show that there exist h^{US}_R and $\rho^{US}_R(h)$ such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \ge h^{US}_R$ and $\rho \ge \rho^{US}_R(h)$. The rest of the proof is similar to the proof of Proposition 2 under the base model. We have that

$$\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} = Pr(D \mid \tilde{D})\psi_2(h) - \frac{pl\beta h}{\bar{v}},$$

where

$$\psi_2(h) = -\frac{\beta(lh^3 - (p-r)lh^2 - (r+h)l\bar{h}h)}{\bar{v}\bar{h}} + \left(1 - \frac{p}{\bar{v}}\right)\frac{(1+l-2\alpha)h^2 + (r(1+l) + 2\alpha\bar{h} - 2\bar{h}l)h - 2\bar{h}rl}{2\bar{h}} + \theta(K_1 h + K_2)\frac{h}{\bar{h}}.$$

If $\widehat{\psi}_2(h) = \psi_2(h) - \frac{pl\beta h}{\bar{v}} < 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\psi}_2(h) \ge 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \ge 0$ if and only if

$$\rho \ge \rho^{US}_R(h) = \max\left\{\frac{\frac{pl\beta h/\bar{v}}{\psi_2(h)} - Pr(D)}{1 - Pr(D)}, 0\right\}.$$

We verify that $\widehat{\psi}_2(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\psi}_2(0) = -rl\left(1 - \frac{p}{\bar{v}}\right) < 0$ and $\widehat{\psi}_2(\bar{h}) = \frac{1}{2\bar{v}}\left[(1-l)(\bar{v}-p)r + 2K_2\theta\bar{v} + \bar{h}((1-l)(\bar{v}-p) + 2K_1\theta\bar{v})\right] > 0$. Therefore, there exists $h^{US}_R \in (0,\bar{h})$ such that $\widehat{\psi}_2(h) \ge 0$ if and only if $h \ge h^{US}_R$. Thus, $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \ge 0$ if and only if $h \ge h^{US}_R$ and $\rho \ge \rho^{US}_R(h)$, where $\rho^{US}_R(h) \in [0,1]$. □

Proof of Proposition 3. The proof is the same as in the base model. □

Proof of Proposition 4. We have that

$$\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} = \widehat{W}^{US}_{(R,NI)} - \widehat{W}^{UK}_{(R,NI)} = -Pr(D \mid \tilde{D}) \cdot \frac{\beta h^2 l(2\bar{v} - 2r - (2+\beta)h)}{2\bar{v}\bar{h}}.$$

Therefore, $\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} > 0$ if and only if $\bar{v} < r + (1 + \frac{\beta}{2})h$. Also,

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} = -\frac{\beta hl}{\bar{v}}\left(\bar{v} - \frac{\beta}{2}h - Pr(D \mid \tilde{D})(r+h)\right).$$

Therefore, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} > 0$ if and only if $\bar{v} < \frac{\beta}{2}h + Pr(D \mid \tilde{D})(r+h)$. □

D.2. Proofs for Appendix C.3: Short-Term Demand Drop After a Product Recall

After a product recall, the demand rate drops to $d(p,\delta h) = 1 - F(p+\delta h)$, where $\delta > 0$, for $\epsilon > 0$ time period. For $j = \{US, UK\}$, we have that $\widehat{\Gamma}^j_{(R,I)} = \Gamma^j_{(R,I)}$ and $\widehat{\Gamma}^j_{(R,NI)} = \Gamma^j_{(R,NI)}$. Moreover,

$$\begin{aligned}
\widehat{\pi}^j_{(R,I)} &= \pi^j_{(R,I)} - Pr(D \mid \tilde{D}) \cdot p\epsilon(d(p) - d(p,\delta h)),\\
\widehat{\pi}^j_{(R,NI)} &= \pi^j_{(R,NI)} - Pr(D \mid \tilde{D}) \cdot \int_0^{1-l} g(\hat{t} \mid D) d\hat{t} \cdot p\epsilon(d(p) - d(p,\delta h)),\\
\widehat{\pi}^j_{(NR)} &= \widehat{\pi}^j_{(R,NI)} - Pr(D \mid \tilde{D}) \cdot \theta(K_1 h + K_2) \int_0^{1-l} g(\hat{t} \mid D) d\hat{t},\\
\widehat{S}^j_{(R,I)} &= S^j_{(R,I)} - Pr(D \mid \tilde{D}) \cdot \epsilon \left(\int_p^{\bar{v}} (v-p) f(v) dv - \int_{p+\delta h}^{\bar{v}} (v-p-\delta h) f(v) dv \right),\\
\widehat{S}^j_{(R,NI)} &= S^j_{(R,NI)} - Pr(D \mid \tilde{D}) \cdot \int_0^{1-l} g(\hat{t} \mid D) d\hat{t} \cdot \epsilon \left(\int_p^{\bar{v}} (v-p) f(v) dv - \int_{p+\delta h}^{\bar{v}} (v-p-\delta h) f(v) dv \right).
\end{aligned}$$

Proof of Proposition 1. We show this result for each country separately.

The U.S. Case. We have that

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_3(h) - \frac{lh}{\bar{v}}\left(\bar{v} - \frac{1}{2}h\right) - C, \quad \text{where } \xi_3(h) = \chi_1(h) - \left(1 - \frac{h}{\bar{h}}\right)\left(\bar{v} - \frac{1}{2}\delta h\right)\frac{\epsilon \delta h}{\bar{v}},$$

using $\chi_1(h)$ defined in (10). If $\widehat{\xi}_3(h) = \xi_3(h) - \frac{lh}{\bar{v}}\left(\bar{v} - \frac{1}{2}h\right) - C < 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_3(h) \ge 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho^{US}_I(h) = \max\left\{ \frac{\frac{(lh/\bar{v})(\bar{v}-h/2)+C}{\xi_3(h)} - Pr(D)}{1 - Pr(D)}, 0 \right\}.$$

We verify that $\widehat{\xi}_3(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\xi}_3(0) = \widehat{\chi}_1(0) < 0$ and $\widehat{\xi}_3(\bar{h}) = \widehat{\chi}_1(\bar{h}) > 0$. Therefore, there exists $h^{US}_I \in (0,\bar{h})$ such that $\widehat{\xi}_3(h) \ge 0$ if and only if $h \ge h^{US}_I$. Thus, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h^{US}_I$ and $\rho \ge \rho^{US}_I(h)$, where $\rho^{US}_I(h) \in [0,1]$.

The U.K. Case. We have that

$$\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_4(h) - C, \quad \text{where } \xi_4(h) = \chi_2(h) - \left(1 - \frac{h}{\bar{h}}\right)\left(\bar{v} - \frac{1}{2}\delta h\right)\frac{\epsilon \delta h}{\bar{v}},$$

using $\chi_2(h)$ defined in (13). If $\widehat{\xi}_4(h) = \xi_4(h) - C < 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_4(h) \ge 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho^{UK}_I(h) = \max\left\{ \frac{\frac{C}{\xi_4(h)} - Pr(D)}{1 - Pr(D)}, 0 \right\}.$$

We verify that $\widehat{\xi}_4(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\xi}_4(0) = \widehat{\chi}_2(0) < 0$ and $\widehat{\xi}_4(\bar{h}) = \widehat{\chi}_2(\bar{h}) > 0$. Therefore, there exists $h^{UK}_I \in (0,\bar{h})$ such that $\widehat{\xi}_4(h) \ge 0$ if and only if $h \ge h^{UK}_I$. Thus, $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h^{UK}_I$ and $\rho \ge \rho^{UK}_I(h)$, where $\rho^{UK}_I(h) \in [0,1]$. □

Proof of Proposition 2. We show that there exist h^{US}_R and $\rho^{US}_R(h)$ such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \ge h^{US}_R$ and $\rho \ge \rho^{US}_R(h)$. The rest of the proof is similar to the proof of Proposition 2 under the base model.

Using $\Omega_1(h)$ defined in (16), we have that

$$\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} = Pr(D \mid \tilde{D})\psi_3(h) - \frac{plh}{\bar{v}}, \quad \text{where } \psi_3(h) = \Omega_1(h) - \frac{p\epsilon\delta h}{\bar{v}}\left(1 - \frac{h}{\bar{h}}\right).$$

If $\widehat{\psi}_3(h) = \psi_3(h) - \frac{plh}{\bar{v}} < 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} < 0$ is always satisfied. If $\widehat{\psi}_3(h) \geq 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \geq 0$ if and only if

$$\rho \geq \rho^{US}_R(h) = \max\left\{\frac{\frac{plh/\bar{v}}{\psi_3(h)} - Pr(D)}{1 - Pr(D)}, 0\right\}.$$

We verify that $\widehat{\psi}_3(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\psi}_3(0) = \widehat{\Omega}_1(0) < 0$ and $\widehat{\psi}_3(\bar{h}) = \widehat{\Omega}_1(\bar{h}) > 0$. Therefore, there exists $h^{US}_R \in (0, \bar{h})$ such that $\widehat{\psi}_3(h) \geq 0$ if and only if $h \geq h^{US}_R$. Thus, $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \geq 0$ if and only if $h \geq h^{US}_R$ and $\rho \geq \rho^{US}_R(h)$, where $\rho^{US}_R(h) \in [0,1]$. □

Proof of Proposition 3. We show that there exists h^{UK}_R such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h^{UK}_R$. The rest of the proof is similar to the proof of Proposition 3 under the base model.

Using $\Omega_2(h)$ defined in (19), we have that

$$\widehat{\pi}^{UK}_{(R,I)} - \widehat{\pi}^{UK}_{(NR)} = Pr(D \mid \tilde{D})\psi_4(h), \quad \text{where } \psi_4(h) = \Omega_2(h) - \frac{p\epsilon\delta h}{\bar{v}}\left(1 - \frac{h}{\bar{h}}\right).$$

We verify that $\psi_4(h)$ is a quadratic function of h, $\psi_4(0) = \Omega_2(0) < 0$, and $\psi_4(\bar{h}) = \Omega_2(\bar{h}) > 0$. Therefore, there exists $h^{UK}_R \in (0, \bar{h})$ such that $\widehat{\pi}^{UK}_{(R,I)} - \widehat{\pi}^{UK}_{(NR)} \geq 0$ if and only if $h \geq h^{UK}_R$. □

Proof of Proposition 4. It is trivial that $\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} = W^{US}_{(NR)} - W^{UK}_{(NR)}$, $\widehat{W}^{US}_{(R,NI)} - \widehat{W}^{UK}_{(R,NI)} = W^{US}_{(R,NI)} - W^{UK}_{(R,NI)}$ and $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} = W^{US}_{(R,I)} - W^{UK}_{(R,I)}$. Therefore, the proof is the same as in the base model. □

D.3. Proofs for Appendix C.4: Demand Drop After a Cover-Up Relevation

This extension affects only the manufacturer's expected profit and consumer surplus in the (NR) scenario under both countries' policies. Specifically, for $j = \{US, UK\}$, we have that

$$\widehat{\pi}^{j}_{(NR)} = \pi^{j}_{(NR)} - Pr(D \mid \tilde{D})\int_0^{1-l} g(\hat{t} \mid D)d\hat{t} \cdot \theta p\epsilon(d(p) - d(p, \delta h)),$$
$$\widehat{S}^{j}_{(NR)} = S^{j}_{(NR)} - Pr(D \mid \tilde{D})\int_0^{1-l} g(\hat{t} \mid D)d\hat{t} \cdot \theta\epsilon\left(\int_p^{\bar{v}}(v-p)f(v)dv - \int_{p+\delta h}^{\bar{v}}(v-p-\delta h)f(v)dv\right).$$

Proof of Proposition 1. The proof is the same as in the base model. □

Proof of Propositions 2. We show that there exist h^{US}_R and $\rho^{US}_R(h)$ such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h^{US}_R$ and $\rho \geq \rho^{US}_R(h)$. The rest of the proof is similar to the proof of Proposition 2 under the base model. We have that

$$\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} = Pr(D \mid \tilde{D})\psi_5(h) - \frac{plh}{\bar{v}}, \quad \text{where} \quad \psi_5(h) = \Omega_1(h) + \theta p\epsilon\frac{\delta h^2}{\bar{v}\bar{h}},$$

using $\Omega_1(h)$ defined in (16). If $\widehat{\psi}_5(h) = \psi_5(h) - \frac{plh}{\bar{v}} < 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. If $\widehat{\psi}_5(h) \geq 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \geq 0$ if and only if

$$\rho \geq \rho^{US}_R(h) = \max\left\{\frac{\frac{plh/\bar{v}}{\psi_5(h)} - Pr(D)}{1 - Pr(D)}, 0\right\}.$$

We verify that $\widehat{\psi}_5(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\psi}_5(0) = -lr(1-\frac{p}{\bar{v}}) < 0$ and $\widehat{\psi}_5(\bar{h}) = \frac{1}{2\bar{v}}[(1-l)(\bar{v}-p)r + 2K_2\theta\bar{v} + \bar{h}((1-l)(\bar{v}-p) + 2K_1\theta\bar{v})] + \theta p\epsilon\frac{\delta\bar{h}}{\bar{v}} > 0$. Therefore, there exists $h_R^{US} \in (0,\bar{h})$ such that $\widehat{\psi}_5(h) \geq 0$ if and only if $h \geq h_R^{US}$. Thus, $\widehat{\pi}_{(R,I)}^{US} - \widehat{\pi}_{(NR)}^{US} \geq 0$ if and only if $h \geq h_R^{US}$ and $\rho \geq \rho_R^{US}(h)$, where $\rho_R^{US}(h) \in [0,1]$. □

Proof of Proposition 3. We show that there exists h_R^{UK} such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h_R^{UK}$. The rest of the proof is similar to the proof of Proposition 3 under the base model. We have that

$$\widehat{\pi}_{(R,I)}^{UK} - \widehat{\pi}_{(NR)}^{UK} = Pr(D \mid \tilde{D})\psi_6(h), \quad \text{where} \quad \psi_6(h) = \Omega_2(h) + \theta p\epsilon\frac{\delta h^2}{\bar{v}\bar{h}},$$

using $\Omega_2(h)$ defined in (19). We verify that $\psi_6(h)$ is a quadratic function of h, and $\psi_6(0) = -rl(1-\frac{p}{\bar{v}}) < 0$ and $\psi_6(\bar{h}) = \frac{1}{2\bar{v}}[(1-l)(\bar{v}-p)(r+\bar{h}) + 2K_2\theta\bar{v} + 2K_1\theta\bar{v}\bar{h}] + \theta p\epsilon\frac{\delta\bar{h}}{\bar{v}} > 0$. Therefore, there exists $h_R^{UK} \in (0,\bar{h})$ such that $\widehat{\pi}_{(R,I)}^{UK} - \widehat{\pi}_{(NR)}^{UK} \geq 0$ if and only if $h \geq h_R^{UK}$. □

Proof of Proposition 4. Scenarios (R,I) and (R,NI) remain unaffected by this extension. Also, it is easy to see that $\widehat{W}_{(NR)}^{US} - \widehat{W}_{(NR)}^{UK} = W_{(NR)}^{US} - W_{(NR)}^{UK}$. Therefore, the proof is the same as in the base model. □

D.4. Proofs for Appendix C.5: Demand Substitution

It is easy to see that only the consumer surplus under the U.S. policy is affected by this extension. Specifically,

$$\widehat{S}_{(R,I)}^{US} = \int_p^{\bar{v}} (v-p)f(v)dv,$$

$$\widehat{S}_{(R,NI)}^{US} = Pr(N \mid \tilde{D})\int_p^{\bar{v}} (v-p)f(v)dv + Pr(D \mid \tilde{D})\left[\int_0^{1-l} g(\hat{t} \mid D)d\hat{t}\int_p^{\bar{v}} (v-p)f(v)dv + Pr(\hat{t}=1 \mid D)\left(\int_p^{\bar{v}} (v-p)f(v)dv - (1-\alpha)hd(p)\right)\right].$$

Proof of Proposition 1. We need to show only the U.S. case.

The U.S. Case. We have that

$$\widehat{W}_{(R,I)}^{US} = W_{(R,I)}^{US} + \frac{lh}{2\bar{v}}(2\bar{v}-2p-h), \quad \text{and} \quad \widehat{W}_{(R,NI)}^{US} = W_{(R,NI)}^{US} + Pr(D \mid \tilde{D})\frac{lh^2}{2\bar{v}\bar{h}}(2\bar{v}-2p-h).$$

Therefore,

$$\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,NI)}^{US} = Pr(D \mid \tilde{D})\xi_7(h) - \frac{plh}{\bar{v}} - C, \quad \text{where} \quad \xi_7(h) = \chi_1(h) - \frac{lh^2}{2\bar{v}\bar{h}}(2\bar{v}-2p-h),$$

using $\chi_1(h)$ defined in (10). If $\widehat{\xi}_7(h) = \xi_7(h) - \frac{plh}{\bar{v}} - C < 0$, then $\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,NI)}^{US} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. If $\widehat{\xi}_7(h) \geq 0$, then $\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,NI)}^{US} \geq 0$ if and only if

$$\rho \geq \rho_I^{US}(h) = \max\left\{\frac{\frac{plh/\bar{v}+C}{\xi_7(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_7(h)$ is a cubic function of h, the coefficient of the cubic term is $-\frac{lh^3}{\bar{v}\bar{h}} < 0$, and $\widehat{\xi}_7(0) = -\frac{rl}{\bar{v}}(\bar{v}-p) - C < 0$ and $\widehat{\xi}_7(\bar{h}) = \frac{1}{2\bar{v}}(r+\bar{h})(1-l)(\bar{v}-p) > 0$. Therefore, there exists $h_I^{US} \in (0,\bar{h})$ such that $\widehat{\xi}_7(h) \geq 0$ if and only if $h \geq h_I^{US}$. Thus, $\widehat{W}_{(R,I)}^{US} - \widehat{W}_{(R,NI)}^{US} \geq 0$ if and only if $h \geq h_I^{US}$ and $\rho \geq \rho_I^{US}(h)$, where $\rho_I^{US}(h) \in [0,1]$. □

Proofs of Propositions 2 and 3. The proofs are the same as in the base model. □

Proof of Proposition 4. We have that

$$\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} = \widehat{W}^{US}_{(R,NI)} - \widehat{W}^{UK}_{(R,NI)} = -Pr(D \mid \tilde{D})\frac{lh^2}{\bar{v}\bar{h}}(p-r-h).$$

Therefore, $\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} > 0$ if and only if $p < r+h$. Also,

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} = -\frac{lh}{\bar{v}}(p - Pr(D \mid \tilde{D})(r+h)).$$

Therefore, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} > 0$ if and only if $p < Pr(D \mid \tilde{D})(r+h)$. □

D.5. Proofs for Appendix C.6: Alternative Objective Function of the Regulator

The consumer harm H is defined as follows.

$$\begin{aligned}
H^{US}_{(R,I)} &= Pr(D \mid \tilde{D})hl \cdot d(p,h),\\
H^{US}_{(R,NI)} = H^{US}_{(NR)} &= Pr(D \mid \tilde{D})\left[\int_0^{1-l} h(d(p)\hat{t} + d(p,h)l)g(\hat{t} \mid D)d\hat{t} + hd(p)Pr(\hat{t}=1 \mid D)\right],\\
H^{UK}_{(R,I)} &= Pr(D \mid \tilde{D})hl \cdot d(p),\\
H^{UK}_{(R,NI)} = H^{UK}_{(NR)} &= Pr(D \mid \tilde{D})\left[\int_0^{1-l} h(\hat{t}+l)d(p)g(\hat{t} \mid D)d\hat{t} + hd(p)Pr(\hat{t}=1 \mid D)\right].
\end{aligned}$$

Proof of Proposition 1. We show this result for each country separately.

The U.S. Case. We have that

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_8(h) - \phi\frac{lh}{\bar{v}}\left(\bar{v} - \frac{h}{2}\right) - C,$$

where

$$\begin{aligned}
\xi_8(h) = \frac{h}{\bar{h}}C + \phi&\left[\frac{(r+h)}{2\bar{v}\bar{h}}((\bar{v}-p)(h(1+l) - 2\bar{h}l) + 2lh(\bar{h}-h)) + \frac{lh^2}{\bar{v}\bar{h}}\left(\bar{v} - \frac{h}{2}\right) + \frac{h(\bar{h}-h)(\bar{v}-p)}{\bar{v}\bar{h}}\right]\\
&- (1-\phi)\left[\frac{hl(\bar{v}-p-h)}{\bar{v}} - \frac{h^2((1+l)(\bar{v}-p) - 2hl)}{2\bar{v}\bar{h}} - \frac{h(\bar{v}-p)(\bar{h}-h)}{\bar{v}\bar{h}}\right].
\end{aligned}$$

If $\widehat{\xi}_8(h) = \xi_8(h) - \phi\frac{lh}{\bar{v}}\left(\bar{v} - \frac{h}{2}\right) - C < 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_8(h) \ge 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho^{US}_I(h) = \max\left\{\frac{\frac{\phi lh(\bar{v}-h/2)/\bar{v}+C}{\xi_8(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_8(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\xi}_8(0) = -\frac{\phi rl(\bar{v}-p)}{\bar{v}} - C < 0$ and $\widehat{\xi}_8(\bar{h}) = \phi\frac{(r+\bar{h})(\bar{v}-p)(1-l)}{2\bar{v}} + (1-\phi)\frac{(1-l)(\bar{v}-p)\bar{h}}{2\bar{v}} > 0$. Therefore, there exists $h^{US}_I \in (0,\bar{h})$ such that $\widehat{\xi}_8(h) \ge 0$ if and only if $h \ge h^{US}_I$. Thus, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h^{US}_I$ and $\rho \ge \rho^{US}_I(h)$, where $\rho^{US}_I(h) \in [0,1]$.

The U.K. Case. We have that

$$\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_9(h) - C,$$

where

$$\xi_9(h) = \frac{h}{\bar{h}}C + \phi\left[h\left(1-\frac{h}{\bar{h}}\right)\left(1-\frac{p}{\bar{v}}\right) + (r+h)\left(1-\frac{p}{\bar{v}}\right)\frac{h(1+l)-2\bar{h}l}{2\bar{h}}\right] - (1-\phi)\left[hl\left(1-\frac{p}{\bar{v}}\right) - \frac{(1+l)(\bar{v}-p)h^2}{2\bar{v}\bar{h}} - \frac{h(\bar{v}-p)(\bar{h}-h)}{\bar{v}\bar{h}}\right].$$

If $\widehat{\xi}_9(h) = \xi_9(h) - C < 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_9(h) \ge 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho_I^{UK}(h) = \max\left\{\frac{\frac{C}{\xi_9(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_9(h)$ is a quadratic function of h, and $\widehat{\xi}_9(0) = -\phi rl\left(1-\frac{p}{\bar{v}}\right) - C < 0$ and $\widehat{\xi}_9(\bar{h}) = \phi(r+\bar{h})(1-\frac{p}{\bar{v}})\frac{1-l}{2} + (1-\phi)\frac{1-l}{2}\frac{\bar{v}-p}{\bar{v}}\bar{h} > 0$. Therefore, there exists $h_I^{UK} \in (0,\bar{h})$ such that $\widehat{\xi}_9(h) \ge 0$ if and only if $h \ge h_I^{UK}$. Thus, $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h_I^{UK}$ and $\rho \ge \rho_I^{UK}(h)$, where $\rho_I^{UK}(h) \in [0,1]$. □

Proofs of Propositions 2 and 3. The proofs are the same as in the base model. □

D.6. Proofs for Appendix C.7: Alternative Distributions of Voluntary Investigation Timing

It is straightforward to see that, for each country, only the manufacturer's profits in the (R,NI) and (NR) scenarios change from the base model, while the manufacturer's profit in the (R,I) scenario as well as the consumer surplus and regulator's cost in all scenarios remain unaffected, because $\int_0^{1-l} g(\hat{t} \mid D)d\hat{t}$ remains unaffected (see equations in Section 3).

D.6.1. $g(\hat{t} \mid D)$ is linearly decreasing in $\hat{t}$

Proof of Proposition 1. We show this result for each country separately.

The U.S. Case. We have that $\widehat{W}^{US}_{(R,I)} = W^{US}_{(R,I)}$ and $\widehat{W}^{US}_{(R,NI)} = W^{US}_{(R,NI)} + Pr(D \mid \tilde{D})\frac{(1-l)(r+h)(\bar{v}-p)h}{6\bar{v}\bar{h}}$. Thus,

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_{10}(h) - \frac{lh}{\bar{v}}\left(\bar{v} - \frac{h}{2}\right) - C, \quad \text{where } \xi_{10}(h) = \chi_1(h) - \frac{(1-l)(r+h)(\bar{v}-p)h}{6\bar{v}\bar{h}},$$

using $\chi_1(h)$ defined in (10). If $\widehat{\xi}_{10}(h) = \xi_{10}(h) - \frac{lh}{\bar{v}}\left(\bar{v}-\frac{h}{2}\right) - C < 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_{10}(h) \ge 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho_I^{US}(h) = \max\left\{\frac{\frac{lh(\bar{v}-h/2)/\bar{v}+C}{\xi_{10}(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_{10}(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\xi}_{10}(0) = -\frac{rl}{\bar{v}}(\bar{v}-p) - C < 0$ and $\widehat{\xi}_{10}(\bar{h}) = \frac{(r+\bar{h})(\bar{v}-p)(1-l)}{3\bar{v}} > 0$. Therefore, there exists $h_I^{US} \in (0,\bar{h})$ such that $\widehat{\xi}_{10}(h) \ge 0$ if and only if $h \ge h_I^{US}$. Thus, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h_I^{US}$ and $\rho \ge \rho_I^{US}(h)$, where $\rho_I^{US}(h) \in [0,1]$.

The U.K. Case. We have that $\widehat{W}^{UK}_{(R,I)} = W^{UK}_{(R,I)}$ and $\widehat{W}^{UK}_{(R,NI)} = W^{UK}_{(R,NI)} + Pr(D \mid \tilde{D})\frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}}$. Thus,

$$\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_{11}(h) - C, \quad \text{where } \xi_{11}(h) = \chi_2(h) - \frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}},$$

using $\chi_2(h)$ defined in (13). If $\widehat{\xi}_{11}(h) = \xi_{11}(h) - C < 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. If $\widehat{\xi}_{11}(h) \geq 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \geq 0$ if and only if

$$\rho \geq \rho^{UK}_I(h) = \max\left\{ \frac{\frac{C}{\xi_{11}(h)} - Pr(D)}{1 - Pr(D)}, 0 \right\}.$$

We verify that $\widehat{\xi}_{11}(h)$ is a quadratic function of h, and $\widehat{\xi}_{11}(0) = -rl(1 - \frac{p}{\bar{v}}) - C < 0$ and $\widehat{\xi}_{11}(\bar{h}) = \frac{(1-l)(\bar{v}-p)(r+\bar{h})}{3\bar{v}} > 0$. Therefore, there exists $h^{UK}_I \in (0, \bar{h})$ such that $\widehat{\xi}_{11}(h) \geq 0$ if and only if $h \geq h^{UK}_I$. Thus, $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \geq 0$ is satisfied if and only if $h \geq h^{UK}_I$ and $\rho \geq \rho^{UK}_I(h)$, where $\rho^{UK}_I(h) \in [0, 1]$. □

Proof of Proposition 2. We show that there exist h^{US}_R and $\rho^{US}_R(h)$ such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h^{US}_R$ and $\rho \geq \rho^{US}_R(h)$. The rest of the proof is similar to the proof of Proposition 2 under the base model.

We have that $\widehat{\pi}^{US}_{(R,I)} = \pi^{US}_{(R,I)}$ and $\widehat{\pi}^{US}_{(NR)} = \pi^{US}_{(NR)} + Pr(D \mid \tilde{D})\frac{(1-l)(r+h)(\bar{v}-p)h}{6\bar{v}\bar{h}}$. Thus,

$$\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} = Pr(D \mid \tilde{D})\psi_{10}(h) - \frac{plh}{\bar{v}}, \quad \text{where } \psi_{10}(h) = \Omega_1(h) - \frac{(1-l)(r+h)(\bar{v}-p)h}{6\bar{v}\bar{h}},$$

using $\Omega_1(h)$ defined in (16). If $\widehat{\psi}_{10}(h) = \psi_{10}(h) - \frac{plh}{\bar{v}} < 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \leq 1$. If $\widehat{\psi}_{10}(h) \geq 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \geq 0$ if and only if

$$\rho \geq \rho^{US}_R(h) = \max\left\{ \frac{\frac{plh/\bar{v}}{\psi_{10}(h)} - Pr(D)}{1 - Pr(D)}, 0 \right\}.$$

We verify that $\widehat{\psi}_{10}(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\psi}_{10}(0) = -lr(1 - \frac{p}{\bar{v}}) < 0$ and $\widehat{\psi}_{10}(\bar{h}) = \frac{(1-l)(r+\bar{h})(\bar{v}-p)}{3\bar{v}} + \theta(K_1\bar{h} + K_2) > 0$. Therefore, there exists $h^{US}_R \in (0, \bar{h})$ such that $\widehat{\psi}_{10}(h) \geq 0$ if and only if $h \geq h^{US}_R$. Thus, $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \geq 0$ if and only if $h \geq h^{US}_R$ and $\rho \geq \rho^{US}_R(h)$, where $\rho^{US}_R(h) \in [0, 1]$. □

Proof of Proposition 3. We show that there exists h^{UK}_R such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h^{UK}_R$. The rest of the proof is similar to the proof of Proposition 3 under the base model.

We have that $\widehat{\pi}^{UK}_{(R,I)} = \pi^{UK}_{(R,I)}$ and $\widehat{\pi}^{UK}_{(NR)} = \pi^{UK}_{(NR)} + Pr(D \mid \tilde{D})\frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}}$. Thus,

$$\widehat{\pi}^{UK}_{(R,I)} - \widehat{\pi}^{UK}_{(NR)} = Pr(D \mid \tilde{D})\psi_{11}(h), \quad \text{where } \psi_{11}(h) = \Omega_2(h) - \frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}},$$

using $\Omega_2(h)$ defined in (19). We verify that $\psi_{11}(h)$ is a quadratic function of h, and $\psi_{11}(0) = -rl(1 - \frac{p}{\bar{v}}) < 0$ and $\psi_{11}(\bar{h}) = \frac{(1-l)(\bar{v}-p)(r+\bar{h})}{3\bar{v}} + \theta(K_1\bar{h} + K_2) > 0$. Therefore, there exists $h^{UK}_R \in (0, \bar{h})$ such that $\widehat{\pi}^{UK}_{(R,I)} - \widehat{\pi}^{UK}_{(NR)} \geq 0$ if and only if $h \geq h^{UK}_R$. □

Proof of Proposition 4. We have that $\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} = W^{US}_{(NR)} - W^{UK}_{(NR)}$, $\widehat{W}^{US}_{(R,NI)} - \widehat{W}^{UK}_{(R,NI)} = W^{US}_{(R,NI)} - W^{UK}_{(R,NI)}$ and $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} = W^{US}_{(R,I)} - W^{UK}_{(R,I)}$. Therefore, the proof is the same as in the base model. □

D.6.2. $g(\hat{t} \mid D)$ **is linearly increasing in** $\hat{t}$

Proof of Proposition 1. We show this result for each country separately.

The U.S. Case. We have that $\widehat{W}^{US}_{(R,I)} = W^{US}_{(R,I)}$ and $\widehat{W}^{US}_{(R,NI)} = W^{US}_{(R,NI)} - Pr(D \mid \tilde{D})\frac{(1-l)(r+h)h}{6\bar{v}\bar{h}}(\bar{v}-p)$. Thus,

$$\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_{12}(h) - \frac{lh}{\bar{v}}\left(\bar{v} - \frac{h}{2}\right) - C, \quad \text{where } \xi_{12}(h) = \chi_1(h) + \frac{(1-l)(r+h)(\bar{v}-p)h}{6\bar{v}\bar{h}},$$

using $\chi_1(h)$ defined in (10). If $\widehat{\xi}_{12}(h) = \xi_{12}(h) - \frac{lh}{\bar{v}}\left(\bar{v} - \frac{h}{2}\right) - C < 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_{12}(h) \ge 0$, then $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho^{US}_I(h) = \max\left\{\frac{\frac{lh(\bar{v}-h/2)/\bar{v}+C}{\xi_{12}(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_{12}(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\xi}_{12}(0) = -\frac{rl}{\bar{v}}(\bar{v}-p) - C < 0$ and $\widehat{\xi}_{12}(\bar{h}) = \frac{2(1-l)(r+\bar{h})(\bar{v}-p)}{3\bar{v}} > 0$. Therefore, there exists $h^{US}_I \in (0,\bar{h})$ such that $\widehat{\xi}_{12}(h) \ge 0$ if and only if $h \ge h^{US}_I$. Thus, $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{US}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h^{US}_I$ and $\rho \ge \rho^{US}_I(h)$, where $\rho^{US}_I(h) \in [0,1]$.

The U.K. Case. We have that $\widehat{W}^{UK}_{(R,I)} = W^{UK}_{(R,I)}$ and $\widehat{W}^{UK}_{(R,NI)} = W^{UK}_{(R,NI)} - Pr(D \mid \tilde{D})\frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}}$. Thus,

$$\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} = Pr(D \mid \tilde{D})\xi_{13}(h) - C, \quad \text{where } \xi_{13}(h) = \chi_2(h) + \frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}},$$

using $\chi_2(h)$ defined in (13). If $\widehat{\xi}_{13}(h) = \xi_{13}(h) - C < 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\xi}_{13}(h) \ge 0$, then $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \ge 0$ if and only if

$$\rho \ge \rho^{UK}_I(h) = \max\left\{\frac{\frac{C}{\xi_{13}(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\xi}_{13}(h)$ is a quadratic function of h, and $\widehat{\xi}_{13}(0) = -rl(1-\frac{p}{\bar{v}}) - C < 0$ and $\widehat{\xi}_{13}(\bar{h}) = \frac{2(1-l)(\bar{v}-p)(r+\bar{h})}{3\bar{v}} > 0$. Therefore, there exists $h^{UK}_I \in (0,\bar{h})$ such that $\widehat{\xi}_{13}(h) \ge 0$ if and only if $h \ge h^{UK}_I$. Thus, $\widehat{W}^{UK}_{(R,I)} - \widehat{W}^{UK}_{(R,NI)} \ge 0$ is satisfied if and only if $h \ge h^{UK}_I$ and $\rho \ge \rho^{UK}_I(h)$, where $\rho^{UK}_I(h) \in [0,1]$. □

Proof of Proposition 2. We show that there exist h^{US}_R and $\rho^{US}_R(h)$ such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \ge h^{US}_R$ and $\rho \ge \rho^{US}_R(h)$. The rest of the proof is similar to the proof of Proposition 2 under the base model.

We have that $\widehat{\pi}^{US}_{(R,I)} = \pi^{US}_{(R,I)}$ and $\widehat{\pi}^{US}_{(NR)} = \pi^{US}_{(NR)} - Pr(D \mid \tilde{D})\frac{(1-l)(r+h)h}{6\bar{v}\bar{h}}(\bar{v}-p)$. Thus,

$$\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} = Pr(D \mid \tilde{D})\psi_{12}(h) - \frac{plh}{\bar{v}}, \quad \text{where } \psi_{12}(h) = \Omega_1(h) + \frac{(1-l)(r+h)(\bar{v}-p)h}{6\bar{v}\bar{h}},$$

using $\Omega_1(h)$ defined in (16). If $\widehat{\psi}_{12}(h) = \psi_{12}(h) - \frac{plh}{\bar{v}} < 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} < 0$ is always satisfied, because $Pr(D \mid \tilde{D}) \le 1$. If $\widehat{\psi}_{12}(h) \ge 0$, then $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \ge 0$ if and only if

$$\rho \ge \rho^{US}_R(h) = \max\left\{\frac{\frac{plh/\bar{v}}{\psi_{12}(h)} - Pr(D)}{1-Pr(D)}, 0\right\}.$$

We verify that $\widehat{\psi}_{12}(h)$ is a cubic function of h, the coefficient of the cubic term is negative, and $\widehat{\psi}_{12}(0) = -lr(1-\frac{p}{\bar{v}}) < 0$ and $\widehat{\psi}_{12}(\bar{h}) = \widehat{\Omega}_1(\bar{h}) + \frac{(1-l)(r+\bar{h})(\bar{v}-p)}{6\bar{v}} > 0$, where $\widehat{\Omega}_1(\bar{h}) > 0$ is defined in (18). Therefore, there exists $h^{US}_R \in (0,\bar{h})$ such that $\widehat{\psi}_{12}(h) \ge 0$ if and only if $h \ge h^{US}_R$. Thus, $\widehat{\pi}^{US}_{(R,I)} - \widehat{\pi}^{US}_{(NR)} \ge 0$ if and only if $h \ge h^{US}_R$ and $\rho \ge \rho^{US}_R(h)$, where $\rho^{US}_R(h) \in [0,1]$. □

Proof of Proposition 3. We show that there exists h_R^{UK} such that, when the regulator always investigates immediately, the manufacturer reports a potential defect if and only if $h \geq h_R^{UK}$. The rest of the proof is similar to the proof of Proposition 3 under the base model.

We have that $\widehat{\pi}^{UK}_{(R,I)} = \pi^{UK}_{(R,I)}$ and $\widehat{\pi}^{UK}_{(NR)} = \pi^{UK}_{(NR)} - Pr(D \mid \tilde{D})\frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}}$. Thus,

$$\widehat{\pi}^{UK}_{(R,I)} - \widehat{\pi}^{UK}_{(NR)} = Pr(D \mid \tilde{D})\psi_{13}(h), \quad \text{where } \psi_{13}(h) = \Omega_2(h) + \frac{(1-l)(\bar{v}-p)(r+h)h}{6\bar{v}\bar{h}},$$

using $\Omega_2(h)$ defined in (19). We verify that $\psi_{13}(h)$ is a quadratic function of h, and $\psi_{13}(0) = -rl(1-\frac{p}{\bar{v}}) < 0$ and $\psi_{13}(\bar{h}) = \Omega_2(\bar{h}) + \frac{(1-l)(\bar{v}-p)(r+\bar{h})}{6\bar{v}} > 0$, where $\Omega_2(\bar{h}) > 0$ is defined in (20). Therefore, there exists $h_R^{UK} \in (0, \bar{h})$ such that $\widehat{\pi}^{UK}_{(R,I)} - \widehat{\pi}^{UK}_{(NR)} \geq 0$ if and only if $h \geq h_R^{UK}$. □

Proof of Proposition 4. We have that $\widehat{W}^{US}_{(NR)} - \widehat{W}^{UK}_{(NR)} = W^{US}_{(NR)} - W^{UK}_{(NR)}$, $\widehat{W}^{US}_{(R,NI)} - \widehat{W}^{UK}_{(R,NI)} = W^{US}_{(R,NI)} - W^{UK}_{(R,NI)}$ and $\widehat{W}^{US}_{(R,I)} - \widehat{W}^{UK}_{(R,I)} = W^{US}_{(R,I)} - W^{UK}_{(R,I)}$. Therefore, the proof is the same as in the base model. □