

Supply Chain Quality, Mandatory Insurance, and Recall Risk

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Abstract

If a supplier shirks on quality, the end manufacturer risks a product recall. The manufacturer can offer a contract stipulating harsh penalties in this event. Mandatory insurance may be required if the supplier cannot be compelled to pay the penalty.

Key words: supply chain efficiency; quality; moral hazard; mandatory insurance; product recalls

JEL classifications: L14; L15; L25

1. Introduction

A major trend in recent years has been an increase in business outsourcing, particularly to foreign suppliers. Along with this trend has come greater difficulty in quality control. More complex supply chains give rise to higher monitoring costs, language barriers, and other logistical differences that make manufacturers more inclined to leave the job of quality assessment to the suppliers. However, given that suppliers incur the costs of quality and quality control without directly or immediately bearing the consequences, they may under-invest in it.

Research supports the claim that outsourcing carries a greater quality risk than internal production. Gray et al. (2007), for example, demonstrate this with an empirical analysis of the quality differences between two different supply chain configurations: contract manufacturer's plants (a two-level chain with an original equipment manufacturer and a contract manufacturer), and internal plants (a vertically integrated chain). They show further that the use of contract manufacturers carries an increase in quality risk that cannot even be mitigated by standard quality certifications such as ISO 9000. Indeed, the past few years alone have seen a number of high-profile product recalls costing businesses billions of dollars. In 2007, for example, Mattel recalled over 9 million Chinese-manufactured toys because of lead paint and small part hazards despite CEO Robert Eckert's Senate testimony that his

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company had in place “some of the most rigorous safety protocols in the toy industry.”¹ In 2010 Toyota had two major recalls, for gas pedal and brake problems, costing the company over \$2 billion.² Later that year Honda, using the same supplier as Toyota, issued its own recall for brake problems.

Reyniers and Tapiero (1995) were among the first to use a contracting model to resolve the conflicting quality incentives among the firms in a supply chain. In their paper, the contract is designed to allow the original equipment manufacturer (OEM) to control the incoming merchandise for defective units.³ In contrast to this and much of the related literature on quality, the present paper assumes that if the contract manufacturer (CM) shirks on quality, all units may become susceptible to recall when investigated by an external agency such as the US Food and Drug Administration (FDA) or the Consumer Product Safety Commission (CPSC).⁴ Furthermore, controlling for all recallable defects is prohibitively expensive for the OEM; thus, thoroughly inspecting for faulty units is not feasible.

The present paper uses contract design to address this type of quality risk. The model depicts the relationship between the OEM and its supplier, the CM, as a principal-agent relationship with asymmetric information, moral hazard, and uncertainty.⁵ We show that given the proper incentives and disincentives, quality risk can be reduced to the levels that a fully integrated supply chain would consider optimal. The disincentives, however, include harsh penalties levied upon the CM in the case of a recall.⁶ These penalties are designed to cover all recall costs, and if these costs are exceedingly large, the OEM may have difficulty enforcing them.

There are various reasons why an OEM may be unable to enforce a penalty imposed on the CM. Liability standards vary from country to country, and the OEM may be unable to collect the penalty through legal channels. Also, the CM may simply not have the financial resources to afford the penalty. Whatever the reason, as the CM's liability in the event of a recall decreases, so does its quality effort. The OEM therefore has an incentive to search for CMs which can afford the penalties and which are located in countries with strict liability laws. By doing this, the OEM is increasing its profits, in part by fostering higher quality.

One option to assist the CM in the event of a recall is insurance. However, because the CM cannot be forced to pay the penalties, it has little incentive to purchase insurance. Furthermore, if the CM purchases full insurance, it may reduce its quality to zero.⁷ We therefore consider the possibility of mandatory insurance, and, as shown in Shavell (1986) and Polborn (1998), the CM will not reduce quality to zero as long as the insurance coverage is not full. Indeed, we show that the OEM prefers to add a mandatory minimum insurance clause to the contract to eliminate its risk, while the CM will choose the minimum coverage stipulated by the contract (i.e., the amount it cannot afford to pay in penalties). In equilibrium, if the OEM has full negotiating power, it achieves a first-best profit solution because it does shed all its profit risk. Part of this profit risk is mitigated by any increase in the CM's quality, and the remainder is mitigated by the insurance. However, while it is still true that quality effort increases as the CM is able to afford more and more of the penalty, the insurance creates an environment in which the OEM has no incentive to find this

kind of CM. Indeed, the insurance creates a moral hazard problem in which the OEM does not care as much about quality and therefore does not expend effort seeking a CM that will provide it. Only when the CM gains negotiating power, and therefore transfers some of the risk to the OEM, does the OEM seek higher-quality CMs to mitigate the risk of a recall.

The following section outlines the basic model. Section 3 examines the vertically integrated and non-integrated, no-contract solutions. Section 4 proposes optimal contract designs when full liability is possible; Section 5 examines contract designs when it is not, and when recall insurance is required of the CM. Section 6 illustrates the results with a numerical example, and Section 7 concludes.

2. The Model

Our model portrays a two-stage supply chain with a manufacturer (the OEM) and a supplier (the CM) of a product for which demand is given. In the first stage, the OEM designs a contract for the purchase of components and offers it to the CM. The contract consists of a menu of prices to be paid to the CM for its products, conditional on whether or not there is a recall. The CM then decides how much to invest in quality effort, e , which costs c per unit. Assume that while the OEM may be able to observe obvious faults in the products (like missing parts or broken units), it does not have the means to observe and detect all less obvious quality issues for each of the units produced by the CM (like lead content in paint).

The OEM cannot observe the CM's quality effort, and because we assume that inspection for (all) quality is not feasible, the OEM must trust that the CM has invested in adequate quality for the products. Once the product hits the market there is a probability of a recall, which is inversely related to the amount of effort put forth in the provision of quality. We assume that the recall is carried out by an external agency (such as the FDA or CPSC). This agency, unlike any other players in our model, has the expertise, means, training, and authority to assess all less obvious issues of product quality.

The OEM's price p is assumed to be fixed, so demand Q is known and exogenous to the model. There is, however, a probability $\lambda(e)$ that an external agency finds a major defect in the product and orders a recall. This recall probability is dependent upon the level of quality effort, such that $\lambda' < 0$ and $\lambda'' > 0$; that is, a higher level of quality effort decreases the probability of a recall at a decreasing rate. Let the per-unit recall costs be given by r . The value r captures all costs from reverse logistics to reductions in the value of the company (such as loss in stock prices or diminished sales in other lines of products made by the same OEM) to compensation of consumers from lawsuits or injuries.

3. The Vertically-Integrated and Non-Integrated, No Contract Solutions

As a benchmark, let us first determine the level of quality effort the OEM would choose if it were manufacturing the good from start to finish. Under such

vertical integration the profit function of this risk neutral principal is given by:

$$\pi^* = (1 - \lambda)Qp - \lambda Qr - ce. \quad (1)$$

The first-order condition for this profit function with respect to effort yields the condition for the optimal level of effort e^* such that the marginal benefit from such effort exactly offsets the marginal cost:

$$-\lambda'Q(p + r) - c = 0. \quad (2)$$

Suppose now that the two firms are not integrated and the OEM pays the CM a price of $w \leq p$ for each of the components. In the case of a recall, the OEM returns the products and gets a full refund, but the CM is not responsible for any further recall costs. Now the profit function for the CM, and the corresponding first-order condition with respect of the optimal level of effort are:

$$\pi_{CM} = (1 - \lambda)Qw - ce \quad (3)$$

and

$$-\lambda'Qw - c = 0. \quad (4)$$

Comparing (2) and (4) one can see given that $w < p$ and that λ is convex in effort; the level of effort chosen by the CM is lower than that chosen by a vertically integrated chain. This is so because the CM is not made liable for any external costs related to the recall and it does not take into account how its effort affects the OEM's profits. Note that if the OEM does not even have the chance of returning the recalled product and getting a full refund, the CM would choose to put no effort into quality provision. It is also easy to see that if the CM subcontracts to other suppliers, adding layers to the supply chain and making it more complex, the effort put forth by additional subcontractors may be lower. For this reason, the OEM faces the challenge of proposing a contract to the CM with incentives to provide high quality.

4. Contract Design when the CM is Fully Liable

Suppose now that the OEM designs a contract in which the CM is paid w_H per unit if there is no recall and is penalized w_L per unit in case of a recall. The profit function for the CM is then:

$$\pi_{CM} = (1 - \lambda)Qw_H - \lambda Qw_L - ce. \quad (5)$$

The OEM then chooses w_H and w_L subject to the CM's participation and incentive compatibility constraints to induce the desired level of effort.

Proposition 1. When the CM can be held fully liable, the OEM offers the CM a compensation package specifying penalty w_L in the event of a recall and payment

w_H if there is no recall, where w_L is equal to the sum of the per-unit recall costs and profit-margin losses. The OEM maximizes its profits, and therefore achieves supply-chain efficiency, by setting w_H just high enough to ensure individual rationality for the CM.⁸

Proof. The first-order condition for the CM's optimal effort, $\partial\pi_{CM}/\partial e = 0$ simplifies to:

$$-\lambda'Q(w_H + w_L) - c = 0, \quad (6)$$

which can be rewritten as

$$Q(w_H + w_L) = \frac{c}{-\lambda'}. \quad (7)$$

Substituting (7) into π_{CM} and assuming the participation constraint binds ($\pi_{CM} = 0$) yields:

$$w_H = \frac{c}{Q} \left(e - \frac{\lambda}{\lambda'} \right). \quad (8)$$

The profit function for the OEM is

$$\pi_{OEM} = (1 - \lambda)Qp - \lambda Qr - (1 - \lambda)Qw_H + \lambda Qw_L. \quad (9)$$

Substituting (7) and (8) into π_{OEM} yields

$$\pi_{OEM} = Q[(1 - \lambda)p - \lambda r] - ce. \quad (10)$$

The OEM chooses w_H and w_L to induce the effort that maximizes its profits. Because $\pi_{CM} = 0$, optimizing π_{OEM} with respect to e yields the same first-order condition as in (2), i.e., the vertically integrated case. The level of effort that maximizes OEM's profits while satisfying the CM's incentive compatibility constraint is then found by solving (2) and (6) simultaneously:

$$-\lambda'Q(p + r) - c = -\lambda'Q(w_H + w_L) - c, \quad (11)$$

which simplifies to $w_L = p + r - w_H$. Given that $w_H < p + r$, it is clear that the penalty w_L transfers the entire recall costs and profit-margin losses from the OEM to the CM. The OEM's profits can then be restated as $\pi_{OEM} = Q(p - w_H)$; hence, the OEM has shifted all risk to the CM and earns the first-best level of profits.

It is not uncommon for OEMs to include penalty clauses in their contracts with their CMs for delayed or unsatisfactory deliveries. The issue then becomes enforcing these clauses; especially when the CM is overseas. There have been many instances of manufacturer unsuccessfully taking their suppliers to court in an attempt to recover these payments. Such was the case of Taishan Gypsun Co. Ltd., a Chinese

supplier of drywall, which failed to show up to US court in 2009 after allegations of defects in their product used for construction of houses in several states.⁹

5. Contract Designs when the CM is Not Fully Liable

In this section we consider the case in which the CM does not or cannot pay all costs in the event of a recall. For example, the CM may simply not have sufficient resources, or the legal liability standards in the CM's home country may not require full reimbursement. In any case, the OEM may have problems collecting the penalties imposed in the case of a recall.

In a judgment-proof problem like this, the CM has less incentive to invest in quality because it cannot be compelled to pay the full penalty. It is therefore in the interest of the OEM to find a CM which it believes can afford to pay high penalties, and which is located in a country with strict liability standards. If the OEM finds a CM like this, it achieves higher profits through increased product quality (and fewer recalls), and decreased liability in the event of a recall. Even if the OEM incurs a cost to search for such a CM, we can expect it will conduct at least some searching, and product quality will improve as a result.¹⁰

5.1 Mandatory Insurance

In lieu of retaining all risk for recalls, OEMs can purchase product-recall insurance which goes beyond basic liability insurance. Rather than buying this insurance itself, however, the risk-neutral OEM may instead wish to require the CM to purchase it. We therefore add a stage in which the CM can purchase "product-recall insurance" prior to choosing its quality effort. Like the OEM, however, a risk-neutral CM may choose not to purchase insurance, and since it cannot afford the recall penalty, it will also not bother putting forth much effort.¹¹ Following the models of Shavell (1986) and Polborn (1998), we show that if the OEM requires the CM to buy a mandatory minimum insurance policy, the judgment-proof problem is solved, and the OEM is still able to shift all risk to the CM. The minimum coverage is set equal to the amount of the penalty the CM cannot (or cannot be compelled to) pay.

Suppose the OEM expects that in the event of a recall the CM can afford to pay only the amount $X \leq w_L$ in penalties, so the CM then needs an extra $p + r - w_H - X$ or $w_L - X$ to compensate the OEM.¹² Suppose also that the OEM requires that the CM purchase an insurance policy covering at least this amount before production takes place. That is, the OEM requires a minimum coverage of $\underline{k} = w_L - X$ per unit. The CM then needs to decide how much coverage to purchase and, given that coverage, how much effort to invest.

With the insurance policy the CM's profit function is given by:

$$\pi_{CM} = (1 - \lambda)Qw_H - \lambda Q(w_L - k) - ce - \gamma, \quad (12)$$

where $\gamma = \lambda(e^*(k))Qk$ is the fair insurance premium for coverage \underline{k} per unit of

output, given the optimal level of effort. Assume also that the OEM keeps the values of w_H and w_L as the optimal values found in the previous section.¹³ The first-order condition $\partial\pi_{CM}/\partial e = 0$ then simplifies to:

$$\lambda'Q(k - (p + r)) - c = 0. \quad (13)$$

Intuitively, as the value of the policy coverage k increases, effort decreases. In fact differentiating with respect to k yields $\partial e/\partial k = -\lambda'/\lambda''(k - (p + r)) < 0$.

Proposition 2. Suppose the OEM offers the CM a compensation package as the one stated in Proposition 1, but the CM cannot be held fully liable. If the OEM requires a minimum insurance coverage of $\underline{k} = w_L - X$ per unit, the CM's optimal constrained coverage, k^* , is equal to \underline{k} . The equilibrium level of effort increases as X increases and reaches the optimal level if $X \geq w_L$.

Proof. The CM chooses \underline{k} to maximize expected profits subject to the constraint $k \geq w_L - X$, where $w_L = p + r - w_H$. The Kuhn-Tucker conditions are given by:

$$\begin{aligned} \frac{\partial\pi_{CM}}{\partial k} &= -\lambda' \frac{\partial e}{\partial k} Q w_H + \lambda' \frac{\partial e}{\partial k} Q(p + r - w_H + k) + \lambda Q - \frac{\partial e}{\partial k} c \\ &\quad - \lambda' \frac{\partial e}{\partial k} Q k - \lambda Q \leq 0 \\ &= \frac{\partial e}{\partial k} [\lambda' Q(k - (p + r)) - c] - \lambda' \frac{\partial e}{\partial k} Q k \leq 0 \end{aligned} \quad (14)$$

and

$$k - (p + r) + w_H + X \geq 0. \quad (15)$$

The first term in (14) is the first-order condition shown in (13), which leaves (14) as $-\lambda'(\partial e/\partial k)kQ < 0$; thus, $k^* = w_L - X$. That is, the CM chooses the minimum coverage. Condition (13) then becomes $-\lambda'Q(w_H + X) - c = 0$. If X is large enough to cover the entire penalty (i.e., $X \geq w_L$), then the CM takes no insurance and exerts the efficient level of effort.

Proposition 2 illustrates several important points. First, the risk-neutral CM always purchases the minimum insurance coverage. Therefore, because a decrease in the amount of coverage increases the amount of the penalty that comes out of the CM's pocket, its quality effort increases as the coverage minimum decreases. In other words, as the CM's ability to pay the penalty increases (e.g., when the CM is wealthier), the higher is its product quality in equilibrium. In order to achieve a first-best level of quality the CM must be able to afford the entire penalty.

It is also important to note that, regardless of how much quality increases, the OEM always achieves the first-best profit level, and the supply chain therefore achieves efficiency. The penalty and the mandatory insurance in the contract shift all profit risk from the OEM to the CM and the insurance company. Some of the

OEM's risk is mitigated through the possible increase in product quality, and the remainder of the risk is mitigated by the insurance. Because of the insurance, the OEM has no incentive to search for a CM that can be compelled to pay the penalty, which is equivalent to finding a CM that will produce a higher-quality product. The moral hazard generated from the insurance hinders the improvement in product quality.¹⁴

The previous analysis assumes the OEM has the power to make a take-it-or-leave-it offer to the CM. Relaxing this assumption implies that the negotiating power shifts from the OEM to the CM, and the CM in turn would demand more favorable contractual terms. This could mean a higher w_H , a lower w_L , or a sharing of the insurance premium. In either of the latter two cases, the OEM incurs higher costs as the likelihood or magnitude of a recall increases, or as the CM's liability decreases. As such, the OEM has a greater incentive to find a CM that can be compelled to pay the penalty. As previously shown, this will increase the CM's effort and therefore product quality.¹⁵

6. An Example

In this section, we illustrate the results with specific functional forms and parameterizations. In keeping with the assumptions of $\lambda'(e) < 0$ and $\lambda''(e) > 0$, the probability of a recall is specified as

$$\lambda = \frac{1}{1 + \theta e}, \quad (16)$$

where θ represents the sensitivity of product quality (and therefore the probability of a recall) to effort. We then set $Q = 1$, $p = 2000$, $r = 500$, and $c = 100$. When there is no insurance and the CM is fully liable, the equilibrium effort, w_H , and w_L are calculated per equations (7) and (11) and plotted in Figure 1.

Not surprisingly, effort generally decreases as θ increases, because effort has a greater impact on product quality. The probability of a recall decreases, however, because the higher θ more than offsets the lower effort. The OEM can therefore pay a lower w_H , which in turn results in a higher w_L .

Figure 2 uses the same functional specification and parameterization to illustrate equilibrium effort under limited liability and full insurance. The horizontal axis measures the amount the CM can be compelled to pay in the event of a recall, X . Separate plots are shown for the values $\theta = 1$ and $\theta = 2$.

Note again the result that as θ increases, effort decreases. Also, as the CM's liability increases, so does effort, underscoring the result that using a CM with a greater capacity to pay recall costs would result in higher quality products and fewer recalls.

Figure 1. Equilibrium Values under Full Liability

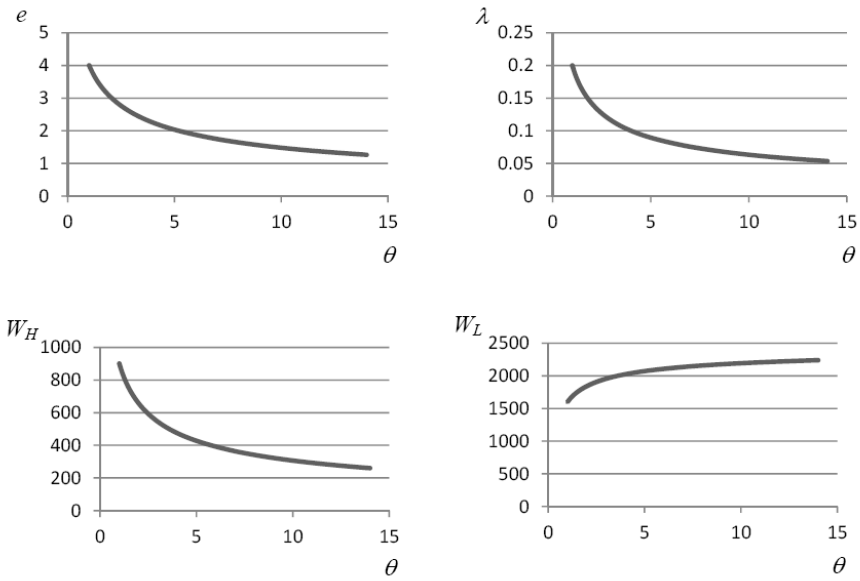
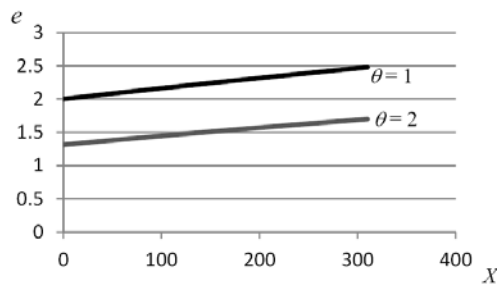


Figure 2: Effort under Limited Liability and Full Insurance



7. Conclusion

The conclusion of this paper is that the increase in quality and/or profit risk due to increased outsourcing can be addressed through incentive contracts, but the improvement in quality can ultimately be hindered by adding mandatory insurance to the contract. If the OEM cannot adequately monitor the quality of components received from its CM, it can shift the risk associated with a product recall to the CM via a penalty contract. The penalty, paid by the CM to the OEM in the event of a product recall, is set equal to the sum of the recall costs and profit-margin losses. The component price in the event of no recall is set just high enough to induce the

risk-neutral CM to accept the contract. This contract elicits a first-best level of quality effort by the CM, a first-best profit for the OEM, and supply-chain efficiency.

A potential moral hazard problem occurs if the OEM expects it cannot collect the full penalty from the CM in the event of a recall. If full liability is not required by law in the CM's home country or if the CM simply does not have adequate resources, the OEM cannot enforce the full penalty. The OEM can proactively mitigate this problem by seeking a CM that is wealthy and that is located in a country with strict liability laws. The higher CM liability ensures it will provide higher quality, and the OEM enjoys higher profits. However, the OEM also has an incentive to require the CM to purchase mandatory minimum insurance to cover the recall costs. If the OEM has full negotiating power then it achieves the first-best profit level, but the recall risk remains high because the insurance eliminates the incentive for the OEM to search for a CM that will produce a high-quality product. As the CM gains negotiating power, recall risk shifts to the OEM in the form of lower penalties and/or more sharing of insurance premiums. In this event the OEM experiences increased incentive to choose a higher-quality CM.

Notes

1. www.senate.gov.
2. Bloomberg Newsweek January 13th 2011 www.businessweek.com.
3. See also Tagaras and Lee (1996), who examine the use of quality inspection to select vendors. Lim (2001) also looks into the issue of quality control under asymmetric information and proposes a contract design with rebates and warranties. Baiman et al. (2000) develop a model with asymmetric information and examine the effects the contracting information has on the cost of quality for the entire supply chain. Wan and Xu (2008) also examine the optimal inspection policy and share of damages costs to induce suppliers to enhance quality.
4. See Spier (2009) and Hua (2009) for some recent studies of voluntary manufacturer buybacks.
5. Our model is designed after the model used by Laffont and Martimort (2002).
6. This paper assumes the penalty is determined by the OEM as an incentive to achieve profit-maximization; that is, the penalty is compensatory. Diamond (2002) examines different possible frameworks in which penalties can be used as a deterrent, a punishment (retribution), or both. The latter approach is more appropriate when considering social welfare implications.
7. See Arnott and Stiglitz (1991), who show that full insurance can eliminate the incentive to put forth any kind of effort to prevent an accident.
8. It is straightforward to consider an extension in which the CM incurs an additional cost (perhaps reputational) from a recall. In equilibrium, the OEM will adjust w_H and w_L upward so that the CM's expected profits are again zero. Effort would increase somewhat, but total profits (i.e., the OEM's profits) will be lower than if the CM incurred no additional costs.
9. www.chinariskmanagement.com.
10. The OEM would continue to search as long as the expected marginal benefit exceeds the marginal cost. We feel this result is sufficiently obvious to forego a formal analysis.
11. See Arnott and Stiglitz (1991) or Shavell (1986) for explanations of this result.

12. Note that X can be less than w_H when the CM has production costs or it can be greater if the CM has reserves.
13. As we shall see, the OEM can maximize its profits with w_L and w_H at these levels.
14. Again, if the CM incurs an additional cost from the recall but if its liability remains the same, the OEM's (and therefore total) profits will decrease in equilibrium. The total coverage from the recall insurance must increase and so will the premium. Because the OEM keeps the CM's profits at zero via w_H and w_L , the OEM absorbs the increased cost of the insurance.
15. In the case with no recall insurance, a change in negotiating power will change w_L and w_H to become more favorable to the CM. This will also have the effect of shifting the cost of a recall to the OEM, increasing its desire to find a CM that can pay the penalty, and thereby increasing product quality.

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