LIABILITY AS A CATALYST FOR PRODUCT STEWARDSHIP

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Updated: January, 2001

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Abstract

Product stewardship is the set of practices related to reducing risks from chemical and process hazards in a company's supply chain. This paper develops an economic framework for evaluating supply chain liability as a driver for adopting product stewardship. Companies that outsource production may face residual liability for damages from use of their products, when liabilities are large enough to exceed supply chain partners' assets. The resulting potential liabilities can be mitigated through product stewardship. This paper shows that extended supply chain liabilities provide incentives for investing in reducing environmental hazards throughout the supply chain.

Key Words:

Liability, Product Stewardship, Mitigation, Environmental Damage

I. Introduction

Under product stewardship companies assist their suppliers and customers in improving Environmental, Health and Safety (EH&S) practices. Product stewardship entails a variety of techniques. Reducing the use of potentially hazardous materials in process design, supplying customers with improved information and training, and tracking and recovering hazardous materials. Together these techniques provide for decreased hazards and wastes and increased use of recyclable materials, leading to both decreased operating costs and reduced liability. The question this paper addresses is the extent to which reduced liabilities can or should motivate investments in product stewardship.

To judge from recent trends, product stewardship has become an essential factor in supply chain design and coordination in environmentally intensive industries. For example, in the chemical industry it is the sixth and final code of Responsible Care, implemented by all members of Chemical Manufacturers Association (CMA) and a large portion of the members of the Synthetic Organic Chemical Manufacturers Association (SOCMA) in 1999. Together member companies of these organizations make up more than 90% of the productive capacity of basic industrial chemical manufacturing and of the chemicals produced in the United States. Similar endorsements of product stewardship are evident in Asia and Europe.

The rationale for product stewardship investments is two-fold. First, product stewardship activities can be used to assure regulatory compliance and technical support for customers in the proper use of a company's products (see, e.g., Kleindorfer and Snir (2001) for a discussion). Second, and of key interest in this paper, under joint and several liability laws large companies may be held liable for environmental damage, even when damages are not a direct consequence of their actions. Identifying and mitigating these liabilities is therefore important. This paper investigates stewardship activities by large companies that have a distribution system in place characterized by supply chain partners with limited assets.

The collection, treatment and disposal of hazardous wastes is the most important area where supply chain liabilities have been a centerpiece of industry concern. The legal framework in the United States is that resulting from the 1976 RCRA (Resource Conservation and Recovery Act), the 1980 CERCLA (Comprehensive Environmental Response, Compensation and Liability Act) and its 1986 revision under SARA (Superfund Amendments and Reauthorization Act), commonly referred to as Superfund. This legislation and its implementing regulations clearly recognize and promote product stewardship in wastes generation and disposal. Under RCRA/Superfund, any company which generates, transports, treats or disposes of hazardous wastes may be held jointly and severally liable for damages caused. In these cases it becomes beneficial to assist others in the supply chain to reduce the risks associated with product manufacture and use. This regulation is not limited to the actual disposal process of wastes, but includes onsite contamination from insufficient attention to possible environmental damage. Companies with potential contaminants are lead to invest in mitigating action to reduce EH&S risks from improper disposal throughout the supply chain. This is especially true for companies with "deep pockets".

A few recent examples illustrate that vicarious liability, where one firm is held responsible for the damage caused by a supply chain partner, is also of great concern for large chemical manufacturers. Dow-Corning has been found liable for damage caused by its silicone breast implants, which caused the company to file for bankruptcy with 170,000 compensation claims against the implant manufacturers and resulted in a $3.2 billion settlement (Washington Post, Jul. 9, 1998; Dec. 1, 1999). Following Dow-Corning's bankruptcy, Dow Chemical, which owns 50% of Dow-Corning, was also sued for its part in testing silicone liquid. Although it never manufactured implants, its R&D role proved sufficient to warrant an initial $14 million verdict against the company by a single plaintiff, in October 1995, and it faces another 13,000 lawsuits (International Chemical Litigation, Feb. 1996), whose status is unclear following the settlement (New York Times, Dec. 23, 1999). Although scientific proof of the connection between cause and effect is weak (e.g., Silverman *et al*., 1996), the jury here, as is often the case, was sympathetic to the plaintiffs' suffering (Chemical Engineering, Sep. 1996).

In Europe, the eco-logistics and EMAS programs are extremely important in promoting product stewardship (see Kleindorfer and Orts, 1998). By requiring companies to initiate backward logistics for reclaiming package wastes, companies have an incentive to invest in assuring that packaging material are reusable or recyclable.

Concerning the legal foundations of product stewardship, these would seem to run counter to one of the basic axioms of legal thought of independent contractors: a company should only be held liable for actions taken by its employees, and not those of others. In the area of EH&S activities, a different set of legal precedents has evolved, however. These precedents recognize that limiting liabilities to a company's organizational boundaries would lead to possible moral hazard. Companies with harmful processes would outsource these to others with limited assets, who would file for bankruptcy once injured parties demand compensation (Goldfarb, 1978; Ringleb and Wiggins, 1990). It would then be left to juries and judges to 'pierce the corporate veil' to identify which arrangements were put in place only to limit liability. Recognizing the transactions costs and the social losses associated with this process, legal thought and precedent has moved to different liability mechanisms. These essentially hold that for abnormally dangerous activities companies may be held vicariously liable for actions of supply chain partners. (See e.g., Evans, 1994, for a discussion of the independent contractor concept and vicarious liability.) Allowing for supply chain liability clearly reduces the moral hazard of under-investment in care and promotes product stewardship.

Current tort reform initiatives would curtail liabilities, especially for small businesses. Supporters would reduce punitive damages for all defendants by requiring plaintiffs to provide clear evidence of negligence, and capping negligence awards to twice the economic loss. In addition, proponents would limit payment by certain businesses even further. For those businesses with less than 25 employees or $5 million in annual revenue, punitive damages could not exceed $250,000, and liability for retailers and implant components suppliers would be limited (Washington Post, July 7, 1998). Such changes in tort rulings may provide additional incentives for product stewardship. Companies whose supply chain partners may be indemnified from certain payments have greater incentives to verify that sufficient care is invested in the development, manufacturing and sale of products.

Against this background, this paper examines the strategic importance of product stewardship, including process and product design changes, under a legal system of strict liability for harm arising from the activities of supply chain partners. The proposed game-theoretic model builds on the earlier work of Shavell (1984) in considering a specific case of joint liability in which suppliers are held liable only when customers' assets are insufficient to compensate for damages. The model extends Shavell's work by analyzing strategic behavior among supply chain partners, where the down-stream partner has limited assets and thus is not able to compensate for all liabilities. It complements Watabe (1999) by introducing the possibility that both parties reduce liabilities in a setting where customer investments are not contractible.

The key result from the game-theoretic model is that product stewardship is a strategic response to limited liability in the presence of insufficient information regarding supply chain partners' actions and assets. When suppliers can perfectly discern down-stream partners' risk-reducing activity suppliers would either curtail their own investment or replace partners' investments. If, however, suppliers are uncertain about customers' investments suppliers are apt to introduce stewardship measures that reduce liabilities throughout the supply chain. Following the supplier's investments only large partners make additional investments in care, while smaller customers, with limited assets (and liabilities), choose not to invest additionally.

The remainder of this paper is organized as follows. Section II analyzes the baseline problem of joint investment in care under perfect information. For the supplier, customer assets drive the investment decision. If the customer has sufficient assets to compensate for possible damage, the customer invests in reducing accident probability, while the supplier would not additionally invest. In this case the customer's assets insure the supplier from environmental liabilities. When, however, faced with a potentially insolvent customer, the supplier has incentives to provide product stewardship, and the customer would not additionally invest. In Section III, where asymmetric information on customer assets is introduced, uncertainty regarding customer assets leads to product stewardship actions by the supplier, and additional investments in care by large customers. Section IV analyzes the advantages to the supplier of third party audits to verify customer asset levels and to monitor protective measures. It is shown that when potential liabilities are large suppliers have an incentive to require customer auditing by third parties. Section V provides generalizations of the proposed model, while Section VI discusses implications of the analytical framework. Section VII concludes the paper.

II. The Model under Perfect Information

Based on the discussion in Section I it appears that joint and several liabilities are of great importance in situations where accidents may cause smaller companies to become insolvent. This induces companies with "deep pockets" to invest in mitigating accidents, even if they play only a small role in the product life cycle. This analysis emphasizes investments in care, by large companies, to reduce the probability of environmental accidents throughout the supply chain, assuming other mitigation actions have been optimally incurred. Such actions could include locating facilities in unpopulated areas or investments in legal teams to reduce the possibility of being held liable for adverse outcomes.

Investments in reducing hazards take on many forms in the production process. During the R&D phase multiple tests are conducted to assure product safety under reasonable use. Investments in capital are essential to assure production processes that strictly adhere to design specification. Other, less visible investments, including employee training and monitoring and internal quality control reduce the possibility of adverse changes during production. While some of these actions are easily observed by outside parties including regulators, customers and supply chain partners - other investments, especially those in ongoing quality control are more difficult to verify (Maxwell and Decker, 2000).

An underlying assumption is that downstream supply chain partners have comprehensive information regarding investment in care by upstream partners. While some of these investments are difficult to verify by outside parties, it is reasonable to assume that customers have good information regarding suppliers' actions. As part of an acceptance policy of hazardous material it is crucial for customers to know the quality and attributes of products received. This is often accomplished by physical evaluation of received inventory as well as quality inspections throughout the upstream production process. Through comprehensive quality assurance of production inputs clients learn about suppliers' investments in reducing potential liabilities.

While clients often observe suppliers' actions, the opposite is rarely true. Under common practices clients receive production inputs with the supplier having only limited information regarding actions taken to reduce potential liabilities. This limits the ability of bilateral contractual arrangements to reduce a supplier's liability. Without verifiable information regarding client behavior, suppliers cannot reasonably require customers to invest in care to reduce the supplier's expected liability. The value of monitoring client action is examined further in Section IV.

The model proposed in this paper extends Shavell (1984) to an inter-organizational (von-Stackelberg) game in which investment in care is a strategic response to liability. Consider two firms, a monopolist supplier with a single customer who jointly produce and distribute a product to end-users. The product has intrinsic risks and may cause environmental damage. Denote $L>0$ as the magnitude of loss caused if damage occurs. The joint liability framework is assumed to be such that the customer is held liable for all damage done, providing he has sufficient assets, with any residual liabilities borne by the supplier. In essence the customer's assets (partially) insure the supplier from liability. To emphasize the importance of environmental liabilities we ignore all other aspects of the bilateral relationship, including the production process and the market for produced goods.

Both parties participate in a strategic game, where the supplier is considered a von-Stackelberg leader, who is required to put in place his level of care, before the customer invests in reducing loss probability. This care may be in the form of improved product design, or training employees in proper maintenance and handling. After the supplier chooses his level of care, the customer implements his optimal level of care. With the physical transfer of the product to the client the client observes product attributes, inferring the supplier's investment in care. By observing the supplier's investments, the client responds strategically by deciding whether to additionally invest, and how much to invest in reducing adverse consequences. Both parties' investments are relationship-specific and have no other value outside the production and distribution of the product that may cause environmental damage.

Denote $A \geq 0$ as the customer's assets. Given our assumptions, the customer is responsible for damages up to A, with residual liabilities of $\max\{L - A, 0\}$ the responsibility of the supplier. The probability of loss $p(x,y)$ is determined by the level of care that each party invests, where $x \geq 0$ is the level of care taken on by the customer, and $y \geq 0$ is the level of care chosen by the supplier. Due to inefficiencies in the legal system, there is a positive probability that parties will not be held liable for damages done. Define q_c ($0 \leq q_c \leq 1$) as the probability that the customer will be held liable given an accident has occurred, and define q_s ($0 \leq q_s \leq 1$) as the probability that the supplier will be held liable for the residual loss unpaid by the customer. The probability of damage depends on their joint investment. For simplicity, we assume that investments in care are perfect substitutes, so we can denote $p(x,y) = p(x + y)$. Since the probability of harm reduces with the level of care invested $p'(x + y) < 0$ (denoting dp/dz as $p'(z)$ and d^2p/dz^2 as $p''(z)$). We also assume this investment has diminishing returns so that $p''(x + y) > 0$.

A crucial element of the strategic game between the two parties is the customer's asset level. These assets represent the customer's ability to compensate for any harm done. This would include all assets the customer has, or can borrow, after loss is incurred. This may be different than the book value of the customer's assets, or other easily observed financial metrics. Thus, the customer's "effective asset level" for compensation is a magnitude, which the customer is likely to have considerably better knowledge about than an external supplier. We begin our analysis under the simplifying assumption that the customer's assets are common knowledge, providing insight into the strategic game between the two parties. We will generalize this to the more realistic case of asymmetric information below.

Before analyzing the strategic game between the two parties it is important to define the socially optimal (also called "first best") level of care. Such a model is proposed and explained by Shavell (1984). This serves as a benchmark for evaluating outcomes of different scenarios. Denote $z \geq 0$ as the level of care taken by society to reduce the probability of environmental harm. The first-best solution for the required level of care is defined as the level z^* which minimizes the cost of investing in care and the expected magnitude of loss, i.e., $z + p(z)L$. Denote the first-best level of care as $z^*(L)$. Assuming an interior solution exists (a sufficient condition for this assumption to hold is that: $p'(0)L < -1$), the First Order Condition becomes:

$$p'(z^*(L))L = -1 \qquad (1)$$

This intuition behind this equation is that marginal benefits of investing in care (the LHS) have to equal the marginal costs of an additional dollar of investment in care (the RHS). Alternatively, equation (1) may be written as:

$$p'(z^*(L)) = -1/L \qquad (1a)$$

Shavell (1984) shows that $z^*(L)$ is increasing in L, which is intuitive since we would expect the level of care to increase with Loss. We can now identify the outcome of the perfect information, von-Stackelberg game and compare it to the first-best solution.

Proposition 1: In the von-Stackelberg perfect information game where the supplier is the leader and the customer is the follower, either the supplier or the customer will invest in care, but not both. Define L_c as the magnitude of loss where the supplier is indifferent between investing in care and abstaining from investment. Then L_c is unique. Moreover, for $L \leq L_c$ only the customer invests in mitigation, while for $L > L_c$ only the supplier invests in care. Furthermore, at the von-Stackelberg equilibrium the aggregate level of care taken by both parties is less than the socially optimal value $z^*(L)$.

Proof: See the Appendix for proofs.

Figure 1: <u>Expected Liability versus Loss</u>

INSERT FIGURE 1 HERE

For an intuitive explanation of the outcome of this model, Figure 1 may be of assistance. Figure 1 depicts the customer's and supplier's expected liability as a function of the loss incurred, assuming damage occurs, compared to the total loss. The customer's liability is always positive but less than the magnitude of the loss, due to the fact that he may not be held liable for damages, and due to his limited assets. The supplier is only be held liable for losses that exceed customer assets, and his liability function is not as steep as the customer's liability, since the supplier may not be held liable either. The intersection between the two lines corresponds to the loss that equates both parties' liabilities.

From the von-Stackelberg model the customer chooses his level of care x, knowing the investment level chosen by the supplier y^*. To find the optimal investment the customer invests so as to equate the *marginal* benefit from care with the *marginal* cost i.e., $p'(x+y^*) = -1/q_c \min\{L, A\}$, (From (1a)). Due to the assumption of perfect substitution the customer is only interested in the aggregate investment. If the supplier invests less than the customer's optimal investment, the customer invests to assure that the *aggregate* investment equals his optimal investment. If the supplier invests more than the customer would invest alone, the customer does not invest additionally.

Knowing the customer's response function the supplier chooses his investment in care. The individually optimal behavior for the supplier becomes: (i) Not to invest in care at all, if the customer's liability (and hence his investment) is greater than the supplier's liability; (ii) If he does invest in care, invest his optimal investment, knowing the customer will not additionally invest. The supplier chooses to invest only if the net benefits of investing (reduced liability minus investment costs) are greater than abstaining from investment, with the customer making his optimal decision. It can be shown that the supplier invests in care only if losses are larger than some critical level L_c. This level of loss is larger than the intersection point between the two liability lines, since at the point of intersection both choose the same level of investment, thus the supplier abstains from investing.

The results of this model do not support the existence of product stewardship. They show that either the supplier or the customer has clear incentives to invest in protective measures, but both parties will not jointly invest in care. These results run counter to product stewardship practices found in the chemical industry today. Large chemical suppliers invest in improved product design and assist their customers in proper handling and use of substances, while customers do their share of training workers and utilizing best available technologies to reduce environmental impacts of their products. This behavior may be the consequence of monitoring by suppliers to assure that customers take sufficient care to cover their liability, while suppliers invest in care to cover their possible liabilities. Other rationales are advanced below.

III. <u>The Case of Asymmetric Information</u>

We now relax the unreasonable assumption that customer assets are common knowledge and provide another explanation for corporate behavior that promotes product stewardship. Consider the case where customer future asset levels are known only to the customer. Because these assets are required to cover future possible losses, should the customer be held liable, a von-Stackelberg game of imperfect information arises between the supplier and the customer. To describe this game, assume that the customer knows his own asset level, which is drawn from a continuous distribution $f(A)$. The supplier has knowledge of the distribution, but not the customer's asset level.

Proposition 2: Assume customer type, defined by asset level, is unknown to the supplier and is drawn from the known distribution of asset levels $f(A)$. At the Bayesian Nash equilibrium of the von-Stackelberg game, the supplier invests in care if the density of small customers is significant; a customer with severely limited assets does not invest in care, while a customer with sufficient assets invests in care. The aggregate level of care will be less than the socially optimal value $z^*(L)$.

Proof: See Appendix.

Proposition 2 explains companies' interest in product stewardship. Suppliers who are uncertain about their customers' future capability to compensate for environmental damage, invest in care, and become product stewards to reduce the probability of liability. Since the possibility of customer bankruptcy is limited, supplier investment decreases with the probability of sufficient assets. Supplier investment increases, as possible losses are large in comparison with future customer assets. On the other hand, customers who have knowledge that they will have sufficient future funds for potential compensation invest additionally in care, to cover the liabilities that the supplier does not sufficiently invest for. Customers with sufficient assets enjoy the stewardship initiatives by suppliers and complement these investments. Other customers find supplier's investment sufficient for their needs, and choose not to invest additionally in care.

A case of interest is one in which there are only two possible customer types. Assume that customers may either be of type 1, for whom $A_1 < L$, with a probability of ρ_1, or of type 2 with probability $\rho_2 = 1 - \rho_1$, where $A_2 > L$. In this case, conditions for supplier and customer investment may be explicitly stated.

Proposition 2a: In the von-Stackelberg game with two customer types and imperfect information, assume two possible customer types, A_1 and A_2 where $A_1 < L \leq A_2$, denoting by ρ_1 the common knowledge probability that customer assets are A_1. Define L_{2c} as the critical level of loss, for which the supplier will invest if and only if losses are greater than L_{2c}. Then at the Bayesian Nash equilibrium of the game:

a) if: L £ L_{2c}:

i) $x_1^*(L,y^*) = z^*(q_c A_1) > 0$;

ii) $y^*(L,x_1^*,x_2^*) = 0$; and

iii) $x_2^*(L,y^*) = z^*(q_c L) < z^*(L)$

b) if: $L_{2c} < L$:

i) $x_1^*(L,y^*) = 0$;

ii) $y^*(L,x_1^*,x_2^*) = z^*(r_1 q_s q_c (L - A_1) > 0$; and

iii) $x_2^*(L,y^*) = \text{Max}\{z^*(q_c L) - y^*, 0\} = z^*(q_c L) - z^*(r_1 q_s q_c (L - A_1) > 0$

Proof*:* See Appendix.

Figure 2: <u>Expected Liability versus Loss – Asymmetric Information</u>

INSERT FIGURE 2 HERE

The simplicity of the case of two customer types allows for graphical explanation, which provides insight into the general case. Figure 2 expands Figure 1 to the case with two customer types. Assuming damage occurs customers with sufficient assets (type 2) will be held solely responsible for any damage caused. Suppliers will be jointly liable only in those instances where customers do not have sufficient assets to compensate (type 1 customers). The supplier's decision is based solely on the parameters of the type 1 customer. Because there is a positive probability that the customer is of type 2, the supplier's expected liability is lower than in the original case. Thus, the intersection between the two liability lines shifts to the right. Similar to the arguments for Proposition 1, there exists some threshold above which the supplier invests, and below which only the customer invests in care. In both cases a customer of type 2 has incentives to invest in care, after the supplier chooses his investment in care, so type 2 customers always invest in care, the magnitude of which depends on the supplier's decision.

Propositions 1 and 2a indicate that when $L \in [L_c, L_{2c}]$ a customer with limited assets would prefer to credibly signal his compensation possibilities, to increase the supplier's investment and reduce his own investments in care. For potential losses within this region a type 1 customer with assets of A_1 invests in care, while he would not invest if the supplier knew his type. Credible revelation is difficult because a type 2 customer, with sufficient assets to compensate for possible losses, would also prefer to state that he has only limited assets to induce the supplier to undertake investments. To achieve this, a large customer may try to hide assets giving the impression that he is not capable of compensating future damages. With all customer types indicating that they have only limited assets, the supplier maintains his beliefs regarding the distribution of customer assets.

Incentives for customer revelation of private information may take on a number of forms. The next section investigates monitoring as one possibility, while the impact of competition on partnership choice is discussed in Section VI. Future research should evaluate other screening mechanisms, where the supplier offers multiple contracts and different customers choose different contracts, revealing their asset level (see e.g., Watabe, 1999 for an example of a screening contract when only clients invest in care).

IV. Monitoring

The environmental movement has witnessed in recent years an increase in the viability of monitoring supply chain partners' environmental behavior. Product stewardship attempts to monitor investment in care using on-site audits by suppliers. Other initiatives to monitor environmental prudence use ISO 14000 as an international environmental monitoring standard. Requiring suppliers to become ISO 14001 certified requires them to undergo periodic reviews by qualified auditors to assure that the company is adhering to its Environmental Management System (EMS). In particular, third party audits may be a viable method for suppliers to verify customers' investment in care (see Kleindorfer, 1997) and it is becoming increasingly common for large companies to require ISO 14001 certification of their suppliers (Chemical Week, Apr. 8, 1998; Industrial Management, 1997).

Currently the supply chain dynamics of ISO 14000 are limited to customers requiring their suppliers to become certified. Verification of customer investment in care often takes other forms such as periodic audits by the supplier or by third parties. Customers may be reluctant to agree to monitoring requested by a supplier, especially if the product has little added value or is produced by many competitors. In these cases suppliers may find monitoring infeasible and decisions regarding investment in care may be dictated by asymmetric information. For those instances where monitoring may be acceptable, because for example, the supplier has proprietary knowledge, customer monitoring may be in the supplier's best interest.

Different customer types have different investments in care, as seen in Section III. Thus, monitoring their level of investment allows insight into their private knowledge of future asset level. As described in Section II, the customer's assets are the funds available to the customer for compensation, given loss has occurred. These include not only physical assets but also any intangible assets (Itami and Roehl, 1987), such as “goodwill” and the value of the business as a going concern, against which the customer may borrow to compensate for loss. Monitoring by the supplier of customer operations is likely to provide considerably more precise estimates of these “effective assets” to meet losses than would result from an arms-length relationship.

Under asymmetric information, the supplier’s decision is based on the distribution function of customer asset levels. With perfect information the supplier may tailor his investment, given the true customer type. It may be worthwhile for the supplier to require the customer to be certified by a third party auditor, and thus reduce his expected losses, which include investment in care and expected liability. Since monitoring does not affect the supplier’s residual liability, but only his investment in care, monitoring should be worthwhile only under certain conditions. In the two customer type example, investigated in Proposition 2a, explicit conditions for the benefits of monitoring may be determined. (See Snir, 1999 for the sufficient conditions in the general case.) Proposition 3 describes necessary condition for monitoring to be warranted, while defining sufficient conditions depends on the fixed costs of monitoring F.

Proposition 3: In the von-Stackelberg game with two customer types and imperfect information, assume two possible customer types, A_1 and A_2 where $A_1 < L \leq A_2$, denoting by ρ_1 the common knowledge probability that customer assets are A_i i=1,2 and assume that $L_c<L_{2c}$. Monitoring by the supplier will be worthwhile when losses are sufficiently large and fixed monitoring costs (F) sufficiently low, or when the expected value of perfect information, $V(L)$, is sufficiently large. Furthermore:

a) If $L_0 < L_1$ and it is worthwhile to monitor when $L = L_0$, then it is also worthwhile to monitor when $L = L_1$.

b) If $F_1 < F_0$ and it is worthwhile to monitor when $F = F_0$, then it is also worthwhile to monitor when $F = F_1$.

c) The expected value of perfect information, $V(L)$, is monotonically non-decreasing.

Proof*:* Omitted - see Snir, 1999.

Proposition 3 shows that as potential losses increase, suppliers are more interested in monitoring customers. Thus, we would expect third party monitoring in those cases where liabilities may be largest. Specifically, in the environmental area, we should find companies using third parties or other audits to verify customers investments in mitigation. Promoting ISO 14001 certification should become prevalent in dispersed supply chains, where certain partners have large potential liabilities and partners' actions are difficult to control. This supports the claim by Kleindorfer (1997) that market-based incentives may be sufficient to promote the widespread use of ISO 14001 as a monitoring mechanism.

The viability of monitoring customers is not limited to monitoring direct behavior and can be extended to realizing the value of a credible signal regarding the customer's assets. When monitoring is justified, from the supplier's view, he may provide incentives for the customer to reveal his asset type. In these instances suppliers may pay for external verification of customer assets or offer discounts to those customers that choose to credibly signal their ability to compensate future loss. A customer would accept this offer when the incentive is greater than the benefit from hiding his type. When the expected value of perfect information $V(L)$ is sufficiently large, such incentive payments are feasible.

One possible arrangement is to require customers to have sufficient insurance to cover all possible liabilities. When this is feasible it provides two advantages. First, it signals that the customer has sufficient assets to cover potential losses. Second, insurance companies monitor customer behavior to assure sufficient investment in care. While this appears attractive, insurance companies are hesitant to provide such comprehensive coverage, for all possible environmental contingencies for an indefinite horizon.

V. Generalizations

An additional method to explain product stewardship is to differentiate between suppliers' and customers' impact on loss reduction. If the supplier and customer each affect a different loss, with a different risk reduction mechanism, then we should find each investing in his respective technologies. Consider the case when the supplier can influence only large scale environmental damage, for example, through product design, reduced B-P-Ts (Biocides, Pesticides, and Toxics), and improved monitoring of his facilities, and he will be held solely liable for damage that occurs from his range of responsibilities. On the other hand the customer may influence only local damage, for example: on-site accidents and emissions. If only the customer will be held liable for his range of responsibilities we will find that each party invests in their respective actions, dependent on the magnitude of loss and the probability of being held liable.

Equilibrium behavior will also be influenced by the relative efficiency of each party's investments. The model analyzed here allowed only for equal efficiency between parties, but in cases where one party may have an advantage in reducing loss probability, due to superior knowledge or capital, we should expect threshold levels for investments to change. Namely, if a supplier may reduce risk using cheaper methods than customers, we should find these methods being implemented before customers' investment. Suppliers provide safety and use information to customers through Material Safety Data Sheets (MSDS), warning labels, training, and customer support help desks.

When a single supplier has a number of customers, who vary in future asset levels, the supplier should invest in care, dependent on customer insolvency probabilities, customer assets relative to loss potential and average asset level, of those customers with limited assets. Customers, who have below threshold assets, choose to not additionally invest, since the supplier's investments suffice given their liability level. Others, who have above threshold assets, find that supplier initiatives do not suffice, and they are motivated to additionally invest in care. In many industries product stewardship takes on this form. Suppliers choose their optimal level of care, given customer heterogeneity. In an industry characterized by large customers average levels of care across the supply chain can be expected to increase.

VI. Discussion

This paper develops an analytical framework to evaluate the importance of joint and several liability as motivating current practices of product stewardship by the largest chemical companies. Limited liability is an important driver of private investments to reduce the probability of adverse events, and leads to under-investment by small customers. Realizing that they will be held liable for residual liabilities, large suppliers invest in care. When suppliers have information regarding customers' compensation possibilities either the supplier or the customer will invest in care, but not both. Under the more reasonable assumption that information regarding future assets is imperfect, we should find product stewardship initiatives where suppliers invest, with additional investment limited to large customers. The need for investments in care when customer assets are uncertain may justify monitoring customer action and asset levels. As potential losses increase the economic viability of monitoring increases, and suppliers may take a more active role in evaluating their customers before supplying hazardous material.

VI.A. Product Stewardship and Monitoring

Based on the analytical framework proposed, the potential for product stewardship may be formulated. Companies who have relative advantages in certain risk reduction factors should implement these to reduce the liability of the entire supply chain. Such factors could include on-site activities such as improved design, and also off-site activities such as distributing information, accident and "near-accident" investigation and customer training. For example, Ashland Chemical, a chemical manufacturer and distributor, supports some of its clients' needs by selling chemicals on a "turn-key" basis, taking on all the responsibilities of providing and disposing of chemicals (Chemical Week, Feb. 2, 1994). When there are economies of scale, such actions should be even more pronounced. For companies with similar clients, a single program, of improved design or recycling, may affect damage probabilities throughout the product life cycle. These appear to be extremely beneficial for companies to pursue, in their attempt to promote stewardship programs. It is evident that such programs will be less common in intermediate process companies, with a limited client base.

Suppliers facing customer heterogeneity should have incentives to promote third party monitoring, especially when customer asset levels are diverse and loss potential is large. Such monitoring will provide suppliers with insight into customer care choice, a proxy for asset level. Given this information, suppliers may tailor their investments in care, to be congruent with customer asset levels. For those customers with few assets product stewardship initiatives should increase, due to customer abstaining from investment, while for large customers, risk reduction investment may decrease, since those partners have an independent interest to invest in care. ISO 14000, as an international standard of environmental action, provides one such mechanism of assurance. Customers who become certified undergo evaluation that they adhere to their own Environmental Management System (EMS). If suppliers believe that customers' EMS prove sufficient investment in care, they may relax their own monitoring of practices (e.g., Kleindorfer, 1997).

VI.B. Supply Chain Design and Care

In a bilateral relationship, with a single supplier and a single customer the customer has no incentive to reveal his future asset level, inducing product stewardship activities by the supplier. These stewardship initiatives are most pronounced when the supplier is uncertain about the customer's future assets available for compensating potential damage. Uncertainty regarding the level of insurance provided by his customer and the resulting residual liability induce the supplier to invest in reducing liability throughout the supply chain.

In a competitive setting, with multiple customers, this result may be reversed. Clients with sufficient assets would prefer to credibly indicate their assets to win distribution contracts from monopolist suppliers. With assets shielding suppliers from potential liabilities, these become a competitive advantage. To credibly indicate their ability to compensate for future losses large distributors would be willing to undergo comprehensive financial scrutiny both by suppliers and by third parties. Smaller customers, without the ability to compensate future losses could do little to mimic their competitors' asset base.

This is most evident in hazardous waste disposal. Facilities with wastes that may be hazardous should prefer disposal companies with sufficient assets to be held liable for any damage incurred. Such large waste management companies should have a distinct competitive advantage due to their ability to limit others' liability. This is especially true in client industries where facilities producing hazardous waste do not have the capability to properly dispose of it, as in the medical or film industries. The Council of Logistics Management finds that the threat of liability, specifically improper disposal by waste contractors, is a key factor in DuPont's success in the film recovery business, which extracts silver and "unzips" polymer material from film used in medical services, offset printing and electronics. (Council of Logistics Management, 1993). For similar reasons transportation of potentially hazardous material should be contracted out to large carriers, who have the financial capability to cover potential liabilities.

VI.C. Directions for Future Research

Investments in environmental protection often require both easily observable actions such as capital improvements and actions that are more difficult to ascertain including ongoing employee training and process control. The private nature of some of these investments, especially by customers, makes contractual solutions difficult to implement. A necessary condition for such contracts includes easily observable and verifiable actions, which form the basis of the contract. Under the less restrictive assumptions of private investments a strategic game between the supplier and customer emerges. Each party makes their investment considering the other party's actions, and responding to these. Future research should complement this research by examining possible contractual remedies to increase mitigation efforts, and the information requirement to implement such contracts. Watabe (1999) examines one such contract in a competitive setting with clients solely investing in care.

The analysis herein evaluates these investments in a supply chain setting where supplier investment both precedes customer investment and is observed by the customer before he makes his investment decision. This leads to a sequential game where the supplier's actions consider the client's best response before undertaking product stewardship initiatives. Other strategic interactions along the supply chain should be considered where the client does not observe supplier investment. This would lead to a Nash game between both parties with simultaneous investments by both parties. While the precise outcomes of this type of interaction are beyond the scope of this paper, simultaneous investments would increase investments by customers and lead to less investment in care by suppliers. As a first-mover suppliers are disadvantaged because customers can react to observed investments. Without the benefits of observing supplier action customers would have to increase investment relative to the results of the von-Stackelberg game (Maxwell and Decker, 2000).

The analytical framework examines the implications for product stewardship for large suppliers but can easily be extended to address other issues regarding supply chain partnerships. In industries with suppliers with limited assets upstream partners have few incentives to privately invest in reducing downstream liabilities. In this context we would find "deep pocket" participants as sole investors, regardless of their position along the supply chain. Alternatively, large partners could contractually require suppliers to invest in care. By examining production processes and delivered products large customers could verify sufficient investments by suppliers, reducing the problems associated with under-investment induced by limited liability.

VII. Conclusion

The model proposed in this paper allows insight into the developing initiatives of product stewardship. These initiatives, it is hypothesized, should be beneficial in reducing liability, in instances where companies may find themselves liable for environmental damage caused by supply chain partners, when those become insolvent. Under current legislation companies may find themselves compensating for independent contractors actions, either in cleaning hazardous waste sites, or when handling abnormally dangerous material (Evans, 1994). Product stewardship and other mechanisms of investing in care should become more common. These efforts are extremely effective when companies sell to heterogeneous customers, or have specific advantages in providing customer support. On the other hand, customer monitoring may be an effective tool in reducing the investments in care taken on by suppliers, by tailoring investment based on customer assets available for compensation.

Acknowledgments

I am grateful to Il-Horn Hann, Lorin Hitt, Howard Kunreuther, Moti Levi participants in the Wharton Supply Chain Seminar and two anonymous reviewers for many helpful comments on previous drafts. I am deeply indebted to Paul R. Kleindorfer for his endless assistance and guidance in this research. Any remaining errors are my sole responsibility. This research is supported in part by the Wharton Risk Management and Decision Processes Center, of the University of Pennsylvania.

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Appendix: Proofs of Propositions

Proof of Proposition 1:

Given any level of care chosen by the supplier y, the customer chooses his level of care $x^*(L,y)\geq 0$ to satisfy:

$$x^*(L,y) \;=\; \underset{x\geq 0}{\text{Argmin}}\,[x + p(x + y)q_c\min\{L, A\}]$$

From (1) we can see that:

$$x^*(L,y) \;=\; \text{Max}\{z^*(q_c\min\{L, A\})\text{-}y,\, 0\} \qquad (2)$$

The supplier chooses $y^*(L,x^*)\geq 0$ to minimize his residual liability, knowing the customer's reaction function $x^*(L,y)$. The supplier's level of care:

$$y^*(L,x^*) = \underset{y\geq 0}{\text{Argmin}}\,[y + p(x^*(L,y)+y)q_sq_c\max\{L - A,\, 0\}] \qquad (3)$$

From (2) it can be seen that if the customer invests in care, any investment by the supplier reduces the customer's investment. Since the supplier's decision is based on the customer's best response function in those cases that the customer does invest the supplier does not invest additionally. The supplier has an incentive to invest in care only if his expected costs from investment are less than the supplier's cost from the customer's investment. Since the investment by the supplier reduces investment by the customer, supplier investment is conditional on the customer's abstaining from investment. So we have that either the supplier or the customer invest in care but not both. From (2) and (3) since each party's loss is less than the social loss (L) the individually rational investment in care is less the social optimal.

The sufficient condition for the supplier to invest in care is:

$$y^*(L,x^*) + p(y^*(L,x^*))q_s q_c \max\{L - A, 0\} < p(x^*(L,0))q_s q_c \max\{L - A, 0\} \quad (4)$$

From (3) if $L \leq A$, it is obvious that $y^*(L,x^*) = 0$, and the supplier has no incentive to invest in care. Thus, condition (4) is of interest only for $L > A$. Define L_c such that condition (4) holds $\forall L > L_c$. To complete the proof it is required to show existence and uniqueness of L_c.

To show existence and uniqueness of L_c define $f(L)$ as the increase in the supplier's objective function in (3) from investing in care, as opposed to having only the customer invest. Thus for $L>A$:

$$f(L) \equiv y^*(L,x^*) + p(y^*(L,x^*))q_s q_c(L - A) - p(x^*(L,0))q_s q_c(L - A) \quad (5)$$

L_c can be implicitly defined as $f(L_c) = 0$.

When the customer chooses not to invest, the supplier's optimal investment from (1) and (3) is given by:

$$y^*(L,0) = z^*(q_s q_c \max(L - A)) \quad (6)$$

replacing (2) and (6) into (5), when $L>A$ we get:

$$f(L) = z^*(q_s q_c(L - A)) + p(z^*(q_s q_c(L - A)))q_s q_c(L - A) - p(z^*(q_c A))q_s q_c(L - A)$$

$$f(L) = z^*(q_s q_c(L - A)) + [p(z^*(q_s q_c(L - A))) - p(z^*(q_c A))]q_s q_c(L - A)$$

It can be shown that has $f(L)$ only one critical point (i.e., $f'(L)=0$) and that point is attained at $L_m \equiv A(1+q_s)/q_s$. In addition, $f(L)$ is maximized at $f(L_m)$; $f(L)>0$ $\forall L \in (A,L_m]$; and $f(L)$ is strictly concave and decreasing $\forall L>L_m$. Thus, L_c exists and is unique.

Q.E.D.

Proof of Proposition 2:

Define A_i as the asset level of a customer of type i from the distribution $f(A)$. It is helpful to order customer types, such that: if $k < l$, $A_k < A_l$.

Given any level of care chosen by the supplier y, customer of type i chooses $x_i(y) \geq 0$ such that:

$$x_i^*(L,y) = \underset{x_i \geq 0}{\text{Argmin}} \, [x_i + p(x_i + y) q_c \min\{L, A_i\}]$$

Solving the customer's problem to find $x_i^*(L,y)$, assuming an interior solution exists, the F.O.C. for each customer type is, analogous to (2):

$$p'(x_i^*(L,y) + y) = -1/(q_c \min\{L, A_i\}) \quad (7)$$

For a customer of type i where $A_i \leq L$, (7) becomes:

$$p'(x_i^*(L,y) + y) = -1/q_c A_i$$

thus:

$$x_i^*(L,y) = \text{Max}\{p'^{-1}[-1/(q_c A_i)] - y, 0\} \quad (8)$$

And for customers of type k where $A_k > L$, (7) becomes:

$$p'(x_k^*(L,y) + y) = -1/q_c L$$

thus:

$$x_k^*(L,y) = \text{Max}\{p'^{-1}[-1/(q_c L)] - y, 0\} \quad (9)$$

The supplier chooses $y \geq 0$ to minimize his expected cost based on his residual liability, knowing the distribution of customer types, and each customer's reaction function $x_i^*(L,y)$. The supplier's objective is thus:

Min $\{y + \text{E[liability]}\}$ =

$y \geq 0$

$$\text{Min}\ \{y + {}_0\!\int^L [p(x_i^*(L,y)+y)q_s q_c (L - A)\, f(A)]dA + {}_L\!\int^{¥} [p(x_i^*(L,y)+y)q_s q_c 0\, f(A)]dA\} \quad =$$
$y \geq 0$

$$\text{Min}\ \{y + {}_0\!\int^L [p(x_i^*(L,y)+y)q_s q_c (L - A)\, f(A)]dA\} \quad =$$
$y \geq 0$

$$\text{Min}\ \{y + p(x_i^*(L,y)+y)q_s q_c {*}\text{Prob}\{A \leq L\}\text{E}[A_L]\} \qquad (10)$$
$y \geq 0$

where: $\text{E}[A_L] \equiv \text{E}[A \mid A \leq L]$

To identify the conditions under which the supplier invests in care, assume there exists $A_b < L$, such that all customers with assets greater than A_b invest in care. Since customers with lower asset levels have less incentive to invest, customer types $i \leq b$, will not invest at all. Formally:

from (8)

$$z^*(q_c A_b) < y \qquad \Rightarrow \qquad z^*(q_c A_i) < z^*(q_c A_b) < y$$

So we have that: $\quad x_b^*(L,y) = 0 \qquad \Rightarrow \qquad x_i^*(L,y) = 0 \qquad \forall i < b.$

Now the supplier's problem is:

$$\text{Min}\ \{y + {}_0\!\int^{Ab} [p(y)q_s q_c (L - A)\, f(A)]dA + {}_{Ab}\!\int^L [p(x_j^*(L,y)+y)q_s q_c (L - A)\, f(A)]dA\}$$
$y \geq 0$

the derivative to the supplier's objective function (8) is, denoting $dx_j^*(L,y)/dy$ as $x_{jy}^*(L,y)$:

$$1 + p'(y)q_s q_c \text{Prob}\{A < A_b\}(L - \text{E}[A_b])(1) + p'(x_j^*(L,y)+y)q_s q_c (x_{jy}^*(L,y) + 1)_{Ab}\!\int^L [(L - A)\, f(A)]dA$$

where: $\text{E}[A_b] \equiv \text{E}[A \mid A \leq A_b]$

and since for $A \leq L$ from (8): $\quad x_{jy}^*(L,y) = -1$

we get the following F.O.C.:

$$1 + p'(y)q_s q_c \text{Prob}\{A < A_b\}(L - \text{E}[A_b]) = 0$$

which requires that:

$$p'(y) = -1/[q_s q_c \text{Prob}\{A < A_b\}(L - \text{E}[A_b])] \quad (11)$$

which yields

$$y^*(L) = z^*(q_s q_c \text{Prob}\{A < A_b\}(L - \text{E}[A_b])) \quad (12)$$

so that the supplier invests in care if $(L - \text{E}[A_b]) > 0$.

The definition of A_b remains to be found. The conditions for (8) to hold, are that:

$\forall i < b$: $\quad p'(y^*) > -1/(q_c A_i)$; and

$\forall j \geq b$: $\quad p'(y^*) < -1/(q_c \min\{A_j, L\})$

from these conditions and (11):

$$-1/(q_c A_i) < -1/[q_s q_c^* \text{Prob}\{A_i < A_b\}(L - \text{E}[A_b])] < -1/(q_c \min\{A_j, L\}) \Leftrightarrow$$

$$A_i < q_s \text{Prob}\{A_i < A_b\}(L - \text{E}[A_b])] < \min\{A_j, L\} \Leftrightarrow$$

$$\text{E}[A_b] + A_i/[q_s \text{Prob}\{A_i < A_b\}] < L < \text{E}\, A_b] + \min\{A_j, L\}/[q_s \text{Prob}\{A_i < A_b\}]$$

So A_b, may be defined by:

$$\text{E}[A_b] + A_b/[q_s \text{Prob}\{A_i < A_b\}] = L \quad (13)$$

To summarize, as shown by (12), the supplier always invests in care; a customer with assets lower than A_b, as defined in (13) does not invest in care; and the investment level for a customer with assets greater than A_b, is, from (9) and (12):

$$x_j^*(L,y) = z^*(q_c \min\{A_j, L\}) - z^*(q_s q_c \text{Prob}\{A_i < A_b\}(L - \text{E}[A^b])) > 0 \quad (14)$$

Since $z^*(L)$ is increasing in its argument, it follows that under-investment is prevalent.

Note that if $\text{Prob}\{A_i < A_b\} = 0$ then $y^*(L) = 0$, as seen in Proposition 1.

Q.E.D.

Proof of Proposition 2a:

In this case a customer of type 1 has future assets A_1, where $A_1 < L$, with Prob($A = A_1$) = r_1; and a customer of type 2 has future assets A_2, where $A_2 > L$, with Prob($A = A_2$) = (1 - r_1).

Given any level of care chosen by the supplier y, customer of type i chooses $x_i(y) \geq 0$ so that:

$$x_i^*(L_i\, y) \;=\; \underset{x_i \geq 0}{\text{Argmin}}\; x_i + p(x_i + y)q_c \min\{L, A_i\} \qquad i = 1,2$$

From (1) we can see that:

$$x_i^*(L,y) \;=\; \text{Max}\{z^*(q_c \min\{L, A_i\}) - y,\, 0\} \qquad i=1,2 \tag{15}$$

The supplier chooses $y^*(L,x_1^*,x_2^*) \geq 0$ to minimize his expected residual liability, knowing both types' reaction functions $x_i^*(y)$. The supplier's level of care is thus:

$$y^*(L,x_1^*,x_2^*) = \underset{y \geq 0}{\text{Argmin}}\; [y + \text{E[liability]}]$$

$$y^*(L,x_1^*,x_2^*) = \underset{y \geq 0}{\text{Argmin}}\; [y + r_1 p(x_1^*(L,y)+y)q_s q_c(L - A_1) + (1 - r_1)p(x_2^*(L,y)+y)q_s q_c 0]$$

$$y^*(L,x_1^*,x_2^*) = \underset{y \geq 0}{\text{Argmin}}\; [y + r_1 p(x_1^*(L,y)+y)q_s q_c(L - A_1)] \tag{16}$$

From (15) it can be seen that a customer invests in care, any investment by the supplier reduces the customer's investment. Since, from (16), the supplier's decision is based only on type 1 customer's best response function in those cases that this customer does invest the supplier does not invest additionally. The supplier has an incentive to invest in care only if his expected costs from investment are less than the supplier's cost from customer type 1's investment. Since the investment by the supplier reduces investment by both customer types, supplier investment is conditional on type 1 customer abstaining from investment. So we have that either the supplier or type 1 customer invest in care but not both.

The sufficient condition for the supplier to invest in care is:

$$y^*(L,x_1^*,x_2^*) + r_1 p(y^*(L,x_1^*,x_2^*))q_s q_c(L - A_1) < r_1 p(x_1^*(L,0))q_s q_c(L - A_1) \quad (17)$$

Define L_{2c} such that condition (17) holds $\forall L > L_{2c}$. To complete the proof it is required to show existence and uniqueness of L_{2c}.

To show existence and uniqueness of L_{2c} define $f_2(L)$ as the increase in the supplier's objective function in (16) from investing in care, as opposed to abstaining from investment. Thus for $L > A_1$:

$$f_2(L) \equiv y^*(L,x_1^*,x_2^*) + r_1 p(y^*(L,x_1^*,x_2^*))q_s q_c(L - A_1) - r_1 p(x_1^*(L,0))q_s q_c(L - A_1) \quad (18)$$

L_{2c} can be implicitly defined as $f(L_{2c}) = 0$.

When type 1 customer chooses not to invest, the supplier's optimal investment from (1) and (16) is given by:

$$y^*(L,0,x_2^*) = z^*(r_1 q_s q_c \max(L - A_1)) \quad (19)$$

replacing (15) for customer type 1 and (19) into (18), when $L > A$ we get:

$$f_2(L) = z^*(r_1 q_s q_c(L - A_1)) + p(z^*(r_1 q_s q_c(L - A_1)))r_1 q_s q_c(L - A_1) - p(z^*(q_c A_1))r_1 q_s q_c(L - A_1) =$$

$$f_2(L) = z^*(r_1 q_s q_c(L - A_1)) + [p(z^*(r_1 q_s q_c(L - A_1))) - p(z^*(q_c A_1))]r_1 q_s q_c(L - A_1)$$

It can be shown that has $f_2(L)$ only one critical point (i.e., $f_2'(L)=0$) and that point is attained at $L_{2m} \equiv A_1(1+r_1 q_s)/\ r_1 q_s$. In addition, $f_2(L)$ is maximized at $f_2(L_{2m})$; $f_2(L)>0\ \forall L \in (A,L_{2m}]$; and $f_2(L)$ is strictly concave and decreasing $\forall L > L_{2m}$. Thus, L_{2c} exists and is unique.

Furthermore, if L £ L_{2c}:

$$y^*(L,x_1^*,x_2^*) = 0$$

and from (15):

i) $x_1*(L,y*) = z*(q_c A_1) > 0$; and

ii) $x_2*(L,y*) = z*(q_c L) < z*(L)$

and if: $L_{2c} < L$ from (15) and (19):

i) $x_1*(L,y*) = 0$;

ii) $y*(L,x_1*,x_2*) = z*(r_1 q_s q_c (L - A_1) > 0$;

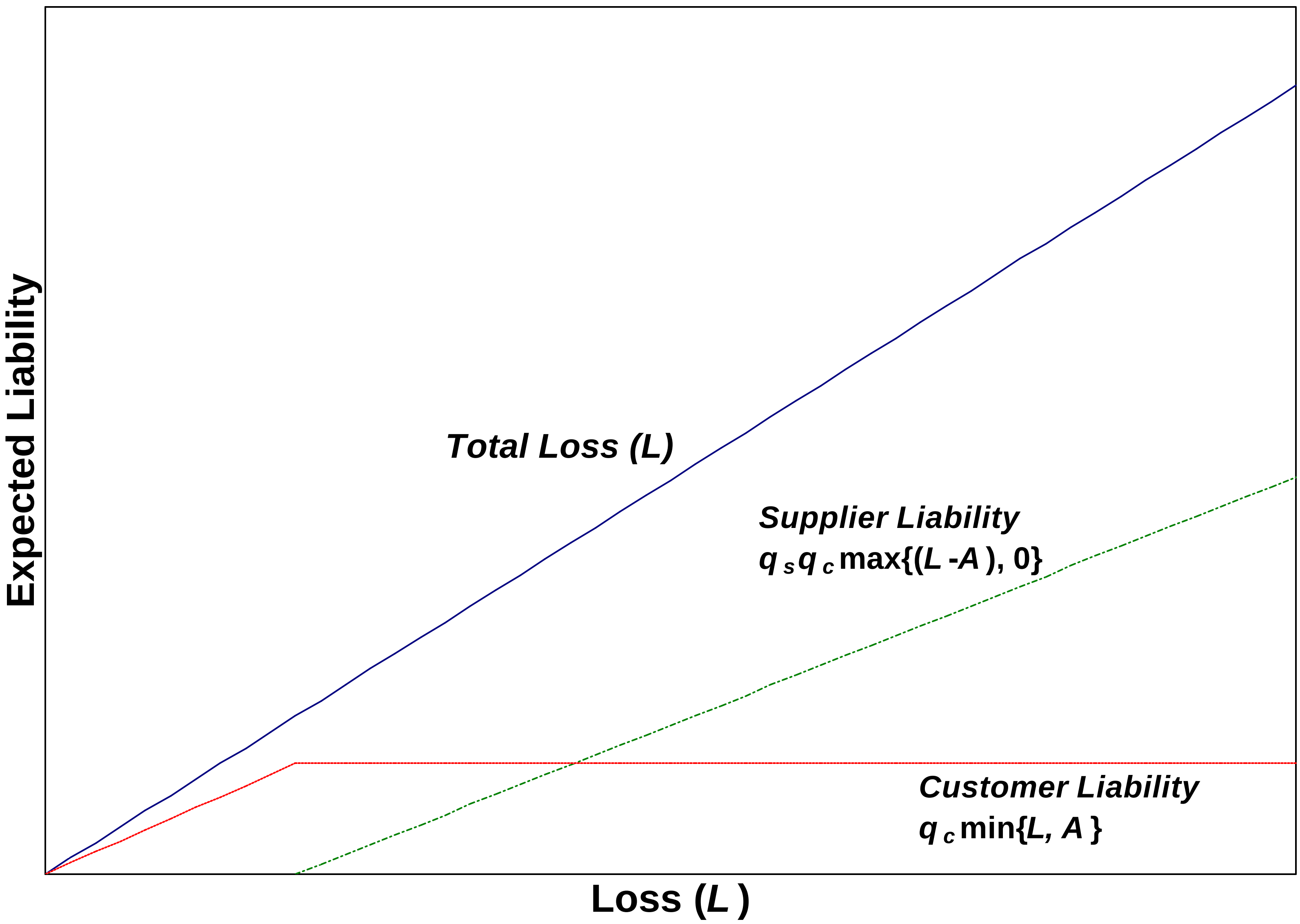
iii) $x_2*(L,y*) = \text{Max}\{z*(q_c L) - y*,0\} = z*(q_c L) - z*(r_1 q_s q_c (L - A_1) > 0$

Again showing that under-investment in care results at the Bayesian Nash Equilibrium.

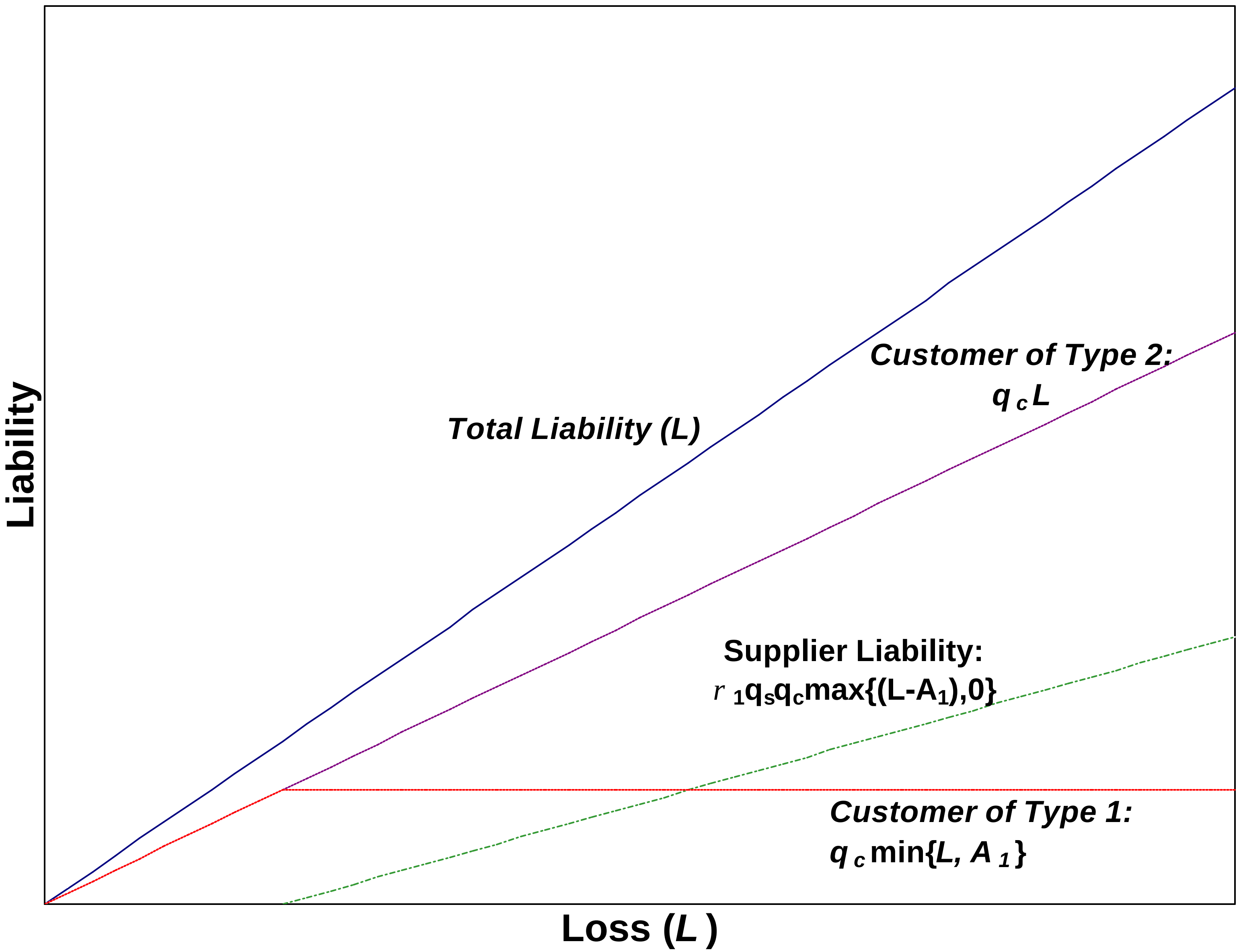
Q.E.D.

Proof of Proposition 3:

Omitted – see Snir, 1999.



Expected Liability
Total Loss (L)
Supplier Liability
$q_s q_c \max\{(L - A), 0\}$
Customer Liability
$q_c \min\{L, A\}$
Loss (L)


Liability
Total Liability (L)
Customer of Type 2:
q c L
Supplier Liability:
r 1qsqcmax{(L-A1),0}
Customer of Type 1:
q c min{L, A 1}
Loss (L)