Industry Self-Governance and National Security: On the Private Control of Dual Use Technologies*

– Work in Progress –

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Abstract

Private sector firms frequently sell "dual use products" that can be used to develop either civilian goods (e.g. medicines) or weapons of mass destruction (e.g. genetically engineered viruses). We assume two risks due to the "dual use" nature. First, the upstream makers face legal liability if their products lead to a disaster. Second, a disaster may produce regulatory backlash, i.e. excessive government regulation that effectively suppresses the tool along with downstream industry's expected profits from developing new products.

This paper explores the economic conditions for downstream firms imposing strong industry-wide regulation on their upstream suppliers. We find that regulatory backlash is never an adequate substitute for perfect (i.e. full) liability and even makes the situation worse. Second, industry regulation enforced by downstream firms and optimal regulation converge when the downstream firms have strong market power. Next, we show that established upstream firms may be able to deter entry in proposing a high regulatory standard. Finally we analyze when and why large downstream firms are able to force their preference for high levels of regulation on upstream suppliers.

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1 Introduction

It is normal to associate industry-wide governance (i.e. developing and implementing a certain regulatory policy) with the formal institutions set and enforced by government. At the same time, US industry frequently discusses and sometimes practices self-governance. This is usually quite limited for bodies that rely on existing or threatened government regulation for enforcement. Here, theory and evidence both suggest that self-governance will usually be limited to relatively small departures from government's officially-defined goals (Khanna & Widyawati 2011; Ashby et al. 2004). However, the case is very different where standards are enforced by non-government actors. In recent years, many large firms have refused to do business unless suppliers adopt stringent, company-wide standards. Typical examples include voluntary standards covering the treatment of manufacturing workers (The Gap), packaging waste and energy efficiency (Walmart), social and environmental practices (Hewlett Packard), business ethics (Astra-Zeneca), and even nuclear non-proliferation standards (US government)—see Gunningham & Rees (1997), Fiorino (2010) Maurer et al. (2011), and Wirtz (2010). Other large firms have extended the principle by demanding that entire industries (e.g., coffee, nanotechnology, artificial DNA) adopt standards (Besshiem & Kahn 2010; Maurer 2010).

Clearly, we would like to know whether these new, market-driven governance models can be trusted to promote welfare and when and why strong, industry-wide standards establish. This paper analyses the typical case in which firms in a downstream market demand standards from their upstream suppliers. We begin by asking what standards up- and downstream firms prefer. In keeping with the traditional governance literature, we assume that firms are profit maximizing actors who face risk associated with (a) a common law duties of care, and (b) regulatory backlash that could cripple or destroy their entire industry (Lenox & Nash 2003; King & Lenox 2000). We also ask how these answers are likely to differ in the face of imperfect information and asymmetric firms size. Finally, we ask how the market mediates the preference of up- and downstream firms to arrive at private standard(s). Strikingly, we find that uniformly industry-wide standards can sometimes emerge even in cases where some consuming firms would have preferred a weaker alternative.

2 Background

2.1 Overview

Private institutions increasingly serve functions that have "historically been the task of governments, most notably that of regulating the negative externalities of economic activity." (Mayer & Gareffi 2010) This often leads to "private politics" in which parties attempt to "influence economic activity... without reliance on public institutions or officeholders." (Baron 2001) Many observers find this problematic since such bodies often "do not derive governing authority from states nor are they accountable to them." (Bernstein & Cashore 2007). At the same time, formal treaties can take decades to negotiate and weak states are often incapable of effective regulation. In these circumstances, private politics will usually be preferable to no regulation at all. (Buthe 2010) More fundamentally, government regulation is also imperfect: This suggests that private regulation may sometimes yield superior outcomes. (Fuchs & Kalfagianni 2010). Answering these puzzles will require a deeper understanding of when self-governance is possible, what government can do to promote it, and when it produces socially efficient outcomes. To date, however, the literature has been dominated by political scientists and sociologists. Except for a handful of isolated papers (*infra*), formal economics modeling has been notably absent.

We begin by noting private governance has a surprisingly long history. Indeed, Gupta & Lad (1983) present a detailed history of industry self-governance since the early 1900s. By the 1970s, an estimated 400 US organizations were administering more than 20,000 private standards. (Rosenberg 1976). During this classical era, compliance usually depended on a mix of three methods: (a) voluntary compliance by firms themselves, (b) formal or informal monitoring by other firms, and (c) formal monitoring by independent auditors. In practice, however, these arrangements all included significant agency problems ($infra$). This meant that private self-governance was usually weak so that "private politics" in Baron's sense did not exist. Conversely, the strongest initiatives generally took place "in the shadow of government," i.e. were backed by existing or threatened government control.[1]

[1] The "shadow of government" takes several forms including formal laws and regulations that require self-governance (Buthe 2010; King & Lenox 2000; Furger 1997; Gupta & Lad 1983); threats that government will intervene if self-governance does not occur (Fiorino 2010; Pizer et al. 2008; King & Lenox 2000; Sinclair 1997) and judicial liability when failure to self-govern leads to lawsuits (Shiel & Chapman 2000; Maurer 2012).

The modern era, by comparison, features strong private regulation without government backing. It began with public criticism of large companies (*e.g.* Nike, Levi Strauss, the Gap) that purchased inventory from suppliers who hired sweatshop labor or harmed the environment. The large companies, in turn, promptly used their purchasing power to force reforms onto their suppliers. (Conroy 2007) These private standards were often remarkably stringent. For example, private standards for aircraft parts (Anon. 2011) and artificial DNA (Maurer 2012) significantly exceed parallel official requirements. On the other hand, the first consumer-driven standards were usually limited to individual firms and their supply chains. This made them much less comprehensive than normal regulation.

The next step was obvious. Soon, several purchasers were pressing their suppliers to adopt *industry-wide* standards. Prominent examples include large canneries' campaign to impose "dolphin safe" practices on tuna fisheries (Gulbrandesen 2009, Conroy 2007), European supermarkets' demand that suppliers adopt uniform food safety standards, the European coffee industry's development of worldwide "4C" standards for coffee production (Auld 2010, Beisheim & Kaan 2010, Conroy 2007, Kolk 2005), and big pharmaceutical companies' demand that artificial DNA makers adopt antiterrorism precautions (Maurer 2012).

Governments and international agencies increasingly see these private standards as an important alternative to regulations and treaties. (Vogel 2005). Furthermore, there is now a large political science and sociology literature devoted to the subject (*infra*). So far, however, economists have paid surprisingly little attention. In particular, they have said little or nothing about the detailed economic conditions under which strong private standards are possible, how firms decide which standards to pursue, and how the market mediates conflicts between firms to arrive at a single standard. Our paper fills this gap. We begin by reviewing the literature. For convenience, we divide the private standards problem into three conceptually distinct phases: Development of formal rules ("governance"), adoption of existing rules by firms ("regulation"), and seeing that the rules are actually implemented ("enforcement"). While we focus on the first two problems, we briefly explain why customer-driven standards are also more enforceable than earlier schemes.

2.2 Governance: Why Firms Develop Standards

Prior to the 1990s, private standards almost always focused on market imperfections. Classical examples included realizing network externalities through interoperable parts; reducing contracting costs through standard agreements and quality metrics (Garvin 1983); protecting insurance companies against adverse selection by auditing policyholders' products and safety practices (Furger 1997); and helping consumers purchase experience goods by providing trusted product reviews and certifications (King & Lenox 2000, Garvin 1983).

Since 1990, the new customer-driven standards have added hundreds of social and environmental standards to the list. These regulate everything from labor conditions to endangered forests to sustainable agriculture. (Conroy 2007). But why do firms develop such standards in the first place? As Vogel (2005) emphasizes, there are at least four reasons. First, and most commonly, large retailers see supplier standards as a way to protect their market share against actual or potential bad publicity. Second, a few smaller firms have successfully used "ethical goods" to gain market share and/or charge higher prices. (Vogel 2005). Economists have anlyzed this strategy using quality ladder and price discrimination models. (Besley and Ghatak 2007; Kotchen 2009). Third, firms that adopt private standards probably find it easier to attract and retain employees, maintain high employee morale and productivity, and (perhaps) resist wage demands.[2] Finally, employees, executives, and/or major shareholders may force firms to pursue social and environmental goals even when it is unprofitable. (Vogel 2005)

The question remains when these same motives also lead firms to pursue industry-wide standards. Clearly, the answer cannot involve quality ladders or any other tactic that depends on gaining a comparative advantage over competitors. This means that we can truncate the foregoing list to three goals: (a) achieving industry-wide benefits, (b) suppressing competition between competing standards, and (c) achieving the personal political goals of employees, executives, and shareholders. Of these, the first rationale is by far the best documented. First, consumers and regulators may not be able to distinguish between firms. This could happen because it is physically impossible to track, say, pollution back to particular offenders. Alternatively, regulators may decide that it is cheaper to regulate an entire industry (or else randomly-selected firms) than to establish blame. (King, Lenox & Barnett 2002) Second, regulations imposed in the wake of scandals are often

[2]This leads to an interesting prediction. Naively, we expect compliance costs to scale with company revenue. On the other hand, executive compensation is known to grow more slowly than company size. (Sigler 2011). All things being equal, we should therefore expect small companies to implement CEO's regulatory preferences more often than large ones. This is indeed what happened in the synthetic DNA industry, where small companies consistently advocated for higher standards. (Maurer 2012).

unusually burdensome. Examples of this "backlash" include regulation of genetically modified foods, chemical plants, nuclear power, and deep water oil drilling.[3] Executives often argue that taking reasonabsteps to prevent accidents is better than allowing backlash that could cripple or destroy their businesses. (Lenox & Nash 2003) Third, community-wide standards may be inherently more effective and therefore more valuable. This is particularly true for national security problems in which intelligent adversaries can be expected to attack whichever firm adopts the lowest standard. (Edmunds & Wheeler 2009) Finally, merging redundant standards offers economic savings. These include eliminating duplicate development costs, supply chains, and compliance bodies. Harmonized standards can also force down prices by increasing the number of suppliers who compete for any order. These factors seem to have been particularly important in harmonizing apparel (Mayer & Gareffi 2010) and food standards (Campbell & LeHeron 2007; Havinga 2006).

A second, more troubling set of theories starts from the proposition that industry-wide standards can suppress competition. This is most worrisome where the ermergence of a single dominant standard suppresses goods competition. For example, Garvie (1999) presents a two stage model in which electricity firms agree on a pollution standard and incur the fixed costs to implement it in stage 1. They then make uncoordinated output decisions in stage 2. He finds that agreeing on a common standard lets them recoup fixed costs that would not otherwise be recoverable. However, it also reduces their stage 2 output and increases revenues. More commonly, firms pursue industry-wide standards in order to suppress other, competing standards. This may be socially useful where existing standards are largely duplicative so that competition offers few benefits and confuses the public. In other cases, however, the emergence of a single industry-wide standard can have significant substantive implications. For example, Conroy (2007) argues that that the forestry, fisheries, apparel, and coffee industries all developed industry-wide standards to prevent even stronger, activist-backed standards from becoming dominant. In effect, the amount of self-regulation was determined by a Silicon Valley-style standards war. Whether this process is legitimate will usually depend on which stable outcomes are possible. We explore this issue below.

Finally, firms may adopt industry-wide standards for private political

[3] Regulatory backlash can be a rational deterrent where violations are hard to monitor and may never be detected. Alternatively, it may reflect bureaucratic desire to avoid criticism in a world where voters and politicians do not have enough information to estimate the "correct" level of regulation for themselves.

reasons, *i.e.* because employees, executives, and/or shareholders consider it the right thing to do. For example, the synthetic DNA industry's standards initiative was clearly driven by idealistic executives. (Maurer 2012) At this point, choice of standards reverts to politics. At the same time, whichever standard prevails still depends on large firms' purchasing power. In such cases it is reasonable to invert the usual formula and talk of a private political process taking place "in the shadow of the market."

2.3 Regulation: Why Firms Adopt Standards

In general, we expect firms to join existing industry-wide standards for the same reasons that they create standards in the first place. We have seen that these reasons include government pressure, a rational estimate of expected benefit, gains from harmonizing competing standards, and the personal, non-economic goals of employees, executives, and shareholders.[4] Beyond this, it is reasonable to expect network effects, *i.e.* situations in which the value (cost) of standards increases (falls) with the number of adopters. We have seen, for example, that the effectiveness of homeland security standards probably increases as they approach unanimity. At the same time, more suppliers are able to compete for any given order and this drives prices down. Both effects imply a typical tipping dynamic in which slight differences in initial popularity are steadily amplified over time.

At the same time, we expect different firms to prefer different standards. Traditional self-governance schemes had no natural way to resolve such conflicts. Customer-enforced standards are fundamentally different because they allow firms that prefer strong industry-wide standards to subsidize firms that do not. We explore how markets mediate firms' conflicting preferences below. For now, we note that the problem has three important features. First, large firms have significant bargaining power. All else being equal, we expect them to prevail more often than small firms. Second, firms that prefer high standards in principle may lack practical information about the best way to design and implement them. This information asymmetry may explain why large coffee processors (Conroy 2007) and food retailers (Fuchs, Kalfagianni & Arendtsen 2009) give their suppliers substantial discretion in selecting standards. Customers in very technical fields (*e.g.* nanotechnology, synthetic DNA) may even cede complete discretion to suppliers. (Maurer 2010). Finally, large and small firms may have systematically different risk preferences. We expect suppliers to mediate these

[4]Non-monetary, so-called "softer" factors also play a role. These include a desire to please public opinion and peer pressure from other firms (Sinclair 1997).

differences through discriminatory pricing. The formal economic logic resembles that facing platform owners in two-sided market.

None of these dynamics guarantee that a single, industry-wide standard will emerge. To the contrary: Competition between standards in forestry (Conroy 2007) and food safety standards (Havinga 2006) have so far ended in stalemate with no clear winner. Instead, retailers and their associations routinely accept multiple standards so that (presumably) only the lowest standard is binding (Bernstein and Cashore 2004; Havinga 2006).

2.4 Enforcement: Why Firms Obey Standards

Prior to the 1990s, private standards were usually enforced through a combination of self-policing by individual firms, self-policing by groups of firms, and paid third party auditors. Much of the existing economics literature focuses on the agency problems that these arrangements produce. On the one hand, self-policing schemes suffer from the fact that firms with a reputation for high standards can earn more by cheating – At least, until consumers find out. (Scarpa 1999). This suggests that self-policing is unstable except for repeat games in which firms earn a sufficiently large, supra-competitive profit in each period. (Shapiro 1983). On the other, third party auditors can similarly earn super-normal profits by reducing monitoring expenditures while continuing to collect certification fees. (Franzoni 1999) Both situations are further destabilized by Prisoners Dilemma effects in which early cheaters earn the largest profits. (King & Toffal 2007). Most empirical studies confirm these predictions by finding that traditional private standards have little or no measurable impact on behavior (Gamper-Rabindran & Finger 2010; Sinclair 1997; King & Lenox 2000; Gupta & Lad 1983).

The case for customer-driven standards is different. This is most obvious where customers perform their own audits so that (by definition) agency problems disappear. This argument is necessarily weaker for, *e.g.* smaller supermarket chains that rely on third party auditing services. (Havinga 2006). Even here, however, it is reasonable to think that these firms can detect cheating faster than individual consumers. This probably explains King & Toffal (2007)'s observation that "the long-standing skepticism about the potential for self-regulation" among scholars has increasingly "given way to a sense of possibility."

2.5 This Paper

This paper presents the first formal economic model of how firms serving downstream markets enforce private standard(s) on their suppliers. In keeping with the preceding discussion, we explore the important sub-cases in which (a) downstream firms' expected business losses greatly exceed their suppliers' legal exposure, (b) downstream firms face different expected losses, and (c) downstream firms lack the technical knowledge to evaluate appropriate levels regulation for themselves. Significantly, our model assumes that the risk of catastrophe is independent of upstream output. This situation is frequently encountered in homeland security problems where a fixed number of adversaries seek dual use materials that can be used to make weapons.

Therefore, in what follows, we will normally focus on the first two categories for their computational convenience. It is worth emphasizing, however, that our enforcement models are more general and shed light on how markets can be used to enforce ethics- and norm-based standards as well.

3 Basic Model Set Up

We analyze the case where an upstream high tech industry makes products that downstream companies use to conduct R&D. We consider upstream firms $j = 1...m$ and downstream firms $i = 1...n$. Furthermore, all products are "dual use," i.e. can be used for either civilian applications (developing a new drug) or military/terrorist uses (developing a genetically engineered virus). Crucially, misuse exposes to incumbents to both individual liability for harm done (i.e. court judgments) and political risk (i.e. backlash and over-regulation) that would cripple or destroy the entire industry. Both risks can be reduced by implementing routine precautions (e.g. screening customers) before each order is filled.

We have the following two stage game:

Stage I Downstream firms select the degree of regulation r which upstream firms have to implement.

Stage II Both markets clear, i.e. the upstream and downstream market prices and quantities reach equilibrium and firms realize profits.

As usual this game will be solved by backward induction.

3.1 Upstream Market

We denote the total social cost of a potential military/terrorist catastrophe by L. Furthermore, we expect the courts to hold firm j legally liable if the military/terrorists weapon was made using output x_j. For full and perfect liability, firm j will have to pay for the entire cost of the disaster. Thus each upstream firm $j = 1...m$ faces expected individual liability costs of e_j (Alternatively, e_j can be thought of as the firm's imputed premium for self-insurance perfect insurance market with no coordination or transaction costs).

The probability that a disaster occurs depends on whether firms implement meaningful routine precautions. We define a regulation as a binding rule that defines the minimal standards or precautionary procedures for all firms. Unless otherwise stated, we will normally assume that all firms in the market are bound by a single level of regulation r. This efficacy of this regulation encounters diminishing returns as r increases:

$$\rho'(r) < 0 \text{ and } \rho''(r) > 0 \text{ i.e. } -\rho''(r) < 0$$

Since $\frac{\partial e_j}{\partial r} < 0$, stronger regulation reduces the individual expected liability cost for each upstream firm.

Because of the nature of the threat, the probability of risk does not scale with the numbers of sales. For example, the chances that a terrorist will attempt to purchase artificial DNA does not depend on the number of orders placed by pharmaceutical companies. In the case of *full and complete* liability this implies that the expected costs of a disaster are $\rho(r)L$ for any given regulation r. Any firm $j = 1...m$ thus faces individual expected liability costs e_j given by:

$$e_j = \frac{1}{m}\rho(r)L$$

Assuming that all firms adopt the same r, we expect terrorists to place their orders at random. In this case, the probability firm j's output will cause the disaster and also that j will be held liable is $\frac{1}{m}$ times the probability of disaster $\rho(r)$.

We assume for simplicity that firms $j = 1...m$ produce their outputs x_j using the same technology. This implies that they incur the same costs $C(x_j, r)$ and marginal cost

$$\frac{\partial C}{\partial x_j} \overset{def}{=} c(x_j, r).$$

We further assume that marginal per-unit costs $c(x_j, r)$ increase with r and also with output, though the latter effect may be very slow:

$$\frac{\partial c}{\partial x_j} > 0.$$

and

$$\frac{\partial c}{\partial r} > 0.$$

The total costs (TC) a firm j bears is therefore the sum of its production costs and liability costs:

$$TC_j = C(x_j, r) + e(r, m)$$

Which leads to the average total costs (ATC) of firm j

$$ATC_j = \frac{C(x_j, r)}{x_j} + \frac{e(r, m)}{x_j}.$$

This implies that the level of regulation r has two opposing impacts on the costs facing upstream firms: On the one hand more regulation increases marginal production costs; On the other it reduces expected liability costs. For sufficiently large[5] L this guarantees that the cost function will be U-shaped in r. Furthermore, there exists a unique cost-minimizing r for every arbitrary output of x_j. Because of symmetry, this is also the cost-minimizing r for the corresponding $x = \sum_{j=1}^{m} x_j = m \cdot x_j$.

We further assume that the upstream market features free entry and exit and as result full contestability so that firms set price equal to marginal cost. Furthermore, our free exit condition implies that the price charged by incumbents always exceeds (or at least equal) their average costs.

In sum, price is determined by the degree of regulation r, the number of upstream firms m, and the total output $x = \sum_{j=1}^{m} x_j = m \cdot x_j$. Furthermore, $x \cdot p$ also includes all costs in producing x, including liability. This means that any change in a parameter that affect total costs will be reflected by a respective change in the price. In the case of regulation, these changes are transmitted through distinct two channels: increased marginal costs of production and lower expected liability.

[5]More precisely: sufficiently large L guarantee that the cost function has its minimum in the positive space.

3.2 Downstream Market

We consider $i = 1...n$ firms who are active in $k = 1...o$ markets, each of which produces and sells y_i^k products. Although several firms may sometimes compete in the same market, we assume without loss of generality that no firm acts in more than one market so that for each firm i there exists only *one* market k for which $y_i^k > 0$. Further, we assume that competition is imperfect, i.e. that each market k is either an oligopoly or a monopoly. This situation is typical in the chemical, biology, and nuclear industries that consume dual use products. In equilibrium, our entry conditions for the downstream markets guarantee that the incumbents in each of our k markets will earn positive profits (imperfect competition). Furthermore, we expect each market to generate social surplus (welfare) $W^k = PS^k + CS^k$ where PS^k is the producer surplus and CS^k is the consumer surplus. For convenience, we will sometimes write each firm's individual producer surplus PS_i^k as a share of total welfare. We do this by defining η_i^k such that $PS_i^k = \eta_i^k W^k$ for all k where $y_i^k > 0$. We also normalize fixed costs in each of the markets to zero so that PS_i^k coincides with the benefit that firm i draws from market k.

Downstream firms use upstream output x as in their R&D processes. This results with probability ρ in a new product that will be produced and sold in market k. For example, artificial DNA is used as input in an R&D process that may eventually lead to a new drug. We assume that purchasing more output x_i increases the probability $\sigma \in [0, ...1[$ that firm i's R&D project will succeed. We denote R&D costs by R_i, who depend on the amount of input used (x_i) and its price $p(x, r)$. This means that downstream firms' expected profits are given by

$$\pi_i^e(x_i, r) = \sigma_k(x_i) \cdot \eta_i^k \cdot W^k - R_i(x_i, p(x, r))$$

The fact that x is "dual use" means that it can be misused for a military or terrorist attack. Industry leaders typically assume that such an incident could, in turn, trigger a political and regulatory backlash that either shut down the industry or made further production prohibitively expensive. Alternatively, public outrage could force highly visible downstream firms to stop using the technology even if it was still legal to do so. In either case, we expect the post-disaster response to overstate the actual risk to society. Regardless of the detailed reasons, we define $\tau(r)$ as the probability that the industry will *not* shut down. Clearly, τ depends positively on the level of regulation: The higher r is, the more likely an industry-ending disaster can be avoided. In general, we expect $\frac{\partial \tau}{\partial r} > 0$. However, we can imagine situations where $\tau = 1$ and thus $\frac{\partial \tau}{\partial r} = 0$. The latter case refers to a situation where there will never be a regulatory/political backlash (or public outrage) even if a disaster occurs. We will refer to such cases as the "zero backlash" case in what follows.

Collecting these terms, we find that the objective function of a downstream firm i is given by

$$\tau(r)\pi_i^e(x_i, r) = \tau(r)\left[\sigma^k(x_i) \cdot \eta_i^k \cdot W^k - R_i(x_i, p(x, r))\right]$$

4 The Symmetric Case

Let us assume a symmetric case with symmetric upstream and symmetric symmetric downstream firms and symmetric information. Thus all n downstream firms have the same (correct) information, including the cost function of the upstream suppliers. Furthermore, the symmetric downstream firms have the same cost function, face the same demand function, and face the same number of competitors. It follows that welfare, producer surplus, probability of success, and R&D costs are all the same. Thus all firms have the same profit function:

$$\tau\pi^e = \tau\left(\sigma\eta W - R\right)$$

and total welfare is then given by

$$\sum_{k=1}^{o} \tau\left(\sigma W - R\right) = o\tau\left(\sigma W - R\right)$$

Because of symmetry, the result of Stage II is the same for all n downstream firms: they all have the same optimal input choice x_i^* for any given price p and therefore—since $p = p(r)$—for any given level of r.

Symmetry also guarantees that the firms will always agree on the same level of r, independent of the mechanism that is used to achieve the agreement.This means that our analysis can focus on the decision of a single arbitrary firm $i \in [1, ..., n]$ in Stage I.

Proposition 1. *With full liability and no risk of regulatory backlash ($\tau = 1$) downstream firms choose the same level of regulation as a welfare-optimizing social planner, so that $r_p^* = r_w^*$ (the subscript p stands for a "private decision" by a downstream firm, the subscript w stands for a "welfare optimal decision").*

Proof. Downstream firm i maximizes its profits over r:

$$\max_r \{\sigma\left(x_i^*\right)\eta W - R\left(x_i^*, p(x^*, r)\right)\},$$

and the resulting FOC is

$$\frac{\partial R}{\partial p}\frac{\partial p}{\partial r} = 0.$$

So profits are maximized for the level r_p^* that satisfies $\frac{\partial p}{\partial r} = 0$ (price minimum).

With full liability, the expected liability costs of an upstream firm $e_j(r)$ fully take into account j's fraction of the total expected costs of a disaster. Moreover, free entry in the upstream market guarantees that the price (which reflects all costs) is driven down to the marginal costs. So the price minimum condition is satisfied iff $p(r) = p^* = ATC_j(r) = c_j(r)$.

A social planner maximizes total net-welfare over r. Because the price p reflects all costs caused by the upstream market (including al risks) this means that the optimization problem is—taking into account the symmetry—given by

$$\max_r \{o \cdot \sigma(x_i^*)W - n \cdot R\left(x_i^*, p\left(x^*, r\right)\right)\}.$$

The resulting FOC is again

$$\frac{\partial R}{\partial p}\frac{\partial p}{\partial r} = 0$$

So welfare is maximized for the level r_w^* that satisfies $\frac{\partial p}{\partial r} = 0$ (price minimum). Again, this is satisfied iff $p(r) = p^* = ATC_j(r) = c_j(r)$. □

Intuition: There are no externalities. The upstream firms' prices reflect their cost functions which include all social costs. The downstream firms take price into account and therefore choose the "right" level of r.

Proposition 2. *In the case of incomplete liability and no backlash risk downstream firms choose less regulation than a welfare-optimizing social planner would, hence* $r_p^* < r_w^*$

Proof skipped. The price of x does reflect the full risk of a disaster and hence downstream firms do not take this risk fully into account where liability is incomplete.

Proposition 3. *In the case of complete liability and risk of backlash* $(0 < \tau(r) < 1)$ *downstream firms demand less regulation than a welfare-optimizing social planner would* $(r_p^* < r_w^*)$*, unless* $\eta = 1$.

Proof. Firm i maximizes its profits over r:

$$\max_r \{\tau(r)\left[\sigma\left(x_i^*\right)\eta W - R\left(x_i^*, p(x^*, r)\right)\right]\},$$

and the resulting FOC is

$$\frac{d\tau}{dr}\left[\sigma\left(x_i^*\right)\eta W - R\left(x_i^*, p(x^*, r)\right)\right] - \tau(r)\frac{\partial R}{\partial p}\frac{\partial p}{\partial r} = 0. \tag{1}$$

The optimization problem with respect to total welfare is given by

$$\max_r \{\tau(r)\left[o\sigma\left(x_i^*\right)W - nR\left(x_i^*, p(x^*, r)\right)\right]\},$$

which leads to the FOC

$$\frac{d\tau}{dr}\left[o\sigma\left(x_i^*\right)W - nR\left(x_i^*, p(x^*, r)\right)\right] - \tau(r)n\frac{\partial R}{\partial p}\frac{\partial p}{\partial r} = 0$$

which is equivalent to

$$\frac{d\tau}{dr}\left[\frac{o}{n}\sigma\left(x_i^*\right)W - R\left(x_i^*, p(x, r)\right)\right] - \tau(r)\frac{\partial R}{\partial p}\frac{\partial p}{\partial r} = 0 \tag{2}$$

In the case of $\sigma\left(x_i^*\right)\eta W - R\left(x_i^*, p(x^*, r)\right) < \frac{o}{n}\sigma\left(x_i^*\right)W - R\left(x_i^*, p(x^*, r)\right)$ the level r_p^* satisfying (1) will be *smaller* than the level r_w^* satisfying (2) because of $\frac{d\tau}{dr} > 0$. Now, $\sigma\left(x_i^*\right)\eta W - R\left(x_i^*, p(x^*, r)\right) < \frac{o}{n}\sigma\left(x_i^*\right)W - R\left(x_i^*, p(x^*, r)\right)$ implies that $\sigma\left(x_i^*\right)\eta W < \frac{o}{n}\sigma\left(x_i^*\right)W$, i.e. that $\frac{n}{o}\eta W < W$.

Because of symmetry, there are $\frac{n}{o}$ firms in any arbitrary market k, which means that $\frac{n}{o}\eta W$ is the total producer surplus of a market k. Therefore $\frac{n}{o}\eta W > W$ is not possible (producer surplus cannot exceed welfare), and $\frac{n}{o}\eta W = W$ would imply that the producer surplus equals the welfare and that thus no consumer surplus is left. Because of symmetry this can only be the case if the n firms are perfectly price discriminating monopolists ($\frac{n}{o} = 1$) and hence $\eta = 1$. □

Downstream firms do not fully internalize the total social costs of a regulatory backlash (that is the loss of welfare $\sum W^k$) because they only care about the loss of their profits in case of an industry shut down . However, market power reduces this externality problem. From the proof of Proposition 3 we know that $r_w^* - r_p^* > 0$ because of $W - \frac{n}{o}\eta W > 0$, i.e. because the total producer surplus is smaller than the total welfare. When firms have more market power this implies that these firms can extract together a higher share of the welfare and this narrows the gap. As result the gap between private and welfare optimization calculus shrinks and hence $r_w^* - r_p^*$ becomes smaller. In the case of perfectly price discriminating monopolists is $\frac{n}{o} = 1$ and $\eta = 1$ and thus $W - \frac{n}{o}\eta W = W - W = 0$ which implies that $r_w^* = r_p^*$.

Proposition 4. *With incomplete liability, increasing backlash even aggravates the gap between the welfare optimal level r_w^* and the r_p^* demanded by the downstream firms.*

From Proposition 3 we know that firms do not fully take into account the negative effects of backlash: they only account for their share of the total welfare created in their markets. So in a world with backlash downstream firms would ask for too little regulation compared to the level of regulation that fully takes into account the effects of backlash (the welfare maximizing level of r).

From Proposition 2 we know that if liability is incomplete, then there is a negative external effect and thus downstream firms would ask for to little regulation compared to the welfare optimal one.

Scholars sometimes speculate that the threat of backlash can correct under-regulation due to incomplete liability. This ignores the fact that the threat of backlash is real, i.e. that over-regulation will sometimes happen. So while backlash does indeed increase r_p^* it widens the gap $r_w^* - r_p^*$ even more so that the mismatch between industry-defined regulation and welfare maximizing regulation increases.

5 Asymmetric Information

Let us now relax our assumptions about information. In particular we now assume that the downstream firms no longer have information about the cost function of their upstream suppliers. Therefore the downstream firms can no longer calculate their ‘optimal’ level of r. They depend on information delivered by upstream firms, or have to pick the regulatory offer proposed by the upstream firms. We now show that, provided that the number of upstream firms (m) is small, established upstream firms may use a low level of r to limit the number of competitors. This can be used to prevent new entrants.

We begin from the observation that firms trying to enter the market prefer a high level of r. This is because stricter regulation (higher r) reduces the minimal efficient size (MES) by reducing risk and hence the expected cost of a disaster. And this lower MES enables more firms to survive in the long run equilibrium. This model result coincides with the experience in real world example of synthetic DNA: the established 'big' US-firms tried to push a lower standard than what the younger EU-based firms preferred.

We choose the simplest possible example in which a single incumbent faces the threat from one potential entrant. Once again we consider two competing regulations r_h and r_l. Note that the incumbent must charge a price equal marginal cost to prevent the newcomer from undercutting its price and driving it out of the market.

Proposition 5. *Established upstream firms may propose a low level of r in order to deter entry.*

Let us assume the specific cost function of the upstream firms $C_j(x_j, r) = \frac{1}{2}x_j^2 r$ and $e_j = \frac{1}{m}\rho(r)L$ with $\rho(r) = \frac{1}{1+r}$. From this we receive as the cumulated supply of the m upstream firms

$$S(x) = \begin{cases} \frac{xr}{m} & \text{if } L \leq \frac{x^2 r(1+r)}{2m} \\ 0 & \text{else} \end{cases}$$

Assuming $\tau(r) = 1 - \rho(r)$ (in case of a disaster there will be regulatory backlash for sure) we also get from our model setup the following cumulated demand function:

$$D(x) = \frac{\left(\sum_{i=1}^{n} \sqrt{PS_i}\right)^2}{(n+x)^2}$$

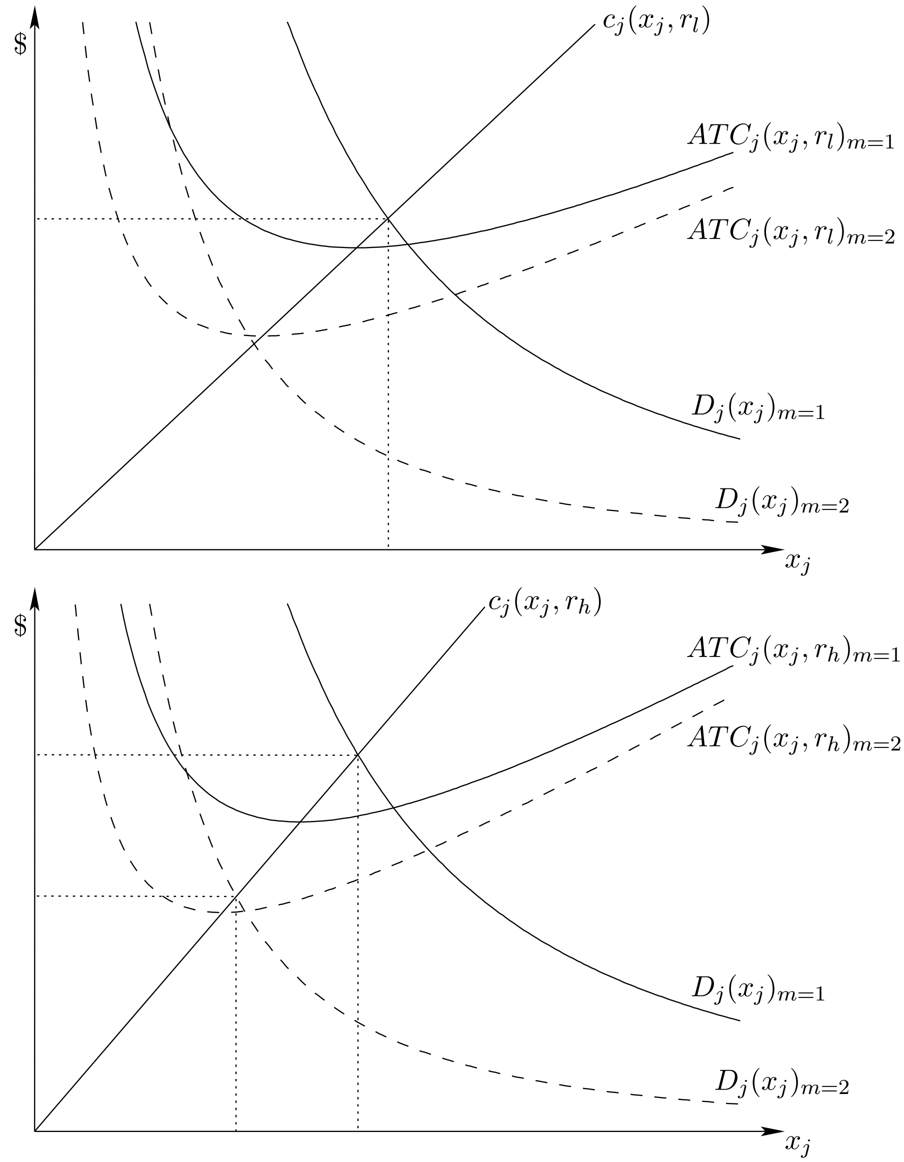
It can now be shown that established upstream firms may propose a low level of r in order to deter entry.

Proof. formal proof to be added □

We will now demonstrate this proposition graphically, using for the sake of simplicity the example of one single established upstream firm j.[6] The upper graph in Figure 1 depicts the situation for r_l. Because of contestability the "price equal marginal cost" rule applies, and the single established supplier j even makes a positive profit as the demand curve $D_j(x_j)_{m=1}$ intersects its supply curve (marginal costs $c_j(x_j, r_l)$ above the average costs $ATC_j(x_j, r_l)_{m=1}$). However, this positive profit does not induce further entry. A new entrant ($m = 2$) would shift both firms' average costs downward

[6] The analysis can easily be extended to examples with more than one established suppliers. However, the argument would be the same.

Figure 1: Incumbent chooses r_l over r_h to block entry



since e_j is now equal to $\frac{1}{2}n\rho(r)L$ (see the dashed $ATC_j(x_j, r_l)_{m=2}$ curve in Figure 1). Because now both firms share expected liability costs this reduces the MES of each firm. But market demand is now split between the two firms so that each firm faces an individual demand $D_j(x_j)_{m=2}$. In this ($m = 2$, r_l) case the firm's supply curve and the (individual) demand no longer intersect. Compare this result to the situation where r_h is adopted (see the second graph in Figure 1). Compared to the r_l-case the slope of the marginal cost curve becomes steeper while the risk of disaster and thus e_j is reduced. Comparing the first and the second graph of Figure 1, it is easy to see that the profits of a single firm are higher. On the other hand, there is now room for more than one firm. In this new $(m = 2, r_l)$ case the two firms' supply and (individual) demand curves intersect. Plainly, the established firm will earn a higher profit in the $(m = 1, r_l)$ case. Therefore, the established supplier would always prefer r_l over r_l and therefore propose the lower level to the downstream firms.

This circumstance provides important information for downstream firms. If would-be entrants (or weak incumbents) favor higher standards, downstream firms can reasonably conclude that more regulation is affordable. This is because the would-be entrant would only choose a higher level of r if it permits entry at positive profit. At the same time, entry will nevertheless drive down prices. This suggests that downstream firms should always favor high recommended standards over low ones.

This is exactly what has happened in the artificial DNA industry: the established (mostly US-based) gene synthesis firms have had proposed a significant lower security standard than the IASB standard proposed by a group of newcomers. As newcomers would propose a higher regulation iff the established firms have chosen an inefficient low one, it was thus rationale for "big pharma" to pick the higher regulatory offer proposed by the newcomers. However, picking a standard by downstream firms is more complicated if the downstream firms do not agree. This refers to the case where downstream firms are not symmetric and therefore would prefer different levels of r. The next section deals with this case.

6 Asymmetric Downstream Firms

We now relax our symmetry assumptions to examine situations where big downstream firms have different regulatory preferences compared to small ones. More specifically, we allow for different individual producer surplus

PS_i. This can be done either[7] by letting firms differ in their ability to capture social welfare η_i^k or by allowing the welfare of different markets to differ. In both cases, the only thing that matters is that firms producer surplus PS_i is different. It is therefore sufficient to explore the case where W^k differs from firm to firm.

Proposition 6. *A downstream firm b with higher (expected) individual producer surplus than firm s will choose a higher level of regulation iff* $\left[\sigma(x_b^*)\eta\, W^b - R(x_b^*,\cdot)\right]/\frac{\partial R(x_b^*,\cdot)}{\partial p} > \left[\sigma(x_s^*)\eta\, W^b - R(x_s^*,\cdot)\right]/\frac{\partial R(x_s^*,\cdot)}{\partial p}$.

Proof. As before the n downstream firms define their x_i^* in Stage II. But because of asymmetry ($W^b > W^s$) the two firms have different x_i^*: $x_b^* \neq x_s^*$.

In Stage I firm $i = b, s$ maximizes its profits over r:

$$\max_r \{\tau(r)\left[\sigma\left(x_i^*\right)\eta\, W^k - R\left(x_i^*, p(x^*, r)\right)\right]\},$$

and the resulting FOC is

$$\frac{d\tau}{dr}\left[\sigma\left(x_i^*\right)\eta\, W^k - R\left(x_i^*, p(x^*, r)\right)\right] - \tau(r)\frac{\partial R(x_i^*,\cdot)}{\partial p}\frac{\partial p}{\partial r} = 0,$$

which leads to

$$\frac{\sigma\left(x_i^*\right)\eta\, W^k - R\left(x_i^*,\cdot\right)}{\frac{\partial R(x_i^*)}{\partial p}} = \frac{\tau(r)}{\frac{d\tau}{dr}}\frac{\partial p}{\partial r}.$$

Note that the right hand site of this is the same for all $i = 1...n$. Therefore a 'big' firm b with $W^b > W^s$ will demand a higher degree of regulation than a small firm s iff

$$\frac{\sigma\left(x_b^*\right)\eta\, W^b - R\left(x_b^*,\cdot\right)}{\frac{\partial R(x_b^*)}{\partial p}} > \frac{\sigma\left(x_s^*\right)\eta\, W^s - R\left(x_s^*,\cdot\right)}{\frac{\partial R(x_s^*)}{\partial p}}$$

□

- *Example:* For $R = x_i p$ and $\sigma = \frac{x_i}{x_i+1}$ the optimal input is given by

  $$x_i^* = \frac{\sqrt{p\,\eta\, W^k}}{p} - 1$$

  which leads to

  $$\frac{\sigma\left(x_i^*\right)\eta\, W^k - R\left(x_i^*,\cdot\right)}{\frac{\partial R(x_i^*)}{\partial p}} = \frac{2\tau\left(\sqrt{p}\sqrt{W^k} - p\right)\left(\sqrt{p}\sqrt{W^k} - W^k\right)}{2\sqrt{p}\sqrt{W^k} - W^k}.$$

[7] A third version is to allow for different η_i^k *and* W^k.

As result, the condition of Proposition 6

$$\frac{\sigma\left(x_b^*\right)\eta\, W^b - R\left(x_b^*,\cdot\right)}{\frac{\partial R(x_b^*)}{\partial p}} > \frac{\sigma\left(x_s^*\right)\eta\, W^s - R\left(x_s^*,\cdot\right)}{\frac{\partial R(x_s^*)}{\partial p}}$$

is fulfilled for a $W^b > W^s$ with $W^b = \delta W^s$ iff

$$\delta > \frac{\left(3\,p\sqrt{W^s} - 2\,W^s\sqrt{p}\right)^2}{W^{s2}\left(-2\,\sqrt{p} + \sqrt{W^s}\right)^2}$$

The intuition is that downstream firms that can gain more from a given R&D investment also have more to lose if a disaster occurs.

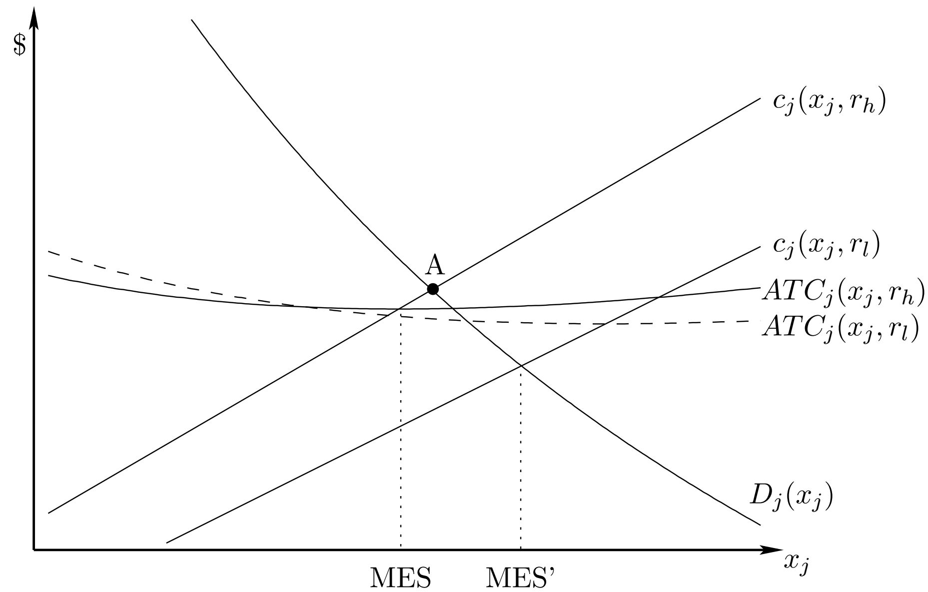
As soon as we admit the possibility that different firms may prefer different standards, the question immediately arises which level(s) of r will the market select. We show here that it is possible for the 'biggest' downstream firm (highest PS_i) to establish its preferred level of r on the entire market if they can apply a "single homing clause".

Assume that—because of technical reasons—there exist two possible regulatory standards r_h and r_l. Consider two downstream firms (b and s) who are monopolists in $k = b$ and $k = s$ respectively. Assume further that $W^b > W^s$ so that firm b prefers the high level of regulation (r_h) while firm b prefers the low one (r_l). Finally, both firms try to impose their standards on the industry by insisting that their suppliers adopt their preferred standard for all of its transactions ("single homing clause"). Such general clauses are common in industries where large highly visible suppliers fear being connected to suppliers who are unethical (pharmaceuticals), violate social justice norms (coffee), or else mistreat their workers (apparel retailers). Furthermore, the US government has similarly exploited its purchasing power to force at least one foreign centrifuge manufacturer (Oerlikon Leybold Vacuum) to adopt a company-wide customer screening policy (Wirtz, 2010). Depending on where regulation enters the supply chain, it will often be cheaper to adopt uniform practices than maintain two parallel standards.

Notice, however, that the two firms have different interests with respect to enforcing their preferred standard. Firm s, which favors the lower standard, does not mind if some upstream firms stick to the higher r_h as long as some upstream firms are still willing to fill its orders according to its preferred r_l. Indeed, it prefers that firm b insists on a higher standard (which reduces the liability risk) since it can free-ride on this "public good" without bearing any implementation costs. For firm b, however, the opposite is true—having upstream firms implement the low standard is a "public bad" since this increases the overall risk of a disaster.

We now use a graphical example to show that equilibria exist in which downstream firm s's threat is not credible so every upstream firm chooses r_h. As before, assume that upstream firms' cost function $C_j(x_j, r) = \frac{1}{2}x_j^2 r$ and $e_j = \frac{1}{m}\rho(r)L$, where $\rho(r) = \frac{1}{1+r}$. Then if all upstream firms choose r_h, firm s refuses to buy (as promised) and the total market demand comes from firm b. Spreading this demand evenly across all m upstream firms allows us to draw the 'individual', or: residual, demand curve $D_j(x_j)$ seen by upstream firm j. (The sum of all m individual demands equals b's total demand.) We assume that there are many upstream firms in the market, but however, each firm's supply curve intersects with its 'residual' demand curve $D_j(x_j)$ somewhere right of the MES, such that the firm j makes some profits, see point A in Figure 2.

Figure 2: When a 'big' downstream firm can determine the level of r



We now show why and when no upstream firm has an incentive to deviate. Suppose a single firm j deviates by switching to r_l. By definition, it has lost its (individual) demand from downstream firm b. On the other hand, it is now the only supplier that can deliver to s. Since s is a small firm, this new demand curve may be smaller than the individual demand curve it had with b. In the interests of simplicity, however, we assume that the new individual demand curve is the same as the old one. In other words: from the perspective of the switching firm j the demand of firm s substitutes the loss of the residual demand from the r_h demanding upstream firm b. On the other hand, this is not the only effect. When j switched from r_h to r_l its marginal cost decreased but the overall risk in the market increased, at least slightly.[8] As result, firm j's MES shifts to the right, (see MES' in Figure 2). As a result, firm j's new supply curve (the part of its marginal cost curve $c_j(\cdot)$ that is above its average costs ATC_j) now does no longer intersect with s's demand curve. Furthermore, the situation is even worse when more than one upstream firm switches from r_h to r_l. Not only does each firm's individual demand from s shrink (D shifts to the left), but the overall risk of disaster increases (MES shifts even more to the right). This shows that no one will sell to s so long as s demands r_l. Since this is common knowledge, firm s's announcement that it will only contract with firms that practice r_l is not credible. More generally, the small downstream firm is unable to compel even a small part of the upstream industry to practice its standard.

This argument can easily be extended to the case where several "big" downstream firms prefer r_h while some small downstream firms prefer r_l. Assume all upstream firms (suppliers) use the high standard (r_h). If supplier j deviates and applies the low standard r_l then this upstream firm automatically looses all its demand from "big" downstream. As before in the two-firm example this may bring the firm below its MES. Applying the "single homing clause" by the big downstream firms is indeed a credible threat because each "big" downstream firm can easily substitute the low standard dissidents supply by spreading the residual demand among the other upstream firms of by buying from a r_h newcomer. Small firms who prefer r_l on the other hand, cannot apply the single homing clause because they have no credible threat as their demand is not sufficient to guarantee survival in the market. So they know if they really insist on their low level they find no supplier, and hence they finally accept to buy a high level product.

Therefore we can conclude the following:

[8] How much the overall risk in the market rise if only one single firm deviates from r_h depend on the number of firms in the market and might be small. If the effect is strong, the MES shifts even more, which makes the argument stronger. This is the case when for example terrorists know which firm(s) apply the low regulatory level and thus send their request to r_l suppliers only. Obviously this would let the expected liability costs of the r_l suppliers increase more rapidly.

Proposition 7. *"Big" downstream firms who purchase more x may be able to enforce their preferred higher r on the entire industry when using a 'single homing clause'.*

7 Conclusion

This paper has examined self-governance in the typical case where firms in a downstream market demand uniform standards from their suppliers. We find that downstream firms systematically demand too little regulation where (a) court liability is expected to be imperfect, and (b) regulatory backlash in the event of a disaster is expected to damage or destroy downstream markets. Regulatory backlash is never an adequate substitute for perfect liability. We find that the gap between optimal regulation and self-governance outcome is smaller when downstream firms have more market power.

We have analyzed the important asymmetric information case downstream must choose from competing proposals by upstream firms. We have argued that downstream firms can almost always benefit themselves (and welfare generally) by picking whichever proposal promises the highest level of regulation.

However, we expect different downstream firms to have different regulatory preferences depending on various factors such as market power and ability to price discriminate. Given these disagreements, much depends on whether downstream firms that favor strong regulation can impose their preferences on the entire industry. We have analyzed a specific case suggesting that this outcome is common. Future versions of this paper will systematically explore the conditions that lead to uniformly high standards, uniformly low standards, and mixed standards.

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