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

– DRAFT –

Sebastian v. Engelhardt * Stephen M. Maurer **

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). Moreover, the global character of these markets makes traditional regulation and treaty solutions difficult. For this reason, governments are increasingly interested in alternative control methods based on self-regulation. Strikingly, existing initiatives by centrifuge and artificial DNA manufacturers have already produced private standards that are significantly stronger than official US policy. This paper explores the economic conditions that make such strong, industry-wide agreements stable.

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.

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 analyze when and why large downstream firms are able to force their preference for high levels of regulation on upstream suppliers. Finally we show that upstream incumbents may be able to deter entry in adopting a high regulatory standard.

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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) (Gunningham & Rees 1997; Fiorino 2010; Maurer *et al.* 2011; 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

The literature on industry self-regulation and self-governance has traditionally focused on private standards that are enforced by (a) existing government statutes and regulations, or (b) plausible threats of future government intervention. In these situations, private standards are mainly important as a potentially cheaper, more nuanced, and/or more nimble alternative to government’s usual implementation methods. To the extent that such schemes also allow the private sector to self-govern, i.e. decide policy in the first place, this almost always seen as inadvertent and undesirable.

The case is very different, however, when firms are able to enforce private standards without government’s help. Since the 1990s, firms have increasingly used market forces to enforce a variety of private environmental, social justice, and/or national security standards. This article presents a detailed model of (a) how customers and suppliers arrive at their respective regulatory preferences, and (b) how markets mediate conflicts between individual firms over which standard(s) to adopt. Here, we set the stage by reviewing the self-regulation literature with a particular focus on instances in which private firms enforce private preferences using private means.

2.1 From Self-Regulation to Self-Governance

Though sometimes used interchangeably, the terms “self-regulation” and “self-governance” are conceptually distinct. In what follows, we will use “self-regulation” to mean *both* the development *and* the implementation of policy. By comparison, we will limit “self-governance” to situations where the regulated possess some meaningful discretion or choice about which policies to pursue. Following this definition, the amount of “self-regulation” in the US economy is enormous. Indeed, scholars have estimated that the US economy already possessed more than 400 standards setting bodies and 20,000 private standards by the mid-1970s (Rosenberg 1976). However, the amount of “self-governance” is less clear. Many widely-studied examples of self-regulation (*e.g.* security dealers, advertising firms, state professional certification boards) were expressly created by statute and/or agency reulations (King & Lenox 2000, Furger 1997, Gupta & Lad 1983). Still others (*e.g.* climate, pollution, and nuclear standards) plainly depend on the explicit or implicit threat that regulators will intervene (King & Lenox 2000; Sinclair 1997). Extensive examples can be found in, for example, Fiorino (2010), Pizer et al. (2008), and Sinclair (1997). In both cases, theorists have convincingly modeled the private sector’s policy input as a limited and generally rent-seeking correction to government regulators’ preferred outcome (Dawson & Segerson 2008; DeMarzo et al 2007).¹

At the same time, actual or threatened government regulation cannot be the whole story. Most obviously, it does not explain cases where government officials are criticized for passing *weaker* regulations than *preexisting* private standards require. *See, e.g.* Maurer 2010 (synthetic DNA) and Anon. 2011 (aircraft parts). In these cases, at least, regulatory preferences and enforcement must both originate in private sector.

2.2 Market-Based Mechanisms for Enforcing Standards

In principle, private standards can be enforced either by market forces or by soft incentives like norms, ethics, and reputation. However, most recent empirical studies suggest that soft incentives are too weak to effect measurable changes in

¹This is not always true. In the 1930s, for example, many fascist regimes enforced policies set by management-labor committees. California used a much more limited scheme to enforce worker safety rules in the 1970s (Gunningham & Rees 1997)

behavior (Lenox & Nash 2003; Pizer et al. 2008; Gamper-Rabindran & Finger 2010; Sinclair 1997; but see Potoski & Prakash 2005). This leaves market forces. Here, the literature has documented many different schemes:

- *Standardization.* Modern electronics and software products often require a single standard. However, different firms typically have different preferences. World Wide Web Consortium (W3C) founder Tim Berners-Lee (1999) has recorded how competing proposals slowly give way to “consensus” under the guidance a self-styled “philosopher king.” At this point, market forces (“tipping”) typically reinforce the standard until it becomes more or less universal (Maurer 2012)
- *Incomplete Contracting.* Many private standards reduce contracting costs by supplying uniform terms that the entire industry can use. Common examples include uniform safety, ethics, and product quality specifications (Doyle, Garvin 1983). These standards are inherently stable since “opting out” would make contracting more expensive.
- *Protecting Suppliers.* Insurance companies often ask third parties (*e.g.* Underwriters Laboratories, National Fire Protection Association, Factory Mutual) to certify and occasionally audit clients’ products and business practices (Furger 1997). Once again, the system is stable, in this case because it reduces adverse selection risk.
- *Protecting Consumers.* Many products and services are experience goods that are difficult or impossible to evaluate in advance. Small consumers routinely overcome this problem by relying on state licensing boards to certify doctors, lawyers, and other professionals (Furger 1997). Similarly, many consumers rely on private organizations to recommend (or censor) which films they see (King & Lenox 2000, Garvin, 1983).
- *Industry Reputation.* Bad behavior by individual firms can damage the reputation of entire industries. This theoretically gives firms a reason to support industry-wide standards for product quality, environmental compliance, worker safety and the like. In practice, however, suppliers often find it hard to certify each other. Empirical studies suggest that private standards based on threats of peer pressure or expulsion have little or no impact on company performance (Gamper-Rabindran & Finger 2010; Sinclair 1997; King & Lenox 2000; Gupta & Lad 1983).

2.3 Customer-Enforced Standards

The foregoing examples suggest that consumer-enforced standards are (a) strong, and (b) much more credible than asking suppliers to police themselves. During the 1990s, many consumers began using these principles to extend private standards into policy areas that had previously been regulated (if at all) by governments.

The new standards typically start with large consumers demanding that their suppliers to adopt certain practices. Here, the best-known example is almost certainly The Gap’s “Sourcing Principles,” which require suppliers to adopt minimum company-wide standards for workers (Gunningham & Rees 1997). However, similar initiatives have been launched by Wal-Mart, Hewlett-Packard, Ford, Johnson & Johnson, and others. Goals range from reduced packaging waste and increased energy efficiency to social and environmental codes (Fiorino 2010). Similarly, many Big Pharma companies formally or informally monitor suppliers to, in Astra-Zeneca’s phrase, ensure “standards of ethical behavior that are consistent with our own” (Maurer 2012). Finally, the US government has forced at least one centrifuge supplier to develop detailed procedures for investigating customers (Wirtz 2010).

More recently, customers have begun asking entire industries to adopt standards. To date, the most spectacular example involves firms that purchase artificial DNA, a “dual use” product that can be used *either* for civilian research *or* to make biological weapons. Starting in the mid-2000s, many of the industry’s biggest customers began quietly asking suppliers what, if any, precautions they were taking to keep terrorists from acquiring the material. In the summer of 2009, a group of small European manufacturers (“IASB”) announced that it had developed and was about to adopt a “Code of Conduct” that required human experts to examine each incoming order. Several weeks later, two of the industry’s largest firms (DNA2.0 and Geneart) announced a competing “fast” and “cheap” alternative that relied on computers instead of experts. This ignited what *Nature* aptly called “a standards war” for several months. While industry giant Astra-Zeneca was careful not to take sides, it followed the debate closely and urged both sides to agree on a common standard. By late November, DNA2.0 and Geneart had dropped their competing proposal and joined several big American companies in announcing a third standard called the “Harmonized Protocol.” This ended the standards war since the Protocol and Code—though written in entirely different language—both require human screeners and appear indistinguishable (Maurer 2012).

Customer-driven standards are similarly important in the coffee industry. Faced with widespread criticism, two of the industry’s five largest brands called on their coffee-grower suppliers to join them in writing new worker protection standards. Strikingly, two more large brands endorsed this standard after it was finalized (Beisheim & Kaan 2010).

Finally, there have also been several instances in which customers have pressed suppliers to adopt standards without (so far) any noticeable result. Two of these involve nanotechnology. In 2006, the UK food chain Tesco joined various government bodies, manufacturers, and advocacy groups in developing a Responsible NanoCode for companies that supply nanotechnology products. More recently, in 2008, the Swiss retail food association—which represents the COOP, MIGROS, and MANOR—called on suppliers who use nanotechnology to “quickly and openly” inform the public about any risk. So far, however, neither initiative has proceeded beyond “non-auditable” generalities. Maurer (2010). A third example involves cybercrime. In late 2011, Chinese security

firms began urging their employees and contacts to adopt a “Chinese Hackers’ Self-Discipline Convention” that outlaws breaking into online accounts and other forms of criminal hacking. The firms stressed that failure to self-regulate would invite new government regulation and damage their industry (Fletcher (2011)). It is too soon to tell whether this initiative will succeed.

2.4 Private Regulatory Preferences

The ability to make private policy choices inevitably begs the question, what does industry want? The literature contains three broad suggestions:

- *Common Law Liability.* Firms clearly worry that they will face legal liability in the event of an accident (Shiel & Chapman 2000). Fears of legal liability seem to have played a significant role in synthetic gene manufacturers’ decision to self-regulate (Maurer 2010).
- *Preempting Regulatory Backlash.* Recent incidents involving genetically modified foods, nuclear power, chemical plants, oil pipelines, and deep water drilling suggest that isolated accidents can invite political backlash and crippling regulation. Certainly, such fears are frequently voiced by industry leaders (Sinclair 1997; Gupta & Lad 1983; Lenox & Nash (2003)).
- *Norms and Personal Ethics.* Real firms often possess sufficient market power to ignore profit maximization in many cases. This potentially gives them room to pursue non-financial, “soft” incentives like a desire to please public opinion, voluntarism, peer pressure and/or a desire to cooperate with other companies (Sinclair 1997). Alternatively, corporate executives often have strong personal feelings about the need for private standards. In these cases, firms’ willingness to adopt private standards could be a form of executive compensation.

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.

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:

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

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

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

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

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 large² 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 that the number of incumbents is sufficiently high 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 $x = \sum_{j=1}^m x_j = m \cdot x_j$. $x \cdot p$ also includes all costs that society has to bear in producing and using 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.

3.2 Downstream Market

We consider $i = 1 \dots n$ firms who are active in $k = 1 \dots o$ markets, each of which produces and sells y_i^k products. Although several firms may sometimes compete

²More precisely: sufficiently large L guarantee that the cost function has its minimum in the positive space.

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 $\sigma \in [0, \dots, 1]$ 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

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

3.3 The Symmetric Information Case: Downstream Firms Decide on r

This section analyzes how downstream firms possessing perfect information choose r . We expect upstream firms to adopt this level so long as it is unanimous; otherwise they would have to leave the market. We address the non-unanimous case in Section 3.3.2.

We thus have the following two stage game:

Stage I Downstream firms define 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.

3.3.1 Symmetric Downstream Firms

Let us assume that all n downstream firms are symmetric, i.e. 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:

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

and total welfare is then given by

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

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 $i \in [1, \dots, n]$ in Stage I.

Proposition 1. *With full liability and zero 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 :

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

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 all risks) this means that the optimization problem is—taking into account the symmetry—given by

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

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 $p(r) = p^* = ATC_j(r) = c_j(r)$. \square

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 zero backlash 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 non-zero 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 :

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

and the resulting FOC is

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

The optimization problem with respect to total welfare is given by

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

which leads to the FOC

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

which is equivalent to

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

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

Proposition 4. *Increasing backlash 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 too 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.

Proposition 5. *In the case of backlash, the gap between industry regulation and welfare optimal regulation ($r_w^* - r_p^*$) is smaller when the downstream firms have more market power. In the special case where there is perfect liability and the firms are perfectly price discriminating monopolists the gap disappears entirely so that $r_w^* - r_p^* = 0$.*

Proof. From the proof of Proposition 3 we know that $r_w^* - r_p^* > 0$ because $W - \frac{n}{o} \eta W > 0$ which is equivalent to

$$\frac{W}{\frac{n}{o}} - \eta W > 0. \quad (3)$$

The share of welfare a firm can extract from a market k depends on its market power and thus on the number of firms in that particular market: $\frac{\partial \eta}{\partial (\frac{n}{o})} < 0$.

In other words: when firms have more market power this implies that (a) the number of firms per market is lower ($d(\frac{n}{o}) < 0$) and (b) each firm can extract a higher share of the welfare ($d\eta > 0$). So, with more market power, the first part in (3) decreases while the second part increases, 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 $\frac{W}{\frac{n}{o}} - \eta W = W - W = 0$ which implies that $r_w^* = r_p^*$. \square

3.3.2 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 either³ 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 individual producer surplus than firm s will choose a higher level of regulation iff $[\sigma(x_b^*) \eta W^b - R(x_b^*, \cdot)] \cdot \frac{\partial R(x_b^*, \cdot)}{\partial p} > [\sigma(x_s^*) \eta W^s - R(x_s^*, \cdot)] \cdot \frac{\partial R(x_s^*, \cdot)}{\partial p}$.*

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 :

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

and the resulting FOC is

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

which leads to

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

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

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

\square

³A third version is to allow for different η_i^k and W^k .

- *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

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

As result, the condition of Proposition 6

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

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

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

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.

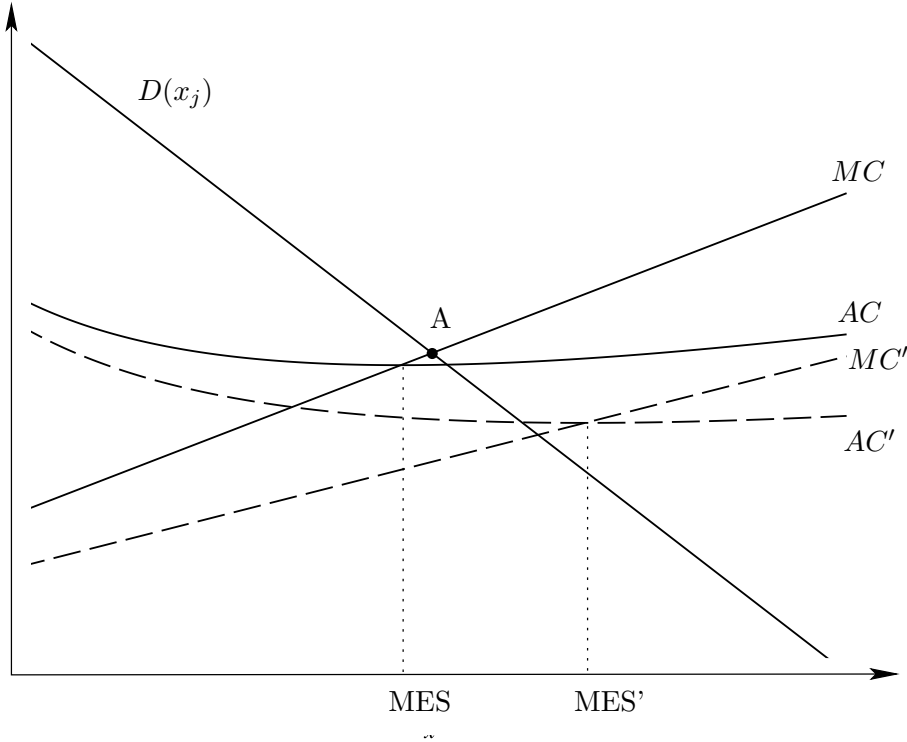
As soon as we admit the possibility that different firms may prefer different standards, the question immediately arises which level(s) of r will the market will select. We show here that it is possible for the ‘biggest’ downstream firm (highest PS_i) to establish its preferred level of r on the entire market. 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 a high level of regulation (r_h) while firm s prefers a 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. 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 they (some other) upstream firms are 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 . Assume for the sake of definiteness 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 $D(x_j)$ seen by upstream firm j . (The sum of all m individual demands equals b 's total demand.) Because each firm's cost function has a characteristic U-shape, each firm has an optimal output, i.e., minimum efficient size (MES). We assume that there are many upstream firms in the market, but however, each firm's supply curve intersects with its ‘residual’ demand curve $D(x_j)$ somewhere right of the MES, such that the firm j makes some profits, see point A in Figure 1.

Figure 1: 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 demand curve is the same as the old one. 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.⁴ As result, firm j 's MES shifts to the right, (see MES' in Figure 1). As a result, firm j 's new supply curve (the part of its marginal cost curve MC' that is above its average costs AC') 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.

Therefore we can conclude the following:

Proposition 7. *"Big" downstream firms that are able to capture high producer surplus and thus purchase more x can sometimes enforce their preferred r on the entire industry.*

3.4 Asymmetric Information: How Upstream Firms Choose r

Let us now turn to the asymmetric information case where downstream firms do not know upstream firms' cost functions. This means that they cannot calculate their preferred level of r and must depend on upstream firms to choose. We now show that, provided that the number of upstream firms (m) is small, incumbents can sometimes use a low level of r to limit the number of competitors. This can be used to prevent new entrants or drive the weak incumbents from the market.

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.

⁴How 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. However, in the calculations on which the graph is based on we even neglected this effect.

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 8. *An incumbent who can determine the industry-wide level of r can sometimes use a lower level to deter entry.*

We will now demonstrate this proposition graphically. As before, we assume the specific cost function $C_j = (x_j, r) \frac{1}{2} x_j^2 r$ and $e_j = \frac{1}{m} \rho(r) L$. We also assume $\rho(r) = \frac{1}{1+r}$ and a linear inverse demand function of the form $D(x) = a - bx$, with $x = \sum_i x_i$.

The upper graph in Figure 2 depicts the situation for r_l . In this case, a single incumbent makes a positive profit as the demand curve $D(x_i)_{m=1}$ intersects its supply curve (marginal costs $c_i(x_i, r_l)$) above the average costs $ATC_i(m=1, \cdot)$. However, a new entrant ($m=2$) would shift both firms' average costs downward since e_j is now equal to $\frac{1}{2} n \rho(r) L$ (see the dashed $ATC_i(m=2, \cdot)$ curve in Figure 2), which reduces the MES. But market demand is now split between the two firms so that each firm faces an individual demand $D(x_i)_{m=2}$. In this ($m=2, r_l$) case the firm's supply curve and the (individual) demand no longer intersect.

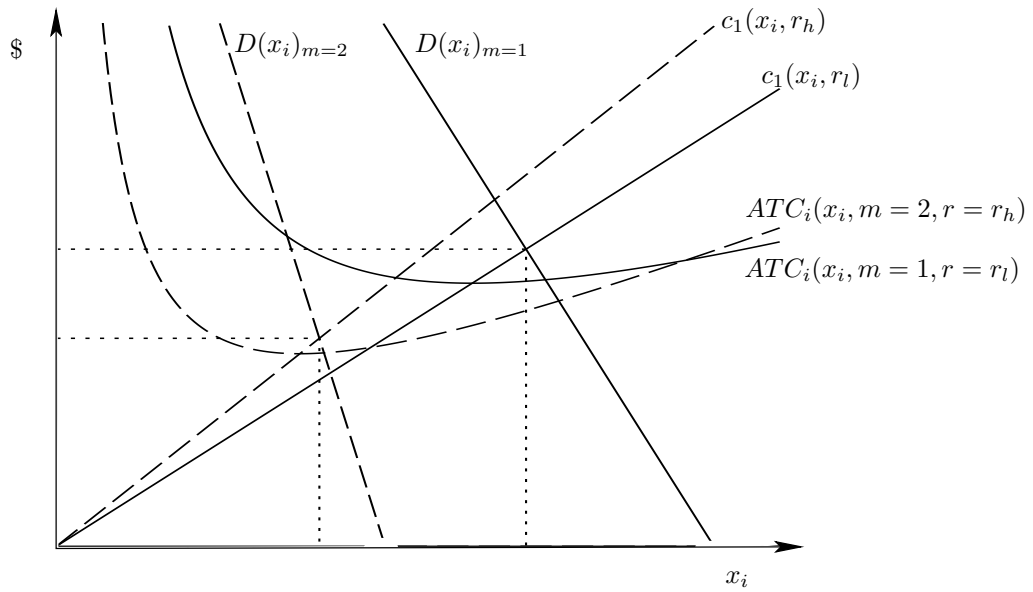
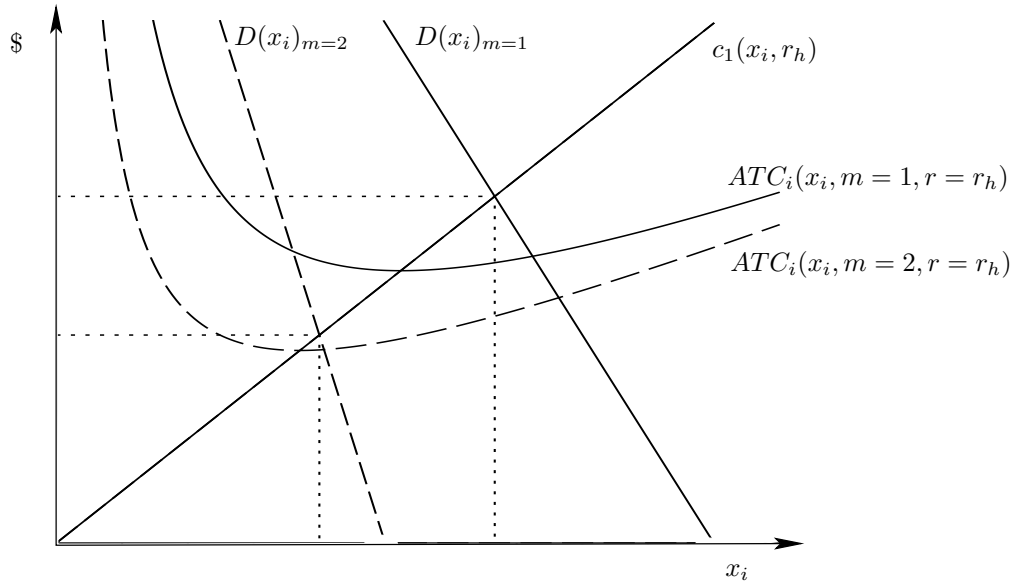
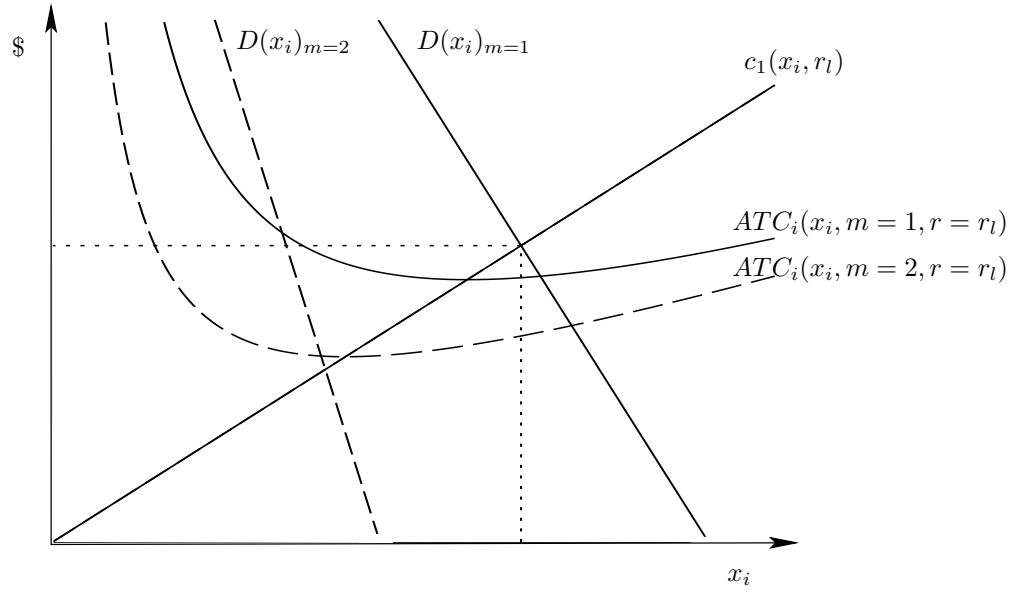
Compare this result to the situation where r_h is adopted (see the second graph in Figure 2). Compared to the r_l -case the slope of the marginal cost curve becomes steeper while the risk of disaster and thus e_j is reduced. Comparing the first and the second graph of Figure 2, it is easy to see that the incumbent's profits 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. The bottom graph in Figure 2 compares the incumbent's choices. Plainly, the incumbent will earn a higher profit in the ($m=1, r_l$) case. Therefore, if the incumbent has a way to determine which level of r will be applied, he will choose the lower.

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.

4 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

Figure 2: Incumbent chooses r_l over r_h to block entry



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. 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. Finally, 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.

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