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

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**Abstract**

High technology firms often produce goods that pose a significant risk of injury. This means that upstream suppliers face legal liability if the products are misused or cause accidents. Alternatively, downstream buyers may lose a technology that could have been used to invent profitable new products. Industry self-regulation is a natural and increasingly important way to reduce these risks.

Our paper explores how upstream and downstream firms form preferences for private regulation. We find that firms characteristically choose too little regulation where liability is imperfect and/or downstream firms fail to extract social surplus from consumers. Furthermore, regulatory backlash does not compensate for imperfect liability and often makes the situation worse. We also examine the conditions under which large downstream firms can impose a single industry-wide standard on suppliers.

Keywords: dual use products; self-governance; self-regulation; private regulation; buyer-power
JEL Classifications: L19; L51; K29

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# 1 Introduction

Many industries produce high technology products that pose significant risk of damage or injury. These risks are traditionally addressed through government regulation. However this process is slow, imprecise, and often stops at national borders. Recent cases in which big downstream firms impose private regulations on suppliers suggest an important alternative. While some of these regulations are limited to individual supply chains, others are industry-wide standards. This paper presents the first economic analysis of how firms form their regulatory preferences and the conditions under which big firms are able to impose these preferences through industry-wide standards.

Scholars have traditionally assumed that industry is incapable of selecting and implementing useful self–regulation. This viewpoint made sense so long as private regulation was overwhelmingly driven by actual or threatened government intervention. In these cases, theory and evidence both suggest that industry merely carries out (or sometimes evades) agendas devised by governments. (Khanna & Widyawati 2011; Ashby et al. 2004). Things changed, however, once businesses began addressing problems that government had ignored or showed no desire to fix. Since the 1990s, many large firms have begun legislating their own private regulations and demanding that suppliers adopt them. This has produced a series of private regulations on topics ranging from working conditions (The Gap), to packaging waste and energy efficiency (Walmart), to social and environmental practices (Hewlett Packard), to business ethics (Astra-Zeneca). Many of these private regulations are remarkably stringent (Gunningham & Rees (1997), Maurer et al. (2011)).

Recently, purchasers have extended this strategy by demanding that *entire* upstream industries adopt particular regulations. Examples include fisheries, coffee, and artificial DNA. In each case, the resulting private standards are comparably stringent to conventional government interventions. Moreover, many have gained widespread and even universal adoption (Besshiem & Kahn 2010; Maurer 2010). At the same time, downstream firms often lack sufficient information to design or evaluate upstream standards for themselves. This information asymmetry gives upstream firms significant influence in selecting the final standard.

Private, buyer-power-based regulations have been extensively studied by political scientists and sociologists. Furthermore, many governments (particularly in Europe) have come to see them as a viable alternative to conventional regulations and treaties (Vogel 2005). Despite this, economists

have paid little attention to the forces that make private industry-wide regulation possible. In particular, they have said little or nothing about how firms decide which standards to pursue, how the market mediates these conflicts, or when economic forces favor the emergence of a single industry-wide standard. We address this gap.

Our paper presents the first formal economic model of how downstream firms form regulatory preferences and impose strong industry-wide regulation on upstream suppliers. We consider the case where downstream firms buy research inputs from upstream suppliers and use them to develop new products. Like many high technology tools, these products carry a significant risk of accident or deliberate misuse. Following the traditional governance literature, we assume that upstream firms face legal liability if their products cause damage or injury. Downstream firms, other hand, worry that public pressure and regulatory backlash following a scandal could make the technology illegal or unaffordable (Lenox & Nash 2003; King & Lenox 2000). This would stop downstream firms from inventing lucrative new products like pharmaceuticals. This expected loss is often much larger than any likely court judgments facing upstream firms.

We proceed as follows. Section 2 reviews the existing literature on why firms self-regulate. Section 3 presents a General Model of how firms form regulatory preferences. We find that a combination of perfect legal liability for upstream firms and strong market power among downstream firms leads to regulatory preferences identical to those that an omniscient social planner would select. Where these conditions are absent, firms adopt too little regulation. Furthermore, the prospect of excessive "backlash" by regulators is never an adequate substitute for perfect (i.e. full) liability and usually reduces social welfare still further. We also show that big downstream firms prefer more regulation than small ones. Section 4 focuses on a high tech industry that makes "dual use" products that can be used for both civil and military purposes. Here, risk comes from deliberate misuse by states, terrorist groups, and other intelligent adversaries. We first analyze the case where downstream firms cannot form complete regulatory preferences because they lack key information about the cost and/or the feasibility of regulation (Section 4.1). We show that established upstream firms can manipulate regulatory standards to increase barriers to entry. Section 4.2 analyzes the case where downstream firms are heterogeneous and prefer different regulatory standards. We find that large downstream firms can use their buyer power to force *industry-wide* standards on upstream industry using single homing agreements. Section 4.3 examines a variant of our model in which upstream firms have zero liability risk but substantial fixed costs. We

find that that the basic results of Section 4.2 still hold. This suggests that our conclusions for "dual use" industries often apply to firms facing more traditional, accident-based risks. Section 5 provides a brief conclusion.

## 2 Background

Industry experiments with self-governance date from the early 1900s. (Gupta & Lad 1983). For most of the 20th Century, strong private regulation almost always depended on the threat (or reality) of government intervention.[1] For this reason, they tended to reflect official policy at least as much as firms' own regulatory preferences.

Private governance in the modern era, by comparison, is far less dependent on government backing. In retrospect, the watershed came in the early 1990s when large retail firms like Nike and Levi Strauss began insisting that suppliers stop using sweatshop labor or harming the environment. Today, there are hundreds of such rules regulating everything from labor conditions to endangered forests and sustainable agriculture (Conroy 2007). Until recently, almost all of these private regulations were limited to individual purchasers and their supply chains. Except for very large retailers like Wal-Mart, this made private regulations much less powerful than conventional statutes and regulations. More recently, however, downstream firms have begun pressing suppliers to adopt industry-wide standards. Prominent examples include tuna distributors' efforts to impose "dolphin safe" practices on fisheries (Gulbrandesen 2009, Conroy 2007), European supermarkets' efforts to impose uniform food safety standards on suppliers, the European coffee industry's development of global "4C" standards for coffee producers (Auld 2010, Beisheim & Kaan 2010, Conroy 2007, Kolk 2005), and big pharmaceutical companies' demand that artificial DNA makers adopt anti-terrorism precautions (Maurer 2012). These private standards can be remarkably stringent. For example, private standards for aircraft parts (Anon. 2011) and artificial DNA (Maurer 2012) significantly exceed all existing government regulations. Unlike national regulation or bilateral treaties, private self-governance is also coextensive with global markets. This explains why Chinese firms that make artificial DNA have adopted Western standards.

[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).

Scholars have devoted extensive effort to investigating why firms implement social regulations that reduce profits. Following Vogel (2005), there are at least five reasons. First, and most commonly, large retailers see supplier regulations as a way to protect themselves against actual or potential bad publicity. This is particularly important for oligopoly industries where market share depends on intangibles other than price. Second, some small firms develop "ethical goods" to attract customers and/or charge higher prices (Vogel 2005). Economists typically analyze this strategy using quality ladder and price discrimination models (Besley and Ghatak 2007; Kotchen 2009). Third, firms that adopt private standards may find it easier to attract and retain employees, maintain high employee morale and productivity. Fourth, employees, executives, and/or major shareholders may force firms to pursue social and environmental goals even when this leads to lower profits (Vogel 2005). Here, motives commonly include ethics, political beliefs, and loyalty to the broader industry. Finally, fear of government action in the event of injury also matters. For suppliers, this usually involves judicial liability. Customers, on the other hand, know that regulations imposed in the wake of scandals can be exceptionally harsh. Examples of this backlash include regulation of genetically modified foods, chemical plants, nuclear power, and deep water oil drilling.

Firms that decide to self-regulate face the further question of when to seek *industry-wide* regulatory standards. In many cases, uniform standards make regulation more valuable. First, industry-wide private regulations are often more effective than individual action. This is particularly true for national security problems in which intelligent adversaries can be expected to attack whichever firm adopts the fewest precautions (Edmunds & Wheeler 2009). Industry-wide regulation can also suppress externality and free-rider problems. Such situations are common where consumers and regulators find it hard to track injury (e.g. pollution) back to individual firms. In these cases, it is often cheaper to regulate an entire industry than to allocate blame (King, Lenox & Barnett 2002). Finally, firms may adopt industry-wide standards to suppress messy and unpredictable standards wars among firms. Conroy (2007) argues that that the forestry, fisheries, apparel, and coffee industries all developed industry-wide standards to prevent even stronger, activist-backed regulations from emerging.

Uniform regulations also offer important cost-savings. Harmonizing around a single standard eliminates the often-significant costs of developing and enforcing redundant regulations. Downstream firms also favor uniformity because it increases the number of suppliers who can bid for any given order. These rationales are known to have played a central role in persuading the

apparel (Mayer & Gareffi 2010) and food industries (Campbell & LeHeron 2007; Havinga 2006) to adopt harmonized standards.

Finally, it is easy to see why firms with identical regulatory preferences would agree to a single, industry-wide regulation. The deeper question is why firms with *different* preferences should do so. In practice, the answer seems to be that large purchasers force them to. This is usually done by announcing that they will only do business with suppliers that have adopted some particular company-wide regulation. Examples include refusing to do business with suppliers who are unethical (pharmaceuticals), violate social justice norms (coffee), mistreat their workers (apparel retailers), pose unknown safety risks (nanotechnology) or fail to screen orders for terrorism risk (artificial DNA) (Maurer, 2011). The US government has similarly threatened to withdraw business from centrifuge makers who sell to rogue states (Wirtz, 2010).

This paper focuses on the conditions under which profit-maximizing firms select and adopt regulatory standards. Nevertheless, we note that purchaser-enforced regulations are almost always more enforceable than classical schemes that require suppliers to police themselves.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."

# 3 A General Model

This section introduces a general model in which an upstream high tech industry makes products $x$ 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 associated with risk. This produces higher expected costs in the form of legal liability for upstream firms and regulatory backlash for downstream firms. We assume that these costs can be reduced by implementing suitable regulations (e.g. security checks) that reduce risk in the production process.

We analyze customer-enforced regulation as a two stage game. In Stage I downstream firms select a preferred level of regulation $r$ and demand that upstream firms implement it. In Stage II the markets clear and upstream and downstream firms earn their profits. As usual we solve the game by backward induction and focus on Stage I.

### 3.1 Upstream Market

We denote the total social cost of a potential catastrophe by $L$ and its probability by $\rho$ so that expected social cost are $\rho L$. In general we consider two kinds of risk. Ordinary accident risk comes from inadvertent accidents and depends on how many products are manufactured and used. We therefore expect it to scale with output. Dual use risk, on the other hand, involves deliberate misuse by malicious, intelligent adversaries. It depends on adversary capabilities and is independent of output so long as at least one firm offers the product for sale. The general model parameterizes both cases by leaving open the extent to which probability of injury ($\rho$) scales with output:

$$\frac{\partial \rho}{\partial x} \geq 0.$$

The probability of disaster also depends on whether firms implement meaningful precautions. We define a regulation $r$ as a binding rule that defines these precautions. Unless otherwise stated, we will normally assume that all firms in the market are bound by a single level of regulation $r$. Stricter regulation (higher $r$) reduces the individual expected liability cost for each upstream firm because it reduces the probability of disaster. However, the efficacy of regulation encounters diminishing returns as $r$ increases:

$$\frac{\partial \rho}{\partial r} < 0 \text{ and } \frac{\partial^2 \rho}{\partial r^2} > 0$$

We expect courts to hold firm $j$ liable if the disaster can be traced back to its output $x_j$. Assuming *full and complete liability,* firm $j$ will have to pay the full cost of the disaster $L$. Thus each upstream firm $j = 1...m$ faces expected individual liability costs $e_j$ given by[2]

$$e_j = \rho_j(x_j, r)L$$

Firms $j = 1...m$ produce their outputs $x_j$ using the same technology with the same cost function $C(x_j, r)$. Marginal production costs increase with output and also with $r$:

$$\frac{\partial^2 C}{\partial x_j^2} > 0 \text{ and } \frac{\partial^2 C}{\partial x_j \partial r} > 0.$$

Firm $j$'s total cost ($TC_j$) is the sum of its production and liability costs:

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

[2]Alternatively, $e_j$ can be thought of as the firm's imputed premium for self-insurance in a perfect market without coordination or transaction costs.

Increasing regulation operates on firm $j$'s cost through two opposing channels: It increases marginal cost but reduces expected liability. This means that the cost function is U-shaped in $r$ and implies that a unique, cost-minimizing $r$ exists for any possible output $x_j$.[3] Because of symmetry, the cost-minimizing $r$ for $x_j$ is the same as the cost-minimizing $r$ for the total industry-wide output $x = \sum_{j=1}^{m} x_j = m \cdot x_j$. Finally, we assume that the upstream market features free entry and exit and therefore full contestability (Baumol 1982; Baumol et al 1982). For this reason firms set price equal to marginal cost $p = \frac{\partial C}{\partial x_j} + \frac{\partial e}{\partial x_j}$. Furthermore the condition of non-negative profits implies that the price is always larger than or equal to any firm $j$'s average total costs: $\pi_j \geq 0 \Leftrightarrow p \geq ATC_j = \frac{TC_j}{x_j}$. This leads to the following *inverse* supply function for firm $j$ in Stage II :

$$p_j^s = \begin{cases} \frac{\partial C}{\partial x_j} + \frac{\partial e}{\partial x_j} & \text{if } \frac{\partial C}{\partial x_j} + \frac{\partial e}{\partial x_j} \geq \frac{C}{x_j} + \frac{e}{x_j} \\ 0 & \text{else} \end{cases} \tag{1}$$

### 3.2 Downstream Market

We consider $i = 1...n$ firms which purchase $x$ as an input for R&D that leads with probability $\sigma$ to a new invention $y_i$. The downstream firm then produce and sells the product. For example, pharmaceutical companies often use artificial DNA to conduct experiments that could lead to new drugs. Because of patent protection a successful firm $i$ that has developed a new product $y_i$ will be a monopolist and gain profits $\phi_i$

Purchasing more $x_i$ increases the probability $\sigma(x_i) \in [0, ...1]$ that firm $i$'s R&D project will succeed with $\sigma''(x_i) < 0$. This increases expected profits $\sigma_i(x_i)\phi_i$. At the same time, purchasing more $x_i$ increases the R&D-input costs $x_i \cdot p$. This yields expected net-profits of

$$\pi_i^e = \sigma_i(x_i)\phi_i - x_i\, p.$$

We have already noted that the output $x$ carries risk and could lead to a political backlash that greatly exceeds any physical injury to society (see Section 2). This backlash could take the form of an outright ban, regulations that make further production prohibitively expensive, or public controversy that forces downstream firms to stop using the technology even though it is still legal to do so. Regardless of these detailed reasons, the likelihood of a disaster ($\rho(x, r)$) contributes significantly to the risk that the industry will

[3] We exclude the trivial case where $L$ is so low that the cost function minimum is negative and the cost-minimizing $r = 0$.

shut down.[4] We define $\tau(r, x)$ as the probability that the industry will *not* be shut down, with

$$\frac{\partial \tau}{\partial r} \geq 0, \text{ and } \frac{\partial \tau}{\partial x} < 0 \text{ iff } \frac{\partial \rho}{\partial x} > 0.$$

Note that $x = \sum_{i=1}^{n} x_i$ and $\tau \in ]0, 1]$.

For the case of $\tau = 1$ (i.e. $\frac{\partial \tau}{\partial r} = 0$) $x$ remains available no matter how much injury occurs. We will refer to this as the *zero backlash* case in what follows.

So finally, downstream firm $i$'s objective function is:

$$\tau(r, x)\pi_i^e = \tau(r, x_i)\big(\sigma_i(x_i)\phi_i - x_i\, p\big).$$

In Stage II each of the $n$ downstream firms chooses the optimal input $x_i$, i.e. solves $\max_{x_i}\Big\{\tau(r, x_i)\big(\sigma(x_i)\phi_i - x_i\, p\big)\Big\}$. This leads to the individual *inverse* demand function of firm $i$

$$p_i^d = \phi_i \frac{\sigma \frac{\partial \tau}{\partial x_i} + \tau \frac{d\sigma}{dx_i}}{x_i \frac{\partial \tau}{\partial x_i} + \tau} \tag{2}$$

### 3.3 Solution of a Symmetric Case

We assume a symmetric case where (a) all upstream firms are identical to one another, (b) all downstream firms are identical to one another, and (c) firms in both sectors possess identical knowledge of all relevant variables.

In Stage II the market for $x$ clears and upstream and downstream firms earn their profits. Because of symmetry market demand is $x^d(p) = n \cdot x_i^d(p)$ and the supply function is $x^s(p) = m \cdot x_j^s(p)$, where $x_i^d(p)$ and $x_j^s(p)$ are the individual demand and supply functions corresponding to the inverse demand and supply functions (2) and (1). This yields a Stage II market equilibrium ($x^*$, $p^*$). Here, the equilibrium output is given by $x^* = x(p^*) = n \cdot x_i(p^*)$ and is parametrized by the degree of regulation since $p^* = p^*(r, \cdot)$.

We now ask what level of upstream regulation $r$ the symmetric downstream firms prefer in Stage I:

**Proposition 1.** *With full liability and no risk of regulatory backlash ($\tau = 1$) downstream firms choose the same level of regulation that a welfare-optimizing social planner would select.*

[4] Other factors include institutions that shape the political process or public opinion. Regulation may interact with these factors: For example, industries which have behaved responsibly through strong self-regulation in the past could be less vulnerable to backlash. Our model is sufficiently general to include these and other effects.

*Proof.* See Appendix. □

The intuition for this result is straightforward. Because liability is perfect, upstream firms' prices reflect their cost functions which include the full social cost of production. Downstream firms take this price into account and therefore select the optimal level of $r$.

Next, we turn to the case of incomplete liability, i.e. where expected court judgments fail to include some fraction of the risk so that the upstream firms generate negative externalities:

**Proposition 2.** *In the case of incomplete liability and no backlash risk ($\tau = 1$) downstream firms choose less regulation than a welfare-optimizing social planner would select.*

*Proof.* Omitted. □

Because liability is incomplete, not all effects are internalized and the price $p$ is too low relative to the social cost. As a result, downstream firms spend too little on precautions.

We now analyze the case of risk of regulatory backlash with complete liability:

**Proposition 3.** *In the case of complete liability and risk of backlash* ($0 < \tau < 1$) *downstream firms demand less regulation than a welfare-optimizing social planner would select.*

*Proof.* See Appendix. □

Downstream firms fail to internalize the full social costs of backlash because their losses are limited to their profits. They therefore ignore expected losses to consumer surplus. Increased market power mitigates this problem by allowing firms to extract a higher share of total welfare. We express each firm's monopoly profits $\phi_i$ as a fraction of total welfare generated by the $y_i$-market: $\phi_i = \eta_i w_i$, with $0 < \eta_i < 1$. For $\eta \to 1$ the profit-maximizing and welfare-maximizing levels of regulation approach each other (see (10) and (11) in the Appendix). They are identical for perfectly price discriminating monopolists ($\eta = 1$).

Finally we analyze the case of risk of regulatory backlash with incomplete liability:

**Proposition 4.** *With incomplete liability, increasing backlash increases the gap between welfare optimal regulation and firms' preferred regulation.*

*Proof.* Follows directly from Proposition 2 with 3. □

Our analysis tells us that upstream firms tend to under-value regulation because of incomplete liability (Proposition 2). Similarly, downstream firms under-value regulation because they fail to internalize the impact of backlash on consumers (Proposition 3). Scholars sometimes claim that backlash can have positive effects by increasing firms' regulatory preferences. This is supposed to compensate for the under-regulation caused by incomplete liability. This argument ignores the fact that the backlash threat is real, i.e. that backlash will sometime happen and destroy welfare-enhancing products. So while backlash does indeed increase the regulation demanded by firms, the gap between firms' preferences and welfare maximizing regulation increases even more. The economic intuition is that it is impossible to fix one negative externality by adding a second one.

### 3.4 Asymmetric Downstream Firms

We now relax our symmetry assumptions by considering cases where downstream firms have different individual monopoly profits $\phi_i$.

**Proposition 5.** *A downstream firm b with higher expected producer surplus than firm s will choose a higher level of regulation.*

*Proof.* The downstream firm $i = \{b, s\}$ maximizes its profits over $r$, that is $\max_r \Big\{\tau(r, x_i)\big(\sigma\left(x_i^*\right)\phi_i - x_i^*\, p^*\big)\Big\}$, with $x_i^* = x_i(p^*)$ and $p^* = p^*(r)$. The FOC then leads to (see proof of Proposition 3)

$$\frac{dp^*}{dr} = \frac{1}{\tau(r, x_i)}\frac{d\tau}{dr}\frac{\sigma\left(x_i^*\right)\phi_i - x_i^*\, p^*}{x_i^*} \tag{3}$$

A greater r.h.s. of (3) implies a higher optimal $r$ (for details see the proof of Proposition 3). It is now straightforward that for $\phi_b > \phi_s$ the firm $b$ chooses a higher $r$ than firm $s$. □

The intuition is that big downstream firms—i.e. those that purchase more $x$—stand to gain more from R&D investments. This means that they also have more to lose if regulatory backlash makes the product illegal or unaffordable.

Large downstream firms often care more about regulation than their small competitors. This is particularly true of dual use markets for chemical and biological technologies. Here, large pharmaceutical and chemical firms often possess enormous purchaser power relative to other firms. The US

government plays a similar role in nuclear technologies. Large firms were the principal driver for persuading the gene synthesis industry to adopt strong security standards in 2009 (Maurer 2012) The next section explores this dual use scenario in detail.

# 4 Dual Use Threats

We now turn to the special case of dual use threats. Because the threat involves intelligent adversaries, the probability of risk is now independent of output. For example, the chances that terrorists will attempt to purchase artificial DNA does not depend on how many orders are placed by pharmaceutical companies. Assuming that all firms adopt the same $r$, we expect terrorists to place their orders at random. In this case, the probability that firm $j$'s output will cause injury so that $j$ will be held liable is $\frac{1}{m}\rho(r)$. We specify upstream firm $i$'s production cost by the function $C(x_j, r) = \frac{1}{2}\, x_j^2\, r^\alpha$, where $\alpha > 0$ is a parameter. For the sake of simplicity we assume zero fixed costs. Thus, firm $j$'s total costs are now specified as $TC_j = \frac{1}{2}\, x_j^2\, r^\alpha + \frac{1}{m}\rho(r)L$. This leads to an aggregated supply function for the entire market

$$p^s(x) = \begin{cases} \frac{x}{m}\, r^\alpha & \text{if } \frac{1}{2\rho(r)}\, \frac{x^2}{m}\, r^\alpha \geq L \\ 0 & \text{else} \end{cases} \tag{4}$$

Furthermore, we specify

$$\sigma(x_i) = \max\left\{0, 1 - \frac{1}{x_i^\beta}\right\}, \quad \beta > 0$$

Maximizing the downstream firms' payoff function now yields the following aggregated inverse demand function:[5]

$$p^d(x) = \frac{\beta\Phi}{x^{1+\beta}} \tag{5}$$

with $\Phi = \left(\sum_{i=1}^n \left(\phi_i^{\frac{1}{1+\beta}}\right)\right)^{1+\beta}$. Equations (4) and (5) lead to the equilibrium price and quantity for Stage II. These are given by

$$x^* = \left(\frac{\beta\, m\, \Phi}{r^\alpha}\right)^{\frac{1}{2+\beta}},\ p^* = \left(\frac{\beta\, r^{\alpha(1+\beta)}\, \Phi}{m^{(1+\beta)}}\right)^{\frac{1}{2+\beta}}.$$

[5]Note that we assume that upstream firms are symmetric but permit asymmetries among downstream firms.

The non-negativity condition for the profits ($\pi_j \geq 0$) and the $p^s(x) > 0$ condition in (4) imply that

$$\frac{1}{2\rho(r)} \left( \frac{\beta^2 \, r^{\alpha\beta} \, \Phi^2}{m^\beta} \right)^{\frac{1}{2+\beta}} \geq L \tag{6}$$

We will refer to the foregoing specifications as the "Dual Use Case" throughout the rest of the paper.

### 4.1 Using Low Regulation to Block Upstream Entry

We now assume asymmetric information so that downstream firms do not know their upstream suppliers' cost-functions. This means that they can no longer calculate their preferred level of $r$ and must choose between whatever proposals upstream firms decide to offer. Provided that the number of upstream firms ($m$) is small, we show that low $r$ standards act as barriers that protect established upstream firms against entry. We expect upstream firms to exploit this effect by proposing levels of regulation that are far lower than a fully-informed customer would select. The underlying intuition is that lower regulation increases firms' minimal efficient size (MES) by increasing risk and the expected cost of disaster. This result coincides with experience in the synthetic DNA industry where large entrenched incumbents have long advocated less regulation than their smaller and less-established rivals. (Maurer, 2012)

For simplicity, we assume two levels of regulation $r_h$ and $r_l$, with $r_h > r_l$.

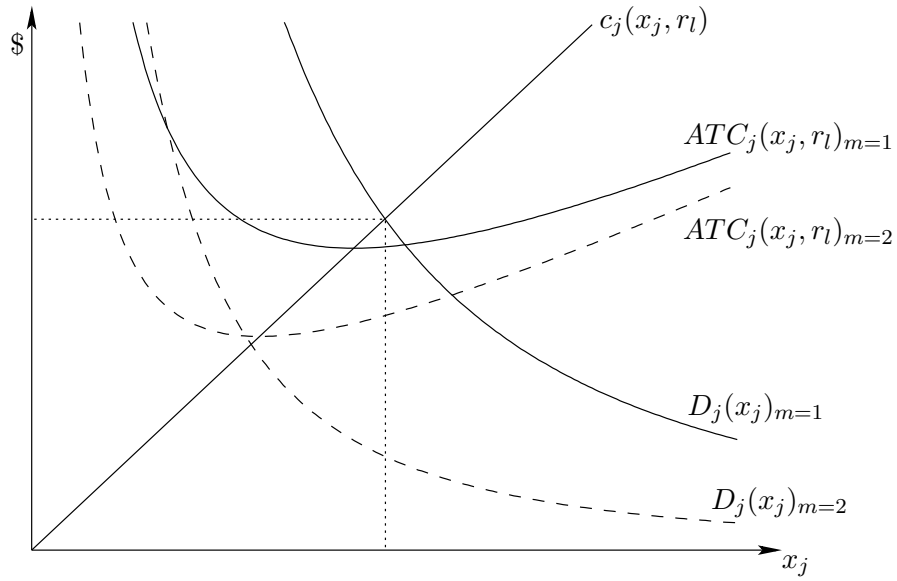
**Proposition 6.** *In Dual Use Cases, established upstream firms may propose a low level of $r$ in order to deter entry.*

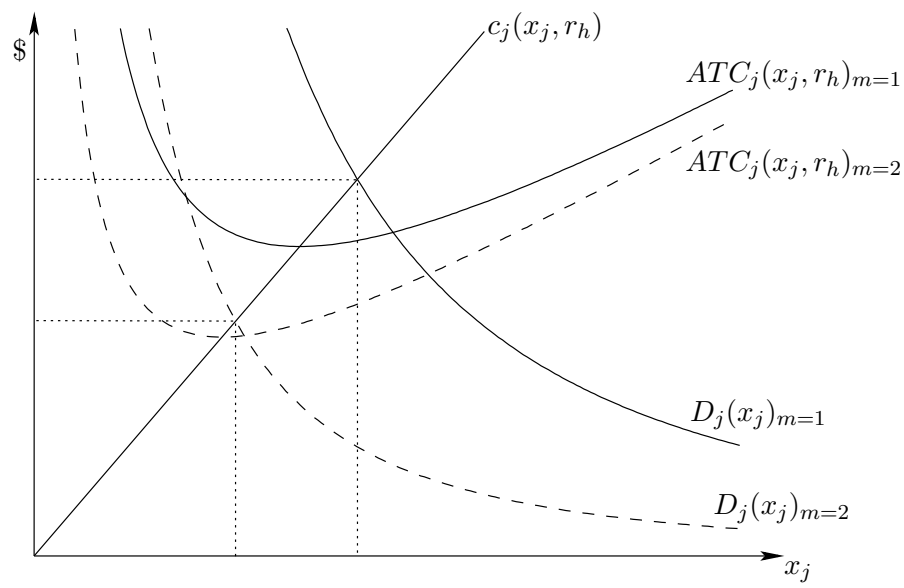
*Proof.* See Appendix. □

We now demonstrate this proposition graphically. For the sake of simplicity we consider the case where there is only one established upstream firm $j$.[6] The upper graph in Figure 1 depicts the situation for $r_l$. Because of contestability, the incumbent $j$'s supply curve is $c_j(x_j, r_l)$. The firm still earns positive profit since its marginal costs intersect $D_j(x_j)_{m=1}$ above its average cost curve $ATC_j(x_j, r_l)_{m=1}$. Despite this, entry does not occur. An entrant would shift both firms' average costs downward since with $m = 2$ $e_j$ is now equal to $\frac{1}{2}\rho(r)L$ (see the dashed $ATC_j(x_j, r_l)_{m=2}$ curve in Figure

[6] The analysis can easily be extended to examples with more than one established supplier.

Figure 1: Incumbent chooses $r_l$ over $r_h$ to block entry



1). Because both firms now share expected liability costs this reduces the MES of each firm. But market demand is also 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 and (individual) demand curves no longer intersect. Compare this result to the situation where $r_h$ is adopted (second graph in Figure 1). Here, 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, we see that the single firm earns higher profits. On the other hand, there is now room for more than one firm. In this new $(m = 2, r_l)$ case the two firms' (individual) supply and demand curves intersect. Plainly, the established firm will earn a higher profit in the $(m = 1, r_l)$ case. For this reason, an established supplier always prefers $r_l$ over $r_l$ and will propose the lower level to downstream firms.

This result offers important advice to downstream firms. If would-be entrants (or newcomers) 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 permitted entry at a positive profit. At the same time, entry will produce lower prices. This suggests that downstream firms should always favor high recommended standards over low ones.

This is exactly what happened in the artificial DNA industry where the large gene synthesis firms repeatedly proposed lower security standards than their smaller and less firmly established rivals.

Picking a proposed standard is simple when downstream firms all have the same preferences and therefore demand the same level of $r$. The situation is more complicated when downstream firms are heterogeneous so that they prefer different levels of $r$. The question remains whether large downstream firms can nevertheless impose their preferred $r$ on all upstream firms. The next section addresses this question.

### 4.2 How Big Downstream Firms Force Their Preferred Regulations on Upstream Industry

Given that different firms may prefer different standards, the question arises which level of $r$ will prevail in the market. We show that 'big' downstream firms (higher $\phi_i$) can frequently use 'single homing clauses' to impose their preferred level of $r$ on all upstream firms.

As before, we consider two levels of regulation $r_h$ and $r_l$. Downstream firms with high $\phi_i$ prefer the high standard (see Proposition 5). This implies that downstream firms can be divided in two groups such that if $r_h \succ_b r_l$

while $r_l \succ_s r_h$ for two arbitrary firms $b$ and $s$ we can conclude that $\phi_b > \phi_s$.

Note that firms' decisions to adopt $r_h$ and $r_l$ generate externalities. Upstream firms that adopt the high standard reduce the risk of backlash for all downstream firms. This even benefits $s$-type downstream firms as long as some suppliers still adopt $r_l$. Conversely, adopting the low standard increases the risk of backlash for all downstream firms. This gives $b$-type firms a strong incentive to implement $r_h$ as a universal, industry-wide standard. They do this by employing 'single homing clauses' that require suppliers to practice $r_h$ for all customers including those that prefer the lower standard.[7] Similarly, $s$-type downstream firms also try to promote their standard by applying 'single homing clauses'. Note that 'single homing clauses' separate the markets into an $r_h$-market and an $r_l$-market and that suppliers cannot deliver both of them but have to decide, i.e. cannot 'multi home'.[8]

**Proposition 7.** *In a Dual Use Case, big downstream firms can use single homing clauses to impose $r_h$ on the entire industry if $m_h^{-\beta}\,\Phi_h^2 > \Phi_l^2$, with $\Phi_r = \left(\sum_{i:r_h \succ_i r_l} \left(\phi_i^{\frac{1}{1+\beta}}\right)\right)^{1+\beta}$ and $\Phi_l = \left(\sum_{i:r_l \succ_i r_h} \left(\phi_i^{\frac{1}{1+\beta}}\right)\right)^{1+\beta}$.*

*Proof.* See Appendix. □

Figure 2 illustrates the conditions under which Proposition 7 holds. The high regulation $r_h$ will become the single industry-wide standard if either (a) a sufficiently large share of downstream firms prefer $r_h$ or (b) the firms that prefer $r_h$ are sufficiently "bigger" than the firms that prefer $r_l$ (expressed by $\frac{\phi_h}{\phi_l}$).

When this condition is not met, both levels of regulation $r_h$ and $r_l$ can coexist:

**Proposition 8.** *In a Dual Use Case with single homing clauses, if $r_h$ and $r_l$ coexist the relative adoption rate among upstream firms is given by $\frac{m_h}{m_l} = \left(\frac{\rho(r_l)}{\rho(r_h)}\right)^{\frac{2+\beta}{\beta}} \frac{r_h^\alpha}{r_l^\alpha} \left(\frac{\Phi_h}{\Phi_l}\right)^{\frac{2}{\beta}}$*

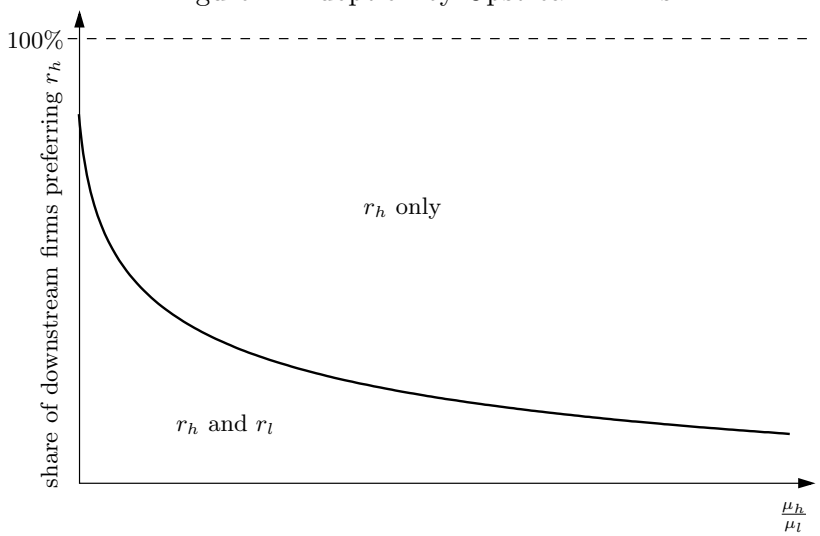
*Proof.* See Appendix. □

When Proposition 8 holds, "single homing clauses" lead to separate markets for $r_h$ and $r_l$ adopters. How many upstream firms adopt each standard depends on the two markets' relative attractiveness.

[7] In many cases, a single homing clause is unnecessary. The practical problems of manufacturing goods under two different standards are often sufficient to enforce uniformity.

[8] The terms 'single homing' and 'multi homing' are common for two-sided markets like platforms. Although there is no access pricing in our case, it is helpful to think of the two separate markets as two platforms.

Figure 2: Adoption by Upstream Firms




### 4.3 Variation: No Liability but Fixed Costs

So far, we have assumed that upstream firms face zero fixed costs. In this case MES is determined solely by potential legal liability. In particular, low levels of risk and liability produce small MES's that erode big downstream firms' power to impose their preferred standard on the upstream industry.

In fact, fixed costs are significant in many industries and this is particularly true of high-tech industries. For example, synthetic gene firms must invest large sums in automation each year to stay competitive. We now show that big downstream firms can still use 'single homing clause' mechanisms to impose a single dominant standard in industries that feature sufficiently large fixed costs.

With positive fixed costs but zero liability firm $j$'s total costs are now specified as $TC_j = \frac{1}{2}\, x_j^2\, r^\alpha + F$. This leads to the (aggregated) market supply function

$$p^s(x) = \begin{cases} \frac{x}{m}\, r^\alpha & \text{if } \frac{1}{2}\, r^\alpha\, \frac{x^2}{m^2} \geq L \\ 0 & \text{else} \end{cases}, \tag{7}$$

and—as before—the (aggregated) inverse demand function

$$p^d(x) = \frac{\beta\Phi}{x^{1+\beta}}. \tag{8}$$

While Stage II equilibrium price and quantities are the same as before, the non-negativity condition for the profits now implies that

$$\frac{1}{2}\left(\frac{\beta^2\, r^{\alpha\beta}\, \Phi^2}{m^{2(1+\beta)}}\right)^{\frac{1}{2+\beta}} \geq L \tag{9}$$

Following the logic of Subsection 4.2, we can now compute (a) the conditions under which 'big' downstream firms can impose their preferred level of regulation on the entire upstream industry, or failing that (b) the relative adoption by upstream firms when the two standards coexist:

**Proposition 9.** *In a Dual Use Case without liability but with fixed costs, applying a 'single homing clause' enables "big" downstream firms to enforce the higher $r$ on the entire industry if $m_h^{-(1+\beta)}\,\Phi_h > \Phi_l$, with $\Phi_h = \left(\sum_{i:r_h \succ_i r_l}\left(\phi_i^{\frac{1}{1+\beta}}\right)\right)^{1+\beta}$ and $\Phi_l = \left(\sum_{i:r_l \succ_i r_h}\left(\phi_i^{\frac{1}{1+\beta}}\right)\right)^{1+\beta}$.*

*Proof.* See Appendix. □

**Proposition 10.** *In a Dual Use Case without liability but with fixed costs and with single homing clauses, if $r_h$ and $r_l$ coexist, the relative adoption by the upstream firms is given by $\frac{m_h}{m_l} = \left(\frac{r_h^\alpha}{r_l^\alpha}\right)^{\frac{\beta}{2(1+\beta)}}\left(\frac{\Phi_h}{\Phi_l}\right)^{\frac{1}{1+\beta}}$*

*Proof.* See Appendix. □

Comparing Proposition 7 with 9 and Proposition 8 with 10 reveals strong similarities. The 'single homing clause' works because upstream firms have a significant MES. This basic logic holds whether the MES stems from expected liability costs, fixed costs, or by both.

This suggests that downstream firms can enforce significant regulation in any upstream industry that features sufficiently large fixed costs. Ceteris paribus, such private regulation will be even stronger when this industry faces significant dual use risks.

# 5 Conclusion

This paper has explored industry self-governance in the case where firms in a downstream market demand uniform standards from their upstream suppliers. We find that downstream firms systematically demand too little regulation compared to a welfare-optimizing social planner where (a) legal

liability is inaccurate or incomplete, or (b) the threat of regulatory backlash is significant. Furthermore, regulatory backlash is never an adequate substitute for perfect liability.

In general, downstream firms facing different expected profits prefer different levels of regulation. In some cases, customers may lack sufficient information to evaluate standards for themselves. When this happens, large established incumbents may advocate inefficiently low standards to deter entry. When suppliers offer competing proposals, customers can normally maximize profit by selecting the highest available standard.

Downstream firms will often disagree over choice of standards. Functioning self-governance systems must find a way to mediate these disputes. The available empirical evidence suggests that large downstream purchasers are remarkably successful in imposing industry-wide standards on their upstream suppliers. Our analysis of the Dual Use Case confirms this intuition by showing that big downstream firms can often use 'single homing clauses' to impose a single standard across the entire upstream industry. Absent sufficient purchasing volume, multiple levels of regulation may coexist. Significantly, 'single homing clause' strategies work whether upstream firms' MES is due to positive expected liability costs, positive fixed costs, or both. This suggests that self-governance is possible in many industries that face traditional, accident-based risks. Ceteris paribus, it will normally be stronger in dual use industries.

## Appendix

Proposition 1 is trivial in the sense that with full liability and no risk of regulatory backlash the price reflects all costs and thus downstream firms take all costs into account. We nevertheless provide the proof of Proposition 1 as this supports the understanding of the proof of Proposition 3.

*Proof of Proposition 1.* Downstream firm $i$ maximizes its profits over $r$, that is $\max_r \{\sigma(x_i^*)\,\phi_i - x_i^*\,p^*\}$, with $x_i^* = x_i(p^*)$ and $p^* = p^*(r)$. As $\frac{d\sigma(x_i)}{dx_i} = \frac{p}{\eta\,w}\,\forall\,x_i = x_i^*$—see (2)—the resulting FOC yields the condition

$$\frac{dp^*}{dr} = 0.$$

So profits are maximized for the level $r^*$ that satisfies $\frac{dp^*}{dr} = 0$ (price minimum) and hence minimizes all costs including expected liability costs.

A social planner maximizes total net-welfare over $r$. With full liability, the welfare optimization problem is—taking into account the symmetry—given by $\max_r \Big\{n\big(\sigma(x_i^*)\,w_i - x_i^*\,p^*\big)\Big\}$, where $w_i$ is the welfare generated by the $y_i$-market. With $x_i^* = x_i(p^*)$, $p^* = p^*(r)$ and $\frac{d\sigma(x_i)}{dx_i} = \frac{p}{\eta\,w}\,\forall\,x_i = x_i^*$—see (2)—the resulting FOC simplifies to $\left(p^*\left(\frac{1}{\eta}-1\right)\frac{dx^*}{dp} - x_i^*\right)\frac{dp^*}{dr} = 0$, which is satisfied iff

$$\frac{dp^*}{dr} = 0$$

because of $0 < \eta < 1$, $p > 0$, $x > 0$, and $\frac{dx^*}{dp} < 0$. So welfare is maximized for the level $r^*$ that satisfies $\frac{dp^*}{dr} = 0$ (price minimum). □

*Proof of Proposition 3.* Each firm's monopoly profits $\phi_i$ can be rewritten as a fraction of total welfare generated by the $y_i$-market: $\phi_i = \eta_i\,w_i$, with $0 < \eta_i < 1$. Because of symmetry $\phi_i = \eta_i\,w_i$ has the same value for all $i = 1...n$. We will therefore write $\eta\,w$ instead.

In the case of complete liability and risk of backlash downstream firm $i$ maximizes its profits over $r$, that is $\max_r \Big\{\tau(r, x_i^*)\big(\sigma(x_i^*)\,\eta\,w - x_i^*\,p^*\big)\Big\}$. A social planner maximizes total net-welfare over $r$. So, because of full liability, the welfare optimization problem is—taking into account the symmetry—given by $\max_r \Big\{n\,\tau(r, x_i^*)\big(\sigma(x_i^*)\,w - x_i^*\,p^*\big)\Big\}$.

With $x_i^* = x_i(p^*)$, $p^* = p^*(r)$ and $\frac{p}{\eta\,w} = \left(\sigma\frac{\partial\tau}{\partial x_i} + \tau\frac{d\sigma}{dx_i}\right)\left(x_i\frac{\partial\tau}{\partial x_i} + \tau\right)^{-1}$

$\forall\, x = x_i^*$—see (2)—the FOCs lead to

$$\frac{dp^*}{dr} = \frac{1}{\tau}\frac{d\tau}{dr}\frac{\sigma\left(x_i^*\right)\eta w - x_i^*\, p^*}{x_i^*} > 0 \tag{10}$$

and

$$\frac{dp^*}{dr} = \frac{1}{\tau}\frac{d\tau}{dr}\frac{\sigma\left(x_i^*\right) w - x_i^*\, p^*}{x_i^* - (\frac{1}{\eta} - 1)\frac{dx^*}{dp}p^*} > 0. \tag{11}$$

Since $p(r)$ is an U-shaped function (i.e. $p(r) > 0$, $p'(r) \lesseqgtr 0$ and $p''(r) > 0$), both conditions (10) and (11) can only be fulfilled for an $r$ that is larger than the price minimal $r$, i.e. for an $r$ that is larger than the $r$ where $p'(r) = 0$. Moreover, because of $p''(r) > 0$ the welfare optimal condition (11) implies a *higher* level of regulation $r$ than the profit optimal condition (10) iff the r.h.s. of (11) is *larger* than the r.h.s. of (10). Because of $0 < \eta < 1$, the numerator of (11) is greater than the numerator of (10) while the denominator of (11) is smaller than the denominator of (10). □

*Proof of Proposition 6.* We have to show that there exist constellations of parameters where $m$ established upstream firms (a) face no entry in the case of $r_l$, but (b) face entry in the case of $r_h$ leading to smaller profits.

For (a) it must be that $\pi_j(r_l, m) \geq 0 > \pi_j(r_l, m+1)$. For (b) $\pi_j(r_l, m) > \pi_j(r_h, m+1) \geq 0$ must hold. Given a suitable value of $L$ this implies

$$r_l\left(\frac{\rho(r_h)}{\rho(r_l)}\right)^{\frac{2+\beta}{\beta\,\alpha}}\left(1+\frac{1}{m}\right)^{\frac{1}{\alpha}} > r_h > r_l\left(\frac{\rho(r_h)}{\rho(r_l)}\right)^{\frac{2+\beta}{\beta\,\alpha}}.$$

Therefore, we can conclude that—given a suitable value of $L$—established upstream firms can block entry to defend their profits by proposing $r_l$ if

$$r_h = r_l\left(\frac{\rho(r_h)}{\rho(r_l)}\right)^{\frac{2+\beta}{\beta\,\alpha}}\left(1+\frac{1}{k}\right)^{\frac{1}{\alpha}} \text{ with } k \in ]0, m[.$$

□

*Proof of Proposition 7 .* Upstream firms unanimously adopt $r_h$ if $\pi_j \geq 0$ for any of the $m_h \geq 1$ firms who have adopted $r_h$ and $\pi_j < 0$ for any of the $m_l \geq 1$ firms who have adopted $r_l$, with

$$\pi_j = \frac{1}{2}\left(\frac{\beta^2\, r_\kappa^{\alpha\beta}\,\Phi_\kappa^2}{m_\kappa^{2(1+\beta)}}\right)^{\frac{1}{2+\beta}} - \frac{1}{m}\,\rho(r_\kappa)\,L, \text{ where } \kappa = \{h, l\}.$$

The stricter conditon that *not a single* firm chooses $r_l$ then leads to the following conditon: $\pi_j(r_h, m_h) \geq 0$ $r_l$ and $\pi_j(r_l, m_l = 1) < 0$. Given a suitable value of $L$ this simplifies and finally yields

$$\left(\frac{\rho(r_l)}{\rho(r_h)}\right)^{(2+\beta)} \frac{r_h^{\alpha\beta}}{r_l^{\alpha\beta}} \frac{1}{m_h^{\beta}} > \left(\frac{\Phi_h}{\Phi_l}\right)^2 \tag{12}$$

Because of $\rho(r_l) > \rho(r_h)$ and $r_h > r_l$ a sufficient condition for (12) is

$$\frac{1}{m_h^{\beta}} \Phi_h^2 > \Phi_l^2.$$

□

*Proof of Proposition 8.* For an equilibrium where no further entry occurs and some upstream firms have adopted $r_h$ and others $r_l$ it must hold that $\pi_j(r_h) = \pi_j(r_l) = 0$, with

$$\pi_j(r_\kappa) = \frac{1}{2}\left(\frac{\beta^2\, r_\kappa^{\alpha\beta}\, \Phi_\kappa^2}{m_\kappa^{2(1+\beta)}}\right)^{\frac{1}{2+\beta}} - \frac{1}{m}\,\rho(r_\kappa)\,L, \text{ where } \kappa = \{h, l\}.$$

Given a suitable value of $L$ this simplifies to

$$\frac{m_h}{m_l} = \left(\frac{\rho\,(r_l)}{\rho\,(r_h)}\right)^{\frac{2+\beta}{\beta}} \frac{r_h^{\alpha}}{r_l^{\alpha}} \left(\frac{\Phi_h}{\Phi_l}\right)^{\frac{2}{\beta}}$$

□

*Proof of Proposition 9 .* Upstream firms unanimously adopt $r_h$ if $\pi_j \geq 0$ for any of the $m_h \geq 1$ firms who have adopted $r_h$ and $\pi_j < 0$ for any of the $m_l \geq 1$ firms who have adopted $r_l$, with

$$\pi_j = \frac{1}{2}\left(\frac{\beta^2\, r_\kappa^{\alpha\beta}\, \Phi_\kappa^2}{m_\kappa^{2(1+\beta)}}\right)^{\frac{1}{2+\beta}} - F, \text{ where } \kappa = \{h, l\}.$$

The stricter conditon that *not a single* firm chooses $r_l$ then leads to the following conditon: $\pi_j(r_h, m_h) \geq 0$ $r_l$ and $\pi_j(r_l, m_l = 1) < 0$. Given a suitable value of $L$ this simplifies and yields

$$\frac{r_h^{\alpha\beta}}{r_l^{\alpha\beta}} \frac{1}{m_h^{2(1+\beta)}} > \left(\frac{\Phi_h}{\Phi_l}\right)^2 \tag{13}$$

Because of $\rho(r_l) > \rho(r_h)$ and $r_h > r_l$ a sufficient condition for (13) is

$$\frac{1}{m_h^{(1+\beta)}}\,\Phi_h > \Phi_l.$$

□

*Proof of Proposition 10.* For an equilibrium where some upstream firms have adopted $r_h$ and others $r_l$ it must hold that $\pi_j(r_h) = \pi_j(r_l) = 0$, with

$$\pi_j(r_\kappa) = \frac{1}{2}\left(\frac{\beta^2\, r_\kappa^{\alpha\beta}\,\Phi_\kappa^2}{m_\kappa^{2(1+\beta)}}\right)^{\frac{1}{2+\beta}} - F, \text{ where } \kappa = \{h, l\}.$$

Given a suitable value of $L$ this simplifies to

$$\frac{m_h}{m_l} = \left(\frac{r_h^\alpha}{r_l^\alpha}\right)^{\frac{\beta}{2(1+\beta)}}\left(\frac{\Phi_h}{\Phi_l}\right)^{\frac{1}{1+\beta}}$$

□

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