Selling a Single Item with Negative Externalities

To Regulate Production or Payments?

Tithi Chattopadhyay, Nick Feamster, **Matheus V. X. Ferreira**, Danny Yuxing Huang, S. Matthew Weinberg

Princeton University

OBJECTIVES

Consider the sale of an Internet-of-Things device that contains security vulnerabilities. Vulnerabilities can be mitigated by:

- A higher **investment in security** from the seller
- A higher effort from the buyer in **adopting security practices**.

When computer systems are compromised, the whole network is affected by cyber attacks and the buyer or seller is only **little affected**. This results in **little incentive** for the seller and the buyer in reducing vulnerabilities:

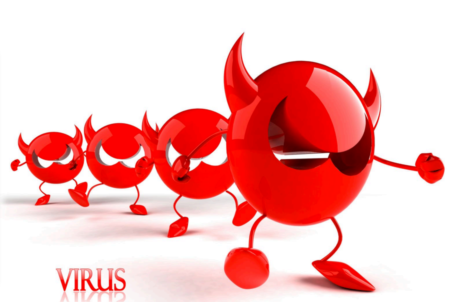
- Implementing security features introduce **extra engineering costs**.
- Security practices may be a **costly endeavor** for many buyers.

For a regulator, there is **uncertainty** and **asymmetry** on how effective the seller or the buyer is in mitigating negative externalities. A regulator can:

- **Regulate production**: by requiring minimum security investment from a seller.
- **Regulate prices**: by penalizing a buyer when they cause externalities.

To avoid pushback from the industry regulations must provide **minimum profit guarantees** to sellers. The same problem is faced by a regulator in other application domains such as regulating air pollution.

Main Question: Which regulation minimizes negative externalities subject to minimum profit guarantees to the seller? Are simple regulations approximately optimal?

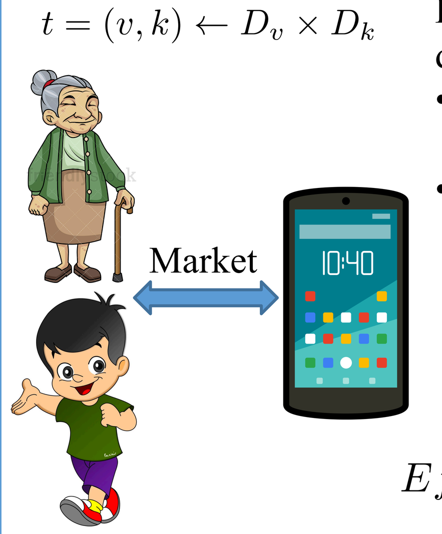


Model

$t = (v, k) \leftarrow D_v \times D_k$

Buyer has two parameters (value and efficiency) drawn independently:

- Value (**v**): buyer's valuation without regulation.
- Efficiency (**k**): quantifies the buyer's efficiency in mitigating externality where **k > 1** is efficient and **k < 1** is inefficient.



Seller's Effort   Buyer's Efficiency   Buyer's Effort

$$Effort(k, c, h) := c + kh$$

Probability of an Externality: $Risk(k, c, h) := e^{-Effort(k,c,h)}$

Regulation

Seller's Minimum Security Investment (Cost)

Buyer's Liability (Fine)   Seller's Price

$$s := (y, c, p)$$

Definition (Simple Regulation): regulates only prices (**c = 0**) or only regulates production (**y = 0**).

Effects of regulation on buyer's utility: buyer increases effort towards higher security.

Buyer's Penalty   Buyer's Effort   Price

Buyer's Utility $u(t, s) := \begin{cases} v - yRisk(k, c, h) - h - p & \text{, if buyer purchase} \\ 0 & \text{, otherwise} \end{cases}$

Optimal Buyer's Effort $h^*(t, s) := \max\left(0, \dfrac{\ln(yk) - c}{k}\right)$

Buyer's Externality under Optimal Effort $risk(t, s) := \min\left(e^{-c}, \dfrac{1}{yk}\right)$

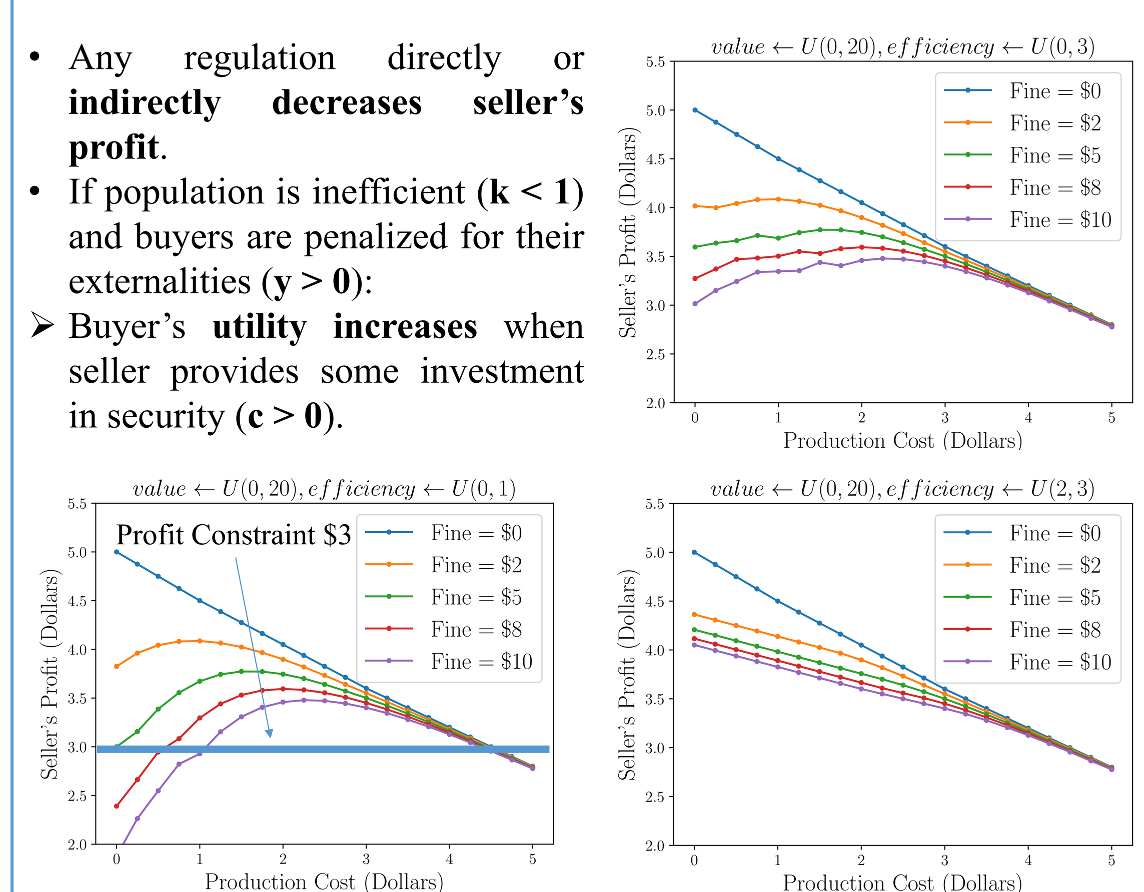
Optimal Regulation

The regulator's objective is to minimize expected externalities **among buyers that purchase** the item subjected to minimum profit guarantees.

Profit	$Profit_D(s) := (p - c)Pr_{t \leftarrow D}[u(t, s) \geq 0]$
Externality	$Ext_D(s) := \dfrac{\mathbb{E}_{t \leftarrow D}[risk(t, s) \cdot \mathbb{I}(u(t, s) \geq 0)]}{Pr_{t \leftarrow D}[u(t, s) \geq 0]}$
Optimal Regulation	$OPT(D, R) := \arg \min_{s \mid Profit_D(s) \geq R} Ext_D(s)$

Optimal Seller's Profit for Different Regulations

- Any regulation directly or **indirectly decreases seller's profit**.
- If population is inefficient (**k < 1**) and buyers are penalized for their externalities (**y > 0**):
  - ➢ Buyer's **utility increases** when seller provides some investment in security (**c > 0**).

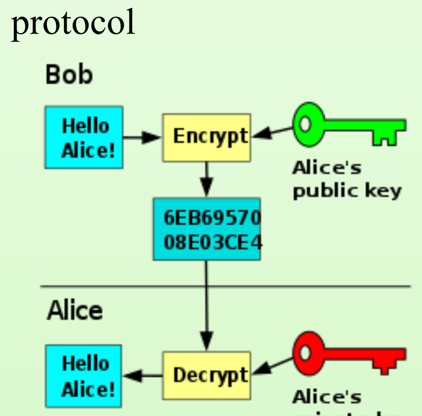


Example: Regulating only production is optimal when buyer is inefficient

Consider a product where the security is **uniquely** determined by the correct use of a public key encryption protocol

Buyers have no knowledge about the technical aspects of public key encryption; therefore, they are always inefficient in reducing risks

$D_k = \{0\}$



- ➢ Buyers have no technical expertise; therefore, they never put in effort in correctly using encryption (even if they are penalized)

$$h^*(t, s) = \max\left(0, \frac{\ln(yk) - c}{k}\right)$$

- ➢ Risk depends only on the seller correctly implementing the public key infrastructure

$$risk(t, s) = \max\left(e^{-c}, \frac{1}{yk}\right)$$

- ➢ Any liability (**y > 0**) on buyer can only hurt buyer's utility and has no impact on externality

$$u(t, s) = v - ye^{-c} - p$$

- ➢ The externality of the population only depends on seller's investment

$$Ext_D(s) = e^{-c}$$

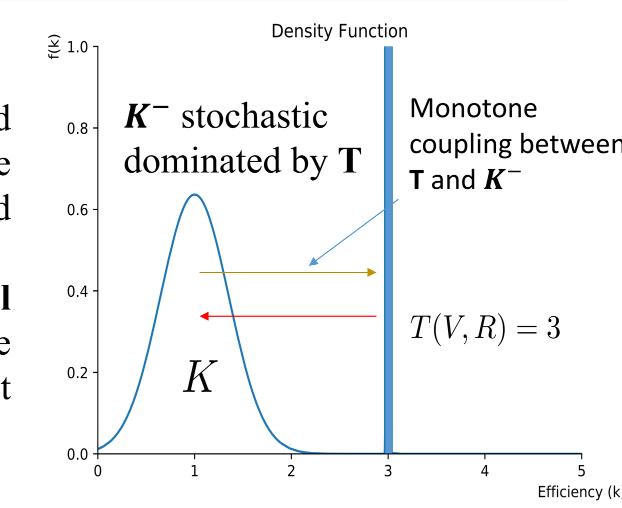
Optimal Simple Regulations

Theorem: For all value distributions **V**, and profit constraint **R**, there is a cutoff **T = T(V, R)** such that

- For all efficiency distributions $\boldsymbol{K^-}$ supported on **[0, T(V, R)]**, regulating only production is optimal.
- for all efficiency distributions $\boldsymbol{K^+}$ supported on **[T, ∞]**, the optimal regulation regulates only prices or it is not profit-maximizing.

There are distributions supported above the cutoff T where the optimal regulation is mixed and not profit-maximizing:

- Regulator sets **non-optimal higher prices** to force inefficient buyers to not purchase.



Approximately Optimal Simple Regulations

- For efficiency distributions supported bellow and above the cutoff **T(V, R)**, the **optimal regulation is mixed**.
- Without relaxing profit constraint, simple regulations are **not approximately optimal**.

Theorem: For all **x > 0**, there is a distribution **D**, profit constraint **R** with optimal regulation **s** and optimal simple regulation **s'** where the externalities of **s'** are at least **x** times bigger than the externalities of **s**.

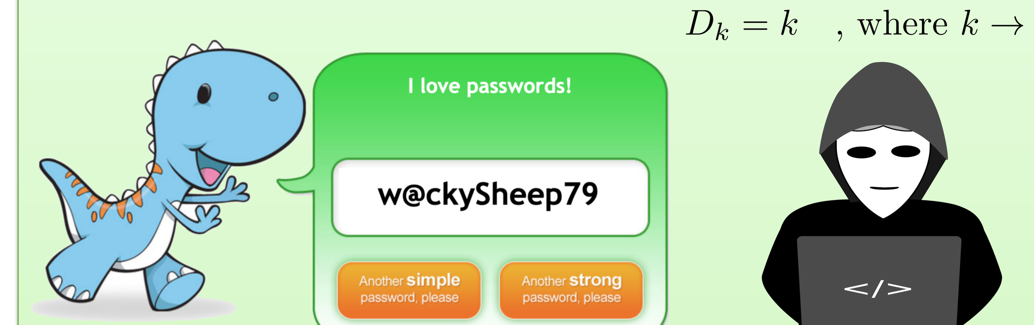
- Bad distribution is supported on two types of buyers.
- Profit constraint that can only be satisfied if the item is **always sold**.
- Both types have the same value but one type is highly efficient and the other type is inefficient.

Example: Regulating only prices is optimal when the buyer is highly efficient

Consider a product where security depends **mostly** on the buyer using strong passwords

Buyer is capable of setting strong passwords

$D_k = k$, where $k \rightarrow \infty$



- ➢ With a small penalty (**y > 0**), buyer sets strong passwords

$$h^*(t, s) = \max\left(0, \frac{\ln(yk) - c}{k}\right)$$

- ➢ Risk depends only on the buyer using strong passwords

$$risk(t, s) = \max\left(e^{-c}, \frac{1}{yk}\right)$$

- ➢ Production cost (**c > 0**) has a big impact on profit and small impact on externality when compared with liabilities (**y > 0**)

$$Rev_D(s) = (p - c)Pr\left[v \geq p + \frac{1 - \ln(yk) - c}{k}\right] \quad Ext_D(s) = \frac{1}{yk}$$

Bicriteria Approximation

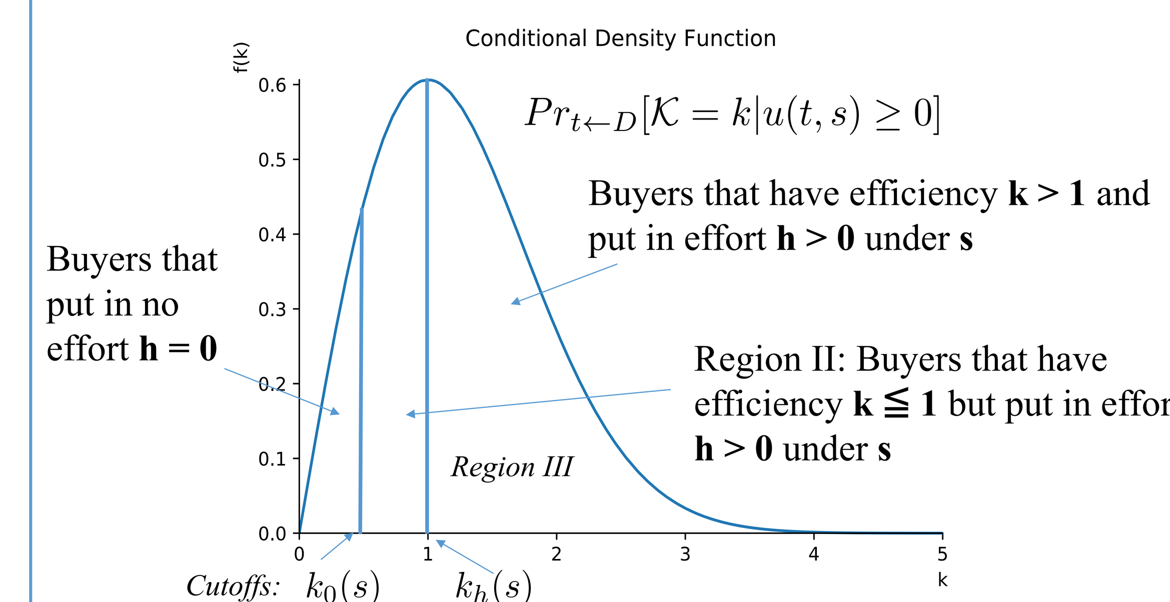
Theorem: For every distribution **D**, for all regulation **s**, there is a simple regulation **s'** such that:

$$Prof_D(s') \geq 1/8 Prof_D(s) \quad Ext_D(s') \leq 40/3 Ext_D(s)$$

Given some arbitrary regulation **s**, we construct a simple regulation **s' targeting** the population that already purchase the item under regulation **s:**

- **Partition buyers** (conditioned on buying under **s**) in three groups.
- Depending on which group contributes the most to profit under **s**, we design a simple regulation **targeting that group**.

Efficiency distribution of buyers that purchase



Case 1: Region 1 and 2 has large density

- Most of the revenue comes from **inefficient buyers**; therefore, regulating only production is approximately optimal.

Case 2: Region 3 has large density

- Regulating only production can still be approximately optimal when:
  - ➢ **K** has **small expected value**.
  - ➢ **V** is a **heavy tail distribution**.

Example: Optimal regulation also depends on value distribution

For every profit constraint **R < 1**, for every externality target **E** there is a regulation (**y = 0, c > 0**) that gets revenue > **R** and externality < **E**.

Value is drawn from Equal Revenue

$$Pr[v \leq x] = \begin{cases} 0 & , x < 1 \\ 1 - \frac{1}{x} & , x \geq 1 \end{cases}$$

- First set sufficiently large **c**:

$$Ext_D(s) = e^{-c} < E$$

- Set sufficiently large price **p**:

$$\begin{aligned} Profit_D(s) &= (p - c)Pr[v \geq p] \\ &= (p - c)(1 - (1 - 1/p)) \\ &= 1 - c/p > R \end{aligned}$$

Contact

Tithi Chattopadhyay, Nick Feamster, **Matheus V. X. Ferreira**, Danny Huang, S. Matthew Weinberg

{tithic, feamster, yuxingh, **mvxf**, smweinberg}@princeton.edu

Checkout the Paper: https://arxiv.org/abs/1902.10008

Scan me