Incentivizing pharmaceutical companies to price drugs fairly

Use Case Report

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Outline

Drug companies at times price their drugs unfairly. Such practices need to be corrected to ensure people suffering from medical conditions can afford their required drugs.

Using game theory, incentivize fair pricing of drugs on the part of drug companies to make drugs more accessible to the public. We aim to design a SCF in which truthfully revealing the production is a weakly dominant strategy. A taxing mechanism will be introduced based on the production cost and selling price.

1 Introduction

With advancements in science, there has been a rapid growth in the quality of healthcare and the number of diseases that humans are able to treat and combat. This growth in quality of healthcare is a result of advancements in various aspects of healthcare, such as surgical improvements, better care and treatment for in-hospital patients, and improvements in the drugs and medicines that are being prescribed to combat various diseases. However, these improvements have become exceedingly expensive and difficult to obtain or make use of for the common man. This is starting to become exceedingly true in the case of prescription drugs. In many parts of the world, the cost of some drugs is greater than all the other healthcare costs, preventing patients who need them from obtaining them.

Furthermore, attempts to control this problem, either by intervening in the market, government influencing on drug pricing and legislation have all had unintended consequences[1][2]. To combat these issues, we propose a mechanism in which revealing the production cost is a Nash equilibrium for the induced game.

2 Formal Statement

For each drug, we can model the scenario with following elements:

- $N = \{1, \ldots, n\}$: Pharmaceutical Companies which sell the drug.
- $\Theta_i \; \forall i \in N$: Each company i reports a production cost value $\theta_i \in \Theta_i$. This reported value may or may not be true production cost (p). $\theta_i \geq 0$, i.e, $\Theta_i = \mathbb{R}^+ \forall i \in N$.
- $s_i \; \forall i \in N$: The market price of the drug sold by company i. The set $s = \{s_1, \ldots, s_n\}$ is common knowledge.
  We assume that the market price cannot be changed once the taxation scheme is revealed. Thus, s is strictly a set of known values and s_i is **not** an action taken by player i.
- X: The set of all outcomes. Each outcome $x \in X$ corresponds to a taxation scheme $x = \{x_1, \ldots, x_n\}$ such that x_i is the tax levied on the particular drug in question for company i.
- $u_i(x, \theta, S)$: The utility of player (company) i for an outcome $x \in X$, the set of valuations θ and the set of market prices s. For this scenario, we have to design a social choice function (SCF) which maps the reported valuations and set of market prices to an outcome such that $\theta_i = p$ is at equilibrium

$$f : S \times \Theta \to X$$

3 Proposed Taxation Scheme

3.1 Intuition for SCF

In order to create a fair and robust social choice function, we aim to penalize a pharmaceutical company on the basis of two parameters. Intuitively, we want pharmaceutical companies to most benefit when they speak the truth. We want pharmaceutical companies to report the true production cost. The true production cost of a single drug should be around the same for all companies manufacturing a specific drug. We can assume this to be true because unlike other products, drugs are always to be made to the highest degree of purity along with the best standards. Assuming most players are more or less truthful and not collaborating with each other, taking an average of the reported production costs will give us a number close to the true production cost. A company looking to stray away from the truth by under or over reporting their production cost can be penalized based on the deviation from the mean reported production cost.

Further, we want to prevent pharmaceutical companies from up-scaling the price and reaping huge profit. To do this, we add a taxation on every pharmaceutical company's estimated profit. We define estimated profit as the difference between the selling price of the drug and the estimated production cost. The selling price of the drug is known information and the estimated production cost is taken as the mean of the reported production cost of all the companies. This will discourage companies from overpricing there goods and gaining a huge profit margin. We formally describe these two concepts below.

3.2 Social Choice Function

For our proposed mechanism, we introduce following new terms:

- $\mu(\theta)$ where, $\theta \in \Theta$: The mean of reported production costs.

$$\mu(\theta) = \frac{1}{n}\sum_{i=0}^{n}\theta_i$$

- σ_i: The deviation of the production cost reported by ith player (θ_i) from the mean production cost.

$$\sigma_i(\theta) = |\theta_i - \mu(\theta)|$$

$$\text{where } |x| \text{ gives the absolute value of } x$$

- p: Actual production cost. This value is known to every pharmaceutical company but unknown to the government.

As explained above, our taxation scheme need to handle 2 specific factors:

- **Deviation of θ from true production cost**: For elicitation of true production cost, it is necessary to ensure that the companies will be penalised for reporting false values. To quantify this deviation we use the deviation $_i$ of θ_i from the mean production cost $\mu(\theta)$.

  Assuming most of the pharmacies are reporting close to the true production cost, the mean μ would be close to true production cost p. If a pharmaceutical company was to report a false production cost, in order to drive up the selling price of it's drug, it would lead to larger deviations for a player from μ, resulting in a larger penalty which would be a function of σ.

- **Estimated Profit**: Even after revealing true production costs, different companies can have different profit margin. To ensure that the prices are as low as possible, we need to ensure that the profit margin is as low as possible. For this we introduce another penalty based on the estimated profit. We define estimated profit ep_i as:

$$ep_i = s_i - \mu(\theta)$$

The final tax (or penalty) for company is a linear combination of these 2 factors. It is given by:

$$x_i = k_d\sigma_i + k_{ep}ep_i$$

$$\text{where}, 0 < k_d \text{ and } 0 < k_{ep}$$

An outcome $x \in X$ is the set of the tax levied upon each company for the drug. Then, the social choice function is given by:

$$f(\theta, s) = \{\ k_d\sigma_i + k_{ep}ep_i \mid \forall i \in N\ \}$$

3.3 Utilities

The Utility for each company i depends on 2 factors:

- **Actual Profit**: The difference between market price, s_i and true production cost, p will give us the actual profit made by company.

$$\textbf{Actual profit} = (s_i - p)$$

- **Tax/Penalty**: The tax x_i levied upon company i will negatively affect it's utility.

The final utility would be a linear combination of these two terms. It is given by:

$$u_i(\theta, s) = k_p(s_i - p) - x_i$$

Which can be expanded to:

$$u_i(\theta, s) = k_p(s_i - p) - k_d\sigma_i - k_{ep}ep_i$$

where,

$$0 < k_p \leq 1$$

3.4 Flexibility of the mechanism

The parameters k_p, k_d and k_{ep} can encapsulate various factors. For example, the parameter k_p can encapsulate multiple factors such as the demand for the drug, losses due to wastage etc. k_{ep} can be adjusted to give us an idea about the importance of the profit margin. For example, if the profit margin is expected to be high, k_{ep} can be given a lower value, thus giving lesser weightage to the deviation from the standard profits. k_d can then be adjusted based on the value of k_{ep} These parameters are subject to some constraints to ensure BNIC (proved in following section), but they provide us a way to adapt the mechanism to different conditions and still ensure BNIC.

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Bayesian Nash Incentive Compatibility

We ensure that being as honest as possible, i.e, reporting your production cost as close to the true value as possible is a Nash equilibrium in this case. For a player i, the deviation is given by:

$$\sigma_i(\theta) = |\theta_i - \mu(\theta)|$$

In the case where every other agent reports the production cost to be the true production cost (p), it is best for the agent to also report the true production cost. Intuitively, this is because they will be penalized based upon their deviation from the average reported production cost (σ_i). As this deviation increases, the utility u_i decreases.

Formally, we want to prove that:

$$u_i(f(\{p, \theta_{-i}\}, s)) \geq u_i(f(\{\theta_i, \theta_{-i}\}, s)) \ \ \forall i \in N$$
$$\text{where } \theta_i \in \Theta_i, \ \theta_{-i} = \{ \ p \mid \forall i \in N \ \}$$

Consider the following cases for some player i, when every other player reports p:

- Player i reports p:

$$\begin{aligned} u_i(f(\{p, \theta_{-i}\}, s)) &= k_p(s_i - p) - k_d\sigma_i - k_{ep}ep_i \\ &= k_p(s_i - p) - k_d(0) - k_{ep}(s_i - p) \\ &= (k_p - k_{ep})s_i + (k_{ep} - k_p)p \\ &= (k_p - k_{ep})(s_i - p) \end{aligned} \tag{1}$$

- Player i reports $\theta_i \neq p$:

$$\begin{aligned} u_i(f(\{\theta_i, \theta_{-i}\}, s)) &= k_p(s_i - p) - k_d\sigma_i - k_{ep}ep_i \\ &= k_p(s_i - p) - k_d(|\theta_i - \mu|) - k_{ep}(s_i - \mu) \end{aligned} \tag{2}$$

Here, we have:

$$\begin{aligned} \mu &= \frac{(n-1)p + \theta_i}{n} \\ &= (\frac{n-1}{n})p + \frac{\theta_i}{n} \end{aligned}$$

We then consider two cases and compare the cases (1) and (2), where $\theta - \mu \geq 0$ and $\theta - \mu < 0$:

- When $\theta_i - \mu \geq 0$:

$$|\theta_i - \mu| = \theta_i - \mu$$

From (2):

$$\begin{aligned} u_i(f(\{\theta_i, \theta_{-i}\}, s)) &= k_p(s_i - p) - k_d(\theta_i - \mu) - k_{ep}(s_i - \mu) \\ &= (k_p - k_{ep})s_i + k_{ep}\mu - k_p p - k_d(\theta_i - \mu) \end{aligned} \tag{3}$$

Comparing (1) and (3), it is sufficient to prove that:

$$\begin{aligned} (k_{ep} - k_p)p \ &\geq \ k_{ep}\mu - k_p p - k_d(\theta_i - \mu) \\ k_{ep}p - k_p p &\geq \mu(k_{ep} + k_d) - k_{ep}p - k_d\theta_i \\ k_{ep}p + k_d\theta_i &\geq (\frac{n-1}{n}p + \frac{\theta_i}{n})(k_{ep} + k_d) \end{aligned}$$

$$\begin{aligned} k_{ep}(p(1 - \frac{n-1}{n}) - \frac{\theta_i}{n}) + k_d(\theta_i(1 - \frac{1}{n}) - \frac{n-1}{n}p) &\geq 0 \\ k_{ep}(\frac{p - \theta_i}{n}) + k_d(n-1)(\frac{\theta_i - p}{n}) &\geq 0 \\ k_{ep}(p - \theta_i) + k_d(n-1)(\theta_i - p) &\geq 0 \\ (k_d(n-1) - k_{ep})(\theta_i - p) &\geq 0 \end{aligned} \tag{4}$$

We know that $\theta_i - p \geq 0$ since the condition chosen is $\theta_i \geq \mu$ and $p < \mu$, and k_d and k_{ep} can we selected such that:

$$k_d \geq \frac{k_{ep}}{n-1}$$

Hence, equation (4) holds and the BNIC conditions are satisfied for $\theta_i - \mu \geq 0$.

- When $\theta_i - \mu < 0$:

$$|\theta_i - \mu| = \mu - \theta_i$$

From (2):

$$\begin{aligned} u_i(f(\{\theta_i, \theta_{-i}\}, s)) &= k_p(s_i - p) - k_d(\mu - \theta_i) - k_{ep}(s_i - \mu) \\ &= (k_p - k_{ep})s_i + k_{ep}\mu - k_p p + k_d(\theta_i - \mu) \end{aligned} \tag{5}$$

Comparing (1) and (5), it is sufficient to prove that:

$$\begin{aligned} (k_{ep} - k_p)p \ &\geq \ k_{ep}\mu - k_p p + k_d(\theta_i - \mu) \\ k_{ep}p - k_p p &\geq \mu(k_{ep} - k_d) - k_{ep}p + k_d\theta_i \\ k_{ep}p - k_d\theta_i &\geq (\frac{n-1}{n}p + \frac{\theta_i}{n})(k_{ep} - k_d) \end{aligned}$$

$$\begin{aligned} k_{ep}(p(1 - \frac{n-1}{n}) - \frac{\theta_i}{n}) - k_d(\theta_i(1 - \frac{1}{n}) - \frac{n-1}{n}p) &\geq 0 \\ k_{ep}(\frac{p - \theta_i}{n}) - k_d(n-1)(\frac{\theta_i - p}{n}) &\geq 0 \\ k_{ep}(p - \theta_i) - k_d(n-1)(\theta_i - p) &\geq 0 \\ (k_d(n-1) + k_{ep})(p - \theta_i) &\geq 0 \end{aligned} \tag{6}$$

Here, we know that $p - \theta_i > 0$ since the chosen condition is $\theta_i < \mu$ and $p > \mu$, and $k_d(n-1) + k_{ep} > 0$ since they are positive constants. Hence, the equation (6) holds and the conditions for BNIC are satisfied for $\theta_i - \mu < 0$.

We have thus proved that truth revelation has a Nash equilibrium and all players are incentivized for telling the truth. The social choice function is hence Bayesian-Nash incentive-compatible (BNIC).

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Examples

5.1

Consider a case where there are 5 pharmaceutical companies trying to sell an anti-viral drug. In this sitation, we have:

$$\begin{aligned} N &= \{ \ 1, 2, 3, 4, 5 \ \} \\ n &= 5 \\ s &= \{ \ 40, 37, 55, 42, 35 \ \} \end{aligned}$$

Since have $n = 5$, we choose k_p, k_{ep} and k_d as:

$$k_{ep} = 3.8$$
$$k_d = 5.0$$
$$k_p = 0.8$$

We can see that the third company is selling at an exorbitant price, $S_3 = 55$. Let our estimated production cost be given by $p = 21$. Consider the reported production costs:

$$\theta = \{\ 23, 21, 30, 25, 21\ \}$$
$$\mu = 24$$

The utilities are given by:

$$u_i(\theta, s) = k_p(s_i - p) - k_d(\theta_i - \mu) - k_{ep}(s_i - \mu)$$
$$u(\theta, s) = \{\ -40.6, -21.6, -120.6, -56.6, -15.6\ \}$$
$$f(\theta, s) = \{\ 55.8, 34.4, 147.8, 73.4, 26.8\ \}$$

As evident in the final outcome taxation scheme, we can see that the ones who are lying and trying to make an extra profit are taxed heavily (here, company 3). The ones that are telling the truth are also taxed but the penalty is reduced for the company selling at a lower price (here, companies 2 and 5).

5.2

We now consider a case where BNIC comes into play. Suppose we have 4 pharmaceutical companies trying to sell a certain drug.

$$N = \{\ 1, 2, 3, 4\ \}$$
$$n = 4$$
$$s = \{\ 230, 253, 233, 225\ \}$$
$$p = 170$$

Since company 2 has a very high selling price, they report their production costs to be extremely high.

$$\theta = \{\ 170, 195, 170, 170\ \}$$
$$\mu = 176.25$$

The parameters are chosen for $n = 4$:

$$k_{ep} = 4.8$$
$$k_d = 6.0$$
$$k_p = 0.8$$

Then, the calculated utilities and social choice function give:

$$u(\theta, s) = \{\ -172.5, -414.5, -184.5, -152.5\ \}$$
$$f(\theta, s) = \{\ 220.5, 480.9, 234.9, 196.5\ \}$$

Company 2 faces a significantly larger penalty as compared to the other companies due to the fact that it over-reported its production costs. If they had instead reported the true cost, we would have:

$$\theta = \{\ 170, 170, 170, 170\ \}$$
$$\mu = 170$$
$$u(\theta, s) = \{\ -228.0, -319.2, -281.2, -209.0\ \}$$
$$f(\theta, s) = \{\ 276.0, 386.4, 340.4, 253.0\ \}$$

We notice that the utility of company 2 increases significantly, whereas that of other companies decreases. This shows us that truth-revelation would be the best strategy in case everyone else is telling the truth.

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Additional Remarks

The mechanism fails when the companies collaborate and report false values together. They can then control estimated production cost (μ) in which case the minority which reports truthfully would be heavily penalised and the collaborating majority will receive no deviation penalty.
A possible solution for this can be by using some other form of estimate for production cost instead of average μ. The government can conduct independent investigations to determine an accurate estimation of production cost, which can then be used to penalise players with largest deviations.

7

Conclusion

We have designed a game that prevents pharmaceutical companies from misusing their position to exploit customers. The game holds as long as we can prevent pharmaceutical companies from colluding. For example, consider a 8 company market, where 1 company has reported truthfully. All the other companies may cooperate and report a different price. Thus, even if the first company tells the truth, the company would face huge penalty - it may only be beneficial to tell the truth when everyone else is also telling the truth. Similarly, companies may co-operate to undermine other companies.

The group conducting the game is responsible for setting k_{ep}, k_d and k_p, these can be considered as the parameters of the game.

We have designed the mechanism in such a way that saying the truth is always a better strategy in expectation that the others are also speaking the truth - that is, we expect that the mechanism is BNIC, and saying the truth is a Nash equilibrium. We also provided some example test cases, where we show how the mechanism performs. We have also coded up a python program that calculates the utility and simulates this game here.

References

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