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MONOPOLISTIC SCREENING WITH BOUNDEDLY RATIONAL CONSUMERS

By Suren Basov[1]

In this paper I revisit the monopolistic screening problem for the case of two types assuming that consumers are boundedly rational. Since the consumers are boundedly rational, the revelation principle does not apply and the choice of the selling mechanism is in general with the loss of generality. I show that if the monopolist restricts attention to mechanisms which offer menus of two choices, the profits are lower than in the case of full rationality by the terms of order $\ln \lambda/\lambda$, where λ is the degree of rationality of the consumers. The monopolist, however, can approximate the profits she earns under assumption of full rationality, by using a more elaborate message game.

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Keywords: Monopolistic screening, bounded rationality, connected product line, revelation principle.

1. Introduction

The mechanism design theory is the main theoretical tool that is used to analyze institutions, which make collective decisions while attempting to take into account the individual preferences. Non-linear tariffs charged by utility companies, auctions, and taxes are all examples of mechanisms, which can be analyzed using the tools provided by the mechanism design theory.

The main difficulty a mechanism designer, who can be a seller of a good, a service provider, or the government, faces is that the participants usually have private information, which is referred to as their type. On a very general level, the mechanism design problem can be formalized in the following way. The designer asks the participants to choose a message from a set of allowable messages and send it to the designer. Based on the messages received, the designer selects a social outcome (the rule, which selects the outcome based on the set of messages received should be announced in advance). The designer can manipulate the set of allowable messages and the rule that translates the set of messages into the outcome to achieve her goals.

Though at the first glance the problem seems unmanageable, the analysis is considerably simplified due to the Revelation Principle.[2] It states that given any Bayes-Nash equilibrium in a message game, there exists another mechanism such that the participants are required to report their type, they report truthfully at the equilibrium, and everybody the participants and the designer get the same payoffs as at the equilibrium of the original message game.

The revelation principle allows a researcher to restrict her attention to direct mechanisms when searching for the optimal mechanism. Once the optimal direct mechanism is found, any other mechanism (not necessarily direct), which reproduces its payoffs is also optimal. An important assumption that underlies the revelation principle is that of sufficiently high degree of rationality on the part of the participants, which allows us to employ the Bayes-Nash equilibrium as the solution concept. Recently, however, a growing empirical evidence called into question the utility maximization par-

[2]For a textbook exposition of the Revelation Principle, see Mas-Colell, Whinston, and Green (1995).

adigm.[3] On the basis of this evidence, Conlisk (1996) convincingly argued for the incorporation of bounded rationality into economic models. A step in that direction was taken by McKelvey and Palfrey (1995), who developed a new equilibrium concept: *quantal response equilibrium (QRE)*, which incorporates idea of bounded rationality, modelled as probabilistic choice, into game theory. The revelation principle, however, does not extend to QRE.

There are two natural responses to the failure of the revelation principle in this context. The first is to search for some generalized version of the principle, which will allow to restrict the set of the mechanisms for the new solution concept. The second is to restrict attention to a particular class of mechanisms, e.g. non-linear tariffs, and look for the optimal mechanism in this class. Though the second approach does not guarantee that one will arrive at the optimal mechanism, it is much more manageable than the first and is practically important, therefore I limit myself here to it, leaving the first approach to the future research.

In this paper I consider a particular problem, which served as an important example of a general mechanism design problem: monopolistic screen-

[3] For a description of systematic errors made by experimental subjects, see Arkes and Hammond (1986), Hogarth (1980), Kahneman, Slovic, and Tversky (1982), Nisbett and Ross (1980), and the survey papers by Payne, Bettman, and Johnson (1992) and by Pitz and Sachs (1984).

ing. Assume a monopolist can produce a unit of good of different quality. Consumer's marginal utility of quality is unknown to the monopolist, but she knows that it can take one of two commonly known values with some commonly known probabilities. Assuming full rationality on the side of the monopolist and the consumers' one can prove that without loss of generality the monopolist can restrict her choice of a mechanism to a choice of a nonlinear tariff.[4] Since the set of types is finite, the equilibrium will be characterized by a discrete set of qualities purchased and transfers made, with cardinality equal to the cardinality of the type space, i.e. consumers of each type will select a quality-transfer pair, which will maximize their utility. Therefore, non-linear tariff defined over all possible qualities will produce the same equilibrium outcome as a direct revelation mechanism.

This equivalence will, however, be broken if the consumers are boundedly rational. I will model bounded rationality using Luce (1959) model. Consumers behaving in accordance with this model will purchase any quality offered with positive probability. Therefore, a non-linear tariff with connected product line will produce a different behavior from the direct revelation mechanism. I will show that offering a pair of contracts and allowing

[4] This statement, known as the taxation principle, was first proved under much more general conditions by Rochet (1985).

the consumers to choose freely among them, offering a non-linear tariff over a connected product line, and playing an elaborate message game with only two payoff relevant outcomes will produce different behavior under bounded rationality, while all three mechanisms are equivalent under full rationality.

The paper is organized in the following way. Section two starts with a reminder of the standard monopolistic screening model under perfect rationality, when the consumer type can take only two values and then moves on to formulate the problem of finding the optimal direct mechanism and optimal nonlinear tariff under bounded rationality. In Section three I define the concept of nearly rational consumer. In Section four I find the optimal menu assuming it has only two items on it, and compare the profits generated by this menu with the ones generated by an elaborate message game. Section five concludes.

2. THE MODEL

Assume a monopolist can produce a unit of good with quality x at a cost

(1) $$c(x) = \frac{x^2}{2}.$$

A consumer who pays amount t for a good of quality x, derives utility

$$u(\theta; x, t) = \theta x - t, \tag{2}$$

where θ is private information of the consumer. However, it is commonly known that $\theta \in \{\theta_L, \theta_H\}$ and that $\Pr(\theta = \theta_H) = \mu$. I also assume that the utility of the outside option is independent of the type and normalize it to be zero.

The task of the monopolist is to devise a mechanism to maximize her expected profits. To do this she has first to make some assumptions about the consumer's behavior. The standard assumption is that the consumer is rational. The solution in that case is well known. I will briefly review it here for the sake of completeness.

2.1. The optimal mechanism with rational consumers[5]

In the case of rational consumers the revelation principle is applicable. It allows us to restrict our attention to a menu of contracts $\{(x_L, t_L), (x_{H,} t_H)\}$ such that at equilibrium the low type will select contract (x_L, t_L) and the high type will select contract (x_H, t_H).[6] Formally, the monopolist selects the

[5] This basic model is thoroughly discussed in Mas-Colell, Whinston, and Green (1995). I present it here for the sake of completeness.

[6] This is equivalent to asking the consumer her type and awarding them contract (x_L, t_L)

menu to solve

$$\max \mu(t_H - c(x_H)) + (1-\mu)(t_L - c(x_L)), \tag{3}$$

subject to the following constraints:

$$x_L\theta_L - t_L \geq 0 \tag{4}$$

$$x_L\theta_L - t_L \geq x_H\theta_L - t_H \tag{5}$$

$$x_H\theta_H - t_H \geq 0 \tag{6}$$

$$x_H\theta_H - t_H \geq x_L\theta_H - t_L. \tag{7}$$

Constraints (4) and (6) state that both types would like to participate in the contract and are known as the *individual rationality* constraints, and the constraints (5) and (7), known as the *incentive compatibility* constraints, ensure that no one would like to choose the contract meant for the other type. The basic results is Stole's *constraint reduction theorem* that states that for the optimal allocation only two of this constraints bind: (4) and (7): that is the lowest type gets her reservation utility (in this case, zero) and the

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if she reports θ_L, contract (x_H, t_H) if she reports θ_H and demanding that at equilibrium she reports truthfully.

high type gets the *information rent* that is just enough to prevent her form pretending to be the low type. This implies that

$$t_L = x_L\theta_L \tag{8}$$

$$t_H = x_H\theta_H - x_L\theta_H + x_L\theta_L. \tag{9}$$

Therefore, the monopolist's solves

$$\max \mu(x_H\theta_H - x_L\theta_H + x_L\theta_L - c(x_H)) + (1-\mu)(x_L\theta_L - c(x_L)). \tag{10}$$

The first order conditions are

$$\begin{cases} x_H = \theta_H \\ x_L = \max(0, \theta_L - \frac{\mu}{1-\mu}(\theta_H - \theta_L) \end{cases}. \tag{11}$$

Note that x_H is at the efficient level (no distortions at the top) and x_L below the efficient level. I will assume below that $\mu < \theta_L/\theta_H$, so $x_L > 0$ and both types of the consumer are served in the rational equilibrium. Corresponding tariffs are:

$$
(12) \qquad \begin{cases} t_L = \theta_L(\theta_L - \frac{\mu}{1-\mu}(\theta_H - \theta_L)) \\ t_H = t_L + \frac{\theta_H(\theta_H - \theta_L)}{1-\mu} \end{cases} .
$$

Note that the same outcome can be implemented by offering product line $X = [0, a]$ and the following tariff $t : X \to R$:

$$
(13) \qquad t(x) = \begin{cases} \theta_L x, \text{ for } x < x_L \\ \theta_L x_L + \theta_H(x - x_L), \text{ for } x_L \leq x \leq a \end{cases} ,
$$

where $a \in [x_H, +\infty)$. Therefore, under assumption of perfect rationality the optimal non-linear tariff is equivalent to the optimal menu of choices. We will see that this equivalence breaks down under bounded rationality.

2.2. A model of boundedly rational behavior

In this paper we assume that the consumers are boundedly rational. To capture the bounded rationality on the side of consumers we assume that the choice is probabilistic, i.e. the utilities associated with different choices determine the probabilities with which these choices are made. The first probabilistic choice model in economics was proposed by Luce (1959). He showed that if one requires that choice probabilities does not depend on a sequence in which choices are made the choice probabilities can be represented by:

$$p_i = \frac{\exp(\lambda u_i)}{\sum_{j=1}^{n} \exp(\lambda u_j)}. \tag{14}$$

Here n is the number of alternatives, p_i is the probability that alternative i is chosen, and u_i is the utility associated with alternative i. Note that according to this model any two alternatives that have the same utility are selected with the same probabilities. Parameter λ, which changes from zero to infinity, can be usefully thought to represent the degree of rationality on the side of the economic agent. If $\lambda \to \infty$ then

$$p_i = \begin{cases} 1/k, \text{ if } u_i = \max\{u_1, ...u_n\} \\ 0, \text{ otherwise} \end{cases}. \tag{15}$$

Integer k here is the cardinality of the set of the utility maximizers. At the other extreme, as $\lambda = 0$ the choice probabilities converge to $1/n$, i.e. the choice becomes totally random independent of the utility level.

The original Luce model was developed for choices from a finite set of alternatives. For the purposes of this paper I will generalize it to allow for choices from any measure space. Let (Ω, Σ, ν) be a measure space, where Ω is a choice set, Σ is $\sigma-$ algebra of its measurable subsets, and ν is a Radon measure on Σ. The preferences of the decision maker are summarized by a measurable function $u : \Omega \to R$, such that

$$\int_{\Omega} \exp(\lambda u(x)) d\nu(x) < \infty \tag{16}$$

for any $\lambda > 0$. For any $A \in \Sigma$ I will postulate that

$$\Pr(x \in A) = \frac{\int_{A} \exp(\lambda u(x)) d\nu(x)}{\int_{\Omega} \exp(\lambda u(x)) d\nu(x)}. \tag{17}$$

I will call the probabilistic choice model defined by (17) *a generalized Luce model.*

Example 1 Let $\Omega = \{x_1, ..., x_n\}$, $\Sigma = 2^{\Omega}$, and for any $A \in \Sigma$

$$\nu(A) = \#(A), \tag{18}$$

where # stands for the cardinality of the set. Then the generalized Luce model reduces to the Luce model.

Example 2 Let $\Omega = R_+$, Σ be the algebra of Lebesgue measurable sets, and ν be the Lebesgue measure. Then choice probability given by (17) possesses a density:

$$f(x) = \frac{\exp(\lambda u(x))}{\int\limits_{\Omega} \exp(\lambda u(x))dx}. \tag{19}$$

Example 3 Let $\Omega = [a, b] \cup \{x_1, ..., x_n\}$ ($x_i \notin [a, b]$ for all i), $\Sigma = 2^{\Omega} \cup L([a, b])$, where $L([a, b])$ is the algebra of Lebesgue measurable subsets of $[a, b]$, and for any $A \in \Sigma$

$$\nu(A) = mes(A \cap [a, b]) + \#(A \cap \{x_1, ..., x_n\}), \tag{20}$$

where mes is the Lebesgue measure. Then

$$\Pr(x \in A) = \frac{\int\limits_{A \cap [a,b]} \exp(\lambda u(x))dx + \sum\limits_{x \in A \cap \{x_1,...,x_n\}} \exp(\lambda u(x))}{\int\limits_{a}^{b} \exp(\lambda u(x))dx + \sum\limits_{x \in \{x_1,...,x_n\}} \exp(\lambda u(x))}. \tag{21}$$

2.3. The monopolistic screening problem with boundedly rational consumers

Since the revelation principle does not apply under bounded rationality, I will start with exogenously restricting the class of allowable mechanism. I will assume that the monopolist has to choose a product line, X, and a tariff $t : X \to R$. Moreover, I will assume $X = [a, b] \cup \{x_1, ..., x_n\}$, for some finite n, where $x_i \notin [a, b]$ for all i.[7] This set of mechanisms is rich enough to encompass both, a pure nonlinear tariff ($X = [0, \infty)$) and the direct mechanism ($X = \{x_L, x_H\}$). The set of choices available to the consumer is:

$$\Omega = X \cup \{x_0\}, \tag{22}$$

where x_0 is the outside option. I will also assume that the consumers are boundedly rational and the choice probabilities are given by (21), where

$$u(x) = \theta x - t(x) \tag{23}$$

[7] In principle, b can be infinite.

for $\theta \in \{\theta_L, \theta_H\}$. The optimal direct mechanism solves:

$$\max_{t(\cdot),x_L,x_H} \mu \frac{\sum\limits_{x\in\{x_L,x_H\}} (t(x)-c(x))\exp(\lambda(\theta_H x - t(x)))}{1+\sum\limits_{x\in\{x_L.x_H\}} \exp(\lambda(\theta_H x - t(x)))} +$$

$$(1-\mu)\frac{\sum\limits_{x\in\{x_L,x_H\}} (t(x)-c(x))\exp(\lambda(\theta_L x - t(x)))}{1+\sum\limits_{x\in\{x_L,x_H\}} \exp(\lambda(\theta_L x - t(x)))}. \tag{24}$$

3. The concept of a nearly rational consumer

Let us return to the Luce's model of boundedly rational behavior, introduced in Subsection 2.2. For the simplicity of exposition, in this Section I will restrict attention to the case, when the choice space is discrete. Note that according to this model any two alternatives that have the same utility are selected with the same probabilities. Parameter λ, which changes from zero to infinity, can be usefully thought to represent the degree of irrationality on the side of the economic agent. If $\lambda = 0$ then

$$p_i = \begin{cases} 1/k, \ \text{if } u_i = \max\{u_1, ...u_n\} \\ 0, \ \text{otherwise} \end{cases}. \tag{25}$$

Integer k here is the cardinality of the set of the utility maximizers. At the other extreme, as $\lambda \to \infty$ the choice probabilities converge to $1/n$, i.e. the choice becomes totally random independent of the utility level.

Let M be the set of the utility maximizers, i.e.

$$M = \{u_i : u_i = \max\{u_1, ...u_n\}\}. \tag{26}$$

Take any $u_j \in M$ and define

$$\Delta = \min_{u_{k \notin M}} (u_j - u_k). \tag{27}$$

Definition 1 *An economic agent whose choice probabilities are given by (14) is called nearly rational if* $\lambda\Delta >> 1$or $1/\lambda << \Delta$. In words, the definition says that an economic agent is nearly rational if her irrationality parameter $1/\lambda$ is *much smaller* that the difference between the optimal and the next to the optimal choice. The exact meaning of "much smaller" depend on the precision with which an econometrician wants to measure relative frequencies of different choices.

Let us specialize the concept of the nearly rational consumer to the monopolistic screening model with two types. As we discussed in Subsection

2.1, in such a model type θ_H earns the informations rents

$$I_{21} = u(x_H, \theta_H) - t_H = u(x_L, \theta_H) - t_L = u(x_L, \theta_H) - u(x_L, \theta_L),$$

while type θ_L strictly prefers her contract to that of the high type. Let

$$\Delta_{IC} = t_H - u(x_H, \theta_L) \tag{28}$$

measure the slack in the incentive compatibility condition for the low type. Define

$$\Delta = \min(I_{21}, \Delta_{IC}). \tag{29}$$

Consumers are nearly rational if the irrationality parameter $1/\lambda$ is much less comparatively to both the high type information rents and the slack in the low type incentive compatibility constraint, i.e. $1/\lambda << \Delta$. Therefore, the fraction of high type consumers who decide not to participate or the fraction of the low type consumers who decide to choose the high type contract is exponentially small. In the next Section I will solve for the optimal pair of contracts under assumption of near rationality and investigate, whether the monopolist can achieve better results by offering more elaborate mechanisms.

4. The optimal menu of contracts and a comparison with some other mechanisms

In this Section I am going to assume that the consumers are nearly rational and the monopolist is bounded to offer a menu of contracts $\{(x_L, t_L), (x_H, t_H)\}$ and allow the consumers to choose freely between these contracts and the option of not participating. For simplicity of exposition, I will also assume that

$$\theta_L - \frac{1-\mu}{\mu}(\theta_H - \theta_L) > 0, \tag{30}$$

i.e. under full rationality both types of consumers are served at the equilibrium. The assumption of near rationality implies that we can assume that low type consumers are randomizing between their contract and the option of not participating, while the high type consumers are randomizing between their contract and the contract designed for the low type, i.e. the monopolists profits are given by:

(31)
$$v_L(t_L - c(x_L)) + (1-\mu)\frac{(t_H - c(x_H))\exp(\lambda(\theta_H x_H - t_H))}{\exp(\lambda(\theta_H x_L - t_L)) + \exp(\lambda(\theta_H x_H - t_H))} + O(\exp(-\lambda\Delta)),$$

where

$$(32)\quad v_L = \frac{\mu \exp(\lambda(\theta_L x_L - t_L))}{1+\exp(\lambda(\theta_L x_L - t_L))} + \frac{(1-\mu)}{1+\exp(\lambda(\theta_H(x_H - x_L) - (t_H - t_L))}.$$

In what follows I will neglect the last term in (31). Expression (31) should be maximized with respect to x_L, x_H, t_L, t_H. Let us now introduce parameters y and z by:

$$(33)\quad \begin{cases} t_L = \theta_L x_L - \frac{y}{\lambda} \\ t_H = \theta_L x_L + \theta_H(x_H - x_L) - \frac{y+z}{\lambda} \end{cases},$$

i.e. y is proportional to the slack in the individual rationality constraint for the low type and z is proportional to the incentive compatibility constraint for the high type. Then the monopolist's profits can be written as:

$$(34)\quad \begin{array}{c} (\frac{\mu}{1+\exp(-y)} + \frac{1-\mu}{1+\exp(z)})(\theta_L x_L - c(x_L) - \frac{y}{\lambda}) + \\ \frac{(1-\mu)(\theta_L x_L + \theta_H(x_H - x_L) - c(x_H) - \frac{y+z}{\lambda})}{1+\exp(-z)} \end{array}$$

The first order conditions are with respect to x_L and x_H are:

$$
(35) \qquad \begin{cases} c'(x_H) = \theta_H \\ c'(x_L) = \theta_L - \frac{(1-\mu)(1+\exp(-y))(1+\exp(z-y))(\theta_H-\theta_L)}{(1+\exp(y-z))(\mu(1+\exp(z-y)+(1-\mu)\exp(-y))} \end{cases} .
$$

The first order conditions with respect to y and z imply:

$$
(36) \qquad \begin{cases} y = \ln(\lambda\pi_L) + \ln\frac{\mu}{2-\mu} + O(\frac{1}{\lambda}) \\ z = \ln(\lambda\pi_L)) + O(\frac{1}{\lambda}) \\ c'(x_L) = \theta_L - \frac{1-\mu}{\mu}(\theta_H - \theta_L) + O(\frac{1}{\lambda}) \end{cases} ,
$$

i.e. in the main approximation with respect to λ the monopolist offers the same qualities, she would have offered to the rational consumers, but adjusts the tariffs. To sum up, using the optimal two contract menu the monopolist earns lower profits against nearly rational consumers than she would have earned against the fully rational ones and the magnitude of the loss is $O(\ln\lambda/\lambda)$. Can the monopolist improve her profits by using more elaborate mechanism? I argue that the answer is yes, if there are no complexity costs. In particular, in this case it is possible to achieve profits, which are exponentially close to the profits under the assumption of full rationality.

Let us consider the following message game: the set of possible messages is $M = M_0 \cup M_L \cup M_H$ with $\#M_0 = 1$, $\#M_L = m_L$, $\#M_H = m_H$[8], if the consumer sends message $s_i \in M_i$ ($i \in \{0, L, H\}$) she commits to the contract (x_i, t_i^R), where (x_0, t_0) is interpreted as the outside option. The probability that the low type consumer will buy option (x_L, t_L^R) is equal to the probability that her message $s_L \in M_L$ and is given by:

$$\Pr(s_L \in M_L) = \frac{m_L}{1 + m_L + m_H \exp(-\lambda \Delta_{IC})}. \tag{37}$$

Similarly,

$$\Pr(s_H \in M_H) = \frac{m_H}{m_L + m_H + \exp(-\lambda I_{12})}. \tag{38}$$

It is clear that by choosing m_L and m_H sufficiently large both probabilities can be made exponentially close to one.

Note that though the message game described above allows the monopolist to achieve profits exponentially close the profits she would have earned against rational consumers, it does it at the cost of expanding the cardinality

[8] $\#M$ stands for cardinality of set M.

of the strategy set of a consumer. Assuming that the consumer experiences complexity costs, which are increasing in cardinality of the strategy set, would restrict values of m_L and m_H. Alternatively, one may assume that the monopolist will experience menu costs. The last approach was taken in Basov and Danilkina (2006) to explain flavor proliferation with quality. Basov, Danilkina, and Prentice (2008) apply this model to explain some empirical regularities of the Australian car market.

5. Conclusions

This paper discusses the problem of mechanism design with boundedly rational consumers. Since the Revelation Principle does not hold under bounded rationality, the choice of a class of mechanisms is with a loss of generality. In this paper I illustrated this by an example. Though the general form of optimal mechanism under bounded rationality is not known I would like to conclude by formulating the following hypothesis:

Assume that the set of types is finite and has cardinality n. Consider an arbitrary message game fix a QRE of this game. Them for any $\varepsilon > 0$ there another message game, such that M is finite,

$$M = \bigcup_{i=1}^{k(n)} M_i, \tag{39}$$

any two messages in M_i are treated as equivalent by the designer, and the new game has a QRE in which each player gets payoffs with ε of the original QRE. Moreover, $k(n)$ is increasing in n.

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