

Towards an Efficient Mechanism for Prescription Drug Procurement

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Abstract

This paper applies ideas from mechanism design to the procurement of prescription drugs. We present a government-funded market-driven drug procurement mechanism that achieves very close to full static efficiency – all members have access to all but at most a single drug – without distorting incentives for innovation.

Prescription drugs are an essential component of modern healthcare. In the U.S. drug spending has skyrocketed in recent years – while in 1980 it amounted to \$12 billion, less than 5% of total health care expenditures, in 2004 that number has increased to \$188.5 billion, over 10% of total expenditures.¹ The Center for Medicare and Medicaid Services (CMS) currently projects drug spending to rise to \$446.2 billion in 2015, approximately 2.2% of projected U.S. GDP.² Those statistics suggest that efficiency improvements in the drug procurement process can lead to significant welfare gains.

Lessons learned from markets for typical healthcare services such as doctor consultations and hospital stays are largely not applicable to markets for prescription drugs. In contrast to healthcare services, prescription drugs are often supplied by patent-protected monopolists and feature marginal costs that are a very small fraction of price. In fact, prescription drugs bear a much stronger resemblance to information goods such as music and software.

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¹Source: CMS Data.

²Source: CMS Data and CBO Projections.

This paper offers a conceptual framework for efficient design of government-funded prescription drug procurement. For drugs that are zero marginal cost, the socially efficient (static) outcome is for all individuals who derive a positive expected marginal benefit from a drug to have access to that drug: in other words, static efficiency entails universal access.³ We describe a mechanism for government drug procurement that approaches efficiency without introducing additional distortions to incentives for innovation. We remain agnostic about what level of profits is too low, too high or just right – that is the topic of a separate, well-developed literature.⁴ We simply show that our mechanism leaves incentives for innovation unchanged from the status quo.

One might argue that some government price intervention will achieve our goals. It is true that in theory, a perfectly visionary government can set and purchase at exactly the correct prices on behalf of its citizens, thereby achieving efficient drug procurement. However, such an arrangement features two major drawbacks: (1) it lacks the power of the market to dynamically correct for inaccurate pricing and (2) it creates perverse incentives for drug manufacturers to manipulate prices via lobbying.

In the U.S. lawmakers consider the drawbacks of centralized price interventions serious enough to exceed their benefits. The Medicare Modernization Act of 2003, which has established a universal drug benefit for the elderly in the form of Medicare Part D, explicitly prohibits the government from negotiating drug prices. Michael Leavitt, the U.S. Secretary of Health and Human Services, has written that, “government should not be in the business of setting drug prices or controlling access to drugs. That is a first step toward the type of government-run health care that the American people have always rejected.” He describes government price-setting as a situation in which “one government official would set more than 4,400 prices for different drugs, making decisions that would be better made by millions of individual consumers.”⁵ At least in the U.S., the most politically feasible way of achieving efficiency seems to be through a market-driven procurement mechanism that avoids regulated prices entirely.

³We recognize that consumption of drugs might impose externalities. For example, the use of antibiotics may create resistance to bacteria or the use of prophylactic drugs may stop an epidemic. For the purposes of this paper, we assume externalities are negligible.

⁴For example, see Boldrin and Levine (2006), Garber, Jones and Romer (2006), Hopenhayn, Llobet and Mitchell (2006), and Scotchmer (1999).

⁵Source: Opinion editorial, *Washington Post*, January 11, 2007.

The main difficulty in designing a market-driven mechanism is that monopolists must be free to set prices. However, any monopolist that faces a downward-sloping demand curve (and that cannot perfectly price discriminate) will set price far above marginal cost. Such pricing restricts access and generates large deadweight losses.

Even when the purchase of drugs is subsidized in the form of traditional insurance, the same problem persists (Newhouse 2004). Intuitively, if the government subsidizes 50% of each drug purchase, prices will double and deadweight losses will remain.

How do we design a market-driven drug procurement mechanism that achieves efficiency without distorting incentives for innovation? The intuition is as follows. Recall that deadweight losses arise because the demand curve is downward-sloping, i.e. different consumers have different willingness to pay. If in fact all consumers were identical, then a monopolist would set price equal to the universal willingness to pay and serve the whole market. The key idea then is to “homogenize” demand.

Conditional on individuals having developed a disease, the essential source of demand heterogeneity arises from different tastes and wealth. We argue that this heterogeneity for prescription drugs takes a specific form. In particular, we assume that *the ratio between willingness to pay for any two drugs is constant across all consumers*.⁶ In other words, Bill Gates is willing to pay twice as much for Drug A as for Drug B if and only if all people are willing to pay twice as much for Drug A as for Drug B (even though Bill Gates might be willing to pay millions of dollars more in absolute value).

Our assumption about the special structure of the demand for drugs is theoretically grounded. In particular, the assumption is motivated by the literature on the value of life, which offers a theoretical and empirical framework for thinking about investments in safety (see Viscusi (1993) for a survey). The main idea is that if a fire detector and an air bag are equally likely to save a life, then all consumers are indifferent between the two devices. In our context, we argue that drugs or insurance for drugs can be viewed as particular cases of safety devices that “produce” life or, more accurately, health. Hence, heterogeneity in demand for drugs arises simply from heterogeneity in *willingness to pay for health*. This special structure is exactly what allows us to construct a market mechanism that “homogenizes” demand.

Main Result. *There exists a government-funded, market-driven drug procurement*

⁶Specifically, we mean the ratio is constant either (a) across all healthy consumers with the same probability of disease, or (b) across all consumers who have already developed the disease.

mechanism that gives all people access to all but at most a single drug, without introducing additional distortions to innovation. Despite monopoly pricing power, near-static efficiency can be achieved.

The timing and structure of the procurement mechanism are as follows:

1. The government sets a per-person subsidy B .
2. Via an auction mechanism, pharmaceutical companies submit bids specifying minimum acceptable fees.
3. Prescription drug plans (PDP's) assemble formularies based on bids and budget constraint B . (Any unspent budget disappears.)
4. Consumers choose PDP's based on formularies in a perfectly competitive market.⁷

The structure of the proposed mechanism conveniently resembles Medicare Part D. The main differences are that our mechanism (1) fixes the budget B on a per-person basis and (2) introduces an auction to structure the price negotiation process.

Fixing the budget serves to homogenize demand: each person now has the same budget to be spent on her behalf, and thus the willingness to pay for a given drug becomes uniform across all people.⁸ Furthermore, fixing the budget forces drug companies to “compete” with one another to get on the formulary; as a result, a monopolist can only charge as much as the relative social value of his product warrants, and we avoid upward pressures on drug prices. Finally, a third effect of fixing the budget is that PDP's compete only on formulary composition, which allows consumers to make comparisons more easily.

In this paper, we present a mechanism in which the unique pure-strategy equilibrium implements full access to all but at most one drug while rewarding drug companies at least as much as they would earn as profit-maximizing monopolists.⁹

⁷Consumers have access to drugs on the PDP's formulary at marginal cost, which we assume to be zero.

⁸This is a consequence of consumers having the same relative valuations for all drugs.

⁹When we make claims about efficiency and near elimination of deadweight losses, we assume that money to fund the benefit is raised without creating additional distortions. Of course, taxation is distortionary, but that distortion remains the same for any government-funded drug benefit of a given cost. Furthermore, given that our mechanism reduces the upward pressures on drug prices created by existing government subsidy schemes, we are inclined to believe that the cost to a government of our proposed drug benefit will not be greater than the cost of an existing drug benefit. See McAdams and Schwarz (2007) for a summary of the perverse incentives featured in the current form of Medicare Part D in the U.S.

In this environment, auction design has efficiency implications. For instance, if all pharmaceutical companies submit bids simultaneously in a sealed-bid format, pure strategy equilibria generically do not exist. Also, if bids are solicited via a descending clock auction, we achieve a more efficient outcome than would be obtained by an ascending clock auction.

Our mechanism is not the first to show that efficiency is attainable in the presence of a monopoly. Kremer has proposed a patent buyout mechanism to achieve efficiency (Kremer 1998). Buying out patents hinges on the notion of a two-part tariff.¹⁰ By transferring lump sums of the appropriate size to inventors (would-be monopolists) in exchange for patents, the government attains static efficiency because the invention can then be made available at marginal cost.

The key difficulty with implementing such a system lies in determining the size of the lump sum. Kremer's proposed mechanism extracts the relevant information from a market of private parties, giving them weak incentives to reveal this information truthfully at the cost of introducing a small inefficiency. He points out that the main problem with his mechanism is that it is susceptible to manipulation. Not only is there the possibility of collusion, but also the expected joint payoff to a patent holder and third parties whom he controls can be arbitrarily large. In the context of pharmaceutical drugs, to which an efficient patent buyout mechanism would be very valuable, manipulation is a serious concern since there are only relatively few pharmaceutical companies and they would be regular repeated participants in patent buyout auctions.

While buying out patents relies on the notion of a two-part tariff, our mechanism does not – in fact, it can be implemented using either linear pricing or two-part pricing. Instead, our mechanism relies on a fundamentally different idea, *homogenizing demand*, which can be leveraged in drug procurement due to the unique demand structure for drugs.

We emphasize that this paper is intended primarily as a thought exercise rather than a specific policy proposal. We ask a relevant question – whether efficiency is attainable in the presence of monopolists without two-part pricing – and then use a highly stylized model to establish a benchmark answer in the affirmative. Our main objective is to apply economic theory to influence the fundamental ways in which

¹⁰Lakdawalla and Sood (2006) also focus on two-part tariffs; in particular, they describe how the two-part design of health insurance contracts combats the inefficiency that results from healthcare providers having market power.

researchers and policymakers think about prescription drugs.

The paper is organized as follows. Section 1 presents a simple example to illustrate the main idea of our mechanism. In Section 2, we introduce a highly stylized model for consumers and drugs, as well as a detailed description of the proposed mechanism. Section 3 presents the base case setup in which there are no substitutes and risk adjustment is perfect. We specify the auction format and prove our main result that the unique pure-strategy equilibrium of that auction implements a near efficient outcome. We then discuss the implications of our mechanism on incentives for innovation of new drugs, and briefly describe an alternative risk adjustment scheme that relaxes the assumption of perfect risk adjustment. Section 4 amends the basic model to include imperfect substitutes and extends the near-efficiency result to that case. Incentives for innovation of substitutes (including “me-too” drugs) are analyzed. Section 5 concludes.

1 A Simple Example

Consider a world in which there are 101 drugs,¹¹ each of which treats a unique disease and is protected by a patent owned by a unique drug company. Given onset of the associated disease, each drug provides the same unit increase in “health” (e.g. quality-adjusted life years (QALYs)).

Suppose there is a unit mass of patients. All are healthy and develop each disease independently with identical probability 0.01. However, patients do not have the same value for drugs due to differences in preferences and in wealth. We summarize those differences as each patient being willing to pay a different amount per QALY. Conditional on patients having developed the disease, we assume that this willingness to pay is uniformly distributed between 0 and 100. Conditional on patients being healthy then, the willingness to pay for insurance of one drug is uniformly distributed between 0 and 1.¹² We assume that a market for actuarially fair insurance exists.

Each pharmaceutical company faces a linear, downward-sloping demand curve. If the company sells as a monopolist, it sets price at the profit-maximizing level of 50 so that actuarially fair insurance costs 0.5 per drug and half of the population,

¹¹Not Dalmatians.

¹²This assumes that patients are risk-neutral towards the risk of disease, which is a good approximation when the risk is small.

i.e. those with willingness to pay above 0.5, purchases insurance. Expected profits to each monopolist are 0.25, and the total amount spent by patients is $25 \times 101 = 25.25$. In such a market, half the population is excluded from all drugs. Even if the government subsidizes the purchase of drugs by covering half their costs, prices will double in response and half of the population will continue to be excluded.

Consider an alternative mechanism of government procurement. The government commits to a maximum budget of 25 for purchasing actuarially fair insurance for all patients and requires each drug company to specify the price at which it is willing to sell its drug. Even though the market price is 50, each company is willing to bid 25 because that implies an expected profit of 0.25, the same profit the company obtains from ignoring the government mechanism and selling on the open market.

In equilibrium, all companies must bid the same price because otherwise lower-bidding companies can shade upwards and just undercut higher-bidding companies. As a result, the only pure-strategy equilibrium involves all drug companies bidding exactly 25. Actuarially fair insurance for each drug then costs 0.25, and the government chooses 100 of the drugs (randomly chosen from the 101) for inclusion on the formulary.

With this alternative mechanism, the entire population has access to all but one drug, i.e. we achieve over 99% efficiency. Furthermore, the total amount spent is 25.25, the sum of 25 from government coverage of 100 drugs on the formulary and 0.25 from the open market purchase of the single drug left off the formulary.

Even though the total spending for drugs remains the same as under the monopoly regime, the share of the population with access to all drugs (almost) doubles.

Remark: Note that we describe the government as purchasing actuarially fair insurance in order to guarantee that the government always spends exactly its budget (rather than only spending exactly its budget in expectation). We could easily ignore insurance and think of the government purchasing drugs directly from drug companies, therefore *in expectation* spending exactly its budget. This does not change the efficiency result (assuming the government is risk-neutral).

In this example, we have implicitly used a simultaneous-move or sealed-bid auction to solicit bids. In more general settings, however, when not every drug is identical and the budget size is flexible, the information structure of the auction becomes important. It turns out that the sealed-bid auction cannot generically guarantee

the existence of a pure-strategy equilibrium. Even among dynamic auctions, the specific format is important, and we will show that in the presence of heterogeneity in drugs, the descending clock auction always leads to a strictly better outcome than the ascending clock auction.

2 Setup

There is a finite number N of diseases $n \in \{1, 2, \dots, N\}$. Each disease is treated by a unique drug, and each drug is sold by a unique drug company (which we assume to be risk-neutral).¹³ Later we introduce substitutes. Drugs are produced at zero marginal cost.

We index consumers by $a \in [0, 1]$. For each disease n , let $\theta_n^a \in (0, 1]$ be the probability that individual a contracts disease n . Let v_n be the ex-post *effectiveness* of drug n . We can think of v_n as the increase in future life quality that the drug provides to an individual who has developed the disease. Define also $z_n^a = \theta_n^a v_n$ as the *expected benefit* of drug n to individual a . To avoid degenerate cases, we assume that for all $i \neq j$, $v_i \neq v_j$.

A consumer's willingness to pay for a drug is related to its ability to increase the quality of her future life-years, i.e. v_n . Let u^a be individual a 's willingness to pay per increased unit of future life quality. We assume u^a is a constant. This implies that a consumer's willingness to pay for drug n , conditional on having developed disease n , is $u^a v_n$. We assume that u^a is distributed in the population according to some probability distribution $\rho(\cdot)$ (with cumulative distribution function $P(\cdot)$). Furthermore, we assume that for a given individual a and any drug n , the values u^a and θ_n^a are statistically independent.

Finally, we present an overview of our proposed mechanism. While we focus on publicly-funded mechanisms, implementation is private – prescription drug plans (PDP's) receive government subsidies but must compete to attract members. The government gives each PDP a *fixed* per-member subsidy B to use in assembling formularies.¹⁴ A PDP serves as an intermediary between its members and pharmaceutical companies, assembling a formulary of drugs to which members have access

¹³In reality, each drug company owns several drugs. In this case, we can rephrase our analysis in terms of each company's portfolio of drugs rather than single drugs, and all the results would remain the same.

¹⁴To accommodate different probabilities of disease, the budget will be risk-adjusted, which we describe later.

for marginal cost (which we assume to be zero).¹⁵ If a member wishes to buy a drug not on her PDP’s formulary, she has the option to purchase the drug on the open market at market prices. We assume that PDP’s are risk neutral.

Prices are set via an auction mechanism. In that auction each pharmaceutical company submits a bid b_n , indicating the minimum price the company is willing to accept for its drug. This creates a vector of bids $b = (b_1, b_2, \dots, b_N)$. Given the fixed budget constraint B and the bid vector b , each PDP assembles a formulary. Any excess budget disappears. Since PDP’s are competing for membership, they act to maximize social welfare.

A formulary consists of a set of drugs that the PDP covers. We allow PDP’s to offer partial coverage. Having a partially covered drug on the formulary means that the drug is covered for a randomly selected fraction of the PDP’s members.¹⁶ In particular, if the remaining budget is ϵ and the next drug the PDP wants to cover has bid $\hat{b} > \epsilon$, then that drug will be covered for a fraction $\frac{\epsilon}{\hat{b}}$ of members.

The strategic component of the mechanism lies in the first step of bid submission by drug companies, which in turn determines formulary composition of PDP’s. In the next section we describe an auction format for collecting bids and show that the unique pure-strategy equilibrium implements a near-efficient outcome in which all but at most one drug is on the formulary.

3 Base Case

We prove our main result under two assumptions, which we later relax: (1) there are no substitutes, so each drug company has a monopoly,¹⁷ and (2) risk adjustment is perfect. With perfect risk adjustment, after the auction is run and the formularies are assembled, the government can perfectly adjust each member’s budget B to reflect his true risk. As a result, we can conduct our analysis by simply considering a “benchmark” individual with average probability of disease θ_n .

We consider two auction formats for soliciting bids:

- *Ascending Clock Auction.* The clock begins at $b = 0$ and increases continu-

¹⁵Note that instead of PDP’s, it would be analytically identical to assume consumers assemble their own “à la carte” formularies.

¹⁶This assumption is included primarily to avoid integer programming issues, which we believe distract from the core ideas.

¹⁷One might argue that true monopolies are rare, but this is the case in which efficiency concerns are the largest.

ously. Each drug company n chooses a level at which to leave the auction, and that becomes its bid b_n . There is no re-entry permitted. Once one bidder observes a dropout at b , he can drop out only at a level strictly higher than b .

- *Descending Clock Auction.* The clock begins at $b = B$ and decreases continuously. Each drug company n chooses a level at which to leave the auction, and that becomes its bid b_n . There is no re-entry permitted. Once one bidder observes a dropout at b , he can drop out only at a level strictly lower than b .

3.1 Reserve Fee: Monopoly Outside Option

Consider a benchmark case in which there is no government interference and each company acts as a monopolist, selling its drug on the open market. This benchmark case defines the value of a company's outside option in our mechanism. Specifically, define a drug company's *reserve fee* as the expected per-person profit the company receives as a monopolist.

Denote the profit-maximizing monopoly price by p^* . We assume that there exists a market for actuarially fair insurance (with perfect risk adjustment). Since an individual is willing to pay $u_a z_n^a$ for insurance coverage of drug n , demand for drug n at price p is the mass of consumers for whom $u_a z_n^a$ exceeds $\theta_n^a p$, i.e. $u_a v_n \geq p$. Since θ_n^a and u_a are statistically independent, we can write (expected) conditional demand in terms of $\theta_n = E[\theta_n^a]$, i.e. as $D(p) = \theta_n \int_{p/v_n}^{\infty} dP(u^a)$. That represents the expected fraction of the population who is willing to buy insurance coverage for drug n . So p^* solves the following profit maximization problem:

$$\max_{p_n} p_n \theta_n \int_{p_n/v_n}^{\infty} dP(u^a)$$

Notice that demand depends only on the ratio between price p_n and effectiveness v_n , and therefore each drug company maximizes its profits by serving the same proportion of the population, i.e. choosing the same ratio of price p_n to effectiveness v_n .

Lemma 1. (Schwarz 2006) *As a monopolist, each drug company maximizes profits by setting its price to serve a constant proportion of the population that is independent of its drug's effectiveness. Furthermore, the monopoly expected profit of a drug company is linear in its drug's expected benefit to the average-risk individual, i.e. $z_n = E[\theta_n^a] v_n = \theta_n v_n$.*

Lemma 1 tells us that the reserve fee of any drug company is conveniently linear in the expected benefit of its drug.

Lemma 2. *Let r_n denote the reserve fee of drug company n . Then $r_n = Kz_n$ where $K > 0$ is a constant.*

Thus, r_n is the minimum expected per-person profit that a drug company requires in the auction.

3.2 Per-Person Pricing

We clarify the pricing formats we are considering for bids. We have in mind two types of prices. The first is a conventional linear price: drug companies specify the price to charge individuals *after* they have contracted a disease. For each drug n that is on the formulary, in expectation PDP's would pay that linear price for the fraction θ_n of members who are expected to contract disease n . The second is a per-person price: drug companies specify a price to charge individuals *before* they contract the disease. Collecting a per-person price for an individual obligates the drug company to provide the drug for free in the event the disease is contracted. For each drug n that is on the formulary, PDP's would pay this per-person price for all members.

In our analysis, we focus on per-person pricing. Such pricing allows for better risk sharing than linear pricing. Because drugs are zero marginal cost, from a social perspective, the financial risk of an individual developing a condition that requires a drug is zero. Paying linear prices in the event that an individual contracts a disease introduces unnecessary risk into the system. Furthermore, per-person pricing eliminates adverse selection and hence obviates features such as government reinsurance, which features prominently in the current form of Medicare Part D.

An important point to emphasize is that even though we focus on per-person pricing, which is related to two-part tariffs (the idea upon which buying out patents hinges), our mechanism *does not rely* on per-person pricing. The essential results of the paper continue to hold under linear pricing. For instance, the simple example in Section 1 achieves over 99% efficiency using linear pricing.

3.3 Equilibrium Analysis

We now characterize equilibria in the proposed auctions. Define a bid b_n as the per-person price a drug company indicates it is willing to accept. We define the

“efficacy factor” of drug company n bidding b_n as $e_n = \frac{b_n}{r_n}$. Thinking of bids in terms of efficacy factors is useful because, given that PDP’s assemble formularies to maximize social value, a PDP will never include a drug with some efficacy factor without also including all drugs with lower efficacy factors.

We have proposed two dynamic auction formats to solicit bids: the ascending clock auction and the descending clock auction.¹⁸ Considering both allows us to emphasize the importance of implementation details. Since we are interested in including as many drugs as possible on the formulary, we focus attention on budgets that are “sufficiently” large. Otherwise, if for example the budget is less than the sum of all drugs’ reserve fees, there will be no hope of satisfying all participation constraints and achieving efficiency. The following two propositions are proved in the Appendix.

Proposition 1. (Ascending Clock Auction) *Let $B \geq \sum_{n=1}^N r_n$. In the unique subgame perfect pure strategy equilibrium of the ascending clock auction, all drugs but one, the last drug to have a bid submitted, get on the formulary.*

So in the ascending clock auction, the highest-value drug, or the drug with the highest expected benefit z_n , is always left off the formulary. The intuition is that in the ascending clock auction, the last bidder to bid, i.e. the highest-value drug, can bid arbitrarily high (∞) so that he collects not only the excess budget but also monopoly profits from the open market (since he is covered on no formularies). Other bidders cannot act to lower the payoffs of this highest-value bidder, because in any other setting he has the last-mover advantage – he can just undercut previous bids and force another bidder off the formulary.

Proposition 2. (Descending Clock Auction) *Let $B \geq \sum_{n=1}^N r_n$. In the unique subgame perfect pure strategy equilibrium of the descending clock auction, all drugs but a fraction of one drug get on the formulary.*

The intuition is similar to the ascending clock auction. The main difference is that now no bidder can deviate to an arbitrarily high bid and therefore any drug that gets a piece of the budget gets positive partial coverage. Hence, only a fraction of one drug remains uncovered. A given bidder’s maximum bid is bounded from above because lower value bidders bid later. No bidder submits a higher bid than what a

¹⁸The choice of auction format is an important one. In fact, if a sealed-bid simultaneous-move auction is used, a pure strategy equilibrium does not exist.

bidder with a higher value has submitted. We find that it is not necessarily the last bidder to bid that is left off the formulary; instead, there may be another bidder that chooses to be partially covered.

As a corollary, we discover that the descending clock auction always performs better (i.e. leads to a higher social value formulary) than the ascending clock auction.

Proposition 3. (Comparison) *Let $B \geq \sum_{n=1}^N r_n$. The formulary obtained in the unique pure-strategy equilibrium of the descending clock auction has a social value strictly greater than that of the ascending clock auction.*

Proof. This is a straightforward corollary of Propositions 1 and 2. In the ascending auction, Proposition 1 tells us that the value of the formulary is $\sum_{n=1}^N z_n - \max_n z_n$. In the descending auction, Proposition 2 tells us that the value of the formulary is strictly greater than $\sum_{n=1}^N z_n - \max_n z_n$. \square

From this point forward, we assume that our procurement mechanism implements the *ascending clock auction with per-person pricing*. We do so because the unique equilibrium of the ascending clock auction is more straightforward in structure than that of the descending clock auction, and hence extensions are easier to discuss. Nonetheless, the qualitative nature of the results still hold if we consider the descending clock auction.

3.4 Incentives for Innovation

Determining what level of profits correspond to “optimal” incentives for innovation is outside the scope of this paper, and we remain agnostic about what profit levels are optimal. However, we can show that our mechanism (1) implements any level of profits between monopoly profits and full social surplus and (2) implements such profits proportionally across all drugs that appear on the formulary (i.e. any excess budget is distributed evenly).

In equilibrium, our mechanism induces all drug companies (but one) to submit bids equal to some constant – the common “efficacy factor” e^* – multiplied by the company’s reserve fee. As we increase the size of the budget, this common efficacy factor increases proportionally.

For example, suppose we want to reward monopolists with their full social surplus. The total social surplus of drug n is given by $z_n \int_0^\infty u^a dP(u^a)$. Meanwhile, a drug that is on the formulary with an efficacy factor of e^* receives profits

$e^*r_n = e^*Kz_n$ (where K is a constant). Choosing a large enough budget so that the equilibrium strategy is for all drug companies (but one) to bid with efficacy factor $e^* = \frac{1}{K} \int_0^\infty u^a dP(u^a)$ leads to all drug companies fully covered on the formulary to be rewarded full social surplus.¹⁹

Proposition 4. *In our mechanism, for any fixed level of profits between monopoly profits and full social surplus, there exists a budget \hat{B} such that in the unique pure-strategy equilibrium all drug companies but one receive that level of profits.*

Therefore, we can think of the budget size B as a tool for calibrating the strength of incentives for innovation.

3.5 Note on Risk Adjustment

In our mechanism, perfect risk adjustment allows us to ignore pre-existing conditions because the per-person budgets and prices can be risk-adjusted to compensate exactly for individuals' different probabilities of disease.

We can relax the perfect risk adjustment assumption, however, by leveraging an alternative, less informationally demanding risk adjustment scheme enabled by per-person pricing. While traditional risk adjustment requires individual-specific health information, the alternative scheme requires only aggregate disease prevalence information. In a companion paper, we describe in detail how such a risk adjustment scheme might work (Fong & Schwarz 2007).

As a preview, consider what happens in our mechanism if there is no risk adjustment and some individuals have pre-existing conditions. Let drug A have expected benefit 100 to individuals with disease n and expected benefit 1 to individuals without disease n . The latter group of healthy individuals will only select a formulary that includes drug A when its price corresponds to a drug of expected benefit 1. However, a drug company will not be content with a price corresponding to an expected benefit of 1, since the company knows that there are individuals in the population whose expected benefit is far greater than 1. A risk adjustment scheme is necessary to reconcile these opposing interests.

One solution, the alternative scheme we suggest, is to introduce side payments from the government to pharmaceutical companies that are proportional to the

¹⁹If we want to reward monopolists a level arbitrarily close to monopoly profits, notice that we need $e^* \rightarrow 1$. Doing so requires B to be arbitrarily close to $\sum_{n=1}^N r_n - \max_n r_n$. Although that is not indicated as a feasible budget in the statement of Proposition 1, we do show that it is a feasible budget in the proof of Proposition 1 (found in the Appendix).

prevalence of the specific disease. Those side payments are constructed such that the drug company in the above example would accept a price corresponding to a drug of expected benefit 1. See Fong & Schwarz (2007) for more details.

4 Case with Imperfect Substitutes

So far we have focused on monopolists – their optimal bids under our mechanism and the incentives to create new monopoly drugs. But what about substitutes? First, how will a drug company whose drug has a close substitute bid in the auction? Secondly, what are the incentives to introduce superior or inferior substitutes?

We find that the bidding strategy for drugs with imperfect substitutes is a straightforward carryover from the bidding strategy for monopoly drugs. In particular, the optimal bid for an imperfect substitute is proportional to its marginal social benefit (i.e. additional benefit given the existence of the substitute). Regarding incentives for innovation, our mechanism in fact improves the incentives for introducing substitutes relative to a baseline of Bertrand competition.

To model imperfect substitutes, we use a specific model in which one drug is more effective than the other. In particular, let drug X and drug Y be substitutes, so they treat the same disease. Drug X offers effectiveness Γv where $\Gamma > 1$, while drug Y offers effectiveness v . Thus, given a choice between drug X at price p_X , and drug Y at price p_Y , a sick individual chooses drug X if and only if $\Gamma v u_a - p_X \geq v u_a - p_Y$, i.e. $(\Gamma - 1)v \geq p_X - p_Y$.

4.1 Reserve Fee: Bertrand Competition as Outside Option

As before, a drug company’s outside option influences its behavior. Because the drugs are substitutes, the outside option of one company depends on whether the substitute from the other company is on or off the formulary. In the event that both drugs are sold on the open market, we model the benchmark case as Bertrand competition.

Suppose drug X is on the formulary and thus available to consumers for marginal cost of zero. Then drug Y ’s off-formulary option gives a payoff of 0. Even if drug company Y sets its price at zero, no one will purchase its drug. So when drug X is on the formulary, drug Y ’s best response is to bid 0 and be included on the formulary.

Suppose now that drug Y is on the formulary. The off-formulary option for drug X is to be sold on the open market, where its expected marginal effectiveness, given drug Y 's availability for free on the formulary, is $(\Gamma - 1)v$. The demand structure for drug X looks identical to a monopoly drug whose effectiveness is $(\Gamma - 1)v$; thus the outside option payoff of drug X is $K(\Gamma - 1)z = K(\Gamma - 1)\theta v$.

Finally, consider when both drugs are off the formulary. We use Bertrand competition to model this scenario. What prices p_X and p_Y will be charged? For simplicity, normalize $v = 1$ so drug X has effectiveness Γ and drug Y has effectiveness 1. Any sick consumer for whom $\Gamma u_a - p_X \geq u_a - p_Y$, i.e. $u_a \geq \frac{p_X - p_Y}{\Gamma - 1}$, will choose drug X . Let $t_{X,Y} = \frac{p_X - p_Y}{\Gamma - 1}$. Similarly, any consumer who doesn't choose drug X and for whom $u_a - p_Y > 0$ will choose drug Y . Finally, a consumer for whom $u_a < p_Y$ is excluded from both drugs.

Solving the profit maximization problem, we can write the respective monopoly profits for companies X and Y as the following:

$$\begin{aligned}\pi_X &= \theta p_X \int_{t_{X,Y}}^{\infty} dP(u_a) \\ \pi_Y &= \theta p_Y \int_{p_X}^{t_{X,Y}} dP(u_a)\end{aligned}$$

where prices p_X and p_Y are derived from the following equations:

$$\begin{aligned}p_X &= (\Gamma - 1) \frac{(1 - P(t_{X,Y}))}{\rho(t_{X,Y})} \\ p_Y &= (\Gamma - 1) \frac{(P(t_{X,Y}) - P(p_Y))}{\rho(t_{X,Y}) + (\Gamma - 1)\rho(p_Y)}\end{aligned}$$

Notice that if $\Gamma = 1$ and the drugs are perfect substitutes, then we get the Bertrand duopoly outcome of both companies charging $p_X = p_Y = 0$.

Simple Example, Revisited. To see a concrete example of Bertrand competition pricing, let's return to our example with uniformly distributed consumer preferences (i.e. $\rho(u_a) = 1$ for $u_a \in [0, 1]$). Solving the two price equations simultaneously, we obtain prices

$$(p_X, p_Y) = \left(\frac{2\Gamma(\Gamma - 1)}{4\Gamma - 1}, \frac{\Gamma - 1}{4\Gamma - 1} \right),$$

which correspond to

$$t_{X,Y} = \frac{2\Gamma - 1}{4\Gamma - 1}.$$

So all consumers for whom $u_a \geq \frac{2\Gamma-1}{4\Gamma-1}$ choose drug X , all for whom $\frac{2\Gamma-1}{4\Gamma-1} > u_a \geq \frac{\Gamma-1}{4\Gamma-1}$ choose drug Y , and finally all for whom $u_a < \frac{\Gamma-1}{4\Gamma-1}$ obtain no drug. Thus, if $\Gamma = 1$, everybody gets the drug, and as $\Gamma \rightarrow \infty$, 1/4 of people buy no drug, 1/4 of people buy drug Y and 1/2 of people buy drug X .

4.2 Equilibrium Analysis

In the case of substitutes, the logic of our base case equilibrium analysis extends in a straightforward fashion: the drug company facing an inferior substitute bids exactly the same as a monopolist whose drug has effectiveness $(\Gamma - 1)v$, and the drug company facing a superior substitute bids 0.

Consider the following summary table, where each entry represents the ordered pair of payoffs (for drugs X and Y respectively) that can be sustained when that outcome results:

payoffs	Y on	Y off
X on	$(e^*K\theta(\Gamma - 1)v, 0)$	$(e^*K\theta\Gamma v, 0)$
X off	$(K\theta(\Gamma - 1)v, e^*K\theta v)$	(π_X, π_Y)

Notice that it is not possible in equilibrium for one drug to be on the formulary while the other is off. In both cases, the company with the off-formulary drug can obtain at least as high a payoff by getting on the formulary. The only possibilities are that both drugs are on the formulary, or both drugs are off the formulary. Suppose both drugs are off the formulary. Then drug company X has an incentive to bid slightly higher than π_X and get on the formulary.²⁰ It is only when both drugs are on the formulary that neither company is able to deviate profitably.

Proposition 5. *In the presence of imperfect substitutes, given a sufficiently large budget, the near-efficiency result continues to hold: the unique subgame perfect pure-strategy equilibrium involves all but at most one drug being included on the formulary.*

²⁰It must be the case that $K\theta\Gamma v > \pi_X$ since $K\theta\Gamma v$ is the payoff to a monopoly drug with effectiveness Γv and π_X is the payoff to a drug with effectiveness Γv that has a substitute.

4.3 Incentives for Innovation

The level of incentives for innovation of substitutes is a topic of much debate – in recent years many have spoken out against drug companies’ wasteful “innovations” that add little or no value, i.e. “me-too” drugs. We now discuss the incentives for introducing substitutes for diseases with existing treatments, comparing the benchmark case of Bertrand competition with the case of our mechanism.

Consider first incentives to innovate under Bertrand competition. One striking observation is that there are incentives to introduce a “me-too” drug that is uniformly worse than an existing treatment. In other words, under Bertrand competition a company is rewarded for introducing an inferior drug.²¹

Under our mechanism, however, a drug company is rewarded the marginal social value of its drug, and if its drug is strictly inferior to an available on-formulary drug, then it receives no reward.

Proposition 6. *For all drugs fully covered on the formulary, introduction of inferior substitutes receives no reward under our mechanism.*

5 Conclusion

In this paper we have presented a highly stylized model for prescription drug procurement. The model enables us to focus on the key features of drugs and to create a novel conceptual framework for drug benefit design. We apply techniques from mechanism design to describe a new procurement mechanism that achieves near efficiency without introducing any additional distortions to incentives for innovation.

Beyond near-efficiency, our mechanism also has several other practical advantages. First, the notion of per-person pricing allows for better risk sharing and eliminates adverse selection in our model. If moral hazard were modeled, per-person pricing would reduce the need for complex utilization management. One major criticism of Medicare Part D in its current form is the complexity of the structure – the donut hole, coinsurance rates, out of pocket maximums, etc. Per-person pricing would make such features unnecessary.

Secondly, our mechanism introduces a tool, budget size, that can be used to calibrate incentives for innovation. Also, in the context of imperfect substitutes

²¹Interestingly, while a company *is* rewarded for introducing an inferior substitute under Bertrand competition, the company is *not* rewarded for introducing a substitute with identical health benefits as an existing drug (since Bertrand duopoly competition implies profits of zero).

that we consider, our procurement mechanism avoids rewarding the innovation of “me too” drugs.

Finally, we note that the setup of our mechanism is quite similar to the current form of Medicare Part D. Amending Part D in the direction of the ideas we emphasize may help avoid some of the issues and difficulties the drug benefit is expected to face.²² For one thing, fixing the budget helps relieve upward pressures on price and downward pressures on formulary quality. Furthermore, restricting competition to a single dimension of formulary composition makes PDP’s easier for beneficiaries to compare.

In this paper, we have applied principles of economic theory to pharmaceutical markets using a highly stylized model. Nonetheless, we believe that the core insights contribute a novel and worthwhile perspective to the discussion of drug benefit design.

A Appendix

A.1 Proofs of Proposition 1 and 2

In the following proofs, we label bidders in the order that they bid. So the first bidder to bid is bidder 1, the second bidder to bid is bidder 2, and so on so that the last bidder to bid is bidder N . It will turn out that in the ascending clock auction then, bidder N is the highest value bidder; meanwhile in the descending clock auction, it will turn out that bidder N is the lowest value bidder.

When we refer to bidders in terms of their values, we use parentheses. For example, the reserve value of the highest value drug is $r_{(1)}$ and the reserve value of the lowest value drug is $r_{(N)}$.

To be precise, a “sufficiently large budget” in Lemmas 3 and 4 corresponds to $B > \sum_{n=2}^N r_{(n)}$ in the ascending clock auction and $B > \sum_{n=1}^{N-1} r_{(n)}$ in the descending clock auction.

Lemma 3. *In a clock auction (ascending or descending) with a sufficiently large budget, there does not exist an equilibrium in which all bidders bid $e = 1$.*

Proof. Suppose all bidders are bidding $e = 1$. Consider the last bidder to bid. He has incentive to deviate and bid as high as possible, which allows him to collect both

²²See McAdams and Schwarz (2007).

the excess budget in addition to monopoly profits. In the ascending clock auction, the last bidder can deviate to ∞ and take excess budget $B - \sum_{n=1}^{N-1} r_n$, in addition to his monopoly profits. In the descending clock auction, the last bidder can deviate to the second last bidder's bid and take excess budget $B - \sum_{n=1}^{N-1} r_n$, in addition to a positive fraction of his monopoly profits. Thus all bidders bidding $e = 1$ is not an equilibrium. \square

Lemma 4. *In a clock auction (ascending or descending) with a sufficiently large budget, there does not exist a pure-strategy equilibrium in which some bidder receives none of the budget.*

Proof. Suppose there were such an equilibrium, and consider the last bidder to bid that receives none of the budget. It cannot be the very last to bid overall because then either (a) some on-formulary bidder has bid $e' > 1$ and the last bidder can bid just below e' and get on the formulary profitably (at an efficacy factor strictly greater than 1) or (b) all on-formulary bidders have bid $e = 1$ and the last bidder can then bid ∞ and take the excess budget.

This last bidder also cannot be the second last drug to bid overall because then either (a) some on-formulary bidder has bid $e' > 1$, and this last bidder can bid just below e' and get on the formulary profitably, or (b) all on-formulary bidders have bid $e = 1$ and this last bidder can bid ϵ above $e = 1$ and leave enough additional budget for the last drug to want to bid ∞ . Iterating this argument, we find that the last bidder to bid that receives none of the budget always has a profitable deviation: either to ϵ below the highest efficacy factor of previous on-formulary bidders if one of them has bid $e' > 1$, or otherwise to an efficacy factor of $1 + \epsilon'$ without affecting incentives of the remaining bidders. Therefore, all bidders receive some of the budget. \square

Lemma 5. *In any pure strategy equilibrium of a clock auction (ascending or descending), exactly one bidder gets less than full coverage.*

Proof. First we show that at most one bidder gets less than full coverage. Suppose there is an equilibrium in which at least two bidders are less than fully covered. Lemma 4 tells us that all such bidders must be receiving some of the budget, which implies that they are all bidding at the same efficacy factor e^* . Lemma 3 tells us that $e^* > 1$. Consider the bidding position - let's call it x - of the last bidder to bid

in that group. We show that $x \neq j$ for any $j = 1, 2, \dots, N$. Therefore, we can only have an equilibrium in which at most one bidder is partially covered.

We prove by induction. For each j , given that all bidders $n > j$ are fully covered, $x \neq j$. We use $j = N$ as the base case. We know that $x \neq N$ (where N denotes the N -th bidder to bid) because otherwise this last bidder can lower his bid by ϵ , just undercut the other partially covered bidders, and gain additional coverage. So in equilibrium bidder N cannot belong to a group of at least two bidders that are less than fully covered.

Now for the inductive step. Consider some $j = 1, \dots, N - 1$ and assume that all bidders $n > j$ are fully covered. We want to show that $x \neq j$ in any equilibrium. Suppose $x = j$ in some equilibrium. But then there must exist an $\epsilon > 0$ such that bidder j can lower his bid (efficacy factor) by ϵ and receive a higher payoff. By undercutting the other partially covered bidders, bidder j gains a higher payoff so long as the remaining bidders do not change their bids in such a way as to lower bidder j 's payoff. Choose ϵ to be sufficiently small that bidder j still bids at an efficacy factor higher than that of the fully covered drugs in the original equilibrium. Thus, bidders following j have the option to receive the same payoff as before by bidding the same amount as they would have bid originally if bidder j hadn't deviated. Because an environment in which some bidder (i.e. bidder j) bids slightly lower is more competitive, it cannot be that a bidding strategy for some bidder $n > j$ gives a higher payoff in this new environment than in the old environment. Therefore, an optimal bid if bidder j doesn't deviate, given that its payoff is unchanged by bidder j 's deviation, must remain an optimal bid after bidder j 's deviation. We conclude then that bidder j has a profitable deviation, so we cannot have an equilibrium in which $x = j$. Thus there cannot be an equilibrium in which at least two bidders are less than fully covered.

Now we show that at least one bidder gets less than full coverage. Suppose there is an equilibrium in which all bidders are fully covered. The last bidder can achieve a higher payoff by deviating and increasing his bid, thereby collecting the excess budget and either remaining fully covered or becoming partially covered and receiving extra payoff from the open market. \square

Lemma 6. *The unique pure strategy equilibrium of the ascending clock auction involves all bidders bidding at the same efficacy factor e^* except for the bidder with the highest benefit drug, who bids ∞ . That last bidder is left off the formulary while*

all the other bidders get on the formulary.

Proof. Suppose there exists a pure strategy equilibrium in which bidder 1 bids $e^* := \frac{B+r_{(1)}}{\sum_{n=1}^N r_n}$. We claim that in such an equilibrium all bidders bid the same efficacy factor except the last bidder. Suppose there exists a pure strategy equilibrium in which the first bidder not to bid the same efficacy factor e^* as all previous bidders is not the last bidder. Let that first bidder who bids efficacy factor $e \neq e^*$ be bidder j (where $1 < j < N$). We assume for now and later show that if bidder j bids e^* , he will get on the formulary for sure at e^* .

First, it must be that $e > e^*$, because if $e < e^*$, then bidder j has a profitable upward deviation to get on the formulary at a higher efficacy factor. We show that bidding $e > e^*$ is never preferred to bidding e^* and getting fully covered on the formulary.

Suppose bidding $e > e^*$ leads to bidder j not being fully covered. In order for $e > e^*$ to be a profitable strategy, its expected payoff must be at least as high as e^*r_j . We know that the remaining bidders will all bid at least e since they can now get on the formulary for sure by just undercutting bidder j .²³ The maximal excess budget bidder j can hope to receive is $B - e^* \sum_{n=1}^{j-1} r_n - e \sum_{n=j+1}^N r_n$. Therefore, an upper bound on bidder j 's payoff from deviating to e and being partially covered on the formulary is $r_j + B - e^*(\sum_{n=1}^N r_n - r_j)$. A necessary condition for the deviation being profitable is for that upper bound to be greater than e^*r_j :

$$e^*r_j \leq r_j + B - e^*\left(\sum_{n=1}^N r_n - r_j\right)$$

$$\implies e^* \leq \frac{B + r_j}{\sum_{n=1}^N r_n} \tag{A.1}$$

But this is a contradiction since we know that $r_{(1)} = \max_n r_n$. Therefore, bidder j cannot find it profitable to bid $e > e^*$. Notice that the above argument implies that, if bidder j bids above $e > e^*$, then he will not be fully covered because no remaining bidder will have incentives to bid above e and choose to be less than fully covered.

We conclude then that it must be the last bidder who receives partial coverage.

²³By undercutting a bidder, we mean the strategy of (a) bidding the same efficacy factor as that bidder if doing so leads to getting on the formulary, and (b) otherwise bidding ϵ below the efficacy factor of that bidder. For simplicity in discussion, when we refer to such undercutting, we will treat it as equivalent to bidding the same efficacy factor as the other bidder.

We know all previous bidders are bidding e^* . Conditional on choosing to be left off the formulary, bidder N 's optimal strategy is to bid ∞ . Notice that the condition for him to be willing to bid ∞ and be left off the formulary rather than bidding e^* is if

$$e^* \leq \frac{B + r_{(1)}}{\sum_{n=1}^N r_n},$$

which is exactly satisfied. Hence, conditional on bidder 1 bidding e^* , the unique pure strategy equilibrium of the continuation subgame is for all remaining bidders except the last bidder to bid also at e^* , and for the last bidder to bid ∞ . All bidders except bidder N are fully covered on the formulary. Note that this requires $B > \sum_{n=2}^N r_{(n)}$ to strictly satisfy participation constraints.

We have shown that bidder 1 is fully covered on the formulary with a bid of e^* . It follows that he will never choose to bid $e < e^*$. What happens if the first bidder bids $e > e^*$? In this case, by the same reasoning as above, no bidder – and in this case, not even the last bidder – will have incentives to bid higher and to be less than fully covered on the formulary. Therefore, the remaining bidders will just undercut the first bidder, and the first bidder will receive less than full coverage. In this case, bidder 1 must receive a strictly lower payoff than e^*r_1 . Why? Recall that the upper bound on bidder 1's payoff from being partially covered when the other bidders are bidding e is $r_1 + B - e(\sum_{n=1}^N -r_n)$. We know that when $e = e^*$, that upper bound is exactly equal to e^*r_1 . As we increase e , the upper bound on bidder 1's payoff from being partially covered decreases and thus becomes smaller than e^*r_1 . We conclude that bidder 1 does not want to bid $e > e^*$, and therefore in the unique pure strategy equilibrium bidder 1 bids e^* . \square

Lemma 7. *The unique pure strategy equilibrium of the descending clock auction involves all but one bidder being fully covered and one bidder being partially covered.*

Proof. We know from Lemma 5 that in any pure strategy equilibrium, exactly one bidder gets less than full coverage. First, we show that this bidder cannot be completely uncovered. One way a bidder can receive no coverage is by bidding ∞ . In the descending clock auction, no bidder bids ∞ in equilibrium because doing so requires that bidder to move first and effectively eliminates him from the auction completely. The only other way in which some bidder j can get no coverage is if he bids at a finite level and all the other drugs bid such that the budget is exactly depleted and bidder j has the highest efficacy factor. But in this case bidder j has a

profitable deviation to a lower efficacy factor near 1 that guarantees himself a spot on the formulary. Hence in any pure strategy equilibrium, exactly one bidder gets partial coverage.

We now claim that in any equilibrium, no later bidder bids strictly less than an earlier bidder (as mentioned in footnote 23, this excludes undercutting). This is obvious if the earlier bidder gets on the formulary in equilibrium because then the later bidder has incentives to undercut him and therefore get on the formulary as well. Suppose the earlier bidder does not get on the formulary. Then again the later bidder has an incentive to undercut him because in equilibrium exactly one bidder gets partial coverage.

Next, we claim that any equilibrium in which exactly one bidder, say bidder j where $j \in \{1, 2, \dots, N\}$, gets partial coverage takes the form of (a) bidders 1 through $j - 1$ bidding at some efficacy factor e_1 , (b) bidder j bidding at some higher efficacy factor $e_2 > e_1$, and (c) all remaining bidders $j + 1$ through N undercutting bidder j . To do so, we show that in any equilibrium, for any two bidders k and $k + 1$, if both bidders are getting on the formulary, then both bidders must be bidding at the same efficacy factor. Suppose not and that bidder k is bidding at a lower efficacy factor than bidder $k + 1$. Then bidder k has a profitable upward deviation, at least by ϵ , that keeps it still fully covered on the formulary. The only concern is if bidder $k + 1$ now revises his bid downward to undercut bidder k . Even if he does so, however, we know there is some other bidder j that, in the original equilibrium, is partially covered and bidding higher than what bidder $k + 1$ was originally bidding. That bidder j will still have incentives to be partially covered because either $j < k$ so he has already bid and the conclusion is trivial, or $j > k + 1$ and he faces a larger excess budget than before.

As a last step, we describe the identity of bidder j that is partially covered and the values e_1 and e_2 . Bidder 1 chooses e_1 . Given e_1 , bidder j is the bidder willing to bid at the highest $e_2 > e_1$ such that all remaining bidders want to undercut bidder j . In other words, he has the loosest incentive constraints of being partially covered by bidding some viable e_2 (high enough to deter other bidders from bidding higher than e_2) and being fully covered at e_1 . So if bidder j 's constraints are binding at some e_2 , then all other bidders' incentive constraints must bind as well.

There are three constraints for a bid $e_2 > e_1$ by bidder j to be viable. First, if all remaining bidders also bid e_2 (which must be true in equilibrium), then it must

be that the excess budget after accounting for fully covered drugs is positive:

$$B - e_1 \left(\sum_{n=1}^N r_n - r_j \right) > 0 \implies e_1 < \frac{B}{\sum_{n=1}^N r_n - r_j}$$

Secondly, the most that a bidder j can bid is the bid of the bidder before him, so it must also hold that

$$e_2 \leq e_1 \frac{r_{j-1}}{r_j}$$

where $r_{j-1} > r_j$.

Finally, the deviation to some $e_2 > e_1$ must be profitable. Let $B_j = B - e_1 \sum_{n=1}^{j-1} r_n - e_2 \sum_{n=j+1}^N r_n$. In particular, it must hold that for $e_1 \frac{r_{j-1}}{r_j} e_2 > e_1$,

$$e_1 r_j \leq B_j + \left(1 - \frac{B_j}{e_2 r_j}\right) r_j.$$

Note that bidder 1 will not choose e_1 to be so high that more than one bidder gets left off the formulary because that means that bidder 1 will be left off the formulary. Instead, he chooses the highest e_1 such that he will still be fully covered on the formulary *and* exactly one bidder has incentives to bid at a higher e_2 and be partially covered. Given e_1 , the identity j of the partially covered and his bid e_2 are chosen in the subgame so that, after bidder j has bid e_2 , no other bidder has an incentive to bid higher than e_2 and be partially covered instead. Continuity tells us that e_1 and e_2 exist and are unique. \square

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