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Towards an Efficient Mechanism for Prescription Drug Procurement

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Abstract

We consider the market for prescription drugs. The question of whether there exists a procurement mechanism that achieves both static efficiency (the elimination of deadweight loss) and dynamic efficiency (optimal incentives for innovation) has thus far remained unresolved. On the one hand, allowing pharmaceutical monopolists to set their own prices creates large deadweight losses and restricts access: monopolists set prices far above marginal costs (which are near zero). On the other hand, government price interventions distort incentives for innovation. In this paper, 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 – while maintaining optimal incentives for innovation. In addition, from a social perspective, the described mechanism eliminates perverse incentives towards development of close substitutes ("me-too" drugs) rather than new treatments. The key feature of the mechanism leverages the unique consumer demand structure of drugs.

1 Introduction

Prescription drugs are an essential component of modern health care. In the U.S. drug spending has skyrocketed in recent years – while in 1980 expenditures on medical drugs 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]

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[1]Source: CMS Data

CMS currently projects drug spending to rise to $446.2 billion in 2015, a substantial 2.2% of projected U.S. GDP.[2]

In most developed countries, the government provides drug coverage to its citizens. In 2006 U.S. lawmakers have implemented a universal drug benefit for the elderly in the form of Medicare Part D. With trillions of dollars at stake, drug procurement deserves careful consideration, and improving efficiency in the procurement process can lead to significant welfare gains.

Prescription drugs differ fundamentally from the typical medical good (e.g. doctor consultations, hospital stays, surgeries, etc.) For one thing, once developed, prescription drugs have essentially zero marginal costs (whereas the typical medical good has high marginal costs). Secondly, drug manufacturers are frequently legal monopolies protected by patents (while markets for the typical health care good almost always have some form of competition).[3]

In this paper we focus on achieving efficiency in drug procurement. Because drugs are near zero marginal cost, the socially efficient (static) outcome is for all individuals who gain a positive marginal benefit from a drug to have access to that drug.[4] Dynamic efficiency, which refers to incentives for innovation, is also important. In particular, to achieve optimal incentives for innovation according to textbook economic theory, monopolists must be compensated the full consumer surplus of their product.[5]

Achieving both static and dynamic efficiency in the pharmaceutical market has thus far proved an difficult task. On the one hand, allowing monopolists to set their own prices in a market-based system achieves a high level of dynamic efficiency, maintaining incentives for innovation. However, doing so sacrifices static efficiency. Any monopolist that faces a downward-sloping demand curve (without the ability to price discriminate perfectly) 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 remains. Intuitively, insurance induces an outward shift in the consumer demand curve. Since heterogeneity in demand (i.e. a downward

[2]Source: CMS Data and CBO Projections

[3]In fact, rather than other health care goods, drugs bear a much stronger resemblance to digital goods, electronic media, and other low-marginal cost goods. The results of this paper have implications in those markets as well.

[4]We assume negative externalities are negligible.

[5]One might argue that optimal incentives for innovation are in fact strictly less than full consumer surplus, but most would agree that optimal incentives are at least as large as monopoly profits.

slope) still exists, monopolists adjust their prices accordingly and large deadweight losses remain.

On the other hand, the government may intervene in the market through price setting or price controls. In these cases, although static efficiency may be improved, dynamic efficiency is likely to be sacrificed. For one thing, the informational demands on the government to unilaterally set "fair" prices are much too great. Also, centralized price interventions lack the power of the market to dynamically correct for inaccurate pricing; they also create incentives for drug manufacturers to manipulate prices via lobbying, bribery and other undesirable activities.

So the question remains: does there exist a drug procurement mechanism, other than price-setting by a perfectly visionary government, such that both static and dynamic social efficiency are achieved? In this paper, we provide an (essentially) affirmative answer to that question by describing a procurement mechanism that achieves very close to static efficiency while maintaining optimal incentives for innovation.

The intuition is as follows. First, we recognize that a market-driven feature must be preserved in order to maintain incentives for innovation. But then how can we avoid deadweight losses caused by monopoly pricing? Recall that deadweight losses arise because different consumers have different willingness to pay: if in fact all consumers were identical, then the monopolist would set price equal to the willingness to pay and serve the whole market. The key idea then is to "homogenize" demand.

To do so, we take advantage of a unique feature exhibited by drugs. Clearly, for two consumers, their willingness to pay for two different drugs may differ. For a given consumer, however, the willingness to pay for a drug is proportional to the marginal value of life that drug creates. Thus, the ratio between willingness to pay for any two drugs is the same across all consumers (ignore pre-existing conditions for now). This special demand structure makes it possible to construct a market mechanism that "homogenizes" demand.

Such homogenizing requires a government intervention that fits naturally into the structure of existing drug benefits. For example, Medicare Part D in the U.S. is implemented through private drug plans (PDP's), which beneficiaries privately select on their own and whose premiums are subsidized (differentially) by Medicare.[6] A simple tweak homogenizes demand: the government simply fixes a per-member

[6]Medicare Part D is a universal drug benefit for the elderly that has been implemented in 2006 as part of the 2003 Medicare Modernization Act.

subsidy, constant across all PDP's, that "commits" each drug plan to a fixed per-member budget (the size of the subsidy).[7] The PDP's, i.e. the demand faced by monopolists, then become homogeneous.

Intuitively, a mechanism constructed along these lines leads to near efficient outcomes because for the purposes of drug purchasing, all consumers become equally wealthy (i.e. each has the same budget for procuring drugs). This mechanism can also be modified to accommodate the case in which some consumers have pre-existing conditions.

In this paper, we investigate the use of auctions to implement an efficient drug procurement mechanism. In our context, a centralized auction serves to solicit bids from pharmaceutical companies. Each PDP then uses those bids to create its own formulary, deciding which drugs to include (by accepting bids) and which drugs to exclude (by rejecting bids). Assuming that PDP's are perfectly competitive and can be differentiated only by formularies implies that PDP's choose formularies to maximize consumer welfare.

In this paper we present an auction design in which the unique equilibrium implements a near efficient static outcome (providing 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.

When we take substitutes into consideration, we find that incentives for innovation are in fact more appropriate in our proposed mechanism than in traditional drug procurement markets. For example, our mechanism rewards equally all innovations of the same marginal social value, a feature absent in a traditional market setup. We also present an interesting result that for any level of profit between monopoly profits and full consumer surplus, there exists a budget size that delivers that level of profit for all drugs on the formulary, while still minimizing deadweight loss.

We should note that our claims about efficiency and eliminating deadweight losses are only proven in a partial equilibrium sense. It is important to acknowledge that if our mechanism causes an increase in government expenditures, then a different type of deadweight loss from increased taxes is created. This is not an unlikely issue since in our mechanism the government completely subsidizes the purchase of drugs. However, given that our mechanism reduces the upward pressures on drug

[7]For now, we assume these subsidies are perfectly risk-adjusted, as Medicare Part D subsidies are intended to be.

prices created by existing government subsidy schemes, we are inclined to believe that the new deadweight losses (if any) are very small relative to those eliminated.

The paper is organized as follows. In Section 2, we set up our analysis with a simple model for consumers, a simple model for drugs, and a detailed description of the proposed mechanism. Section 3 presents the basic model in which there are no substitutes and no pre-existing conditions. We specify the auction format and prove our main result that the unique equilibrium of that auction implements a near efficient outcome in which all but at most one drug are fully covered on the formulary. Section 4 amends the basic model to include imperfect substitutes and extends the near-efficiency result to that case. Incentives for innovation of both substitutes ("me-too" drugs) and brand new drugs are analyzed. In Section 5, pre-existing conditions are considered, and we specify an amendment to the mechanism that keeps drug companies' incentives aligned in the procurement auction. Section 6 concludes.

2 Setup

To begin, we present a simple model for consumers, motivated by typical models found in the literature on the value of life (Viscusi 1993). Consumers have state-dependent utilities in which there are two distinguishable states: life and death. Utility in the life state is u_a, where a captures consumer heterogeneity and consumers are indexed by a; and utility in the death state is normalized to 0. The value u_a is distributed according to some distribution $\rho(\cdot)$ (with cumulative distribution function $P(\cdot)$). Thus, given a probability q of death, a consumer's expected utility is the following:

$$U_a = (1-q)u_a$$

A consumer's willingness to pay for a drug, then, is related to its ability to reduce her probability of death. Consumers are endowed with a quasi-linear utility function where an outcome that costs price p and gives a probability q of death has value $U(q) = U_a - p = (1-q)u_a - p$.

Next we present a model for prescription drugs. There are a finite number N of diseases $n \in \{1, 2, \ldots, N\}$: 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). Later

we introduce substitutes. Drugs are produced at zero marginal cost. Let $\theta_n \in [0,1]$ be the probability that any given individual (without the disease) contracts disease n. Once an individual has disease n, she needs the drug for some positive number τ_n of periods. For each disease, let q_n be the probability of death if an individual contracts disease n, and let q_n^* be the probability of death if an individual contracts disease n and is treated with drug n (so $q_n^* < q_n$). We define the *value* v_n of drug n to be its reduction in probability of death: $v_n = q_n - q_n^* = \Delta q_n$. So the expected value of drug n to a consumer without the disease is $\theta_n v_n u_a$.[8] We also define the *weighted value* z_n of drug n to be its probability-weighted value: $\theta_n v_n$. To avoid degenerate cases, we assume that for all $i \neq j$, $z_i \neq z_j$.

Finally, we give an overview of the proposed mechanism. While funding of the mechanism is public, implementation is private – PDP's receive government subsidies but must compete to attract members. A PDP serves as an intermediary between members and drug companies, assembling a formulary of drugs to which members have access (for marginal cost, which we assume to be zero).[9] We assume that PDP's are risk neutral.

There are two essential features of our mechanism. First, subsidies are *fixed* on a per-person basis. The government gives a PDP a subsidy B for each member, which determines the budget per person the PDP has to allocate among drugs in creating its formulary.[10] This feature "homogenizes" demand, as described in the introduction.

The second feature of our mechanism is that the market determines drug prices. Each pharmaceutical company specifies the price it is willing to accept by submitting a bid for its drug, and each PDP uses those bids to assemble the best formulary possible within the budget. Since PDP's are competing for members, the plans choose formularies to maximize social value.

There are several implications of such a design. First, by having drug companies submit bids and possibly be excluded, the mechanism effectively creates "competition" among monopolists. A monopolist can only charge as much as the social value of his product warrants. Secondly, since each PDP faces the same subsidy, a level

[8]Notice that, given two individuals with parameters u_a and $u_{a'}$, their values for any given drug differ by a constant factor (namely $u_a - u_{a'}$).

[9]If a member wishes to a buy a drug not on her PDP's formulary, she has the option of purchasing the drug on the open market at market prices.

[10]Technically a PDP is able to charge its members some amount and increase the budget accordingly, but we assume the budget B is large enough that any individual's drug needs can be met by a formulary that costs no more than B.

playing field is created and PDP's compete along a single dimension (formularies). Thirdly, since all members have access to drugs on the formulary, efficient levels of consumption are achieved for on-formulary drugs. On the other hand, drugs off the formulary are sold on the open market at monopoly prices, with corresponding deadweight losses. Thus, maximal social efficiency is achieved when all drugs are on the formulary.

Formally, there are two stages in our procurement mechanism. First, each drug company submits a bid b_n specifying the fee it is willing to accept in order to have its drug available on the formulary. This creates a vector of bids $b = (b_1, b_2, \ldots, b_N)$. Given the budget B, the bid vector b and the weighted value vector $z = (z_1, z_2, \ldots, z_N)$, a PDP chooses a formulary $f^* \in [0,1]^N$ to maximize social value, subject to the budget constraint.

Notice that we allow PDP's to include fractions of drugs on the formulary. Having a fraction of a drug on the formulary means that the drug is covered for a randomly selected fraction of the PDP's members.[11]

The strategic component of the mechanism clearly lies in the first step of bid submission. In the next section we describe an auction format for collecting bids and show that the unique equilibrium implements a near-efficient outcome in which all but a fraction of one drug is on the formulary.

3 Basic Model

We begin by looking at the basic model in which (a) there are no substitutes (each drug has a monopoly) and (b) there are no pre-existing conditions (every individual has the same probability of contracting a given disease, or alternatively $\tau_n = 1 \; \forall n$). We later relax these assumptions.

3.1 Reserve Fee: Monopoly as Outside Option

In order to participate voluntarily in the mechanism, a drug company must do as well as its outside option, which is to sell the drug on the open market at a monopoly profit-maximizing price. In other words, the drug company demands an expected per-person profit that is at least as large as the company's per-person monopoly profits, which we call its "reserve fee."

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

Let p^* be the monopoly price charged. Notice that if an individual contracts disease n, she is willing to purchase drug n for price p if and only if her value exceeds the cost: $v_n u_a \geq p$, i.e. $u_a \geq \frac{p}{v_n}$. We can thus write conditional demand as $D(p) = \int_{p/v_n}^{\infty} dP(u_a)$ (representing the fraction of the population with disease n willing to buy the drug), and p^* solves the following profit maximization problem:

$$\max_{p_n} p_n \int_{p_n/v_n}^{\infty} dP(u_a)$$

Notice that demand depends only on the ratio between price p_n and value v_n! Thus, 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 value v_n.

Lemma 3.1. *As a monopolist, each drug company maximizes profits by setting its price to serve a constant proportion of the population that is independent of the value of the drug. Furthermore, the monopoly expected profit of a drug company is linear in its drug's weighted value z_n.*[12]

Lemma 3.1 tells us that the reserve fees of the drug companies are conveniently linear in the weighted social values of their drugs.

Definition 3.1. *The* reserve fee *of drug company n is defined as the per-person profits it would receive as a monopolist. We denote the fee by r_n where $r_n = z_n u(a^*)^2 \rho(u(a^*)) = K z_n$ and K is a constant.*

Thus, the reserve fee is the minimum expected per-person profit that a drug company will demand in the auction.

Note: Not surprisingly, the monopoly outcome is socially inefficient (leads to deadweight losses) since there are individuals for whom the social marginal benefit of providing them a drug clearly exceeds the social marginal cost, but they are unable to afford the monopoly price of the drug.

3.2 Procurement Auction Design and Equilibrium Analysis

In this section we present an auction format for soliciting bids from drug companies in our procurement mechanism. We assume that pharmaceutical companies take actions to maximize expected payoffs. Also, we assume that the weighted value z_n of any one drug is not too large relative to the others, i.e. $\max_n z_n \leq \sum_n z_n - \max_n z_n$.

[12] See Appendix for details.

Per-Person Fee Bidding. In the auction, we have specified that each drug company submits a bid. However, the auction can be specified in terms of two types of bids. The first is a unit price bid: drug companies specify the *ex post* price of their drug (after individuals contract the disease). In expectation, PDP's pay that price for a fraction θ_n of their members. The second is a per-person fee bid: drug companies specify an *ex ante* per-person fee (before individuals contract the disease). PDP's pay this fee for all members.

The auction format we specify is a clock auction in which drug companies take actions in order of their bid values. As a result, the type of bid is important in that it determines the order of bidding. Notice that a clock auction with per-person fee bidding is a special case of a clock auction with unit price bidding (i.e. where θ_n is constant across all drugs). In our analysis, we focus on the special case of per-person fee bidding. Because the budget constraint B is specified on a per-person basis, equilibria are much more straightforward and more easily described with per-person bidding.

Furthermore, while there are no general advantages to unit price bidding (except that it is the *status quo*), pricing on a per-person basis has the distinct advantage of eliminating artificial risks.[13] 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. Having PDP's pay on a per-unit basis in the event that an individual contracts a disease simply introduces risk into the system that did not previously exist. In the event that PDP's are even slightly risk averse, elimination of risk through per-person pricing is a Pareto improvement.

We define a bid b_n as the per-person fee a drug company is willing to accept. Without loss of generality, we label the drugs in decreasing reserve fee order: for any two drugs i and j, if $i > j$, then $r_i \leq r_j$.[14] If all drug companies set their bids b_n equal to their reserve fees r_n, then the order of bidding is according to reserve fees.

The PDP's optimization problem is the following: given B, the vector of bids b and the reserve fee vector $r = (r_1, r_2, \ldots, r_N)$, solve

$$\max_{f \in [0,1]^N} f \cdot r \text{ s.t. } f \cdot b \leq B$$

[13] Under specific parameter values, an ascending clock auction with unit price bidding performs better (results in a higher value formulary) than an auction with per-person bidding, but there is no robust advantage in general.

[14] Recall that r_n refers to the reserve fee of drug company n and is equal to Kz_n.

In fact, we can restate the PDP's problem in terms of "efficacy factors" of drug companies' bids. Define the *efficacy factor* e_n of drug company n bidding b_n as $e_n = \frac{b_n}{r_n}$. Each bid for a drug company n can be uniquely identified by e_n.

The PDP solves its optimization problem by ordering bids from lowest to highest efficacy factors (dealing with ties according to a pre-determined, deterministic algorithm), and including from the top as many drugs on the formulary as it can until the budget is depleted.[15]

We propose a dynamic clock auction to solicit bids. We consider both the ascending and the descending clock auctions, setting them up in a standard fashion. Note that the bid increment $\epsilon > 0$ is fixed in any auction, but can be chosen *a priori* to be arbitrarily small. We consider both types of auctions in order to emphasize the importance of implementation details. Since we are concerned with efficiency, we focus attention on budgets that are "sufficiently" big.

Ascending Clock Auction. In the ascending clock auction, the clock begins at $b = 0$ and ticks up by bid increment ϵ in each bid period. Each drug company n chooses a fee level b at which to leave the auction, and that becomes its bid b_n. There is no re-entry permitted. There are no equal reactive bids in the sense that once one bidder observes a dropout at b, he can only drop out at $b + \epsilon$.

Proposition 3.2. *Let $B > B^{A*} = \sum_{n=1}^{N} r_n - r_1$. In the unique subgame perfect equilibrium of the ascending clock auction, all drugs are fully covered on the formulary except the last drug to bid (drug 1), which is not covered. In particular, drugs $2, \ldots, N$ bid at an efficacy factor of $e^* = \frac{B+r_1}{\sum_{n=1}^{N} r_n}$, i.e. $b_n = e^* r_n$, while drug 1 bids ∞.*

Proof. See Appendix. □

Corollary 3.3. *As B increases, the excess budget is distributed proportionally across all on-formulary drugs.*

Notice that the equilibrium in the ascending clock auction is always bounded away from efficiency, since the highest-value drug is left off the formulary.

[15] Note that we are not explicitly disallowing partial coverage of multiple drugs, but we will find that such formularies will not exist in equilibrium.

Descending Clock Auction. In the descending clock auction, the clock begins at $b = B$ and ticks down by bid increment ϵ in each bid period. Each drug company n chooses a bidding level b at which to leave the auction, and that becomes its bid. There is no re-entry permitted. There are no equal reactive bids in the sense that once one bidder observes a dropout at b, he can only drop out at $b - \epsilon$. The clock stops at $b = 0$ and all bidders remaining are forced to leave the auction at that time.

Proposition 3.4. *Let $B \geq B^{D*} = \sum_{n=1}^{N} r_n$. In the unique subgame perfect equilibrium of the descending clock auction, all drugs are fully covered on the formulary except for one drug, which is partially covered. All fully covered drugs bid at the same efficacy factor of $e^* > 1$, while the partially covered drug bids at an efficacy factor strictly greater than e^*.*

Proof. See Appendix. □

Corollary 3.5. *When $B = \sum_{n=1}^{N} r_n$ and $\frac{r_{n-1}}{r_n} \to 1$ for all n, full efficiency is achieved, i.e. all drugs are fully covered on the formulary. Holding the r_n's fixed, as B increases, coverage of the partially covered drug strictly decreases.*

Remark: Clearly, the choice of auction format is an important one. In fact, if a sealed-bid simultaneous auction is chosen, a pure strategy equilibrium does not exist.

Remark: Notice that our efficiency results hinge only upon the budget being large enough rather than it being a specific value. Furthermore, any excess budget is distributed proportionally amongst all on-formulary drugs.

Ascending versus Descending. Finally, let's compare the performance of the ascending and the descending clock auctions. It turns out that the descending clock auction always performs better (leads to a higher social value formulary) than the ascending clock auction.

Theorem 3.6. *For $B > B^{D*}$ the unique subgame perfect equilibrium formulary of the descending clock auction has a social value strictly greater than that of the ascending clock auction.*

Proof. See Appendix. □

From this point forward, we assume that our procurement mechanism implements the descending clock auction with per-person fee bidding.

3.3 Optimal Incentives for Innovation

In the benchmark case, where a monopoly drug company sells directly to consumers and is unable to price-discriminate, incentives for innovation may be suboptimal because monopoly profits are less than full social surplus: according to textbook economics, optimal incentives for innovation arise when profits are equal to social surplus. Upon closer examination, however, it appears that profits equal to social surplus may in fact be too high and lead to over-innovation. Profits that cover a penny more than the costs of innovation (often much lower than full social surplus) seem sufficient.

Determining what level of profits correspond to "optimal" incentives for innovation is outside the scope of this paper, and for now we assume that the "optimal" level of profits is somewhere between monopoly profits and full social surplus. We now show that our mechanism can implement any such level of profits.[16]

In equilibrium, our mechanism induces all drug companies to submit bids equal to some constant (the "efficacy factor") multiplied by monopoly profits (reserve fee). This efficacy factor is increasing in the size of the budget B. When $B = B^{D*}$, the constant is equal to one and all drug companies on the formulary receive monopoly profits.

We can also achieve profits equal to full social surplus. First, note that 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 $er_n = eKz_n$. Choosing a large enough budget B so that $e = \frac{1}{K}\int_0^\infty u_a dP(u_a)$ yields textbook optimal incentives for innovation, since drug companies on the formulary receive profits equal to social surplus.

Proposition 3.7. *In our mechanism, for any level of profits between monopoly profits and full social surplus, there exists a budget B such that all drug companies (except the single drug that is not fully covered) receive that level of profits in equilibrium. In other words, B can be chosen such that all but one drug company faces "optimal" incentives for innovation.*

[16] Technically, these incentives for innovation are only near-optimal since incentives are changed only for drugs on the formulary and in equilibrium a fraction of one drug is left off the formulary. However, this is very close to optimal.

4 Model with Imperfect Substitutes

So far we have focused on monopoly drugs - their optimal bids under our mechanism and the resulting incentives to create new monopoly drugs. But what about substitutes? First, how will a drug company whose drug has a close substitute bid in our mechanism? Secondly, what are the incentives to create substitutes, whether or not they are improvements upon existing drugs?

We consider a model of imperfect substitutes in which one drug is more effective than the other. Let drug X and drug Y be substitutes, so they treat the same disease. Drug X offers value Γv where $\Gamma > 1$, while drug Y offers value v. Thus, given a choice between drug X with price p_X and value Γv, and drug Y with price p_Y and value v, an individual with the disease chooses drug X if and only if $\Gamma v u_a - p_X \geq v u_a - p_Y$.

4.1 Reserve Fee: Bertrand Competition as Outside Option

As before, in order to participate voluntarily in the mechanism, a drug company must do as well as its outside option. Because the drugs are substitutes, the outside option of one drug company depends on whether the substitute from the other company is on or off the formulary.

Suppose drug X is on the formulary and thus available to consumers for marginal cost. Then drug Y's off-formulary option gives a value of 0. Even if drug Y's company sets its price as low as possible (i.e. marginal cost), no consumers will buy drug Y. So when drug X is on the formulary, drug Y prefers to bid 0 and just get 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 marginal value above drug Y is $(\Gamma - 1)v$. The demand structure for drug X looks identical to a monopoly drug whose value is $(\Gamma - 1)v$; thus the outside option of drug X is $K(\Gamma - 1)z$.

The last scenario to look at is when both drugs are off the formulary. Consider Bertrand competition as the benchmark - what prices p_X and p_Y will each drug company charge? For simplicity, normalize $v = 1$ so drug X has value Γ and drug Y has value 1. Any 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 $u_a < p_Y$ chooses neither. Let's write down the profit functions:

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

Taking the first order conditions[17], we arrive at the following prices:

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

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

Example: Uniform Distribution To gain intuition, consider an example with a uniform distribution over consumer heterogeneity. So $P(u_a) = u_a$ for $u_a \in [0, 1]$. Solving the above two simultaneous price equations, 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 $u_a < \frac{\Gamma-1}{4\Gamma-1}$ buy no drug. Thus, if $\Gamma = 1$, everybody gets the drug, and as $\Gamma \to \infty$, 1/4 of people buy no drug, 1/4 of people buy drug Y and 1/2 of people buy drug X.

[17] We calculate the optimal reaction functions by taking FOC:

$$\begin{aligned} \frac{d\pi_X}{dp_X} &= (1 - P(t_{X,Y})) + \frac{p_X}{\Gamma - 1}(-\rho(t_{X,Y})) = 0 \\ \frac{d\pi_Y}{dp_Y} &= (P(t_{X,Y}) - P(p_Y)) + \frac{p_Y}{\Gamma - 1}(-\rho(t_{X,Y}) - (\Gamma - 1)\rho(p_Y)) = 0 \end{aligned}$$

4.2 Equilibrium Analysis

Proposotion 3.4 tells us that it is the unique equilibrium for each drug company to bid at an efficacy factor of e^*. In the case of substitutes, the logic extends in a straightforward fashion: a drug company facing a substitute bids exactly $e^*r = e^*K\theta v$ where v is the marginal value of the drug to the formulary.

The question, then, is whether it is in the drug company's interests to have its drug included on the formulary. Consider the following summary table, where each entry represents the ordered pair of payoffs (to 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 for one drug to be on while the other is off. In either case, the off-formulary drug can obtain at least as high a payoff by getting on the formulary, which it prefers. So 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 X's company has an incentive to bid slightly higher than π_X and get on the formulary.[18] Therefore, the only possibility is for both drugs to be on the formulary. When both drugs are on the formulary, neither company is able to deviate and achieve higher payoffs.

Proposition 4.1. *In the presence of imperfect substitutes, the unique subgame perfect equilibrium in our mechanism involves drug X's company bidding $e^*K\theta(\Gamma-1)v$, drug Y's company bidding 0, and both drugs being included on the formulary.*[19]

4.3 Incentives for Innovation

Incentives for innovation of imperfect substitutes is a topic of much debate – in recent years many have spoken out against drug companies' wasteful "innovations"

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

[19] Extending the result to the case of N substitutes (instead of two) is straightforward. Suppose there are S substitutes, all of which treat the same disease but are of different effectiveness. Specifically, we have factors $\Gamma_1, \Gamma_2, \ldots, \Gamma_S$, where $\Gamma_i < \Gamma_j$ if $i < j$, and we normalize $\Gamma_1 = 1$. The value of drug s for $s \in \{1, 2, \ldots, S\}$ is $\Gamma_s v$. Under Bertrand competition, the S substitutes divide up the market, each obtaining a positive profit with drug S obtaining the greatest profits. Under our mechanism, however, all drugs are included on the formulary with the highest value drug obtaining a profit of $e^*K\theta(\Gamma_S - \Gamma_{S-1})v$, and all the other substitutes obtaining 0 profits.

that add little or no value, often termed "me-too" drugs. We now consider the incentives under our mechanism for introducing substitutes for diseases that have existing drug treatments.

First, compare the payoffs under our mechanism with those under Bertrand competition. Under Bertrand competition, drug Y obtains positive profits; under our mechanism, drug Y obtains no profits. For the better drug, drug X, in both cases it generates positive payoffs, but in one case (our mechanism), its competitor is charging 0 whereas in the other (Bertrand competition) its substitute is charging a positive price. Thus, drug X must generate a lower payoff under our mechanism.

Lemma 4.2. *Under our mechanism, imperfect substitutes generate lower profits than under Bertrand competition.*

A corollary of that result is that there are perverse incentives to innovate under Bertrand competition. Suppose drug X is the first drug on the market. Consider the incentives to innovate and create a "me-too" drug (drug Y) that is uniformly worse than drug X. From a social perspective, there is no value to the innovation of drug Y given the presence of drug X. Under our mechanism, the "me-too" drug is rewarded appropriately with zero profits. However, under Bertrand competition drug Y receives a sizable payoff. This is indeed perverse: there is an incentive to introduce a drug with no social value.[20]

Proposition 4.3. *Introduction of "me-too" drugs is rewarded under Bertrand competition; under our mechanism, such innovation receives no reward.*

We highlight an important inconsistency generated by Bertrand competition in a traditional market setup.

Corollary 4.4. *Suppose there exist two drugs, drug I and drug II, with the same marginal social value, but drug I is an imperfect (better) substitute for an existing drug while drug II is a new chemical entity that is granted a monopoly. Under Bertrand competition, drug I generates more profits from being introduced in the*

[20]Note that we use the term "social value" to refer to the additional potential health benefit introduced by the drug. An alternative specification, which we do not use, is actual social surplus generated. Under Bertrand competition, because drug A is at such a high price point above marginal cost that many consumers cannot purchase it, the introduction of drug B actually generates social surplus because it can be priced at a lower price point. The fact that the suppliers of drug A limit its quantities through high per-unit pricing leaves social surplus on the table for drug B to tap into. In our use of "social value," however, we refer to the contribution to society of the actual technological advance.

market than drug II even though both have the same marginal social value. On the other hand, under our mechanism, the two innovations are rewarded equally.

5 Extension: Pre-Existing Conditions

Consider the case of pre-existing conditions. So far we have assumed that all individuals have the same probability of contracting a given disease. In reality, some individuals are already known to have a disease. In the context of our model, pre-existing conditions arise when $\tau_n > 1$ so there are individuals who become sick in one period and who are then sick with probability 1 for the next $\tau_n - 1$ periods.

To avoid the complexities of a multi-period model, we look for a steady state to describe the proportion of the population that will be sick with disease n in any period, given that the probability of disease is θ and the duration of disease is τ periods. A straightforward calculation shows that in the steady state, for small θ (which seems reasonable in our context), the proportion of the population that is sick in any one period is approximately $\tau\theta$.

Lemma 5.1. *For any given disease with probability of disease θ and duration of disease τ, if $\theta < \frac{1}{\tau - 1}$, then the expected proportion of the population with the disease in steady state is $\frac{\tau\theta}{1+\theta}$. If θ is close to 0, then the proportion with the disease is approximately $\tau\theta$.*

Notice that we cannot simply redefine a drug's weighted value as $\tau\theta v$ as opposed to θv. For individuals without the disease, the (weighted) value of the drug is only θv. A PDP that includes a drug at a value of $\tau\theta v$ (the drug's value to individuals with pre-existing conditions) will be less valuable to individuals without pre-existing conditions than a PDP that adds τ drugs instead, each at a value of θv. So there is the potential for discrimination against individuals with pre-existing conditions. Because of this selection issue, there is a need to disentangle value to individuals with pre-existing conditions from value to individuals without.

To do so, we propose the following. Every drug company bids as usual according to its drug's one-period social value θv. Then PDP's assemble their formularies, optimizing according to social value without concern for pre-existing conditions. Then, to account for the value to those with pre-existing conditions, using the $\tau\theta$ approximation, the government provides each PDP a subsidy of $(\tau_n - 1)b_n$ per drug n, where b_n is the per-person bid. This way, two companies whose drugs have

the same one-period social value but differing lengths of disease will be reimbursed appropriately different amounts.

6 Discussion

In this paper we have described a novel procurement mechanism that achieves near-efficiency in both the static sense and the dynamic sense. Previously, a tradeoff between the two types of efficiency has seemed inevitable, but we are able to reconcile the two.

Beyond near-efficiency, our procurement mechanism features several additional advantages. For one thing, PDP's receiving subsidies and paying fees on a per-person basis dampens incentives to engage in "cream-skinning" through deterioration of formulary quality.[21] Per-person fees also eliminate artificial risks that are created by traditional insurance setups: under the zero marginal cost assumption, neither consumers, PDP's nor pharmaceutical companies bear any risk.

Moreover, our procurement mechanism leads to more desirable incentives for innovation. We show that there exists a budget such that drug companies face optimal incentives for innovation. Furthermore, we eliminate perverse incentives that favor development of drugs with a substitute rather than new drugs, even when they are of the same marginal social value. Another practical advantage of our mechanism is that fixing budgets make PDP's easier for beneficiaries to compare: competition is along only a single quality dimension rather than both price and quality.

Nonetheless, there are several important issues to recognize and extensions to explore further. One major question is what happens when there is single ownership of multiple drugs. What if a drug company is able to bundle its drugs together into one bid? Even if we disallow bundling, single ownership of multiple drugs may influence bidding strategies. Are the efficiency properties of our mechanism robust to such amendments?

Another question concerns whether committing to a fixed budget is a credible threat: is the government able to exclude a blockbuster drug if its bid is excessive? Note that there are practical ways to force a purchaser to commit to a fixed budget and to exclude drugs when appropriate. For example, the budget can be announced beforehand, and as the auction proceeds, the account is depleted in real-time so that

[21] This is an issue addressed in McAdams and Schwarz (2006).

no money remains by the time the auction ends.

Finally, we again note that our procurement mechanism is fully funded by the government. To the extent that government expenditures increase, a different type of deadweight loss is created (namely that from increased taxes). However, given that our mechanism reduces upward pressures on drug prices, we believe that the new deadweight losses (if any) are small relative to those eliminated so that on net, even in a general equilibrium sense, efficiency is increased.

This paper describes a government-funded, market-driven drug procurement mechanism that highlights methods by which both static and dynamic efficiency can be improved. While the model used is highly stylized, we believe that the core insights contribute a novel and valuable perspective to the design of drug benefits.

A Appendix

A.1 Monopoly Profit Maximization

So we have the following profit maximization problem for drug company n:

$$\max_p p\theta_n \int_{p/v_n}^{\infty} dP(u_a).$$

To solve it, we take first order conditions and get $p^* D'(p^*) + D(p^*) = 0$. Notice that $D'(p) = -\frac{\theta_n}{v_n}\rho(\frac{p}{v_n})$ so the FOC is:

$$\begin{aligned} \theta_n \int_{p^*/v_n}^{\infty} dP(u_a) &= p^* \frac{\theta_n}{v_n}\rho(\frac{p^*}{v_n}) \\ \implies \int_{p^*/v_n}^{\infty} dP(u_a) &= \frac{p^*}{v_n}\rho(\frac{p^*}{v_n}) \end{aligned}$$

Recall that the given a price p, all consumers for whom $u_a \geq \frac{p}{v_n}$ will purchase the drug, so given the optimal p^*, there is a corresponding $u_a^* = \frac{p^*}{v_n}$ such that for all $u_a \geq u_a^*$, the individual purchases the drug. Rewriting, we get:

$$\begin{aligned} \int_{u_a^*}^{\infty} dP(u_a) &= u_a^* \rho(u_a^*) \\ \implies u_a^* = \frac{\rho(u_a^*)}{1 - Pr(u_a \leq u_a^*)} &= \frac{1}{h(u_a^*)} \end{aligned}$$

Notice that the RHS is the inverse of the hazard rate, which we label $h(u_a^*)$. Finally, we can write down an expression for profits:

$$\pi = u_a^* v_n \theta_n u_a^* \rho(u_a^*) = [\rho(u_a^*)(u_a^*)^2] z_n$$

A.2 Proof of Proposition 3.2

Lemma A.1. *In any equilibrium, at most one drug is partially covered, and no drug is completely uncovered.*[22]

Proof. Suppose there are at least two drugs that are partially covered. Consider the partially covered drug that bids the last. It cannot be the very last drug to bid overall because otherwise it can lower its bid by ϵ, just undercut the other partially covered drugs, and get additional coverage. Therefore, the last drug to bid must be fully covered. Similarly, the partially covered drug that bids last cannot be the second last drug to bid overall because otherwise it can lower its bid by ϵ, just undercut the other drugs while not affecting incentives of the very last drug (which can bid the same as before and get fully covered), and take additional coverage. Therefore, the second last drug to bid must be fully covered. Iterating this argument, we have a contradiction and conclude that there is at most one drug that is partially covered.

Now suppose some drug is completely uncovered. It cannot be the very last drug to bid overall because either it can bid just below the highest efficacy factor of an on-formulary drug and get on the formulary profitably (at an efficacy factor strictly greater than 1) or else the highest efficacy factor of an on-formulary drug is $e = 1$ and the last drug can bid ∞ and take the excess budget since $B > B^{A*}$. It also cannot be the second last drug to bid overall because either it can bid just below the highest efficacy factor of an on-formulary drug and get on the formulary profitably, or all the other drugs are bidding $e = 1$, so this drug can bid ϵ above $e = 1$ and leave enough additional budget for the last drug to still want to bid ∞. Iterating this argument, we find that a completely uncovered drug always has a profitable deviation to either ϵ below the highest efficacy factor without affecting incentives of the remaining drugs, or ϵ above $e = 1$ without affecting incentives of the remaining drugs. Therefore, no drug is ever completely uncovered. □

[22]Note that being "completely uncovered" means that the drug receives none of the budget B. In particular, a drug with a bid of ∞ that receives the excess budget but is on 0% of formularies is not completely uncovered.

Proof. **(Proof of Proposition)** First, we prove that the equilibrium described is the unique equilibrium in which all bidders bid the same efficacy factor except for the last bidder, which bids infinity. Consider the last bidder, drug 1. Suppose all previous bidders have bid at efficacy factor e^*. The last bidder can choose either to bid at a factor e^* as well and get fully covered on the formulary (best case tie-break rule), or to bid ∞ and stay off the formulary. The bidder prefers to bid ∞ if and only if

$$e^* \leq \frac{B + r_1}{\sum_{n=1}^{N} r_n}$$

This is a necessary condition for the last bidder to bid ∞ and stay off the formulary.

Consider bidder 2. Suppose all previous bidders have bid at efficacy factor e^*. If bidder 2 bids e^* and e^* satisfies the condition above, then the last bidder bids ∞ and bidder 2 receives an efficacy factor of e^*. Does bidder 2 want to deviate and bid higher? If bidder 2 bids at a higher efficacy factor $e' > e^*$, then bidder 1 can bid the same e' and at least partially displace bidder 2 off the formulary. When will bidder 1 choose to displace bidder 2 off the formulary when it bids $e' > e^*$? Only when bidder 2 does not prefer to be displaced off the formulary. The reasoning is that the condition for bidder 2 preferring to be displaced off the formulary implies the condition for bidder 1 also preferring to be left off the formulary. As a result, bidder 1 will bid ∞, leaving bidder 2 on the formulary.[23] So when will bidder 2 not be displaced off the formulary? It needs to bid e' such that[24]

$$e'r_1 = B - e^* \sum_{n=3}^{N} r_n - e'r_2 + r_1.$$

When $e^* = \frac{B+r_1}{\sum_{n=1}^{N} r_n}$, then $e' = e^*$ satisfies that condition. Therefore $e^* = \frac{B+r_1}{\sum_{n=1}^{N} r_n}$ is a necessary condition for bidder 2 to bid at the same efficacy factor as the other bidders.

Now consider bidder j. Suppose all previous bidders have bid at efficacy factor e^* and that all remaining bidders bid the highest efficacy factor of the previous bidders

[23] A necessary condition for bidder 2 to prefer to be displaced off the formulary with a bid of e' is $e'r_2 \leq B - e^* \sum_{n=3}^{N} r_n - e'r_1 + r_2$, where the right hand side is an upper bound on bidders 2's payoff from being left off the formulary. That condition is equivalent to $e'r_1 \leq B - e^* \sum_{n=3}^{N} r_n - e'r_2 + r_2$, which implies $e'r_1 \leq B - e^* \sum_{n=3}^{N} r_n - e'r_2 + r_1$. That is a necessary and sufficient condition for bidder 1 to prefer to bid ∞ and be left off the formulary rather than undercut bidder 2 with a bid of e'.

[24] We use equality because bidder 2 wants to maximize its payoff by making bidder 1's constraint bind.

(except for the last bidder). Any deviation to a higher efficacy factor $e' > e^*$ will allow remaining bidders to raise their bids to e' as well. For the same reasoning as with bidder 2, bidder j only wants to bid $e' > e^*$ if it stays on the formulary in equilibrium. This can only happen if bidder 1's constraint holds:

$$e' r_1 \leq B - e^* \sum_{n=j+1}^{N} r_n - e' \sum_{n=2}^{j} r_n + r_1$$

$$e' \leq \frac{B + r_1 - e^* \sum_{n=j+1}^{N} r_n}{\sum_{n=1}^{N} r_n - \sum_{n=j+1}^{N} r_n}.$$

Since $\frac{B+r_1}{\sum_{n=1}^{N} r_n} > \frac{B+r_1-e^* \sum_{n=j+1}^{N} r_n}{\sum_{n=1}^{N} r_n - \sum_{n=j+1}^{N} r_n}$, this condition does not hold if $e^* = \frac{B+r_1}{\sum_{n=1}^{N} r_n}$. So a sufficient condition for bidder 2 to bid the same efficacy factor as the previous bidders is also a sufficient condition for any bidder j to bid the same efficacy factor as the previous bidders.

Therefore, we conclude that the only equilibrium in which all bidders bid at the same efficacy factor except for bidder 1, which bids ∞, involves an efficacy factor of $e^* = \frac{B+r_1}{\sum_{n=1}^{N} r_n}$. In order to be individually rational, $e^* > 1$, i.e. $B > \sum_{n=1}^{N} r_n - r_1$.

To complete the proof of uniqueness, we need only show that any subgame perfect equilibrium in this game must take the form of all bidders bidding the same efficacy factor except for the last bidder.

Suppose there exists a subgame perfect equilibrium in which all bidders do not bid the same efficacy factor. Let bidder j be the first bidder not to bid the same value as the previous bidders, which have all bid some e^*. By Lemma A.1, those previous bidders must all be getting on the formulary. Thus, bidder j can also get on the formulary with a bid of e^*, so any profitable deviation must involve $e' > e^*$ and bidder j getting on the formulary with that bid.[25] If bidder j can get on the formulary with that bid though, then all remaining bidders $j-1, \ldots, 1$ can also get on the formulary with that bid and will bid at least e'. This implies that

$$B \geq e^* \sum_{n=j+1}^{N} r_n + e' \sum_{n=2}^{j} r_n$$

In this case, however, bidder $j+1$ has a profitable deviation to $e' - \epsilon > e^*$. The

[25] Bidder j cannot prefer to be left off the formulary because if it does, then bidder 1 will want to be left off the formulary and has the ability to make that happen.

only way such a deviation is not possible is if it causes bidder $j+1$ to be left off the formulary. But in order for that to happen, all remaining bidders must revise their bids downwards. But doing so will leave enough room on the budget for bidder $j+1$, so it will still be on the formulary. Therefore, such an equilibrium cannot exist and all bidders must bid the same efficacy factor.

The last step is to show that in any subgame perfect equilibrium, the last bidder must bid ∞. If it does not bid ∞, this means that it makes some lower bid and gets on the formulary. But doing so leaves some other drug off the formulary (because $e \geq \frac{B+r_1}{\sum_{n=1}^{N} r_n}$ for drug 1 not to bid ∞.). As a result, that drug has a profitable deviation to get on the formulary lowering its bid.

To complete our proof, we show that no mixed-strategy equilibria exist (to be inserted).

□

A.3 Proof of Proposition 3.4

Lemma A.2. *In any equilibrium, at most one drug is partially covered, and no drug is completely uncovered.*

Proof. (Very similar to Lemma A.1.) Suppose there are at least two drugs that are partially covered. Consider the partially covered drug that bids the last. It cannot be the very last drug to bid overall because otherwise it can lower its bid by ϵ, just undercut the other partially covered drugs, and get additional coverage. Therefore, the last drug to bid must be fully covered. Similarly, the partially covered drug that bids last cannot be the second last drug to bid overall because otherwise it can lower its bid by ϵ, just undercut the other drugs while not affecting incentives of the very last drug (which can bid the same as before and get fully covered), and take additional coverage. Therefore, the second last drug to bid must be fully covered. Iterating this argument, we have a contradiction and conclude that there is at most one drug that is partially covered.

Now suppose some drug is completely uncovered. It cannot be the very last drug to bid overall because either it can bid just below the highest efficacy factor of an on-formulary drug and get on the formulary profitably (at an efficacy factor strictly greater than 1) or else the highest efficacy factor of an on-formulary drug is $e = 1$ and the last drug can bid as high as possible and take the excess budget since $B > B^{A*}$. It also cannot be the second last drug to bid overall because

either it can bid just below the highest efficacy factor of an on-formulary drug and get on the formulary profitably, or all the other drugs are bidding $e = 1$, so this drug can bid ϵ above $e = 1$ and leave enough additional budget for the last drug not to have incentive to change its bid. Iterating this argument, we find that a completely uncovered drug always has a profitable deviation to either ϵ below the highest efficacy factor without affecting incentives of the remaining drugs, or ϵ above $e = 1$ without affecting incentives of the remaining drugs. Therefore, no drug is ever completely uncovered. □

Proof. **(Proof of Proposition: Sketch)** We know that in any equilibrium, there is one drug that is either fully covered or partially covered at its highest possible bid (which is the bid of the immediately preceding (higher) drug); all other drugs are fully covered. For each drug n, we can define a cutoff efficacy factor $\hat{e}_n$ such that if all other drugs bid the same efficacy factor, then drug n is indifferent between being fully covered at $\hat{e}_n$ and being partially covered at $\hat{e}_n r_{n-1}$, i.e. the bid of the drug just higher than it. More precisely, $\hat{e}_n$ satisfies:

$$\hat{e}_n r_n = \left(B - \hat{e}_n \sum_{i \neq n} r_i \right) + r_i \left(1 - \frac{B - \hat{e}_n \sum_{i \neq n} r_i}{\hat{e}_n r_{n-1}} \right)$$

Notice that the above does not define $\hat{e}_n$ for drug $n = 1$ because r_{n-1} is undefined. We can define $\hat{e}_1$ analogously as corresponding to the maximal profit that drug 1 receives when it is the partially covered drug. In particular, first we find e^* that maximizes drug 1's partial coverage profits (when all other drugs bid e^* as well):

$$\max_e \left[B \frac{e-1}{e} - (e-1) \sum_{i \neq 1} r_i + r_1 \right]$$

which is maximized by $e^* = \sqrt{\frac{B}{\sum_{i \neq 1} r_i}}$. Then, $\hat{e}_1$ is equal to the profits obtained by plugging e^* into the objective function, divided by r_1.

The drug with the highest $\hat{e}_n$, say n^*, is the one chosen to be left off the formulary because such an efficacy factor gives incentives to all other drugs to bid the efficacy factor and get fully covered on the formulary, while drug n^* is indifferent between being partially covered and fully covered. Notice that in equilibrium this indifference must be resolved by drug n^* bidding the efficacy factor and being partially covered because otherwise other drugs would have incentive to deviate. (Note that n^* is

associated with having the highest ratio $\frac{r_{n-1}}{r_n}$.)

Any other drug $n \neq n^*$ does not want to bid higher than the efficacy factor $\hat{e}_{n^*}$ and be partially covered because it would be doing strictly worse than being partially covered when all drugs are bidding $\hat{e}_n$. Neither does any drug want to bid lower than the efficacy factor $\hat{e}_{n^*}$ because doing so can only lower its payoff. Therefore, no drug has incentive to deviate.

Notice that as $\frac{r_{n-1}}{r_n} \to 1$ for all n, $\hat{e}_n \to \frac{B - r_{n-1}}{\sum_{i \neq n} r_i}$, implying the excess budget to the partially covered drug is $r_{n-1} = r_n$. Therefore, when $B = \sum_i r_i$, $\hat{e}_n = 1$ and we achieve full efficiency with all drugs being fully covered. (This is an extreme case when all reserve values are equal.) As B increases, the amount of excess budget remaining for the partially covered drug stays the same while the efficacy factor increases. Therefore, a smaller fraction of the partially covered drug is covered as B increases.

To complete our proof, we show that no mixed-strategy equilibria exist (to be inserted). □

A.4 Proof of Theorem 3.6

This is essentially a corollary of Propositions 3.2 and 3.4. In the ascending auction, Proposition 3.2 tells us that the value of the formulary is $\sum_{n=1}^{N} z_n - z_1$. In the descending auction, Proposition 3.4 tells us that the value of the formulary is strictly greater than $\sum_{n=1}^{N} z_n - z_1$.

A.5 Proof of Lemma 5.1

In period 1, the expected sick proportion is θ. In period 2, the expected sick proportion is $\theta + \theta(1-\theta)$. In period τ, the expected sick proportion is $\theta + \theta(1-\theta) + \theta(1-\theta(1-\theta)) + \theta(1-\theta(1-\theta(1-\theta))) + \ldots + \theta(1-\theta(1-\theta(1-\ldots)\ldots)$. Generally in any given period, in steady state, the expected sick proportion is:

$$\begin{aligned} \tau(\theta(1-\theta(1-\theta(1-\ldots)\ldots) &= \tau(\theta - \theta^2 + \theta^3 - \theta^4 + \ldots) \\ &= \tau\theta(1 - \theta + \theta^2 - \theta^3 + \ldots) \\ &= \frac{\tau\theta}{1+\theta} \end{aligned}$$

Notice that it must be the case that $\theta \leq \frac{1}{\tau - 1}$ in order for the calculation above to be valid. Also, when θ is small and close to 0, the steady state proportion of sick is

approximately $\tau\theta$.

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