

Contracting over Rebates: Formulary Design and Pharmaceutical Spending *

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Abstract

We investigate how formularies used by pharmacy benefit managers (PBMs) to steer consumer demand can constrain spending by affecting manufacturer rebates for branded drugs. We present a theoretical model of multidimensional contracting in which a PBM offers multiple drug manufacturers a menu of formulary-contingent rebate payments and then selects a formulary. We estimate how formulary placement affects drug demand for statins using data from Princeton University, a large employer that contracts with a single PBM to offer prescription drug coverage to its employees. Using our model and demand estimates, we predict the magnitude of rebates with one preferred and one non-preferred tier; we also examine the impact of changing the number of drug tiers or allowing for complete exclusion. Our predicted magnitudes align with aggregate rebate data, and we predict that allowing a PBM to flexibly place branded drugs on preferred- and non-preferred tiers can substantially increase rebate payments.

JEL Codes: D86, I11, L14

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1 Introduction

Prescription drug spending in the U.S. is high and increasing. While data on list prices tend to overstate spending increases, net spending data that account for discounts negotiated with pharmacy benefit managers (PBMs) still indicate high and rising expenditure. The National Health Expenditure data issued by the Centers for Medicare and Medicaid Services (CMS) estimate net spending on drugs dispensed in the retail setting (excluding those administered in hospitals and doctors’ offices), net of manufacturer rebates and discounts but including intermediary markups, of \$329.9 billion in 2016 or approximately 10% of total US health expenditures¹. Spending increased by between 2% and 6% per year in the following three years.

There is a growing literature examining the role of PBMs in contributing to or stymieing this rising spending (Sood et al. (2020), Garthwaite and Scott-Morton (2017), Grassley and Wyden (2021)). Yu, Atteberry and Bach (2018) estimate that two thirds of US spending on prescription drugs in 2016 was captured by drug manufacturers; the remainder went to pharmacies, providers, wholesalers and PBMs. In 2022, the Federal Trade Commission opened an inquiry into the impact of PBMs on drug access and affordability. In the public sector, the Inflation Reduction Act (2022) introduced a new method to determine Medicare drug prices, initially for a small number of drugs, with little role for PBMs.² However, the price-setting system in the commercial sector is not affected by this change. Examining PBMs’ ability to negotiate *rebates*, or manufacturer discounts on (primarily branded) drugs, remains important. The intuition is straightforward. By designing a “formulary” where some branded drugs are available at lower out-of-pocket prices than others, PBMs may be able to stimulate price competition between branded drug manufacturers, generating discounts which may then be passed on to sponsors and final consumers.

One of the primary challenges facing researchers studying drug spending is data availability. In particular, accessible rebate data are so far at best only available at an aggregated level (rather than separately by PBM or sponsor) and this may not be sufficient for policy analysis. This paper provides a model and empirical estimates to infer rebates that may be unobserved, and to predict changes in rebates under alternative formulary designs (e.g., allowing for additional branded drug tiers or alternative cost sharing schemes).

Our analysis has two parts.

In the first part, we develop a theoretical model of contracting between drug manufacturers and a PBM over rebates. We account for the fact that the contract agreed upon by one manufacturer may condition not just on its own drug’s tier placement but also on the placement of rivals’ drugs. This component is needed to reflect the details of the actual contracts. It is different from most previous models of vertical negotiations in health care and other markets, in which contracts depend only on the product’s own inclusion or exclusion from the network.³

¹Source: National Health Expenditures by type of service and source of funds, calendar years 1960-2019.

²The negotiation between the Centers for Medicare and Medicaid Services (CMS) and manufacturers will cover 10 major drugs in 2023.

³See, e.g., Gowrisankaran, Nevo and Town (2015), Ho and Lee (2016, 2019); and Lee, Whinston and Yurukoglu (2021) for a survey.

The theoretical model has a single PBM that represents a set of consumers making private simultaneous take-it-or-leave-it *rebate contract* offers to multiple branded drug manufacturers. A rebate contract specifies a contingent per-unit rebate paid by a drug manufacturer to the PBM that conditions on the formulary that is chosen—that is, the rebate paid may differ depending on the drug’s own selected tier and those for its rivals. Rebates represent a discount off the list price for the drug, which is otherwise paid for by the PBM and end consumers. After drug manufacturers have accepted or rejected the set of offers they receive, the PBM then chooses its formulary, which in turn influences consumers’ demand for drugs.

We allow drug manufacturers’ profits and the PBM’s objective function (representing a combination of drug payments and consumer welfare) to depend on the overall formulary. By influencing the PBM’s choice of formulary, each manufacturer’s rebate contract affects the tier placement of its drug and therefore the volume sold and the manufacturer’s revenue as well as its costs.

When evaluating a given rebate contract offer from the PBM, each manufacturer contemplates not only what formulary will be chosen if it accepts, but also what potential alternative formulary might be chosen if it rejects. This latter object will depend on the rebates that other rival drug manufacturers are willing to pay for alternative formularies that are not necessarily chosen in equilibrium. These interactions between manufacturers, together with the lack of equilibrium constraints governing rebates for formularies not chosen in equilibrium, often lead to equilibrium multiplicity. We introduce a refinement that pins down the equilibrium conditions and reduces the set of equilibria to be considered. In such equilibria, rebate contracts ensure that, whenever a manufacturer pays a positive rebate, it earns the same profits regardless of the formulary chosen by the PBM. We derive necessary and sufficient conditions for a set of rebate contracts to comprise an equilibrium satisfying our refinement, and provide an algorithm for computing all potential equilibria.

In the second part of our analysis, we specify and estimate a demand system to predict the volume response to any change in tier placement, or exclusion, for any given drug. These estimates depend on the extent to which rival drugs in the category are substitutes, and are important inputs into the contracting model. Our empirical application uses detailed claims data from Princeton University. We focus on statins, a large drug category in our data, where there were three major branded drugs plus generic equivalents during our sample period. We find that tier placement substantially shifts volume.

With this estimated demand system and data on list prices, we use our model to predict equilibrium rebates in 2011 in the observed case where formulary placement was determined solely by generic availability, compared to the (later) case where the PBM had flexibility to move branded drugs across tiers. Predicted rebates are zero when there is only one branded tier. In the case with PBM flexibility we predict rebates that are always positive, but that always allow the manufacturer to retain a positive share of the surplus. The magnitude of predicted rebates is consistent with those reported in published papers, on the order of 30% of list prices. We also show how the ability for a PBM to have additional tiers in its formulary, or exclude drugs from the formulary, can lead

to higher rebates.

Related Literature. Our paper is related to the literature that discusses the effects of PBMs on prices and spending, incentives, and welfare more broadly. Kakani, Chernew and Chandra (2020), Sood et al. (2020), and Hernandez et al. (2020) use novel datasets from SSR Health, Inc to quantify rebate growth, compare list prices to net prices, and investigate the contribution of net price growth to drug spending growth over time. Garthwaite and Scott-Morton (2017) discuss the reasons why PBMs have an incentive to capture some share of the surplus they generate, and the ways in which they do so. Agha, Kim and Li (2021) consider the impact of PBM formulary management, particularly drug exclusion, on pharmaceutical companies’ incentives to innovate.⁴ Similar to our paper, Conti et al. (2021) develops a theoretical model of rebate contracting to address questions regarding why PBMs exist and why list prices—as well as rebates—are high, but does not quantify magnitudes.⁵

A small number of working papers estimate models of PBM-manufacturer rebate negotiations. Demirer and Olssen (2021) estimate rebates in Medicare Part D using a partially identified method based on the optimality of observed tier placements, without characterizing the equilibrium outcome of the contracting game. They use their estimates to ask how formularies would adjust in response to a change in government rebates. Feng and Maini (2021) use SSR Health data on rebates to estimate a model of contracting between PBMs and manufacturers in Medicare Part D, using an all-pay auction and abstracting away from the menu-based aspect of the model. Their focus is the impact of switching costs on the dynamics of the problem.

Our theoretical model builds on insights from the (vertical) contracting in industrial organization literature (see, e.g., Hart and Tirole, 1990; McAfee and Schwartz, 1994; Segal, 1999). Closest to our work are Bernheim and Whinston (1986) and Segal and Whinston (2003).⁶ Bernheim and Whinston (1986) examine “menu auctions,” in which multiple principals propose a menu of contingent bids to influence a single agent’s decision. As in their setting, in our analysis principals (manufacturers) use constrained bids (rebates) to affect the action (formulary) chosen by a single agent (PBM). Instead of assuming that principals make bids to the agent, our model assumes the reverse; hence, using the terminology of Segal and Whinston (2003), our model is an “offer game” variant of the menu auction examined in Bernheim and Whinston (1986). Segal and Whinston (2003) studies the role of “menu contracts” in bounding equilibrium outcomes in contracting games. Our rebate contracts are versions of such menu contracts, in that they specify a set of

⁴There are also papers that consider other important inputs to drug sales and pricing. For example, Dafny, Ody and Schmidt (2017) and Dafny, Ho and Kong (2021) focus on the impact of manufacturers providing drug coupons that allow consumers to avoid paying some of the cost-sharing contributions that their insurance plans require for particular drugs.

⁵The baseline model examined in Conti et al. (2021) is one in which two drug manufacturers make rebate offers to the PBM which do not condition on the formulary chosen, or condition only on the the drug’s own tier (and not those of rivals); and the PBM is restricted to only placing a single drug on the higher of two tiers.

⁶Our environment is also related to that studied in Jehiel, Moldovanu and Stacchetti (1996) given the presence of negative contracting externalities: e.g., a higher rebate contract from one manufacturer can lead the PBM to put its rival on a worse tier, even if the rival had not signed any rebate contract in the first place.

actions (formularies) and payments from which the principal (PBM) can choose.⁷ We discuss these connections further in Section 3.

2 Institutional Details

Net prices (representing list prices minus discounts) for branded drugs are determined through a series of negotiations, primarily between PBMs and pharmaceutical manufacturers. Manufacturers set a list price for their products. Sponsors contract with a PBM to manage their pharmacy claims, design formularies, and negotiate discounts from the list price that determine the net prices paid.⁸ The details of the contracts are kept confidential and we do not observe them directly.⁹

Interview evidence indicates that in our setting, where a self-insured employer contracts with a single PBM, the formulary and rebate-setting process is structured as follows. PBMs negotiate the rebate with branded drug manufacturers.¹⁰ The manufacturer agrees to pay a rebate defined as a dollar amount per day’s supply—to be passed back to the sponsor, in whole or in part—that varies with the tier on which its drug is placed.¹¹ (The rebate may be as low as zero for a drug placed on a non-preferred tier.) Rebates often also effectively or explicitly condition on the entire formulary, not just the particular drug’s tier placement. For example, they may be directly linked to volume, with rebate payments increasing when the manufacturer’s share of the drug category passes a volume threshold, or they may condition on tier placement for rival drugs.¹²

The PBM-manufacturer negotiation determines not just one, but a schedule of rebates spanning a menu of different formularies, where the tier placement of the manufacturer’s drug, and its rivals, differ across formularies. The manufacturer may agree to a different rebate for each formulary. One interviewee described negotiations over rebates covering as many as 60 different formulary options. In cases where multiple drugs exist within the drug category (as with statins), the PBM’s

⁷In addition, our focus on equilibria in which manufacturers are indifferent over formularies is closely related to “Truthful Nash Equilibria” as defined in Bernheim and Whinston (1986) in the context of menu auctions, and is also similar to restricting attention to equilibria utilizing “Rothschild-Stiglitz-Wilson” menus as described in Segal and Whinston (2003).

⁸The sponsor is the agent that bears risk for the cost of branded drugs purchased by consumers. In our setting this is a self-insured employer, but it can also be an insurance carrier offering a fully-insured plan which includes prescription drug coverage.

⁹We learned details of the contracting process and contract terms through interviews with industry practitioners and government reports (e.g., Grassley and Wyden (2021), Government-Accountability-Office (2019)).

¹⁰In reality there are two forms of discount. In addition to rebates, which are our focus, list prices are also discounted by an amount that differs by sales channel (mail order or retail, accounting for the surplus captured by pharmacies in the retail channel). We condition on, but abstract from modeling, these channel-specific list-price discounts.

¹¹Most Favored Nation (MFN) clauses exist for Medicaid (under the Medicaid Prescription Drug Rebate Program or MDRP) and for safety net providers that serve vulnerable populations (the 340B drug discount program). These programs require drug manufacturers to agree to a Medicaid rebate amount that is set in statute and generally ensures that Medicaid and eligible providers under the 340B program get the lowest price. These programs may influence prices paid by other payers to the extent that manufacturers “seek to avoid triggering Medicaid ‘best price’ when developing their bids for commercial plans” (Grassley and Wyden 2021). See Conti et al 2021 for further discussion. We abstract away from these issues in our analysis, assuming that rebates in our sample are never large enough to trigger these considerations.

¹²These observations, suggesting that rebates are contingent on the formulary, are consistent with papers considering rebate setting in Medicare Part D (Olssen and Demirev 2020).

negotiations with different manufacturers are likely to be staggered over time. The PBM then offers a menu of formularies to plan sponsors. Each sponsor chooses a formulary that trades off employee surplus (higher for a more inclusive formulary) against net costs (lower when branded drugs have high out-of-pocket prices because consumers are steered towards generics, but also lower when the rebate payment is high). The PBM may move the sponsor across formularies during the year to account for changes in the marketplace such as the introduction of a new generic drug or to improve its terms with manufacturers (e.g., to generate a volume discount). At the end of the period, the sponsor receives a rebate payment that is updated via a reconciliation process to account for any additional rebates earned during the year.

What we model. We model PBM-manufacturer contracting over a menu of rebates corresponding to different potential formularies, with the PBM subsequently making a formulary choice from the menu.

We simplify by assuming a single plan sponsor contracts with the PBM, and that the PBM has the same preferences as the sponsor. Given this, we view the sponsor and the PBM as interchangeable in our analysis. We abstract away from PBM rents, modeling sponsor net payments as equal to PBM net payments, and assume that the PBM offers a single formulary from the negotiated schedule that it knows the sponsor will accept¹³.

Previous studies note the potential for manufacturers to respond to PBM rebate pressure by raising their list prices; this has been argued to be important for some particular drugs in recent years (see, e.g., Grassley and Wyden (2021) for insulin pricing; Kakani, Chernew and Chandra (2020) for insulin and diabetes drugs). Our analysis focuses on rebate negotiations, holding list prices fixed. In reality, list prices are likely determined accounting for the price responsiveness of a larger population of consumers than is covered by our sample—i.e., across multiple PBMs and sponsors, and including consumers who pay a high fraction of list prices either because their health plan provides incomplete coverage or because they are uninsured for prescription drugs—as well as the rebate negotiation.¹⁴

3 A Model of Rebate Negotiations and Formulary Choice

There is a single pharmacy benefit manager (PBM) and M branded drug manufacturers, each of whom produces a single drug in a particular therapeutic market. The PBM, acting on behalf of a plan sponsor, first negotiates rebate contracts with manufacturers, and then chooses a formulary which affects the realized demand for each drug. Our main theoretical results characterize equi-

¹³We do not model the extent to which PBM incentives are misaligned from the sponsors they represent, or the activities PBMs may engage in to capture rents. We also do not address distributional issues such as those that arise if sponsors respond to high rebates by reducing premiums rather than out of pocket prices (as discussed in emails between PBMs and manufacturers, Grassley and Wyden (2021)), thereby generating a surplus transfer from sick to healthy patients. Both are important areas for further research.

¹⁴In Section 3.6 we outline one approach to incorporating adjustments to list prices, but note that this extension (as well as extending our analysis to multiple PBMs or sponsors) is outside the scope of this paper.

librium formularies and rebates as a function of other (fixed) inputs, which include discounted list prices that the PBM pays per prescription fill, and retail pharmacy markups and dispensing fees.

We make two assumptions that are supported by institutional realities. First, we allow the PBM to place a drug on its formulary even without a rebate contract, in which case the PBM compensates the manufacturer based on the list price for the drug. This provides additional flexibility for the PBM to re-optimize its formulary under disagreement; it also implies that a manufacturer’s worst-case profit with no rebate payment may still be greater than zero if the PBM still chooses to place the drug on its formulary. Second, rebates are modeled as a linear payment per prescription fill.¹⁵

3.1 Setup

Notation and Preliminaries. A *formulary* is represented by $\mathbb{F} = \{\mathbb{F}_1, \dots, \mathbb{F}_M\}$, where each element $\mathbb{F}_i \in \{P, NP, E\}$ corresponds to the tier that drug i is placed on: preferred (P), non-preferred (NP), or excluded (E).¹⁶ Denote the set of all formularies by $\mathcal{F} \equiv \{P, NP, E\}^M$.

The PBM negotiates a profile of *rebate contracts* $\mathbb{C} = \{\mathbb{C}_1, \dots, \mathbb{C}_M\}$ with manufacturers, where the rebate contract for manufacturer i , given by $\mathbb{C}_i : \mathcal{F} \rightarrow \mathbb{R}_0^+$, specifies the per-unit rebate payment that manufacturer i pays the PBM for each formulary. Hence, if the PBM chooses a formulary $\mathbb{F} \in \mathcal{F}$, then under contract \mathbb{C}_i manufacturer i agrees to pay a per-unit rebate of $\mathbb{C}_i(\mathbb{F})$ to the PBM. A particular manufacturer’s rebate thus depends on both its own tier placement and the tier placement of rivals. We restrict rebates to be weakly positive.¹⁷ Denote by \mathbb{C}^0 the *null contract*, which is the contract that specifies a zero rebate under any formulary: i.e., $\mathbb{C}^0(\mathbb{F}) = 0$ for all \mathbb{F} . We assume that the null contract is also the contracting outcome when the PBM and manufacturer fail to agree to any rebate contract.

Timing. Our model has three stages, played sequentially:

1. The PBM and manufacturers negotiate rebate contracts $\mathbb{C} = \{\mathbb{C}_1, \dots, \mathbb{C}_M\}$ as follows:
 - (a) The PBM offers each manufacturer i a *privately observed* contract \mathbb{C}_i .
 - (b) Each manufacturer i then simultaneously decides to accept or reject its contract offer.
2. Given the profile of accepted rebate contracts, the PBM chooses a formulary \mathbb{F} .
3. Given the formulary \mathbb{F} , consumers choose which drugs to purchase.

¹⁵In our model, linear rebates can be also modeled as lump-sum payments without affecting results. This is because realized drug demand is affected by the formulary but not rebate payments, and rebate payments can vary flexibly across formularies; hence any linear rebate can be expressed as an equivalent lump-sum payment.

¹⁶We assume that generic drugs do not pay rebates, and are all placed on a common generic tier.

¹⁷Theoretically, a PBM can benefit from using negative rebates with some drug manufacturers (in which case the PBM pays an additional per-unit fee on top of the list price) in order to strengthen its bargaining leverage with other manufacturers. For example, if threatening to choose formulary \mathbb{F}' instead of \mathbb{F}'' upon disagreement with manufacturer i would allow the PBM to negotiate a higher rebate with i , then the PBM could potentially agree to negative rebates with other manufacturers under formulary \mathbb{F}'' in order to make such a threat to choose \mathbb{F}' credible. We do not consider such strategies here.

Payoffs. The PBM’s payoff, represented by $\Pi_P(\cdot)$, is a function of the formulary \mathbb{F} chosen and the profile of negotiated rebate contracts \mathbb{C} , and is a weighted difference of the consumer welfare that it generates for its plan sponsor and the drug costs (net of rebates and consumer out-of-pocket payments) that it incurs:

$$\Pi_P(\mathbb{F}, \mathbb{C}) = \gamma W(\mathbb{F}) - \sum_i D_i(\mathbb{F}) \times (p_i - p^{oop}(\mathbb{F}_i) - \mathbb{C}_i(\mathbb{F})) , \quad (1)$$

where $W(\mathbb{F})$ is a measure of consumer welfare generated by formulary \mathbb{F} , multiplied by some weight $\alpha \geq 0$; $D_i(\mathbb{F})$ is the number of units of drug i sold under formulary \mathbb{F} ; p_i is the list price for drug i ; and $p^{oop}(\mathbb{F}_i)$ is the consumer out-of-pocket price for drug i , which is assumed to depend only on the tier that the drug is placed on. One important assumption, consistent with and maintained in our empirical application, is that conditional on the formulary \mathbb{F} that is chosen, each drug’s realized demand $D_i(\mathbb{F})$ does not vary with the negotiated rebate payment.

Drug manufacturer i ’s payoff, represented by $\Pi_i(\cdot)$, is a function of the formulary \mathbb{F} chosen and its per-unit rebate payment under that formulary $\mathbb{C}_i(\mathbb{F})$; it is equal to the demand that it receives times its margin (list price minus rebate payments):

$$\Pi_i(\mathbb{F}, \mathbb{C}_i(\mathbb{F})) = D_i(\mathbb{F}) \times (p_i - \mathbb{C}_i(\mathbb{F})) . \quad (2)$$

We assume that marginal costs are zero for each drug.

Equilibrium and Solution Concept. An equilibrium of our game consists of a profile of rebate contracts $\hat{\mathbb{C}}$ that are offered to manufacturers by the PBM in Stage 1(a), a profile of acceptance decisions on the part of manufacturers over which contracts to accept and beliefs over the contracts received by their rivals in Stage 1(b), and the PBM’s choice of formulary conditional on which profile of contracts have been accepted in Stage 2. (We assume that consumer demand for drugs in Stage 3, for any arbitrary formulary, is known and well defined.)

Our solution concept is pure-strategy weak Perfect Bayesian equilibrium (WPBE) with passive beliefs (Hart and Tirole, 1990; McAfee and Schwartz, 1994). Because contract offers made by the PBM in Stage 1(a) are private and there are contracting externalities—a manufacturer’s realized payoff depends on the contracts accepted by other manufacturers, as they influence the formulary that is chosen—each manufacturer must have beliefs over the contract offers made to rivals to determine whether to accept a contract offer in Stage 1(b). Passive beliefs strengthens WPBE by requiring that each manufacturer, upon receiving an off-equilibrium offer from the PBM, holds the same beliefs over rivals’ contract offers as those that it holds on the equilibrium path. Perfection implies that the PBM’s choice of formulary in Stage 2 maximizes its payoff given the profile of contracts that are agreed to (or “signed”) in Stage 1.

Relation to Prior Literature. Stage 1 of our game is a version of what Segal and Whinston (2003) refer to as an *offer game* with private offers, in which a single principal (here, the PBM)

makes simultaneous privately-observed take-it-or-leave-it offers to multiple agents (here, drug manufacturers). Such a game has been widely used in the industrial organization literature to model vertical contracting (e.g., Hart and Tirole, 1990; McAfee and Schwartz, 1994; Segal, 1999), and we follow certain conventions from this literature, including the use of WPBE with passive beliefs as our solution concept.

Moreover, our rebate contract—which allows the per-unit rebate paid by each manufacturer to vary depending on the formulary that is chosen by the PBM—is a version of a *menu contract* discussed in Segal and Whinston (2003).¹⁸ There are two important distinctions between our analysis and theirs. First, Segal and Whinston derive equilibrium contracting outcomes that are robust to menu contracts deviations by the principal under *arbitrary* beliefs that agents can hold over the principal’s off-equilibrium offers to other agents. We instead restrict any contract offer to be a menu contract, and impose a passive beliefs restriction on agents’ off-equilibrium beliefs. Second, Segal and Whinston assume that payoffs for an agent that does not sign a contract with the principal do not depend on the contracts signed with others; using the language of Segal (1999), this is referred to as “no externalities on nontraders.” In our setting, the payoff for a manufacturer that does not sign a rebate contract is not constant, and can depend on the profile of contracts signed by rivals’ when those contracts affect the formulary that is chosen by the PBM.¹⁹

If instead of the PBM making take-it-or-leave-it offers to the manufacturers in Stage 1, the manufacturers made rebate contract offers to the PBM (and the PBM would then accept or reject any subset of offers), our game would be a version of a “menu auction” introduced and analyzed in Bernheim and Whinston (1986). We discuss the relationship between our game and the menu auction variant below in Section 3.5.

Last, we do not allow the PBM to commit in Stage 1 to a particular formulary in Stage 2. This sets our analysis apart from mechanism design approaches to contracting with externalities, wherein the principal might be able to secure more desirable outcomes if it could engage in commitment (e.g., Jehiel, Moldovanu and Stacchetti, 1996). Here, a PBM cannot threaten a manufacturer with the choice of an arbitrary formulary in Stage 2 if the manufacturer rejects a contract offer; under a WPBE, whatever formulary the PBM chooses must be credible (i.e., optimal) given the profile of contracts signed with the manufacturers’ rivals.

3.2 Equilibrium Analysis

In Stage 2, for any profile of rebate contracts \mathbb{C} , the PBM chooses a formulary that maximizes its payoff. We assume that there is always a unique maximum, so that we can define this formulary as $f(\mathbb{C}) \equiv \arg \max_{\mathbb{F}} \Pi_P(\mathbb{F}, \mathbb{C})$.²⁰ This characterizes equilibrium Stage 2 behavior for the PBM. We

¹⁸As noted by these authors, such menu contracts can be viewed a way of screening the different “types” of the PBM, where each type corresponds to a different profile of contracts that the PBM has signed with other manufacturers.

¹⁹This is one reason why we do not follow Segal and Whinston and consider arbitrary beliefs: in our game, different beliefs can lead to different perceived rejection payoffs, and hence a PBM may not be able to induce a manufacturer to always accept a particular contract offer regardless of the manufacturer’s beliefs even with arbitrary menu contracts.

²⁰Generically, a PBM will not be indifferent over any two formularies when rebates are zero. Further, in a manner similar to Jehiel, Moldovanu and Stacchetti (1996), we can also assume that there exists a smallest money unit for

say that such a formulary $f(\mathbb{C})$ is induced by rebate contracts \mathbb{C} .

One useful object to define is $\Pi_i^d(\mathbb{C}_{-i}) \equiv \Pi_i(f(\{\mathbb{C}^0, \mathbb{C}_{-i}\}), \mathbb{C}^0)$ which is what we refer to as manufacturer i 's perceived *disagreement payoff* given rivals' contracts \mathbb{C}_{-i} . This object represents what i expects to earn if it rejects a contract offer from the PBM (or agrees to a null contract), and it believes its rivals sign contracts \mathbb{C}_{-i} so that the PBM chooses the alternative *disagreement formulary* $f(\{\mathbb{C}^0, \mathbb{C}_{-i}\})$.

Now consider any equilibrium in which contract offers $\hat{\mathbb{C}}$ are accepted in Stage 1 and the PBM chooses formulary $\hat{\mathbb{F}} = f(\hat{\mathbb{C}})$ in Stage 2.²¹ In such an equilibrium, the following two necessary conditions must hold.

Condition 1. Each manufacturer earns its disagreement payoff, given the contracts signed by others. It must be that for each manufacturer i , $\Pi_i(\hat{\mathbb{F}}, \hat{\mathbb{C}}_i(\hat{\mathbb{F}})) \geq \Pi_i^d(\hat{\mathbb{C}}_{-i})$, and each manufacturer i weakly prefers accepting its equilibrium contract offer $\hat{\mathbb{C}}_i$ and earning payoff $\Pi_i(\hat{\mathbb{F}}, \hat{\mathbb{C}}_i(\hat{\mathbb{F}}))$ to earning disagreement payoff $\Pi_i^d(\hat{\mathbb{C}}_{-i})$. In equilibrium, these inequalities must bind:

Lemma 3.1. *In any equilibrium in which contract offers $\hat{\mathbb{C}}$ are accepted and the PBM chooses formulary $\hat{\mathbb{F}}$, each manufacturer i earns its disagreement payoff given rivals' contracts $\hat{\mathbb{C}}_{-i}$:*

$$\Pi_i(\hat{\mathbb{F}}, \hat{\mathbb{C}}_i(\hat{\mathbb{F}})) = \Pi_i^d(\hat{\mathbb{C}}_{-i}), \quad (3)$$

and its equilibrium rebate payment satisfies:

$$\hat{\mathbb{C}}_i(\hat{\mathbb{F}}) = p_i - \frac{\Pi_i^d(\hat{\mathbb{C}}_{-i})}{D_i(\hat{\mathbb{F}})}. \quad (4)$$

If (3) did not hold for some manufacturer i so that i earned strictly more than its disagreement payoff, the PBM would have a profitable deviation by offering i a contract specifying a higher rebate under the equilibrium formulary that i would still accept. Equation (4) follows directly from (3) given the definition of $\Pi_i(\cdot)$. (All proofs are contained in the Appendix.)

Condition 2. The equilibrium formulary maximizes the bilateral surplus for all PBM-manufacturer pairs, given the contracts signed by others. Holding fixed the contracts $\hat{\mathbb{C}}_{-i}$ of other manufacturers, the equilibrium formulary $\hat{\mathbb{F}}$ chosen must maximize the bilateral surplus between the PBM and each manufacturer i :

$$\Pi_P(\hat{\mathbb{F}}, \hat{\mathbb{C}}) + \Pi_i(\hat{\mathbb{F}}, \hat{\mathbb{C}}_i(\hat{\mathbb{F}})) \geq \Pi_P(\mathbb{F}', \{\mathbb{C}^0, \hat{\mathbb{C}}_{-i}\}) + \Pi_i(\mathbb{F}', \mathbb{C}^0) \quad \forall \mathbb{F}' \neq \hat{\mathbb{F}} \quad (5)$$

To show this, we prove that a stronger condition must hold in any equilibrium:

rebates that is large enough so that the PBM is never indifferent over different formularies for any arbitrary set of rebate contracts.

²¹Since the PBM can offer null contracts, without loss of generality we restrict attention to equilibria in which contract offers are accepted by all manufacturers.

Lemma 3.2. *In any equilibrium in which contract offers \hat{C} are accepted and the PBM chooses formulary \hat{F} , then the following necessary conditions must hold:*

$$\Pi_P(\hat{F}, \hat{C}) \geq \Pi_P(\mathbb{F}', \{\mathbb{C}^0, \hat{C}_{-i}\}) + \max \left\{ \Pi_i(\mathbb{F}', \mathbb{C}^0) - \Pi_i^d(\hat{C}_{-i}), 0 \right\} \forall i, \mathbb{F}' \neq \hat{F}. \quad (6)$$

If condition (6) did not hold, then there would then exist a profitable deviation for the PBM to offer another (potentially null) contract to manufacturer i that i would accept, would lead the PBM to choose some alternative formulary $\mathbb{F}' \neq \hat{F}$, and would lead to strictly higher payoffs for the PBM.²²

These necessary conditions given by (3) and (6) are established by ruling out PBM deviations involving offers to a single manufacturer, and are analogous to those derived in Segal (1999) and Segal and Whinston (2003). These two conditions alone are also sufficient for an accepted profile of contracts \hat{C} and associated formulary \hat{F} to comprise what we refer to as a *delegated-agent equilibrium* (or DA-equilibrium), which is an equilibrium of our game when the PBM is only able to engage in deviations involving a single manufacturer in Stage 1.²³ This follows from arguments used in the proofs for Lemmas 3.1-3.2, which can be used to establish that the PBM cannot engage in a deviation with only a single manufacturer i that results in strictly higher payoffs by (i) paying less to i and still choosing the equilibrium formulary \hat{F} , or (ii) offering an acceptable deviant contract to i and choosing any other formulary $\mathbb{F}' \neq \hat{F}$.

Without the restriction to single-manufacturer deviations, these two conditions are not sufficient for a profile of contracts to comprise an equilibrium, and an additional condition is required to rule out PBM deviations that involve multiple manufacturers. In Appendix A.2, we derive an additional *no multilateral deviation (NMD) condition* that, alongside the above two, are necessary and sufficient for a profile of accepted contracts \hat{C} and associated formulary \hat{F} to comprise an equilibrium.

3.3 Equilibrium Multiplicity and Refinement

The equilibrium conditions derived in Section 3.2 impose restrictions on the rebate payments that are made in equilibrium. However, given the contracts signed by rivals \hat{C}_{-i} , these conditions do not place restrictions on manufacturer i 's rebates $\hat{C}(\mathbb{F}')$ for any formulary $\mathbb{F}' = \hat{F}$ that is *not* chosen

²²To see why (6) implies (5), recall that Lemma 3.1 establishes that in any equilibrium where all offers are accepted, each manufacturer i earns its disagreement payoff: $\Pi_i(\hat{F}, \hat{C}_i(\hat{F})) = \Pi_i^d(\hat{C}_{-i})$. Note that the max operator on the right-hand side of (6) is required due to the non-negativity constraint imposed on rebates: whenever $\Pi_i(\mathbb{F}', 0) < \Pi_i^d(\hat{C}_{-i})$, the PBM can deviate and choose formulary \mathbb{F}' without paying a rebate to (or being able to extract a rebate from) manufacturer i .

²³This referred to as a “delegated agent” equilibrium as it is an equilibrium of a modified game in which the PBM sends separate representatives to negotiate with each manufacturer prior to Stage 1, and these representatives cannot coordinate their offers in Stage 1. Such a concept has been previously employed in the vertical contracting literature. For example, early micro-foundations of the “Nash-in-Nash” solution concept used in applied work invoked a version of a delegated agent equilibrium (see discussion in Collard-Wexler, Gowrisankaran and Lee, 2019). See also Ho and Lee (2019) and Rey and Vergé (2020) who use a model of delegated negotiations when providing a micro-foundation for their alternative bargaining concepts.

in equilibrium (as long as it is still optimal for the PBM to choose $\hat{\mathbb{F}}$). As the following example illustrates, there can thus be multiple equilibria.

Example 1. *There are two manufacturers M1 and M2 and two formulary tiers $\{P, NP\}$ for each drug, so that there are four potential formularies: $\mathcal{F} = \{(P, P), (P, NP), (NP, P), (NP, NP)\}$, where each pair corresponds to the tiers chosen for manufacturer 1 and 2 (respectively). Manufacturers' payoffs without rebate payments are,*

$$\begin{array}{ll} \pi_1(P, P) = 10 & \pi_2(P, P) = 10 \\ \pi_1(P, NP) = 16 & \pi_2(P, NP) = 6 \\ \pi_1(NP, P) = 6 & \pi_2(NP, P) = 12 \\ \pi_1(NP, NP) = 8 & \pi_2(NP, NP) = 8 \end{array}$$

and PBM payoffs, before rebate payments, are zero for all formularies.

Consider the following two equilibria:

1. The PBM offers contracts $\mathbb{C}_1 = (0, 8, 0, 0)$ and $\mathbb{C}_2 = (0, 0, 0, 2)$, where each element of \mathbb{C}_i corresponds to the total rebate payment manufacturer i makes under each formulary in \mathcal{F} : e.g., if formulary (P, NP) is chosen, \mathbb{C}_1 would require that M1 pay a total rebate of 8.²⁴ Both contracts are accepted, and the PBM chooses formulary (P, NP) . After rebate payments, the PBM earns 8, M1 earns 8, and M2 earns 6.
2. The PBM offers contracts $\mathbb{C}_1 = (4, 10, 0, 2)$ and $\mathbb{C}_2 = (4, 0, 6, 2)$. Both contracts are accepted, and the PBM chooses formulary (P, NP) . After rebate payments, the PBM earns 10 and M1 and M2 earn 6.

Even though in both equilibria the formulary (P, NP) is chosen by the PBM, M1's rebate is less in the first equilibrium than in the second. This arises due to differences in manufacturer 1's perceived disagreement formulary $f(\{\mathbb{C}^0, \hat{\mathbb{C}}_2\})$: in the first equilibrium, M1 anticipates that the PBM would choose formulary (NP, NP) if M1 rejected its contract offer (yielding the PBM its highest rebate payment under $\hat{\mathbb{C}}_2$); in contrast, in the second equilibrium, M1 anticipates that the PBM would choose formulary (NP, P) upon rejection. Hence, M1 is willing to pay a higher rebate under formulary (P, NP) in the second equilibrium.²⁵

The example illustrates how equilibrium rebate payments for a given manufacturer are affected by rivals' agreed-to rebate payments for formularies that are not chosen in equilibrium through their impact on perceived disagreement formularies. Further, it clarifies how equilibrium multiplicity arises as a consequence of contracting externalities.

²⁴We present total rebate payments here for convenience; it is straightforward to convert total rebate payments to per-unit rebates by dividing through by the demand for each drug realized under each formulary.

²⁵It is straightforward to show that manufacturers are willing to accept their contracts, and that both profiles of contracts comprise delegated-agent equilibria. In Appendix A.2, we also show that both remain equilibria when the PBM can engage in multilateral deviations under an additional requirement that the PBM cannot offer contracts that, under any formulary, results in manufacturers earning less than their disagreement payoffs.

Nonetheless, there may be reasons why the first equilibrium in the prior example is plausibly less reasonable than the second. In particular, in the first equilibrium, the PBM only demands positive rebates from $M2$ for a single formulary (NP, NP) (which is not selected in equilibrium), but not under any other formulary—including formularies such as (NP, P) under which $M2$ would earn significantly higher payoffs, and hence be willing to pay a positive rebate. Similarly, the PBM only demands a positive rebate from $M1$ under the equilibrium formulary (P, NP) even though $M1$ would be willing to pay positive rebates under alternative formularies.

In contrast, in the second equilibrium, the PBM utilizes rebate contracts to extract from manufacturers what they would be willing to pay to avoid the anticipated disagreement formulary from being chosen under *any* formulary, and not just under the equilibrium formulary. As the PBM is able to make take-it-or-leave-it offers, the PBM might reasonably use rebate contract offers to, if possible, hold manufacturers to their reservation payoffs across all potential formularies.

Based on this reasoning, we introduce the following equilibrium refinement that imposes restrictions on the value of rebate payments for formularies not chosen in equilibrium.

Definition 3.3. Consider any equilibrium in which contract offers \hat{C} are accepted in Stage 1 and the PBM chooses formulary $\hat{F} = f(\hat{C})$ in Stage 2. Equilibrium contracts \hat{C} satisfy **manufacturer indifference (MI)** if, for all manufacturers i and all formularies $F' \neq \hat{F}$, the rebate $C_i(F') = \max\{X, 0\}$, where X is the solution to

$$\Pi_i(F', X) = \Pi_i(\hat{F}, \hat{C}_i(\hat{F})) , \quad (7)$$

and represents the hypothetical (potentially negative) rebate paid by manufacturer i under formulary F' that would earn it the same equilibrium payoff $\Pi_i(\hat{F}, \hat{C}_i(\hat{F}))$.²⁶

In any equilibrium that satisfies manufacturer indifference, the equilibrium contract \hat{C}_i restricts rebate payments for formularies $F' \neq \hat{F}$ in the following manner for each manufacturer i : either (i) the manufacturer is indifferent between F' and equilibrium formulary \hat{F} so that $\Pi_i(F', \hat{C}_i(F')) = \Pi_i(\hat{F}, \hat{C}_i(\hat{F}))$; or (ii) the manufacturer earns less under F' so that $\Pi_i(F', C_i(F')) < \Pi_i(\hat{F}, \hat{C}_i(\hat{F}))$, and $C_i(F') = 0$.

In Example 1, Equilibrium 1 does not satisfy MI, but Equilibrium 2 does. Under Equilibrium 2, contracts are $C_1 = (4, 10, 0, 2)$ and $C_2 = (4, 0, 6, 2)$, and rebate contracts for both manufacturers are set so that each always earns payoffs of 6 (equal to their equilibrium payoffs) regardless of which formulary is chosen. Equilibrium 2 is also the unique equilibrium which satisfies MI.

Using this example, we discuss additional properties of equilibria that satisfy MI (MI-equilibria).

First, focusing on MI-equilibria captures the idea that the PBM is able to play off manufacturers against one another in the event that there is disagreement, even in a one-shot contracting game. To see this, note that $M2$ pays 0 under the equilibrium formulary (P, NP) given the contract $C_2 = (4, 0, 6, 2)$. However, in the off-equilibrium event that the PBM disagrees with $M1$, $M2$ would be willing to pay a higher rebate if formulary (NP, P) were chosen—under the MI-equilibrium

²⁶The solution is $X = p_i - \Pi_i(\hat{F}, \hat{C}_i(\hat{F}))/D_i(F')$.

contract, $M2$ is willing to pay up to 6 which earns it the same payoffs as its earns in equilibrium. In turn, this has an impact on what the PBM can extract from $M1$. In Equilibrium 1 of the example, $M1$'s perceived disagreement formulary was (NP, NP) , which meant that $M1$ was willing to pay no more than 8 under the equilibrium formulary. In Equilibrium 2 of the example, because $M2$ is willing to pay more under formulary (NP, P) , it becomes credible for the PBM to choose (NP, P) if it disagreed with $M1$, thereby allowing the PBM to extract a higher rebate payment of 10 from $M1$.

Second, MI-equilibria can be viewed as providing a form of protection for manufacturers in that if their formulary placement were ever unexpectedly adjusted in a way that lowered their payoffs, their rebate would adjust. In the example, consider $M1$'s contract \mathbb{C}_1 which pays the PBM a rebate of 10 under the equilibrium formulary (P, NP) . If $M1$ was ever placed on a lower tier following the contracting stage of the game—say, due to a deviant contract offer made by the PBM to $M2$ which now made choosing (NP, P) more profitable— $M1$'s rebate payment under its equilibrium contract is reduced, ensuring $M1$'s net payoffs remain the same.²⁷

Importantly, MI-equilibria have the property that the equilibrium formulary chosen is *efficient* for the contracting parties:

Proposition 3.4. *In any MI-equilibrium, the equilibrium formulary $\hat{\mathbb{F}} = \mathbb{F}^*$, where \mathbb{F}^* is the formulary that maximizes joint payoffs between the PBM and all manufacturers:*

$$\mathbb{F}^* = \arg \max_{\mathbb{F}} \Pi_P(\mathbb{F}, \mathbb{C}^0) + \sum_i \Pi_i(\mathbb{F}, \mathbb{C}^0)$$

Intuitively, this result follows because equilibrium contracts that satisfy manufacturer indifference, by holding manufacturers to their disagreement payoffs, allow the PBM to internalize differences in their payoffs across different formularies.

3.4 Computing Equilibria

In Appendix A.3, we provide an algorithm that computes all MI-equilibria of our game in which all contract offers are accepted.²⁸ A brief overview follows.

Given Proposition 3.4, any MI-equilibrium involves the PBM selecting the formulary $\hat{\mathbb{F}} = \mathbb{F}^*$ in Stage 2. Given \mathbb{F}^* is chosen in Stage 2, the algorithm searches over all potential profiles of *perceived disagreement formularies*. A given profile of perceived disagreement formularies specifies what each manufacturer believes will be chosen by the PBM if the manufacturer rejects the PBM's contract offer. Given the equilibrium formulary $\hat{\mathbb{F}}$ and profile of perceived disagreement formularies, we then compute the unique profile of *implied rebate contracts* that satisfy necessary condition 1 given by

²⁷More generally, if a manufacturer is worse off under an alternative formulary, its MI-equilibrium contracts would specify either a zero rebate or a positive rebate that would generate the same payoffs as under the equilibrium formulary.

²⁸Using payoffs derived from our empirical application and examining up to three tiers and three drugs, we have always computed a unique MI-equilibrium.

Lemma 3.1 (equation (3)) and the MI-conditions specified in Definition 3.3. We then check whether, given these implied rebate contracts, (i) the PBM would choose formulary $\hat{\mathbb{F}}$ in equilibrium; (ii) upon disagreement with each manufacturer, the PBM would optimally choose the manufacturer’s perceived disagreement formulary; and (iii) necessary condition 2 given by equation (6) is satisfied for all manufacturers and alternative formularies. If these conditions are satisfied, then these implied rebate contracts and the equilibrium formulary $\hat{\mathbb{F}}$ is a delegated-agent equilibrium of our game that satisfies the MI refinement. Last, we test whether the PBM can engage in a profitable multilateral deviation; if the delegated-agent equilibrium survives, then it also is an MI-equilibrium of our game.

3.5 “Bidding game” variant of the model

Consider a variant of the above model with the following alternative structure that assumes manufacturers make rebate contract offers to the PBM:

1. Each manufacturers i simultaneously offers a rebate contract \mathbb{C}_i to the PBM.²⁹
2. Given the profile of submitted rebate contracts, the PBM chooses a formulary \mathbb{F} .
3. Given the formulary \mathbb{F} , consumers choose which drugs to purchase.

Using the terminology of Segal and Whinston (2003), this adjustment transforms our “offer game” (whereby the PBM makes *offers* to the manufacturers) into a “bidding game” (whereby manufacturers submit *bids* to the PBM in order to influence its choice of formulary). Because rebate contracts are menus that depend on the PBM’s choice of formulary, this bidding game is a “menu auction” as defined and analyzed in Bernheim and Whinston (1986): as in their analysis, here bids (rebate contracts) are restricted to be non-negative and allowed to vary based on the action (formulary) chosen by the PBM.

Our manufacturer indifference condition (Definition 3.3) imposed on equilibrium contract offers coincides with Bernheim and Whinston (1986)’s restriction to *Truthful Nash Equilibria* in a menu auction. In Truthful Nash Equilibria, bidders employ *truthful strategies*, which in the bidding-game variant of our setting are rebate contracts submitted by manufacturers that, for any potential formulary chosen by the PBM, (i) provide each manufacturer with the same net payoff as it would obtain under the equilibrium formulary, or (ii) provide each manufacturer with strictly lower payoffs than under the equilibrium formulary, in which case the manufacturer pays no rebate. These conditions also hold for MI-equilibria, given by condition (7). Furthermore, Bernheim and Whinston (1986) establish that, in a menu auction, every bidder’s best-response set contains a truthful strategy;³⁰ that all Truthful Nash Equilibria are Coalition-Proof Nash Equilibrium (Bernheim, Peleg and Whinston, 1987); and, hence, Truthful Nash Equilibria may be seen as quite “focal.”

²⁹Note that because rebate contracts are non-negative, it is not optimal for the PBM to reject any rebate contract offer.

³⁰In contrast, a PBM’s optimal deviation from a candidate equilibrium will not necessarily be contracts satisfying our manufacturer indifference condition (see Appendix A.2 which constructs optimal multilateral deviations).

In any Truthful Nash Equilibrium of the bidding-game, as in all MI-equilibria of our offer game, rebate contracts provide a way for the PBM to internalize manufacturers’ preferences over different formularies, and hence it is perhaps intuitive that the PBM selects the formulary which maximizes joint-payoffs between the PBM and all manufacturers (Proposition 3.4, Bernheim and Whinston (1986) Theorem 2). Because the selected formulary will be the same, any differences in outcomes between MI-equilibrium of the offer game and Truthful Nash Equilibrium of the bidding game will be restricted to the net payoffs received by manufacturers and the PBM.

In the Appendix A.4, we use results from Bernheim and Whinston (1986) to characterize equilibrium payoffs and rebate offers under the bidding-game variant of our model. In Section 5.2, we compare predictions between the offer- and bidding-game variants of the model within our empirical application.

3.6 List Prices

In the above analysis, equilibrium formularies and rebate contracts are determined holding list prices fixed. List prices affect these equilibrium outcomes through their impact on PBM and manufacturer payoffs at both formularies chosen in equilibrium, and formularies not chosen (e.g., manufacturers’ perceived disagreement formularies).

One natural extension to our model is to add an initial stage, prior to the negotiation of rebate contracts, whereby list prices are determined (e.g., via simultaneous price-setting by the manufacturers). In such an extension, it will be important to account for constraints on list prices that can arise outside of the bargaining context. One such constraint would be allowing for realized demand for manufacturers’ drugs to be affected by list prices \mathbf{p} —i.e., for each drug i , demand is given by $D_i(\mathbf{p}, \mathbb{F})$, where $\mathbf{p} = \{p_i\}$. This can arise if list prices are set for a larger population of consumers, some of whom may be uninsured or face cost-sharing instruments that depend on the list price (e.g., coinsurance or deductibles). We believe that this extension is important for determining how changes in rebate negotiations impact list prices, and is the subject of ongoing work.³¹

4 Empirical Application

We now specify and estimate a demand system for branded drugs within our focal therapeutic class (statins) that allows us to predict demand for each drug under any potential formulary. This demand system, combined with the theoretical model developed in the previous section, allows us in Section 5 to simulate and predict equilibrium rebates and formularies under different contracting environments.

³¹In our empirical application where these cost-sharing instruments are not present and consumers are not uninsured, we assume the impact of list prices do not affect consumer demand.

4.1 Data and setting

Our primary dataset comprises enrollment information, pharmaceutical claims, and drug formularies from Princeton University for 2011-2018. Within prescription drugs, we focus on statins—a class of cholesterol-lowering drugs—for several reasons. First, statins are costly for both the enrollee and the sponsor, amounting to 10% of total consumer out-of-pocket spending on prescription drugs in our sample, and 6% of employer drug spending. Second, there are a small number of branded options. In 2011, only Crestor, Lipitor and Vytorin had substantial market shares, with a few other branded drugs also available³². Finally, we observe movement in tier placement for all major branded statins during the time period of our data, providing useful variation for identifying the impact of formulary placement on demand.

Enrollment and claims data. We use enrollment and claims data for Princeton employees and their dependents who enroll in a drug plan offered by Princeton. We restrict our sample to enrollees who are present in our data for at least a full calendar year and who are observed to have at least one filled prescription for a statin.³³ For each enrollee, we observe the date of any prescription statin purchase; the drug name; out-of-pocket price; the amount paid by the PBM (but not the rebate received at year-end); number of days’ supply; and retail channel (retail pharmacy or mail order) for the purchase. We calculate the discounted list price for each fill as the sum of patient and PBM payments per 30 days’ supply. The median value for the drug-year is used as an input into our contracting simulations.³⁴ We also observe demographic information including age, gender, salary band, and family identifiers.

Table 1 contains summary statistics for this sample. There are 1,965 enrollees (employees plus dependents) who take a statin during the eight years covered by our data.³⁵ Approximately 50% of these enrollees take their first-ever statin during those years; the average number of different statins taken is 1.5. These two features of the data will be useful in estimating switching costs separately from underlying enrollee preferences over drug characteristics. Two-thirds of statin-takers are between the ages of 45–64, and one-third are female. Just over half of statin fills are

³²Vytorin was a branded drug which combined the active ingredients in two other branded drugs, Zetia (a cholesterol absorption blocker) and Zocor (a statin). Zocor’s patent expired in 2006. In 2008, the ENHANCE trial showed that Vytorin was no better than Zocor alone; the American Academy of Cardiologists recommended that doctors no longer prescribe Vytorin shortly afterwards (Greenland and Lloyd-Jones 2008, Sinkinson and Starc 2018). These studies help explain the relatively low market share of Vytorin in our data. However, a more recent and larger study found Vytorin to be more effective than Zocor alone (Blazing et al 2014).

³³We include active employees aged over 65 since they are enrolled in the same plans with the same coverage as younger employees; we exclude retirees who enroll in Medicare Part D plans. We exclude enrollees taking cholesterol-lowering drugs that are not statins; this involves dropping 8% of the enrollees taking cholesterol-lowering drugs.

³⁴We take one additional step to account for differences between purchasing channels. We take the median across fills in the drug-channel-year, noting that this value is higher for drugs purchased through the retail rather than mail order channel. The difference (approximately \$20 for statins) is due to dispensing fees and the spread between pharmacy and PBM discounts on the list price. We define the “retail wedge” to be the difference between median retail and mail order discounted list prices for the drug-year, and assume that the PBM pays this retail wedge but the manufacturer does not receive it.

³⁵There are 8,495 enrolled employees in total; 6,834 take a prescription drug. Our sample includes dependents as well as employees.

Table 1: Summary statistics

	Pooled	2011	2012	2013	2014	2015	2016	2017	2018
Number of enrollees taking statins	1965	867	1012	1128	1172	1100	1093	1087	1076
Number of different statins per person	1.52	1.02	1.04	1.04	1.05	1.03	1.19	1.05	1.05
Percent taking first-ever statin (1st fill)	0.51	0.11	0.08	0.15	0.13	0.10	0.14	0.11	0.12
For enrollees taking statins:									
% 75k-150k	0.36	0.36	0.34	0.33	0.34	0.35	0.35	0.36	0.38
% above 150k	0.18	0.19	0.20	0.19	0.19	0.21	0.22	0.23	0.21
% aged 45-64	0.67	0.72	0.71	0.72	0.70	0.67	0.69	0.68	0.68
% aged over 64	0.22	0.19	0.21	0.20	0.22	0.26	0.25	0.26	0.25
% female	0.37	0.36	0.36	0.37	0.36	0.35	0.34	0.34	0.34
For statins filled:									
Total fills per year	35220	1614	2967	4827	5082	4944	4753	5369	5664
% mail order	0.56	0.70	0.68	0.65	0.60	0.61	0.50	0.48	0.44
% tier 2 (\$25)	0.14	0.62	0.22	0.21	0.21	0.21	0.06	0.00	0.00
% tier 3 (\$40)	0.01	0.00	0.03	0.02	0.02	0.00	0.01	0.01	0.01
% tier 4 (excluded or MPTD)	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00
Lipitor (pooled LP is fill-weighted average)									
Share (% of fills)	0.03	0.37	0.025	0.02	0.01	0.00	0.00	0.00	0.00
Tier (at January 1)		2	3	3	3	MPTD	MPTD	MPTD	MPTD
LP	158.85	136.45	147.59	169.07	201.90	246.38	300.70	362.49	399.56
Crestor (pooled LP is fill-weighted average)									
Share	0.11	0.20	0.18	0.18	0.18	0.18	0.07	0.01	0.00
Tier		2	2	2	2	2	2	MPTD	MPTD
LP	164.86	120.19	138.70	147.06	165.27	189.39	223.62	234.02	231.76
Vytorin (pooled LP is fill-weighted average)									
Share	0.01	0.03	0.02	0.02	0.02	0.02	0.01	0.00	0.00
Tier		2	2	2	2	2	3	2	MPTD
LP	164.76	113.51	124.79	143.68	166.65	208.02	232.70	278.79	
Other branded (LP is fill-weighted average)									
Share	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
LP	169.21	103.58	121.32	137.63	154.27	177.17	189.00	219.53	247.01
Generic statins (LP is fill-weighted average)									
Share	0.84	0.38	0.75	0.77	0.77	0.79	0.92	0.98	0.99
LP	20.97	8.94	17.60	12.44	8.34	8.60	32.54	34.64	24.98

Notes: Age statistics are computed for the first appearance of each individual in the data for the pooled sample.

by mail order, although this proportion decreases over the time period. The proportion of fills for generic statins increases from 38% in 2011 to 99% in 2018, consistent with significant generic entry during the sample. Finally, the list prices of the branded products averaged between \$160 and \$170 per 30 days' supply (increasing over time with generic introduction), compared to \$20 on average for generics.³⁶

Formulary data. Princeton contracted with two PBMs between 2011–2018: Express Scripts between 2011–2015, and Optum between 2016–2018. Both of these PBMs operated formularies

³⁶The increase in the average generic list price in 2016 is attributable to the introduction of Rosuvastatin, the generic version of Crestor, at a higher price than other generic drugs.

Table 2: Formulary tiers and out-of-pocket prices

2011-2014		2015		2016-2018	
Tier	Retail price	Tier	Retail price	Tier	Retail price
Generic	\$5	Generic	\$5	Generic	\$5
Branded	\$25	Branded	\$25	Tier 2	\$25
Multisource	\$40	Multisource	MPTD*	Tier 3	\$40
				Tier 3 Multisource	MPTD*

Notes: Retail prices are per 30 days' supply. Mail order prices are double, for 90 day's supply. Contract with Express Scripts 2011-15; Optum 2016-18.

* Member Pays the Difference (MPTD) applied for the branded version of multi-source drugs (i.e., molecules for which both generic and branded versions are available), and involved the enrollee paying the difference between branded and generic list prices plus the generic copay.

with multiple tiers. Out-of-pocket prices and other details are provided in Table 2.

Express Scripts (2011–2015) determined co-pays for branded drugs included on the formulary on the basis of generic availability. From 2011–2014, retail out-of-pocket payments for 30 days' supply were \$5, \$25, and \$40 for generic, branded, and multisource drugs respectively, where a multisource drug is a branded product for which a generic equivalent is available.³⁷ In 2015, Express Scripts changed its pricing for multisource drugs to an arrangement called “Member Pays the Difference” (or MPTD). The out-of-pocket price under MPTD was determined to be the difference between the branded and generic drugs' list prices, plus the generic copay (so that the sponsor's effective price was the same as it would have been if the generic was purchased).

Optum (2016–18) introduced flexibility in the tier placement for branded drugs, which could now be placed on Tier 2 (“Preferred”) or Tier 3 (“Non-Preferred”). Generic drugs and multisource drugs had the same out-of-pocket prices as in 2015 under Express Scripts; however, Tier 2 and non-multisource Tier 3 drugs had copays of \$25 and \$40, respectively.³⁸ Note that this formulary structure was different from the earliest version employed by Express Scripts in 2011–2014 in two ways: the two branded tiers (Tier 2 and 3), and the much higher out-of-pocket price for Tier 3 multisource drugs.³⁹

We use our data to infer and validate the tier placement of every statin at the monthly level, across all years of our sample, using a combination of plan benefit data and claims data. For

³⁷In all years, the price was doubled for a 90-day supply if purchases were made through the mail order channel.

³⁸MPTD applied only to multisource drugs that would otherwise be on the non-preferred branded tier. That is, it was possible for a drug to be placed on Tier 2 rather than MPTD even though a generic equivalent was available. We do not observe this for statins in our data.

³⁹An exception to MPTD pricing was made for patients whose physician demonstrated a clinical need for the branded over the generic product. Princeton interpreted this clause generously: a high proportion of enrollees are observed in our data to continue taking the branded product, after generic entry, at the tier 3 out-of-pocket price (\$40). For this reason, our demand estimates indicate only a mild disutility from drugs offered under MPTD. We do not use this estimate in our counterfactuals; instead we consider the impact of complete exclusion from the formulary, interpreted as making the drug unavailable to the consumer through insurance and requiring an outlay of the full list price.

Table 3: Drug tier placements

	Pooled	2011	2012	2013	2014	2015	2016	2017	2018
Lipitor (Atorvastatin)									
Tier		2	3	3	3	MPTD	MPTD	MPTD	MPTD
Share (of fills)	0.026	0.373	0.025	0.017	0.015	0.005	0.002	0.004	0.002
Generic?		0	1	1	1	1	1	1	1
Crestor (Rosuvastatin)									
Tier		2	2	2	2	2	2 / MPTD	MPTD	MPTD
Share	0.111	0.204	0.185	0.180	0.181	0.175	0.071	0.007	0.001
Generic?		0	0	0	0	0	0/1	1	1
Vytorin (Ezetimibe/Simvastatin)									
Tier		2	2	2	2	2	3	2 / MPTD	MPTD
Share	0.012	0.026	0.023	0.020	0.020	0.017	0.005	0.002	0.000
Generic?		0	0	0	0	0	0	0/1	1

Notes: For 2011-14, Tier “2” corresponds to branded drugs (\$25 copay) and tier “3” corresponds to multi-source (\$40). PBM is Express Scripts for 2011-2015; Optum for 2016-2018. Generic rosuvastatin was introduced in May 2016; Crestor’s tier also changed that month. Similarly, generic Ezetimibe/Simvastatin was introduced during the first half of 2017; Vytorin tier changed very soon afterwards. These mid-year adjustments are accounted for in our demand model.

2016-2018 we observe the prescription drug lists mailed to members by Optum; these include the tier placement for covered drugs. However, these documents are provided annually, while we know from our interviews that tier placement can change within a year. They may also not represent a complete list of drugs; enrollees not finding their drug are referred to a longer list that was available online. The data appendix provides details of our process.

Table 3 presents the recovered tier placements of the three branded statins with the highest market share—Lipitor, Crestor and Vytorin—over the 8 years covered by our data. Their generic equivalents are Atorvastatin (introduced to the market at the end of 2011); Rosuvastatin (available from 2016 onwards) and Ezetimibe/Simvastatin (from 2017) respectively.⁴⁰

Tier changes. Key empirical objects for our analysis are the impacts on statin demand when drugs are moved across tiers in the formulary. One challenge for estimating these objects is that, while the three largest branded statins do change formulary tiers during our sample, many of these changes were contemporaneous with the entry of a generic alternative.

Here, we briefly describe the variation in the data that we leverage to estimate the impact of moving tiers on branded-drug demand separately from generic entry.⁴¹ In 2011, when only branded versions of these statins were available, all three were on the “branded” tier of the formulary, with retail out-of-pocket prices of \$25. Lipitor was moved to the multisource tier, with a \$40 copay,

⁴⁰Several other branded statins or statin combinations were also offered during our panel. Each is included as a separate potential choice in the demand model, along with the generic equivalent when available. Details of these branded drugs and their tier placement are in the data appendix.

⁴¹In addition to estimating the demand system, we could have used data on rebates to estimate a coefficient on consumer welfare in the PBM objective function. However, we were reluctant to use the available rebate data for estimation because the only information available—from SSR Health—was an average across payers. We were also reluctant to assume the observed formulary placement was a strategic choice by the PBM; as noted, for the drugs we use in our empirical work, tier assignment was almost always a response to generic entry.

in 2012 in response to entry of its generic equivalent, and then to MPTD in 2015. It remained on that least-preferred tier through the end of 2018.⁴² Crestor remained on the branded tier with \$25 copays until its generic equivalent became available, when it was moved to MPTD. Vytorin followed a similar path except that in 2016—the year before generic introduction—when Princeton switched to Optum, it was available only on the less-preferred tier 3 with a \$40 copay; it was moved to MPTD the following year. These adjustments have substantial effects on demand. For example, Lipitor had the highest share of fills in 2011, at 37%. Its share fell substantially in 2012 when its generic equivalent entered and it was moved to tier 3 of the formulary. Vytorin had a much lower share of around 3.5% in 2011. Its share fell from approximately 2.5% to 1.5% in 2016 when it was moved to tier 3 without generic entry.

4.2 Demand Model

Our demand model is estimated using data on enrollees who are observed to ever take a statin. The model allows for switching costs when enrollees consider switching drugs. We condition on the observed sequence (timing and quantity) of fills for each consumer.⁴³

4.2.1 Utility Specification

Consider an individual k with a sequence of drug fills $f = 1, \dots, F_k$. For each fill f , the individual chooses purchase channel $c \in \{R, M\}$, corresponding to retail or mail-order, and selects among drugs $i \in \mathcal{I}_{t(f)}$, where $t(f)$ is the month associated with fill f . Each drug i is associated with molecule $m(i)$, and $b(i) \in \{0, 1\}$ is an indicator for whether drug i is branded. Let $\text{tier}(i, t) \in \{1, 2, 3, 4\}$ denote the formulary tier for drug i in month t (where tier 4 represents “MPTD”).

Each individual k ’s utility in month t for a given drug i , purchase channel c and fill f is given by:

$$\begin{aligned}
 u_{kic}(i_{f-1}, c_{f-1}) = & \underbrace{\gamma_{m(i)}}_{\text{molecule FEs}} + \underbrace{\gamma_{\text{tier}(i,t),c}}_{\text{tier-channel FEs}} + \underbrace{\alpha_k \times \mathbf{1}_{(c=M)}}_{\text{channel prefs}} + \underbrace{\beta_k^B \times b(i)}_{\text{branded prefs}} & (8) \\
 & + \underbrace{\beta^M \times \mathbf{1}_{(f=1,c=M)}}_{\text{channel pref for 1st fill}} - \underbrace{SC(i, i_{f-1}, c, c_{f-1})}_{\text{switching cost}} + \varepsilon_{kic}. & (9)
 \end{aligned}$$

Channel preferences α_k depend on whether or not the fill was mail order (given by the indicator $\mathbf{1}_{(c(f)=M)}$), and are parameterized as $\alpha_k = \mathbf{z}'_k \alpha + \alpha_k^M$, where \mathbf{z}_k represent individual characteristics and α_k^M is a random coefficient normally distributed across individuals with standard deviation

⁴²The Optum drug list for 2016 denotes Lipitor as excluded; for 2017 it is MPTD; for 2018 it is again excluded. However, given that some enrollees accessed the drug throughout this time period and that the MPTD price is very similar to the out-of-pocket price if the drug is excluded, we assume the drug was available under MPTD in all three years. Effectively, we combine “excluded” and “MPTD” tiers for branded multisource statins in our data, and label the combination “MPTD”.

⁴³Some enrollees in our sample choose a combination of a statin with a different drug. We treat each combination as a separate product.

σ_M .⁴⁴ Branded preferences are given by β^B which is a mean-zero random coefficient with standard deviation σ_B .⁴⁵ We allow individuals to have different preferences for mail order for their first fill (β^M). The term $SC(\cdot)$ is a switching cost term that is non-zero only for $f \geq 2$, parameterized as:

$$\begin{aligned} SC(i, i_{f-1}, c, c_{f-1}) = & \zeta^{molecule} \times \mathbf{1}_{(m(i) \neq m(i_{f-1}))} \\ & + \zeta^{R \rightarrow M} \times \mathbf{1}_{(c=M, c_{f-1}=R)} + \zeta^{M \rightarrow R} \times \mathbf{1}_{(c=R, c_{f-1}=M)} \\ & + \zeta^{B \rightarrow G} \times \mathbf{1}_{(b(i)=0, b(i_{f-1})=1)} + \zeta^{G \rightarrow B} \times \mathbf{1}_{(b(i)=1, b(i_{f-1})=0)}, \end{aligned} \quad (10)$$

with $\zeta^{molecule}$ representing the cost of switching molecules; $\zeta^{R \rightarrow M}$ ($\zeta^{M \rightarrow R}$) representing the cost of switching from retail to mail-order (or vice versa); and $\zeta^{B \rightarrow G}$ ($\zeta^{G \rightarrow B}$) the cost of switching from branded to generic (or vice-versa). Last, ε_{kicf} are iid idiosyncratic preference shocks distributed Type I EV.

For a given fill f , the probability that individual k chooses drug i via purchase channel c is given by:

$$s_{kf}(i, c, i_{f-1}, c_{f-1}) = \frac{\exp(\delta_{kic})}{\sum_{l \in \mathcal{J}_i(f), c \in \{R, M\}} \exp(\delta_{klc})}$$

where δ_{kic} represents all terms on the right-hand side of (8) excluding the logit error ε_{kic} .

We estimate parameters $\theta = \{\alpha, \sigma, \beta^M, \zeta\}$ using simulated maximum likelihood over the observed sequence of drug fills $\{i_f^o, c_f^o\}_{f=1, \dots, F_i}$ for all individuals k , where $\sigma \equiv \{\sigma_M, \sigma_B\}$ and ζ are all switching-cost coefficients on the right-hand side of (10).

Comments. We do not include a price variable in the utility equation. Out-of-pocket price differences across drugs are absorbed by the tier-channel fixed effects, except for the MPTD tier, where patients either pay a price close to the discounted list price or (if they receive an exemption) the \$40 tier 3 copay. In practice, Princeton had a generous policy in granting exemptions, and we estimate only a mild disutility from the MPTD tier. We do not need a price coefficient to predict changes in market shares when drugs are moved across tiers (the primary purpose of this demand model). We use the \$15 copay difference between tiers 2 and 3 to renormalize our estimates and generate a dollar-valued consumer surplus variable as an input into the PBM's objective function.

We address two potential endogeneity issues related to tier placement. The first is the concern that the PBM chooses the drug's tier, and moves drugs across tiers, in response to unobserved demand effects. As discussed above, in 2011–2015 tier placement was determined only by branded/generic status. The broad entry of generics meant that this policy largely persisted, i.e. branded statin tiers were primarily determined by generic availability, in 2016–2018. In any exceptional cases, where drugs might have been assigned to particular tiers in response to enrollee preferences, we assume that the random coefficients and interactions with enrollee observables in

⁴⁴We use the following individual characteristics: age categories (under 45, 45-64, over 64); gender; and income categories (under \$75K, \$75-150K, over \$150K).

⁴⁵Since each tier is exclusively generic or branded, the mean of β_k^B will not be separately identified from α_k .

our demand specification are sufficiently detailed to account for the issue.

The second potential issue relates to changes in branded drug tier in response to entry of a same-molecule generic. We assume that all statins will eventually have a generic equivalent (a realistic assumption in our panel) and that timing of generic entry is uncorrelated with unobserved demand shocks. The remaining issue is the potential for short-term advertising of the generic, or of the branded good to protect demand. We address this in a robustness test, under the assumption that such advertising continues for no more than 3 months, by dropping the 3 months following generic introduction or following a tier change for a branded drug within the category.⁴⁶ Our estimates are very similar under this robustness test.

Inertia. We consider three different specifications to account for switching costs. In every case we drop the first six months of claims data in 2011. Our first specification considers only consumers with no statin claims in those first six months; we assume that their first observed fill, after June 2011, is their initial statin fill and therefore incurs no switching costs. We simulate forwards from there, allowing every subsequent choice to be affected by inertia if it involves a switch from one drug or channel to another. However, this approach involves dropping almost half the data sample. Our second approach addresses this by assuming that, for enrollees with a fill in the first six months of 2011, this observed choice was their first statin fill. This has the benefit of allowing for estimation using the full dataset; if the point estimates are similar to the first specification, we will use it as our baseline. Finally, we check robustness to including the full sample and removing random coefficients from demand. This removes the selection issue but if preferences for branded goods or the retail channel vary across consumers in a way that is not captured by observable interactions, removing random coefficients will lead this preference to be reflected in switching costs, generating an upward bias on the switching cost estimates.

Drug switching is defined as a move to a different statin without switching back for at least six months. As a robustness test, we increase the requirement from six to twelve months. This has little effect on the estimates.

4.2.2 Demand Estimates

Table 4 reports demand estimates, normalized into dollar terms using the \$15 copay difference between tiers 2 and 3. The underlying parameter estimates are provided in Appendix Table A1.

Results are reported for all three demand specifications. Specification 1 drops all consumers who have a statin fill in the first half of 2011; specification 2 keeps these consumers and assumes their first observed statin fill is truly their first fill; and specification 3 removes random coefficients. Estimates are quite similar for specifications 1 and 2, so we will use specification 2 as our baseline; these are the results discussed below. Estimated switching costs are substantially larger when

⁴⁶For example, assume that fill $f = 3$ for an individual occurs a month following the entry of a new generic, but all other fills do not. We include the probability of an individual choosing the particular drug for fills $f = 1, 2, 4, 5, \dots$; for fill $f = 4$, we still condition on the drug chosen for fill $f = 3$ even though we do not include the probability of choosing the drug for fill $f = 3$.

Table 4: Demand estimates (implied magnitudes)

		I. No claims Jan-Jun 2011		II. Jan-Jun 2011 are 1st claim		III. No random coefficients	
		Estimate	SE	Estimate	SE	Estimate	SE
Switching Costs	Molecule	24.670	2.764	32.417	3.102	46.806	7.386
	To Retail	7.439	1.071	10.517	1.263	21.956	3.684
	To Mail	16.960	2.044	20.814	2.122	37.147	5.891
	To Generic	8.025	1.824	6.956	1.086	25.584	4.518
	To Branded	7.236	2.465	10.542	1.921	18.979	4.802
Random Coefficient Variance	Mail	1.682	0.093	1.662	0.100		
	Branded	1.977	0.320	1.821	0.087		
Channel and Tier Preference	Mail	1.994	1.206	4.444	1.145	5.987	1.334
	Mail x First Fill	-10.404	1.418	-7.533	1.107	-16.164	2.619
	Mail x 75K To 150K	-0.624	0.805	0.363	0.606	0.973	0.596
	Mail x Above 150K	0.579	0.895	2.594	1.746	1.852	0.819
	Mail x 45 To 64	1.518	0.967	2.022	0.862	0.980	0.841
	Mail x Above 64	3.101	1.290	3.177	1.077	1.019	1.009
	Mail x Female	1.124	0.821	0.490	0.815	1.268	0.589
	Tier 2	-8.258	1.401	-7.131	1.015	-7.772	1.837
	Tier 3	-23.258	1.401	-22.131	1.015	-22.772	1.837
	MPTD	-29.921	3.074	-29.961	2.461	-28.793	3.581
	Tier 2 x Mail	2.199	0.837	4.141	0.721	1.466	0.768
	Tier 3 x Mail	0.138	1.956	-4.553	1.854	-11.192	4.215
	MPTD x Mail	-1.671	3.406	-8.315	2.449	-14.911	5.264
	Drug Fixed Effects	Atorvastatin	0.000	0.000	0.000	0.000	0.000
Ezetimibe/Simvastatin		-12.302	1.611	-13.827	1.437	-19.464	3.244
Fluvastatin Sodium				-20.256	2.511	-26.441	4.750
Lovastatin		-13.663	1.922	-18.343	2.054	-23.817	4.062
Niacin/Simvastatin		-22.876	3.242	-25.926	3.302	-34.885	5.921
Pitavastatin Calcium		-8.883	1.521	-13.524	1.637	-13.932	2.841
Pravastatin Sodium		-6.045	0.809	-9.200	1.021	-10.408	1.806
Rosuvastatin		-0.925	0.443	-2.255	0.410	-1.484	0.718
Simvastatin		-5.565	0.717	-6.729	0.740	-10.362	1.720
N	Individuals	1098		1992		1965	
	Fills	15413		37157		35219	

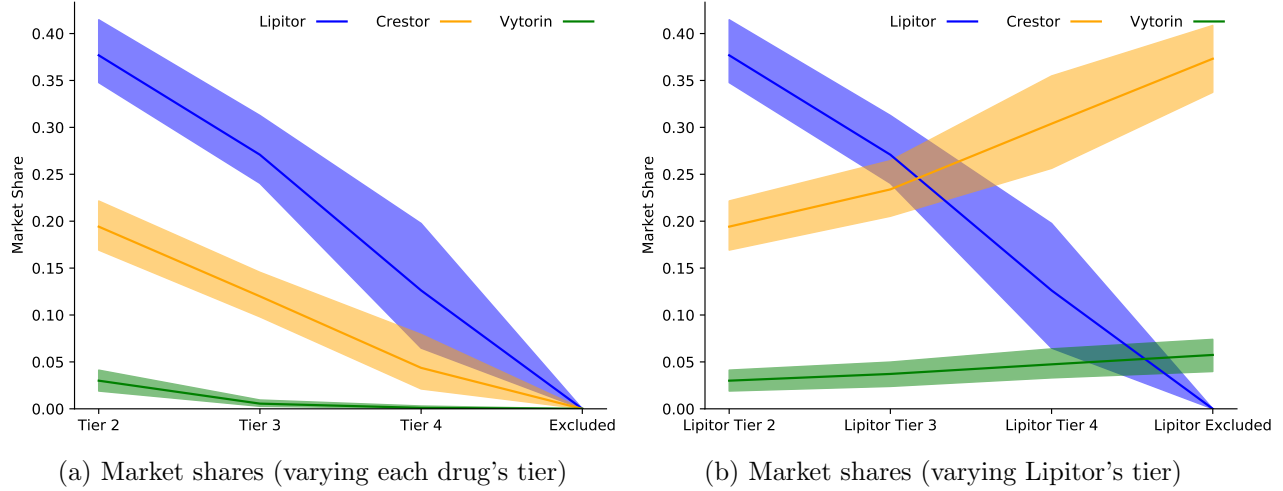
Notes: Magnitudes in \$ terms derived by dividing estimated parameter by a price coefficient implied by the difference between tier 2 and tier 3 utility and then multiplying by \$15, the difference in out-of-pocket prices across these tiers.

random coefficients are removed, underlining the importance of this individual-specific component of preferences for consumer behavior.

The top panel of Table 4 provides estimated switching costs. The magnitudes are larger than the per-fill saving from moving from tier 3 to 2 (\$15 per fill) or from tier 2 to the generic option (\$20 per fill), but small enough to rationalize the drug switching—an average of 1.5 statins per enrollee—observed in the data. In the baseline specification 2, we estimate a \$32 per enrollee cost of switching drug molecules. Moving from mail order to retail incurs a cost of \$10.52; not surprisingly, given the required paperwork, moving from retail to mail order generates a higher cost of \$20.81. The costs of moving from generic to branded, and from branded to generic, are \$6.96 and \$10.54 respectively.

The remaining panels of the table provide preference estimates over channels, tiers and drug molecules. We estimate a significant preference for mail order, particularly for enrollees aged over 64 and for high-income enrollees, except for the first fill where the retail channel is preferred. The random coefficients on mail order and brand have variances of \$1.66 and \$1.82 respectively, both statistically significant.

Figure 1: Impact of tier placement on market shares and quantities



Notes: Implications of estimated demand model (Specification II) for the relation between tier placement and market shares. We begin with all three drugs on tier 2, as observed in 2011. We then plot market shares under that observed formulary, and after moving any single drug (in panel (a)) or Lipitor (in panel (b)) to tier 3 or to excluded, i.e. unavailable. All other statins are held fixed in their observed 2011 tiers.

As expected, preferences over formulary tiers are monotonically ranked, for both retail and mail order channels. Choosing a drug from tier 2 incurs an effective cost of \$7.13 relative to the generic tier for retail sales, and \$2.99 (\$7.13 - \$4.14) under mail order. Both estimates are smaller than the \$20 difference in retail copays because the tier fixed effects absorb average brand preferences as well as price effects. The estimated disutilities from tier 3 and MPTD, relative to the generic tier, are \$22.13 and \$29.96 respectively under retail, and \$26.68 and \$38.28 under mail order. Note that the difference between tiers 2 and 3 under the retail channel is normalized to equal the \$15 out-of-pocket price difference. The difference between tier 3 and MPTD is relatively small, unsurprising given Princeton's generous policies regarding MPTD (discussed above). Finally, pricing under mail order is different from under retail: enrollees pay twice the price in return for three times the volume, so the per-unit price difference between tiers is reduced (\$0.55 per day's supply between generic and tier 2, compared to \$0.83 under retail). The smaller mail order disutility from tier 2 likely reflects this, while the larger disutility from tiers 3 and MPTD suggests enrollees are more successfully steered to generics under mail order than under the retail channel.

Figure 1 displays the market share effects associated with changes in drug tier placement, as predicted by the demand model. We begin by simulating demand under the observed 2011 formulary, when Lipitor, Crestor and Vytorin are all on tier 2. Consistent with the observed data, Lipitor's predicted share is just under 38%; Crestor 20% and Vytorin 3%. On the left panel, we predict the shares that the model predicts for a drug's own market share (accounting for switching costs) if the drug was moved to tier 3, to MPTD, and then excluded, holding all other products fixed in their observed tiers. Lipitor's predicted share falls to 26% under tier 3; Crestor's to 13% and Vytorin's to 0.6%. On the right panel, we predict shares for all drugs adjusting only the tier

that Lipitor is placed on. As Lipitor’s tier moves away from Tier 2, the predicted shares of the other two statins increase.

Note that the predicted volume effects are substantially smaller than those in the raw data. The reason is that the predictions isolate the effect of changing a branded drug’s formulary tier, without also accounting for the entry of generic equivalents. Our volume predictions are an essential input into the contracting simulations in the next section.

5 Simulations: Contracting over Rebates and Formulary

In this section, we use our theoretical model from Section 3 and demand estimates from Section 4 to predict the rebates that Express Scripts, Princeton University’s PBM in 2011, could have negotiated had it introduced Preferred and Non-Preferred branded tiers (used by Optum for Princeton employees from 2016 onwards).⁴⁷

Details. Following the objective functions presented for our theory model in Section 3 (see equations (1)-(2)), we parameterize drug manufacturers’ and the PBM’s objectives as follows.

Each branded drug manufacturer i ’s objective in period t from enrollees served by the PBM is given by:

$$\Pi_{i,t} = \left(\sum_{k,f,c,i} Q_f \times s_{k,i,f,c,t}(\mathbb{F}) \times (p_{i,c,t} - \mathbb{C}_{i,t}(\mathbb{F})) \right)$$

where the summation is over all individuals k and statin prescription fills f through channel c within period t , Q_f is the number of 30-days’ supplies associated with a given fill f , $s_{k,i,f,c,t}(\cdot)$ is the probability that the individual chooses drug i through channel c given the formulary \mathbb{F} (predicted from the demand model), p_{ict} is the list price, and $\mathbb{C}_{i,t}(\cdot)$ is the rebate paid by the manufacturer to the PBM. We hold fixed Q_f for each fill, and allow consumers to choose either retail or mail-order for each fill (both for observed, and for counterfactual fills); for p_{ict} , we use the median payment (including both the sponsor and patient payment) for the drug, re-scaled to a price per 30 days’ supply, on average across patients for the drug-month.⁴⁸ The manufacturer’s marginal production cost is assumed to be zero.

⁴⁷Our simulations are conducted using demand predictions from the second half of 2011. During this period, Express Scripts offered all three branded drugs to consumers at an out-of-pocket price of \$25 per 30 day’s supply, and no generics for these drugs were yet available. We use data from the first half of 2011 to identify new and existing statin users. In our simulations, we assume that enrollees are affected by our estimated switching costs, and condition on the drugs that enrollees are taking prior to the second half of 2011. Feng and Maini (2021) uses a model based on an all-pay auction to consider the dynamic effects generated by switching costs when PBMs and manufacturers predict the volume effects from moving formulary tiers.

⁴⁸As noted above, we account for dispensing fees and the spread between pharmacy and PBM discounts on the list price by defining the “retail wedge” to be the observed difference between median retail and mail order discounted list prices for the drug-year. We assume the PBM pays this retail wedge but the manufacturer does not receive it. This is the reason why the LP is channel-specific; however, for simplicity the model specification abstracts from this detail.

The PBM’s objective is

$$\Pi_{P,t} = \gamma W_t - \sum_{k,f,c,i} Q_f \times s_{kifct}(\mathbb{F}) \times (p_{i,c,t} - p_{c,t}^{OOP}(\mathbb{F}_i) - \mathbb{C}_{i,t}(\mathbb{F}))$$

where γ represents the weight that the PBM places on consumer welfare W_t (generated from the demand system for the population of enrollees who require statins).⁴⁹ We conduct simulations under both $\gamma = 1$ (where the PBM equally weights consumer welfare and its expenditures) and $\gamma = 0$ (where the PBM only minimizes expenditures).

Note that when the PBM only has a single branded tier and cannot exclude drugs, the theoretical model predicts that rebates are zero for all branded drugs: the manufacturer will not agree to a positive rebate when its drug will be offered, at the branded out-of-pocket price, even without one.

We conduct two counterfactual simulations that provide the PBM with additional flexibility.

The first counterfactual simulation allows the PBM to use both Preferred and Non Preferred tiers, priced at \$25 and \$40 per 30 days’ supply in the retail channel, without excluding drugs.⁵⁰

The second counterfactual simulation allows the PBM to also exclude branded drugs. However, we cannot use the data to predict the volume effect of excluding drugs, as we did for movement across tiers, because we do not observe such exclusions in the data. Instead we make a simple assumption. Consistent with prior papers (Agha, Kim and Li, 2021), we assume that the effect of moving a branded drug from formulary inclusion to exclusion is an out-of-pocket price increase that would generate approximately a 70-75% reduction in volume relative to all drugs being on their observed (Preferred) tiers.⁵¹ We implement this by assuming that excluding a drug is equivalent to requiring consumers to pay a \$55 out of pocket price in both retail and mail order channels (which generates approximately a 75% volume reduction).

5.1 Results

We present the results of our simulations in Table 5. We allow the PBM to negotiate rebates and adjust tiers, first for only two branded drugs (Crestor and Lipitor), and then for all three branded drugs.

We also present results using estimates from two demand specifications. Recall that Specification 1 drops all consumers who have a statin fill in the first half of 2011, while Specification 2 (the baseline) assumes this early statin fill is the consumer’s first, generating no switching costs. Since the two specifications imply qualitatively similar simulation results, the discussion below focuses only on the baseline.

⁴⁹We convert measures of consumer welfare into dollars based on the relative values of tier 2 and tier 3 fixed effects (for the retail channel). Only differences in consumer welfare are necessary to determine the formulary that maximizes the PBM’s objective.

⁵⁰Prices in the mail order channel are assumed to be double the retail value, for three times the volume, as is the case in reality in our setting.

⁵¹For example, Agha, Kim and Li (2021) describe Express Scripts as saying that “nearly 70% in volume moved away from the non-covered drugs into covered drugs...” when drugs were excluded.

Table 5: Simulation results

A. Demand sample 1 (2 branded drugs)						
	PBM CS weight	Formulary	Disagreement formulary		Estimate	Rebate (% of list price)
			Lipitor	Crestor		
No exclusion	0	(NP, NP)	(NP, P)	(P, NP)	(11.5%, 16.0%)	[0%, 53.9%], [0%, 64.4%]
	1	(P, P)	(NP, P)	(P, NP)	(32.0%, 38.9%)	[22.0%, 53.9%], [26.8%, 62.0%]
With exclusion	0	(NP, NP)	(E, P)	(P, E)	(85.6%, 88.6%)	[68.2%, 98.0%], [70.6%, 98.8%]
	1	(P, P)	(E, P)	(P, E)	(89.0%, 91.7%)	[73.3%, 98.3%], [78.6%, 98.8%]

B. Demand sample 2 (2 branded drugs)						
	PBM CS weight	Formulary	Disagreement formulary		Estimate	Rebate (% of list price)
			Lipitor	Crestor		
No exclusion	0	(NP, NP)	(NP, P)	(P, NP)	(10.0%, 17.4%)	[0%, 11.5%], [13.4%, 56.4%]
	1	(P, P)	(NP, P)	(P, NP)	(28.1%, 38.2%)	[22.8%, 34.4%], [32.2%, 45.9%]
With exclusion	0	(NP, NP)	(E, P)	(P, E)	(58.1%, 69.9%)	[18.2%, 76.0%], [0%, 90.8%]
	1	(P, P)	(E, P)	(P, E)	(66.5%, 77.5%)	[46.4%, 81.6%], [59.8%, 89.0%]

C. Demand sample 2 (3 branded drugs)							
	PBM CS weight	Formulary	Disagreement formulary			Estimate	Rebate (% of list price)
			Lipitor	Crestor	Vytorin		
No exclusion	0	(NP, NP, P)	(NP, P, P)	(P, NP, P)	(NP, P, NP)	(10.0%, 17.4%, 80.3%)	[6.9%, 13.4%], [10.3%, 22.5%], [59.1%, 86.2%]
	1	(P, P, P)	(NP, P, P)	(P, NP, P)	(P, P, NP)	(28.1%, 38.2%, 81.6%)	[22.8%, 34.4%], [32.2%, 45.9%], [75.2%, 86.9%]
With exclusion	0	(NP, NP, P)	(E, P, P)	(P, E, P)	(E, NP, E)	(58.1%, 69.9%, 89.4%)	[21.3%, 77.3%], [0%, 84.4%], [49.6%, 98.4%]
	1	(P, P, P)	(E, P, P)	(P, E, P)	(P, P, E)	(66.5%, 77.5%, 99.6%)	[18.4%, 81.6%], [30.0%, 89.0%], [84.2%, 98.8%]

Notes: Demand sample 1 includes only consumers who have no claims in first 6 months of 2011. Demand sample 2 includes consumers with a statin claim in those 6 months and assumes it is their first statin claim. Formulary and rebate outcomes correspond to (Lipitor, Crestor) with two branded drugs, and (Lipitor, Crestor, Vytorin) with three branded drugs.

The first row for each specification shows results when the PBM’s objective function places a zero weight on CS; it responds only to its own costs. In the second row, we consider the model’s predictions when the PBM weights CS and profits equally. In both cases, the negotiated rebates are always positive. They are also always less than 100% of the list price: that is, the manufacturer always retains a positive portion of the surplus, despite the take-it-or-leave-it offers game being played.

Consider first the case where the PBM can move two branded drugs (Lipitor and Crestor) between tiers but cannot exclude drugs. Vytorin is held fixed on the Preferred tier. When the PBM puts a zero weight on CS, the formulary that emerges in equilibrium places both branded drugs on the Non Preferred tier. This is likely to steer many consumers towards generic drugs which are cheaper for consumers and also reduce the PBM’s costs. An additional effect is that each manufacturer’s disagreement formulary is not much less profitable than the equilibrium formulary: it simply moves the manufacturer’s rival up to Preferred status, keeping the manufacturer itself Non Preferred. Lipitor, for example, is willing to pay only 10% of its list price to avoid this outcome in our main specification; Crestor pays a slightly higher 17%.

Now consider how things change when the PBM’s objective function puts an equal weight on CS and on its costs. The equilibrium formulary places both branded drugs on the Preferred tier, which is cheaper for consumers and results in higher CS. The disagreement formulary for each manufacturer now changes its own status from Preferred to Non Preferred, holding its rival fixed on the Preferred tier. This generates a substantial reduction in manufacturer profits; Lipitor agrees to pay 28% of its list price as a rebate to avoid this, while Crestor pays 38%.⁵² These predicted rebates are similar to those reported in the previous literature, generated from SSR Health Data. Kakani, Chernew and Chandra (2020) and Sood et al. (2020) obtained different years of SSR Health data between 2012 and 2015, and analyzed them in slightly different ways, but both sets of authors report rebates of between 24% and 35% of list prices.

The next set of simulations in Table 5 allows drugs to be excluded (in addition to movements between Preferred and Non Preferred tiers), under the assumption that exclusion generates an increase in out-of-pocket prices that would reduce demand by 70-75%. The predicted equilibrium formulary is always the same as that without exclusion. However, disagreement formularies look different: in every case, disagreement leads the PBM to exclude the relevant manufacturer. Rebates are high—between 58% and 78% of the list price given the baseline demand specification—because manufacturers are willing to pay a substantial amount to avoid this outcome. However we caution that, as noted, we do not observe the PBM excluding popular branded drugs in our data. In reality, competition between PBMs to secure a contract with this sponsor, together with the sponsor’s preference for covering popular drugs, makes 2011 exclusion of Lipitor or Crestor unlikely. For this reason, our preferred model for this time period allows the PBM to move branded drugs between Preferred and Non Preferred tiers but not to exclude drugs.

⁵²The existence of generic drugs as an outside option make demand changes asymmetric: moving from P to NP with the rival branded drug fixed at P generates a bigger profit reduction than remaining fixed at NP while the rival branded drug moves from NP to P.

Table 6: Comparison of results under offer and bidding game

B. Demand sample 2 (2 branded drugs, PBM CS Weight 1)			
		Rebate (% of list price)	
		Formulary	CI
		Estimate	
No Exclusion	Offer Game	(P,P)	(28.1%, 38.2%) [22.8%, 34.4%], [32.2%, 45.9%]
	Bidding Game	(P,P)	(24.7%, 32.9%) [19.9%, 30.3%], [27.4%, 39.1%]
With Exclusion	Offer Game	(P,P)	(66.5%, 77.5%) [46.4%, 81.6%], [59.8%, 89.0%]
	Bidding Game	(P,P)	(57.5%, 64.8%) [45.1%, 67.7%], [53.8%, 72.7%]

Notes: Offer game results correspond to Demand Sample 2 specification described in Table 5. Bidding game results correspond to model where manufacturers make offers to PBM, as described in Section 3.5. Formulary and rebate outcomes correspond to (Lipitor, Crestor).

The third vertical panel of Table 5 considers the same simulations, but endogenizes the tier placement of all three branded drugs, including Vytorin as well as Lipitor and Crestor. This has very little effect on the results discussed above: in fact Lipitor and Crestor’s predicted rebates are identical to those predicted when Vytorin is held fixed on the Preferred tier. The reason is that endogenizing Vytorin has no effect on the predicted equilibrium formulary, or on the disagreement formularies of the other branded drugs.⁵³ Vytorin’s own predicted rebates are large: it is a relatively low-demand drug, so a move from Preferred to a less preferred tier has a large effect on volume that the manufacturer is willing to pay to avoid.

Finally, in simulations that are not reported in Table 5, we consider the effect of giving the PBM flexibility to move drugs to a tier between Preferred and Non Preferred that is priced at \$32.50 in the retail channel. For simplicity we remove the ability to exclude drugs. In most cases the additional flexibility is beneficial to the PBM: its objective function increases in equilibrium. However, we find that under certain consumer-surplus weights, the PBM may be worse off due to this flexibility. Its inability to commit to a disagreement point that substantially reduces manufacturer surplus—e.g., choosing to place the manufacturer on the intermediate tier if it refuses to pay a rebate, rather than the Non Preferred tier—can generate lower equilibrium rebates.

5.2 Bidding game rebates and payoffs

Table 6 presents results for two drugs under both our baseline (offer-game) model and under the bidding-game variant of our model (see Section 3.5).⁵⁴ As noted in Section 3.5, for both variants of our model the equilibrium formulary is the one that maximizes PBM and manufacturers’ payoffs—here, (P, P) . The differences in equilibrium outcomes between the two variants are the magnitude of rebates, which are higher when the PBM makes offers than when the manufacturers make offers.

⁵³This will not always be the case. In other situations, the third drug’s tier placement might change in the other drugs’ disagreement formularies and this would affect their rebates.

⁵⁴As we discuss in Appendix A.4, given our estimated payoffs, there is a unique Truthful Nash Equilibrium for the bidding-game variant of our model.

Perhaps more surprising is how similar the predicted rebates are across the variants of the model. Under the bidding game variant, each manufacturer earns the difference between what the PBM and all manufacturers could earn jointly, and what the PBM and the manufacturer’s rival could generate without it (see Appendix A.4, Bernheim and Whinston (1986)). This implies that the manufacturer is able to capture some of the increase in consumer welfare (included in the PBM’s payoff) and in its own payoff arising from its inclusion on the preferred formulary tier. In contrast, under the baseline offer-game specification, each manufacturer obtains only its disagreement payoff—i.e., what it would expect to obtain if it did not pay any rebates to the PBM, and the PBM chose the formulary that maximized its payoff given the contract negotiated with the other manufacturer.

Given our estimated payoffs, these results indicate that each manufacturers’ disagreement payoffs are relatively substantial (partly reflecting the value attributed to each drug by consumers), enabling each to obtain payoffs when the PBM makes contract offers that are close to what they would obtain if they instead made offers to the PBM.

6 Concluding Remarks

This paper develops a model of PBM-manufacturer negotiations over formularies and rebates that fits the institutional details of the industry, can be taken to the data, and enables out-of-sample prediction. The model captures the idea that rebates may not be fixed; they may vary with the drug’s own formulary placement and those of its rivals. The results are encouraging because, given the degree of flexibility we have given the PBM to move branded drugs across tiers, the predicted rebates are close to the aggregate numbers reported in published data (Kakani, Chernew and Chandra, 2020; Sood et al., 2020).

As we note above, PBMs’ role in negotiating formularies and rebates is likely to remain important in the U.S. commercial sector even after the Inflation Reduction Act (2022) has changed pricing for drugs within Medicare Part D. Rebates are also negotiated between PBMs and manufacturers, and unobserved by policy-makers, in countries outside the U.S.. It therefore remains important to model PBMs’ impact on drug accessibility and rebates, particularly in the absence of detailed and reliable rebate data, in order to understand and forecast future drug spending.

Beyond this, a natural direction for future research is to use insights from this analysis to examine broader changes in the pharmaceutical and drug industry. For example, a model of PBM-manufacturer negotiations, perhaps similar to the one developed in this paper, is likely needed to assess the impact of manufacturer mergers on payments and hence on firm incentives. Further, while welfare-relevant issues including drug innovation incentives and the matching of consumers to drugs are somewhat separate from this model, the payments made to firms clearly affect their incentives and therefore help determine these outcomes.

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A Theory Appendix

A.1 Proofs

A.1.1 Proof of Lemma 3.1

Proof. Let $A_i \equiv p_i - \Pi_i^d(\hat{C}_{-i})/D_i(\hat{\mathbb{F}})$. First, note that A_i must be weakly positive if $\hat{\mathbb{F}}$ is chosen in equilibrium: if not, then $\Pi_i(\hat{\mathbb{F}}, \hat{C}(\hat{\mathbb{F}})) < \Pi_i^d(\hat{C}_{-i})$ for any weakly positive rebate payment $\hat{C}(\hat{\mathbb{F}}) \geq 0$, and i would have a strictly profitable deviation to reject its contract offer \hat{C}_i . We next establish that $\hat{C}(\hat{\mathbb{F}}) = A_i$. By similar reasoning as above, it cannot be that $\hat{C}_i(\hat{\mathbb{F}}) > A_i$ else $\Pi_i(\hat{\mathbb{F}}, \hat{C}(\hat{\mathbb{F}})) < \Pi_i^d(\hat{C}_{-i})$ and manufacturer i would have a strictly profitable deviation to reject. If instead $\hat{C}_i(\hat{\mathbb{F}}) < A_i$ (but is still weakly positive), then the PBM has strictly profitable deviation: the PBM can offer an alternative contract C'_i where $C'_i(\hat{\mathbb{F}}) = \hat{C}_i(\hat{\mathbb{F}}) + \varepsilon < A_i$ for $\varepsilon > 0$ sufficiently small, and $C'_i(\mathbb{F}') = \hat{C}_i(\mathbb{F}')$ for all $\mathbb{F}' \neq \hat{\mathbb{F}}$. This deviation demands a strictly higher rebate from manufacturer i under formulary $\hat{\mathbb{F}}$, but does not adjust rebates under other formularies. To see why this is a profitable deviation, first note that manufacturer i anticipates that the PBM would still choose formulary $\hat{\mathbb{F}}$ if it accepted the deviant offer: given passive beliefs, manufacturer i still believes contracts \hat{C}_{-i} are offered and accepted by other manufacturers, and since $f(\hat{C}) = \hat{\mathbb{F}}$, it follows that $f(\{C'_i, \hat{C}_{-i}\}) = \hat{\mathbb{F}}$ as well. For sufficiently small $\varepsilon > 0$, manufacturer i will accept the deviation as it expects to earn more from accepting the deviant contract and anticipating formulary $\hat{\mathbb{F}}$, than rejecting the deviant contract and anticipating disagreement formulary $f(\{C^0, \hat{C}_{-i}\})$. This deviation earns the PBM strictly greater profits. Contradiction. Hence, $\hat{C}_i(\hat{\mathbb{F}}) = A_i$. Last, substituting $\hat{C}_i(\hat{\mathbb{F}}) = A_i$ into manufacturer i 's profits given by (2) establishes that condition (3) and (4) are equivalent. \square

A.1.2 Proof of Lemma 3.2

Proof. Proceed by contradiction, and assume that (6) does not hold for some i and $\mathbb{F}' \neq \hat{\mathbb{F}}$. This implies that

$$\Pi_P(\hat{\mathbb{F}}, \hat{C}) < \Pi_P(\mathbb{F}', \{C^0, \hat{C}_{-i}\}) + \max \left\{ \underbrace{\Pi_i(\mathbb{F}', 0) - \Pi_i^d(\hat{C}_{-i})}_X, 0 \right\}. \quad (11)$$

First, consider the case where $X \leq 0$. Then (11) implies that $\Pi_P(\hat{\mathbb{F}}, \hat{C}) < \Pi_P(\mathbb{F}', \{C^0, \hat{C}_{-i}\})$, and hence the PBM has a profitable deviation in Stage 1 to offer the null contract C^0 to manufacturer i and \hat{C}_{-i} to the other manufacturers, and then choose formulary \mathbb{F}' . Contradiction. Next, consider the case where $X > 0$. Consider the following deviant contract C'_i offered by the PBM to manufacturer i : $C'_i(\mathbb{F}') = X - \varepsilon$ for some arbitrarily small $\varepsilon > 0$ so that $\Pi_i(\mathbb{F}', C'_i) - \Pi_i^d(\hat{C}_{-i}) > 0$ and $\Pi_P(\mathbb{F}', \{C'_i, \hat{C}_{-i}\}) > \Pi_P(\hat{\mathbb{F}}, \hat{C})$; and $C'_i(\mathbb{F}'') = 0 \forall \mathbb{F}'' \neq \mathbb{F}'$. If the deviant contract was accepted by i (and all other contracts \hat{C}_{-i} still accepted), the PBM would choose formulary \mathbb{F}' in Stage 2. Hence, such a deviation would be accepted by manufacturer i , as i would anticipate a payoff strictly greater than rejecting. Furthermore, such a deviation would be profitable for the PBM. Contradiction. \square

A.1.3 Proof of Proposition 3.4

Proof. Assume not, and there exists some other \mathbb{F}' which generates strictly greater joint surplus. This implies

$$\begin{aligned} \Pi_P(\mathbb{F}', C^0) + \sum_i \Pi_i(\mathbb{F}', C^0) &> \Pi_P(\hat{\mathbb{F}}, C^0) + \sum_i \Pi_i(\hat{\mathbb{F}}, C^0) \\ &= \Pi_P(\hat{\mathbb{F}}, C^0) + \sum_i \left(\hat{C}_i(\hat{\mathbb{F}}) + \Pi_i(\hat{\mathbb{F}}, \hat{C}_i(\hat{\mathbb{F}})) \right) \\ &\geq \Pi_P(\hat{\mathbb{F}}, C^0) + \sum_i \left(\hat{C}_i(\hat{\mathbb{F}}) + \Pi_i(\mathbb{F}', \hat{C}_i(\mathbb{F}')) \right) \\ &= \Pi_P(\hat{\mathbb{F}}, C^0) + \sum_i \left(\hat{C}_i(\hat{\mathbb{F}}) - \hat{C}_i(\mathbb{F}') + \Pi_i(\mathbb{F}', C^0) \right) \end{aligned}$$

where the third inequality follows contract offers \hat{C} satisfying manufacturer indifference. Rearranging terms yields:

$$\Pi_P(\mathbb{F}', C^0) + \sum_i \hat{C}_i(\mathbb{F}') > \Pi_P(\hat{\mathbb{F}}, C^0) + \sum_i \hat{C}_i(\hat{\mathbb{F}})$$

which implies that the PBM is not choosing its profit maximizing formulary ($\hat{\mathbb{F}} \neq f(\hat{C})$), a contradiction. \square

A.2 Multilateral Deviations

Condition 3. No multilateral deviations (NMD).

Lemma A.1. *In any equilibrium in which contract offers $\hat{\mathbb{C}}$ are accepted and the PBM chooses formulary $\hat{\mathbb{F}}$, then:*

$$\Pi_P(\hat{\mathbb{F}}, \hat{\mathbb{C}}) \geq \Pi_P(\mathbb{F}', \tilde{\mathbb{C}}^{\mathbb{F}'}) \quad \forall \mathbb{F}' \neq \hat{\mathbb{F}}, \quad (12)$$

where for each i , define

$$\tilde{\mathbb{F}}^i \equiv \arg \max_{\mathbb{F}} \Pi_P(\mathbb{F}, \{\mathbb{C}^0, \hat{\mathbb{C}}_{-i}\}) + \max \left\{ \Pi_i(\mathbb{F}, \mathbb{C}^0) - \Pi_i^d(\hat{\mathbb{C}}_{-i}), 0 \right\}, \quad (13)$$

to be the formulary that maximizes what the PBM and manufacturer i can jointly earn above i 's disagreement point given contracts $\hat{\mathbb{C}}_{-i}$; and the contract $\tilde{\mathbb{C}}_i^{\mathbb{F}'}$ satisfies:

$$\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\tilde{\mathbb{F}}^i): \quad \Pi_i(\tilde{\mathbb{F}}^i, \tilde{\mathbb{C}}_i^{\mathbb{F}'}(\tilde{\mathbb{F}}^i)) = \Pi_i^d(\hat{\mathbb{C}}_{-i}); \quad (14)$$

$$\begin{aligned} \tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}'): \quad & \Pi_P(\mathbb{F}', \{\mathbb{C}^0, \hat{\mathbb{C}}_{-i}\}) + D_i(\mathbb{F}') \times \tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}') = \\ & \Pi_P(\tilde{\mathbb{F}}^i, \{\mathbb{C}^0, \hat{\mathbb{C}}_{-i}\}) + \max \left\{ \Pi_i(\tilde{\mathbb{F}}^i, \mathbb{C}^0) - \Pi_i^d(\hat{\mathbb{C}}_{-i}), 0 \right\} - \varepsilon \quad \text{if } \tilde{\mathbb{F}}^i \neq \mathbb{F}'; \end{aligned} \quad (15)$$

$$\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}'') = 0, \quad \text{for all } \mathbb{F}'' \neq \tilde{\mathbb{F}}^i, \mathbb{F}' \quad (16)$$

for arbitrarily small $\varepsilon > 0$.

Consider an equilibrium where contract offers $\hat{\mathbb{C}}$ are accepted and the PBM chooses formulary $\hat{\mathbb{F}}$. Given necessary condition 1 in the main text, equilibrium rebate payments hold each manufacturer i to its disagreement payoff (given rivals' contracts $\hat{\mathbb{C}}_{-i}$), and a PBM cannot obtain greater rebate payments while still finding it optimal to choose formulary $\hat{\mathbb{F}}$.

If instead the PBM wishes to deviate to some alternative formulary $\mathbb{F}' \neq \hat{\mathbb{F}}$, the most profitable way to do so is to offer each manufacturer i a deviant contract \mathbb{C}'_i that is designed in a way to pay the highest rebate possible under formulary \mathbb{F}' . With passive beliefs, each manufacturer i that accepts a deviant contract \mathbb{C}'_i believes that formulary $\tilde{\mathbb{F}}^i = f(\mathbb{C}'_i, \hat{\mathbb{C}}_{-i})$ will be chosen by the PBM. (Under a delegated-agent equilibrium in which a PBM can only engage in unilateral deviations, this belief will be correct.) However, if the PBM is able to engage in multilateral deviations, then it may be the case that although each manufacturer i receiving a deviant contract \mathbb{C}'_i believes $\tilde{\mathbb{F}}^i$ will be chosen, the PBM by having multiple deviant contract offers accepted may find it optimal to choose some other formulary \mathbb{F}' that may be different than $\tilde{\mathbb{F}}^i$.

In the statement of the Lemma, for each formulary $\mathbb{F}' \neq \hat{\mathbb{F}}$, the deviant contract $\tilde{\mathbb{C}}_i^{\mathbb{F}'}$ that is offered to each manufacturer i is constructed to yield the highest rebate payment under formulary \mathbb{F}' among any deviant contract that manufacturer i will accept, given rivals' contracts $\hat{\mathbb{C}}_{-i}$. To construct this contract, first for each manufacturer i the formulary $\tilde{\mathbb{F}}^i$ is defined in (13) to be the formulary that maximizes the sum of the PBM's profits and the part the manufacturer's profits in excess of its disagreement point. Next, equations (14)-(15) define $\tilde{\mathbb{C}}_i^{\mathbb{F}'}$ so that the rebate under formulary \mathbb{F}' is as large as possible while still making it appear manufacturer i that the PBM would choose $\tilde{\mathbb{F}}^i$ if the deviant contract is accepted (i.e., $\tilde{\mathbb{F}}^i = f(\{\tilde{\mathbb{C}}_i^{\mathbb{F}'}, \hat{\mathbb{C}}_{-i}\})$). This is done by setting the rebate under formulary $\tilde{\mathbb{F}}^i$ to hold i to its disagreement point (equation (14)), and then if $\mathbb{F}' \neq \tilde{\mathbb{F}}^i$, setting the rebate under formulary \mathbb{F}' to ensure the PBM earns less choosing formulary \mathbb{F}' than under $\tilde{\mathbb{F}}^i$ if contracts $\hat{\mathbb{C}}_{-i}$ do not change (equation (15)). Last, the rebate under all other formularies other than \mathbb{F}' and $\tilde{\mathbb{F}}^i$ are set to zero (equation (16)).

In sum, these deviant contracts are in essence designed to "trick" each manufacturer i into believing that some potentially alternative formulary $\tilde{\mathbb{F}}^i$ will be chosen (which due to passive beliefs, $\tilde{\mathbb{F}}^i = f(\tilde{\mathbb{C}}_i^{\mathbb{F}'}, \hat{\mathbb{C}}_{-i})$), and $\tilde{\mathbb{F}}^i$ is chosen to maximize the amount that i is willing to pay under formulary \mathbb{F}' given the requirement that i still thinks $\tilde{\mathbb{F}}^i$ will be chosen by the PBM. (Note that it may be the case that for some manufacturers i , $\tilde{\mathbb{F}}^i = \mathbb{F}'$.)

Proving necessity is thus straightforward: if (12) did not hold for some formulary $\mathbb{F}' \neq \hat{\mathbb{F}}$, then the PBM would have a strictly profitable multilateral deviation to offer the contracts as defined above, as each manufacturer would accept their deviant contract and the PBM would then earn strictly higher profits.

Restriction on Contract Space. In our empirical application, we assume that the PBM cannot offer any manufacturer i a contract that, under any formulary, provides the manufacturer with a payoff less than i 's worst-case payoff under no contract, denoted $\underline{\Pi}_i \equiv \min_{\mathbb{F}} \Pi_i(\mathbb{F}, 0)$; i.e., each contract \mathbb{C}_i must satisfy:

$$\Pi_i(\mathbb{F}, \mathbb{C}_i(\mathbb{F})) \geq \underline{\Pi}_i \quad \forall \mathbb{F}. \quad (17)$$

This restriction places an upper bound on the rebate that a PBM can demand from a manufacturer payment under any formulary, including those formularies that the manufacturer believes may not be chosen by the PBM. This limits the scope for multilateral deviations that can be used to “trick” manufacturers, and ensures that manufacturers always earn under any contract, regardless of the formulary chosen, at least their worst-case payoff $\underline{\Pi}_i$.

Example 1 Revisited. Consider Example 1 from the main text. Without the restriction on the contract space described above, equilibrium 1 under which the PBM offers contracts $\mathbb{C}_1 = (0, 8, 0, 0)$ and $\mathbb{C}_2 = (0, 0, 0, 2)$ and obtains profits of 8 after choosing formulary (P, NP) is no longer a WPBE when the PBM can engage in multilateral deviations. To see why, consider the deviant contracts $\mathbb{C}'_1 = (7.9, 8, 0, 0)$ and $\mathbb{C}'_2 = (7.9, 0, 0, 0)$. Under passive beliefs, both $M1$ and $M2$ are willing to accept their deviant contracts as both believe the PBM will still choose formulary (P, NP) , and hence both believe they will continue to earn their equilibrium payoffs. The key is that both $M1$ and $M2$ believe their rival is still signing a contract that pays 0 under formulary (P, P) . However, once both deviant contracts are accepted, the PBM now finds it more profitable to choose (P, P) and earn 15.8.

In the above deviation, both $M1$ and $M2$ pay rebates under (P, P) that, if (P, P) were chosen, generate net payoffs to each manufacturer less than their disagreement payoffs of 8 for $M1$ and 6 for $M2$.

However, if we require restriction (17), then the deviant contracts that demand the most from each manufacturer under formulary (P, P) are $\mathbb{C}'_1 = (2, 8, 0, 0)$ and $\mathbb{C}'_2 = (4, 0, 0, 0)$; now, the PBM does not find it strictly profitable engage in this deviation as it cannot earn more than its equilibrium payoffs. Hence, both equilibria in the example are robust to multilateral deviations.

Sufficiency. Assume contract offers $\hat{\mathbb{C}}$ and induced formulary $\hat{F} = f(\hat{\mathbb{C}})$ satisfy (3) and (6). First, note that the PBM does not have any profitable deviations in Stage 2, and by (3), no manufacturer has a strictly profitable deviation to reject its contract in Stage 1(b). Next, note that there are no strictly profitable unilateral deviations for the PBM in Stage 1(a): (3) implies the PBM cannot obtain a higher rebate payment from any manufacturer i at the equilibrium formulary, and (6) implies the PBM is not be able to profitably deviate by offering a contract that manufacturer i would accept and then choosing a different formulary. Last, if the contract offers also satisfy the conditions provided in Lemma A.1, then the PBM does not have any strictly profitable multilateral deviations. Hence, these conditions are sufficient for contract offers $\hat{\mathbb{C}}$ and formulary \hat{F} to comprise an equilibrium.

A.3 Computing Equilibria

For the efficient equilibrium formulary $\mathbb{F}^\circ = \arg \max_{\mathbb{F}} \Pi_P(\mathbb{F}, \mathbb{C}^0) + \sum_i \Pi_i(\mathbb{F}, \mathbb{C}^0)$ chosen by the PBM in Stage 2:

1. For every *profile of perceived disagreement formularies* $\bar{\mathbb{F}} = \{\mathbb{F}^{d,1}, \dots, \mathbb{F}^{d,M}\} \in \mathcal{F}^M$ (where each element of $\bar{\mathbb{F}}$ corresponds to the perceived disagreement formulary contemplated by each manufacturer i):

- (a) Denote by $\mathbb{C}^{\bar{\mathbb{F}}} = \{\mathbb{C}_1^{\mathbb{F}^{d,1}}, \dots, \mathbb{C}_M^{\mathbb{F}^{d,M}}\}$ the profile of *implied rebate contracts* for all manufacturers given perceived disagreement formularies $\bar{\mathbb{F}}$, and define each implied rebate contract $\mathbb{C}_i^{\mathbb{F}^{d,i}}$ as:

$$\mathbb{C}_i^{\mathbb{F}^{d,i}}(\mathbb{F}^\circ) = \max \left\{ p_i - \frac{\Pi_i(\mathbb{F}^{d,i}, \mathbb{C}^0)}{D_i(\mathbb{F}^\circ)}, 0 \right\} \quad (18)$$

$$\mathbb{C}_i^{\mathbb{F}^{d,i}}(\mathbb{F}') = \max \left\{ p_i - \frac{\Pi_i(\mathbb{F}^\circ, \mathbb{C}_i^{\mathbb{F}^{d,i}}(\mathbb{F}^\circ))}{D_i(\mathbb{F}')}, 0 \right\} \quad \forall \mathbb{F}' \neq \mathbb{F}^\circ \quad (19)$$

Equation 18 prescribes the largest rebate payment under formulary \mathbb{F}° that i would be willing to accept if i believed the formulary chosen upon agreement would be \mathbb{F}° and upon disagreement would be $\mathbb{F}^{d,i}$, and Equation 19 sets the rebate payments under other formularies $\mathbb{F}' \neq \mathbb{F}^\circ$ to satisfy the manufacturer indifference conditions given in Definition 3.3.

- (b) Test the following conditions:

- i. If $\mathbb{F}^{d,i} = f(\{\mathbb{C}^0, \mathbb{C}_{-i}^{\bar{\mathbb{F}}}\})$ for all manufacturers i (given the profile of other implied rebate contracts $\mathbb{C}_{-i}^{\bar{\mathbb{F}}}$, the formulary induced if manufacturer i rejects its rebate contract is its perceived disagreement formulary $\mathbb{F}^{d,i}$), we say that the set of perceived disagreement formularies $\bar{\mathbb{F}}$ and implied rebate contracts $\mathbb{C}^{\bar{\mathbb{F}}}$ are *consistent* with one another.
- ii. If $\mathbb{F}^\circ = f(\mathbb{C}^{\bar{\mathbb{F}}})$ (the profile of implied rebate contracts induce the candidate equilibrium formulary \mathbb{F}°), then we say that candidate equilibrium formulary \mathbb{F}° is *supportable* with contracts $\mathbb{C}^{\bar{\mathbb{F}}}$.
- iii. For all manufacturers i and formularies $\mathbb{F}' \neq \mathbb{F}^\circ$, check:

$$\Pi_P(\mathbb{F}^\circ, \mathbb{C}^{\bar{\mathbb{F}}}) \geq \Pi_P(\mathbb{F}', \{\mathbb{C}^0, \mathbb{C}_{-i}^{\bar{\mathbb{F}}}\}) + \max \left\{ \Pi_i(\mathbb{F}', \mathbb{C}^0) - \Pi_i(\mathbb{F}^{d,i}, \mathbb{C}^0), 0 \right\}. \quad (20)$$

If this condition (corresponding to (6)) is satisfied, then we say there is *no profitable unilateral deviation* for the PBM.

2. If a profile of perceived disagreement formularies $\bar{\mathbb{F}}$ and implied rebate contracts $\mathbb{C}^{\bar{\mathbb{F}}}$ are consistent with one another, support \mathbb{F}^o , and do not allow for any profitable unilateral deviations for the PBM, then there exists a DA-equilibrium that satisfies manufacturer indifference in which the PBM offers contracts $\mathbb{C}^{\bar{\mathbb{F}}}$, all are accepted, and formulary \mathbb{F}^o is chosen by the PBM.

Last, note that any equilibrium that satisfies MI is associated with a profile of perceived disagreement formularies, and given those perceived disagreement formularies equilibrium rebate contracts must satisfy equations (18)-(19). Hence, any DA-equilibrium that satisfies MI is identified by this algorithm.

To determine if a candidate DA-equilibrium $(\hat{\mathbb{F}}, \hat{\mathbb{C}})$ also satisfies the multilateral deviation conditions provided in the statement of Lemma A.1, for every $\mathbb{F}' \neq \hat{\mathbb{F}}$ (representing a potential formulary that the PBM contemplates deviating to),

1. Compute the maximal rebate that the PBM is able to induce manufacturer i to accept to pay under formulary \mathbb{F}' , denoted $\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')$, as follows:

- (a) Determine $\tilde{\mathbb{F}}^i$ that satisfies (13);
- (b) If $\mathbb{F}' = \tilde{\mathbb{F}}^i$, then set $\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')$ to solve (14):

$$\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}') = \max\left\{p_i - \frac{\Pi_i^d(\hat{\mathbb{C}}_{-i})}{D_i(\tilde{\mathbb{F}}^i)}, 0\right\};$$

else, if $\mathbb{F}' \neq \tilde{\mathbb{F}}^i$, then set $\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')$ to solve (15):

$$\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}') = \frac{\Pi_P(\tilde{\mathbb{F}}^i, \{\mathbb{C}^0, \hat{\mathbb{C}}_{-i}\}) - \Pi_P(\mathbb{F}', \{\mathbb{C}^0, \hat{\mathbb{C}}_{-i}\}) + \max\left\{\Pi_i(\tilde{\mathbb{F}}^i, \mathbb{C}^0) - \Pi_i^d(\hat{\mathbb{C}}_{-i}), 0\right\}}{D_i(\mathbb{F}')}.$$

- (c) Check whether $\Pi_i(\mathbb{F}', \tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')) \geq \underline{\Pi}_i$, where $\underline{\Pi}_i \equiv \min_{\mathbb{F}} \Pi_i(\mathbb{F}, \mathbb{C}^0)$. If not, replace $\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')$ with the value that sets $\Pi_i(\mathbb{F}', \tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')) = \underline{\Pi}_i$; i.e.,:

$$\tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}') = p_i - \frac{\underline{\Pi}_i}{D_i(\tilde{\mathbb{F}}^i)}.$$

2. Check whether $\Pi_P(\hat{\mathbb{F}}, \hat{\mathbb{C}}) \geq \Pi_P(\mathbb{F}', \{\mathbb{C}^0\}) + \sum_i D_i(\mathbb{F}') \times \tilde{\mathbb{C}}_i^{\mathbb{F}'}(\mathbb{F}')$.

If the condition holds for every alternative formulary $\mathbb{F}' \neq \hat{\mathbb{F}}$, then the PBM does not have a strictly profitable multilateral deviation in Stage 1, and $(\hat{\mathbb{F}}, \hat{\mathbb{C}})$ is an equilibrium.

A.4 Bidding Game Payoffs

Consider any Truthful Nash Equilibrium of the bidding game variant of our model among two manufacturers, $i \in \{1, 2\}$. Define $\bar{\Pi}(\mathbb{F}) \equiv \Pi_P(\mathbb{F}, \mathbb{C}^0) + \sum_i \Pi_i(\mathbb{F}, \mathbb{C}^0)$ to be the sum of PBM and manufacturers' payoffs under formulary \mathbb{F} . Let $\mathbb{F}^* \equiv \arg \max_{\mathbb{F}} \bar{\Pi}(\mathbb{F})$ be the formulary that maximizes total PBM and manufacturers' payoffs, $\mathbb{F}^k \equiv \arg \max_{\mathbb{F}} \Pi_P(\mathbb{F}, \mathbb{C}^0) + \Pi_k(\mathbb{F}, \mathbb{C}^0)$ be the formulary that maximizes the PBM and manufacturer k 's payoffs, and $\mathbb{F}^0 \equiv \arg \max_{\mathbb{F}} \Pi_P(\mathbb{F}, \mathbb{C}^0)$ the formulary that maximizes only the PBM's payoff (all without accounting for rebate payments).

Theorem 2 of Bernheim and Whinston (1986) establishes that in any Truthful Nash Equilibrium, equilibrium net payoffs n_i to each manufacturer i , defined as $n_i \equiv \Pi_i(\hat{\mathbb{F}}, \hat{\mathbb{C}}_i)$, must be on the Pareto efficient frontier of all payoff vectors (n_1, n_2) satisfying the following three conditions:

$$\begin{aligned} n_1 &\leq \bar{\Pi}(\mathbb{F}^*) - \left(\Pi_P(\mathbb{F}^2, \mathbb{C}^0) + \Pi_2(\mathbb{F}^2, \mathbb{C}^0)\right) \\ n_2 &\leq \bar{\Pi}(\mathbb{F}^*) - \left(\Pi_P(\mathbb{F}^1, \mathbb{C}^0) + \Pi_1(\mathbb{F}^1, \mathbb{C}^0)\right) \\ n_1 + n_2 &\leq \bar{\Pi}(\mathbb{F}^*) - \Pi_P(\mathbb{F}^0, \mathbb{C}^0) \end{aligned}$$

If the first two inequalities above imply the third, then there is a unique set of Truthful Nash Equilibrium payoffs; by adding the first two inequalities and comparing it to the third, a sufficient condition for this is

$$\bar{\Pi}(\mathbb{F}^*) + \Pi_P(\mathbb{F}^0, \mathbb{C}^0) \leq \left(\Pi_P(\mathbb{F}^1, \mathbb{C}^0) + \Pi_1(\mathbb{F}^1, \mathbb{C}^0)\right) + \left(\Pi_P(\mathbb{F}^2, \mathbb{C}^0) + \Pi_2(\mathbb{F}^2, \mathbb{C}^0)\right)$$

which we confirm holds in our empirical application with two drugs (Section 5.2). Thus, payoffs are unique in any Truthful Nash Equilibrium, and equilibrium rebates under \mathbb{F}^* ensure that the first two inequalities above bind.

B Data Appendix

We infer the tier placement of every drug, by month, in our sample using a combination of plan benefit data and claims data. For 2016-2018 we observe the prescription drug lists provided to members by Optum, which include the tier placement for all covered drugs.⁵⁵ However we only observe the pdf version of these documents, which may not list all covered drugs; members are referred to a online resource if they do not find their drug listed. We also note that the documents are provided annually, while tier placement may change within-year. We therefore use the observed out-of-pocket prices in the claims data to infer each drug’s tier, by month, across all years of the sample, and use Optum’s drug lists to validate our results. We assign an implied tier for every claim based on out-of-pocket prices, and infer the monthly tier based on the modal price for a Princeton enrollee who purchases the drug in our claims data. We manually check any outliers; discrepancies compared to Optum’s prescription drug list; and tier changes close to generic introduction.

Appendix Table 1 sets out the tier placement of all branded statins in our data (including Lipitor, Crestor and Vytorin, which are already covered in Table 3). For 2011-14, Tier “2” corresponds to branded drugs (\$25 copay) and tier “3” corresponds to multisource (\$40). The PBM is Express Scripts for 2011-2015 and Optum for 2016-2018.

Note that Lipitor is classified as “MPTD” in all years after 2015. It was explicitly listed in Optum’s drug list as Excluded in 2016; MPTD in 2017; Excluded in 2018. Lipitor’s market share falls from 0.4% in 2015 (when Express Scripts denoted it MPTD) to 0.2% in 2016; 0.4% in 2017; 0.2% in 2018. Almost all purchases were priced at \$40 per fill (i.e. with an exemption from the MPTD status). Since some enrollees purchase it in all three years, at essentially the same offered and realized prices across years; we classify it as MPTD in all three years. As a robustness test, we repeat the demand analysis with Lipitor on Tier 3 in 2016-18, reflecting its realized price for most fills. The estimated difference in preferences between Tier 3 and MPTD is somewhat smaller than in the baseline model but otherwise the results are very similar.

Crestor and Vytorin both have mid-year tier changes. Generic rosuvastatin was introduced in May 2016; Crestor’s tier also changed that month. Similarly, generic Ezetimibe/Simvastatin was introduced during the first half of 2017; Vytorin tier changed very soon afterwards. The timing of these mid-year adjustments is accounted for in the inferred drug tiers and hence in the demand model.

Several other branded statins were also offered during our panel. Each is included as a separate option in the demand model, along with the generic equivalent when available. The branded (generic) drug names are: Zocor (Simvastatin); Pravachol (Pravastatin Sodium); Livalo (Pitavastatin Calcium); Simcor (Niacin Simvastatin); Lescol (Fluvastatin Sodium). In addition Lovastatin (generic only) was available throughout our panel.

Tier assignment is more challenging for drugs with smaller market shares, since they have zero claims—and hence no observed out-of-pocket prices—in some years. We use an analogous approach to that used for Lipitor to assign Zocor and Pravachol to tiers in years where they have no claims. Both drugs have a generic equivalent throughout the sample. They are not listed in Optum’s drug list in 2016-18, which might imply that they are excluded or that they are listed online as MPTD. As for Lipitor, we note that these two categories are very similar in terms of out-of-pocket prices, and hence it is reasonable to classifying both drugs as MPTD from 2015-18. Effectively, we combine “MPTD” and “excluded” tiers for branded multisource drugs, unless otherwise specified, and label it “MPTD”. For consistency, we also classify Lescol XL as MPTD in 2016-2018 when it has zero claims, despite Optum not including it in the pdf drug list.

Simcor was listed as Tier 2 in 2016; we assume it remained on this tier from 2017-18 (and was small enough to be moved off the pdf drug list, where it is not mentioned). Livalo, which has no generic equivalent, was listed as excluded (but with quantity limits and step therapy) in 2016; but as Tier 3 in 2017 and 2018. Since it was purchased at essentially the same prices in all three years, and the step therapy designation in 2016 suggests that some coverage was available then too, we hold it fixed in Tier 3 from 2016-18. As a robustness test, we re-estimated the demand model under the assumption that Livalo moved to MPTD in 2016 and then back to Tier 3 in 2017. This had little effect on the estimates.

⁵⁵These documents also note limits such as Step Therapy and Quantity Limits. These are generally introduced around the time of generic entry.

C Additional Tables

Table A1: Demand parameter estimates

		I. No claims Jan-Jun 2011		II. Jan-Jun 2011 are 1st claim		III. No random coefficients	
		Estimate	SE	Estimate	SE	Estimate	SE
Switching Costs	Molecule	5.206	0.090	5.422	0.064	5.2309	0.0594
	to Retail	1.570	0.137	1.759	0.115	2.4537	0.0906
	to Mail Order	3.579	0.158	3.481	0.144	4.1515	0.1003
	to Generic	1.694	0.395	1.163	0.170	2.8592	0.2142
	to Branded	1.527	0.397	1.763	0.193	2.1210	0.2400
Random Coefficient	log SD for Mail	0.520	0.056	0.508	0.060		
	log SD for Branded	0.681	0.162	0.599	0.048		
Branded and Channel	Mail	0.421	0.247	0.743	0.181	0.6691	0.1137
Preferences	Mail x First Fill	-2.196	0.166	-1.260	0.143	-1.8064	0.1059
	Mail x 75K To 150K	-0.132	0.169	0.061	0.101	0.1088	0.0634
	Mail x Above 150K	0.122	0.189	0.434	0.288	0.2070	0.0843
	Mail x 45 To 64	0.320	0.202	0.338	0.140	0.1096	0.0918
	Mail x Above 64	0.654	0.264	0.531	0.173	0.1138	0.1111
	Mail x Female	0.237	0.173	0.082	0.136	0.1418	0.0612
	Tier 2	-1.743	0.204	-1.193	0.107	-0.8686	0.1221
	Tier 3	-4.908	0.393	-3.702	0.245	-2.5450	0.2640
	Tier 4	-6.315	0.570	-5.011	0.224	-3.2179	0.3235
	Tier 2 x Mail	0.464	0.158	0.693	0.090	0.1638	0.0791
	Tier 3 x Mail	0.029	0.414	-0.761	0.261	-1.2508	0.3237
Tier 4 x Mail	-0.353	0.709	-1.391	0.361	-1.6664	0.4514	
Molecule Fixed Effects	Atorvastatin						
	Ezetimibe/Simvastatin	-2.596	0.271	-2.313	0.143	-2.1753	0.1521
	Fluvastatin Sodium			-3.388	0.284	-2.9550	0.2952
	Lovastatin	-2.884	0.235	-3.068	0.169	-2.6618	0.1681
	Niacin/Simvastatin	-4.828	0.548	-4.336	0.424	-3.8987	0.3467
	Pitavastatin Calcium	-1.875	0.274	-2.262	0.170	-1.5570	0.1948
	Pravastatin Sodium	-1.276	0.096	-1.539	0.082	-1.1631	0.0774
	Rosuvastatin	-0.195	0.096	-0.377	0.065	-0.1659	0.0797
Simvastatin	-1.174	0.080	-1.126	0.060	-1.1581	0.0659	
N	Individuals	1098		1992		1965	
	Fills	15413		37157		35219	