Title
Reference Pricing for Healthcare Services

Journal
Manufacturing & Service Operations Management, 24(2)

ISSN
1523-4614

Authors
Nassiri, Shima
Adida, Elodie
Mamani, Hamed

Publication Date
2022-03-01

DOI
10.1287/msom.2021.0986

Reference Pricing for Healthcare Services

Shima Nassiri
University of Michigan, Ann Arbor, Ross School of Business, snassiri@umich.edu

Elodie Adida
University of California, Riverside, School of Business Administration, elodie.goodman@ucr.edu

Hamed Mamani
University of Washington, Seattle, Michael G. Foster School of Business hmamani@uw.edu

Problem definition: The traditional payment system between an insurer and providers does not incentivize providers to limit their prices, nor patients to choose less expensive providers, hence contributing to high insurer expenditures. Reference pricing has been proposed as a way to better align incentives and control the rising costs of healthcare. In this payment system, the insurer determines the maximum amount that can be reimbursed for a procedure (reference price). If a patient selects a provider charging more than the reference price, the patient is responsible for the entire portion above it. Our goal is to understand how reference pricing performs relative to more traditional payment systems.

Academic/practical relevance: Our results can help healthcare leaders understand when reference pricing has the potential to be a successful alternative payment mechanism, what its impact on the different stakeholders is, and how to best design it.

Methodology: We propose a game-theoretical model to analyze the reference pricing payment scheme. Our model incorporates an insurer who chooses the reference price, multiple competing price-setting providers, and heterogeneous patients who select a provider based on a multinomial logit choice model.

Results: We find that the highest-priced providers reduce their prices under reference pricing. Moreover, reference pricing often outperforms the fixed and the variable payment system both in terms of expected patient utility and insurer cost, but incurs a loss in the highest-priced providers' profit. Furthermore, we show that in general the insurer utility is often higher under reference pricing unless the insurer is a public non-profit insurer that weighs the providers' utility as much as its own cost.

Managerial implications: Overall, our findings indicate that reference pricing constitutes a promising payment system for "shoppable" healthcare services as long as the insurer does not act similar to a public non-profit insurer.

Key words: healthcare, payment models, reference pricing, fee-for-service
History: December 28, 2020

---

1. Introduction

The cost of a given medical procedure varies widely not just across the nation, but also across medical providers within the same geographic area (Newman et al. 2016). For example, the maximum price charged by a provider for a knee replacement in Atlanta, GA is over 6 times that charged by the lowest-priced provider (Cooper et al. 2015). The price charged for a procedure does not generally reflect the quality of the care provided (Newhouse et al. 2013). Rather, the price variation results from variation in the providers' market power in their negotiations with insurers, the extent of provider competition within a geographic area, the type of facility offering the procedure, the lack of price transparency, and who is footing the bill – Medicare, Medicaid, private insurer or patient (Rosenthal 2013).

The current payment system does little to incentivize patients to be price-conscious in their selection of a provider. Usually, patients pay either a fixed co-payment or a co-insurance, that is, a fraction of the billed charges, subject to a maximum yearly out-of-pocket. In the case of a co-payment, patients pay the same amount regardless of what the provider actually charges. In the case of a co-insurance, for an expensive procedure the co-insurance may exceed the maximum yearly out-of-pocket; the patient is then unaffected by what the insurer is charged. Therefore, patients have limited incentives to select a less expensive provider. As a result, providers have every incentive to raise prices.

To induce better decisions and reduce costs, insurers have used cost-sharing with patients, with the goal of reducing the use of expensive and unnecessary care. Such mechanisms may lead to a reduction in the use of high-value services such as preventive care and chronic disease management (Robinson 2010). Insurers may also narrow down the provider network, hence channelling patients to high-quality providers who are willing to discount their prices for a higher market share (e.g., managed care organizations and center of excellence contracting). This approach often severely limits choices available to patients.

To better align incentives and control rising healthcare costs, a *reference pricing* (RP) payment system has been proposed, incentivizing patients to use lower-priced providers. Reference pricing has been used for pharmacy benefits and it has recently expanded to healthcare procedures. One of the major implementations of reference pricing is through the California Public Employees' Retirement System (CalPERS), covering 1.3 million people. In 2011, implementation of reference pricing for knee and hip replacement resulted in \$2.8 million in savings for CalPERS and \$0.3 million in lower cost-sharing for CalPERS members (Robinson and Brown 2013). Since then, CalPERS has expanded the program to cataract surgery, colonoscopy, and arthroscopic knee surgery (White and Eguchi 2014). The idea of reference pricing is to set a "reference price" as the upper limit of charges to be reimbursed by the insurer. If a patient selects a provider charging the reference price or less (known as a “value-based” provider), she pays a co-payment or co-insurance. However, if the patient selects a provider charging more than the reference price (i.e., a “non-value-based” provider), she has to pay the full portion of the charge above the reference price (not applicable towards a yearly maximum out-of-pocket), in addition to the co-payment or co-insurance from the portion below the reference price.

Reference pricing can be applied to any *shoppable* medical service – not emergency care. Patients must be able to shop around and compare providers based on their prices and other attributes before making a selection. Such a comparison requires price and quality transparency. Reference pricing has been (and should be) applied to services for which quality of care is either (a) relatively standardized (such as diagnostic imaging), or (b) can be relatively easily compared (such as joint replacement) (Robinson et al. 2017). Patients cannot successfully shop for complex treatments whose outcomes are heavily dependent on disease severity. Note that in the CalPERS implementation of reference pricing, “quality was deemed to be better or equivalent – as measured by post-surgery complications, infection rates, and hospital readmission rates” (Fronstin and Roebuck 2014).

Additionally, even though there may be a lack of price and quality transparency for many health services, the availability of price and quality information has improved in recent years. Many quality metrics are publicly available for a given healthcare provider. For example Medicare’s “Hospital Compare” platform provides general information about facilities and services provided at hospitals as well as patient experience surveys, effectiveness of care, complications, mortality, etc. (CMS 2013). Also, going forward, price comparisons will be easier for patients since, starting January 1, 2019, providers are required to post price lists online in an effort to increase price transparency (CMS 2018).

Finally, in successful implementations of reference pricing, insurers have exerted a lot of communication efforts to inform patients of their options and help them make an informed decision. This communication strategy can include a list of recommended (value-based) providers, such as the one CalPERS supplied to its enrollees (Robinson and Brown 2013). Anthem Blue Cross engaged in both broad-based and targeted communications with consumers (Lechner et al. 2013). Other examples of providing price and quality information to patients include: Safeway collaboration with Castlight Health to set up its reference pricing program for certain outpatient services (NBCH 2012), Aetna’s iTriage price comparison from Healthcare Bluebook, UnitedHealthcare's MyEasyBook online healthcare shopping tool, Guroo price information based on claims data from four major insurers, and Health in Reach comparison of licensed providers (Robinson 2016).

Reference pricing has some clear advantages. Proponents argue that it provides patients with incentives to make a price-conscious provider selection while maintaining access to a large set of providers. Moreover, the most expensive providers may have to reduce their prices to maintain their market share with price-sensitive patients (Robinson and McPherson 2012). However, it may also have unintended consequences. Critics argue that reference pricing could force patients to bear a larger share of the cost, especially if the reference price is set low, reducing patient welfare. Moreover, providers who used to charge below the reference price may *increase* their prices (*shadow pricing*), which could negate the effect of a potential price decrease by higher-priced providers.

Our goal is to analyze the reference pricing payment scheme and its effect on all agents involved – patients, competing medical providers, and insurer, from an analytical perspective. We propose to answer the following research questions: (1) Does reference pricing reduce prices set by providers? (2) Are each of the stakeholders (patients, providers, insurer) better or worse off under reference pricing relative to a system where the patient pays either a fixed amount (e.g., co-payment) or a variable amount (e.g., co-insurance)?

This paper introduces a new model of reference pricing payment system that considers competition among differentiated medical providers. While most of the closest existing research takes an empirical approach to evaluating the effect of reference pricing on prices and insurer spending, our analytical approach enables to extract managerial insights useful to policy-makers. Our model incorporates heterogeneous patients influenced by monetary and non-monetary motives. We obtain the patients' optimal provider selection decisions and the providers' optimal pricing strategy under a fixed payment system, a variable payment system, and a reference pricing system. We compare the prices and the utility of patients, providers, and insurer across the different payment schemes. We find that reference pricing leads the highest-priced providers to lower their prices. As a result, patients are in general better off under reference pricing. In contrast, providers favor a variable or a fixed payment system as such payment systems generate higher prices. Moreover, we investigate the effect of varying the reference price and we obtain that setting it too low may lead to no provider selecting to be value-based, which has detrimental consequences on the patient and insurer utility. Finally, we analyze the effect on the insurer's objective. We obtain that reference pricing performs well for many types of insurer except for a public non-profit insurer who values the patient utility and the provider benefit as much as its own cost. Our findings indicate that reference pricing constitutes a promising payment system for shoppable healthcare services, as long as the reference price is not set too low considering the cost, to maintain a sufficient number of value-based providers, except for a public non-profit insurer. We also explore the effect of letting the reference price be endogenously determined and of heterogeneous price sensitivity for patients.

2. Literature Review

Four streams of research informed and inspired this paper: research that studies healthcare payment systems; research that focuses on reference pricing in the pharmaceutical market; research that investigates reference pricing for healthcare services; and research that captures consumers' (or patients') choice using a multinomial logit (MNL) model.

The first stream of research evaluates the performance of payment systems departing from the traditional fee-for-service most commonly used presently in the US. These new payment systems aim at realigning incentives to improve patient outcomes and curb costs. Capitation and the prospective payment system focus on volume of care by reducing incentives for unnecessary treatments. However, healthcare providers did not adopt these payment schemes to the extent predicted due to the complete shift of risk to the providers (Zuvekas and Cohen 2016). Pay-for-performance models typically focus on quality of care. Yet, pay-for-performance may also result in cherry-picking the healthier patients, ignoring aspects of care that are not captured in the quality measures, reducing the intrinsic motivation of providers, upcoding, and manipulating healthcare outcomes (Eijkenaar et al. 2013). Mak (2018) finds that both the prospective payment system and pay-for-performance should be complemented by co-payments that vary according to each provider's marginal service cost (consistent with reference pricing) and that are adjusted based on consumer misperceptions. Bundled payments focus on healthcare outcomes and on keeping healthcare providers accountable. In this payment system, a fixed lump sum payment is provided for a given episode of care regardless of the procedures implemented and of possible complications (Gupta and Mehrotra 2015). Guo et al. (2019) show that bundled payments can improve the readmission rate, waiting time, and patient welfare. Yet, Adida et al.

(2017) find that bundled payments, while removing incentives to over-treat, could generate patient selection by providers. Andritsos and Tang (2018) show that pay-for-performance is generally more effective at reducing readmissions than bundled payments.

The second stream of research focuses more specifically on the use of reference pricing for pharmaceuticals (López-Casasnovas and Puig-Junoy 2000). Reference pricing was first implemented for drugs in Europe in the 1990s (Brekke et al. 2007) and was credited for improving price competition, making demand more price-elastic, and hence reducing expenditures. However, critics argue that it removes patent protection and could negatively impact research and development efforts by pharmaceutical firms. In addition, it may introduce difficult trade-offs for patients who must choose between a lower out-of-pocket or a better-suited drug. Reference pricing for pharmaceuticals has been empirically shown to reduce the price of generic and brand-name drugs and shrink the brand-name drugs' market share (Kaiser et al. 2014). Yet, Danzon and Ketcham (2004) find that reference pricing in the US may hurt pharmaceutical innovation, new compound availability, and competition. Reference pricing for pharmaceuticals has also been studied analytically. Bardey et al. (2010) show that reference pricing negatively impacts research investment and deters innovation. Ghislandi (2011) finds that reference pricing can work well only if the market for generics is competitive, and a poorly-set reference price can lead to collusion among generic firms. Brekke et al. (2016) show that reference pricing discourages entry and, in some cases, can lead to a price increase. While in the pharmaceutical context, questions related to generic drugs, innovation and market entry are essential, in contrast we focus on healthcare services with provider competition and the effect of reference pricing on prices and patient, provider and insurer welfare.

The third stream of research investigates the use of reference pricing for healthcare services. Reference pricing has been implemented for healthcare services in the US only fairly recently. These implementations have motivated some empirical studies on the effect of reference pricing for medical procedures. Fronstin and Roebuck (2014) find that implementing reference pricing for carefully-selected medical procedures could reduce prices and save 1.6% of health care spending, but they warn that the value of the reference price is critical to the success of the pricing scheme. Brown and Robinson (2016) study reference pricing with both exogenous (i.e., externally selected) and endogenous (i.e., varying with market prices) reference price. Whaley et al. (2019) analyze empirically whether improving price transparency can lower the prices selected by providers. They also consider a simple analytical model that evaluates the role of varying search costs under reference pricing compared to a plan with a co-insurance. They show that the price-reducing effects of reductions in search costs are stronger under reference pricing than under a co-insurance system because in the latter, the presence of insurance coverage attenuates the effect. Hence, reductions in search costs lead to little change in consumer choices under regular insurance coverage; however, reference pricing amplifies the effect of reduced search costs. Note that while they are able to compare the strength of the effects, they do not quantify the size of each effect individually. A major distinction with our work is that in Whaley et al. (2019), providers do not optimize prices, and the authors do not study what the prices are and the resulting welfare of the agents of the system. In contrast, we have a different focus than the effect of search costs. Our analysis determines the equilibrium prices and analyzes how the agents' welfare compares across payment systems. This allows us to compare the payment system beyond the effect of a reduction in search cost. Except for Denoyel et al. (2017), who propose an algorithm to help the insurer select value-based providers when the reference price is exogenous and the demand parameters are uncertain, most papers to date on this topic take an empirical approach. In contrast to most existing literature, we adopt a model-based analytical approach to help derive managerial insights. Moreover, while the empirical literature is primarily focused on how prices and insurer spending are affected by reference pricing, we analyze the effect on the welfare of all stakeholders involved, including patients, providers, and insurer.

Finally, to model the patients' choice across different providers, we use a multinomial logit (MNL) choice model similar to Aksoy-Pierson et al. (2013). The MNL model has been widely used in the operations, marketing, and economics literatures (Anderson et al. 1992). It has also been used to model patient choice within the healthcare operations literature (Truong 2014). The MNL model captures the heterogeneity of preferences of different patients and has several attractive properties. It is conceptually appealing, analytically tractable, and it has been shown to have excellent empirical fit (Jain et al. 1994).

3. Modeling Framework

We consider a medical procedure with a fairly uniform protocol, covered by a given insurer. The insurer's network includes two competing and profit-maximizing providers who offer the procedure to a population of m heterogeneous patients under the insurer's plan. The cost split between patients and the insurer depends on the specific payment scheme. We model three payment structures and establish measures to assess their performance. In a fixed payment system (FP), the patient is responsible for a fixed amount regardless of the selected provider. In a variable payment system (VP), the patient pays a fraction of the price charged. Under reference pricing (RP), the price selected by a provider determines whether it is value-based or not. The patient pays a fixed co-payment and in addition, if she selects a non-value-based provider, the entire portion of the price above the reference price. Our duopoly setting allows us to simultaneously examine the effect of competition among providers as well as the role of different payment mechanisms and their performance.

Some of our results are generalizable to the case of more than two providers, as illustrated in the proofs in Appendix D. However, analytically comparing different payment models with more than two providers is intractable. Yet, we confirm numerically that these comparisons continue to hold for more than two providers in Section 7. We next analyze different stakeholders. Table 3 in Appendix A summarizes the notation.

3.1. Patients

For a given payment system, after observing the providers' prices and non-price attributes, each patient selects her utility-maximizing provider. Patients also have the option of selecting alternative treatments. The utility U_{ij} that patient i gains when receiving care at provider j results both from non-monetary and monetary factors, and is modeled as

$$U_{ij} = a_j - \gamma o_j + \eta_{ij}, \quad i = 1, \ldots, m, \ j = 1, 2. \tag{1}$$

Parameter a_j represents the non-idiosyncratic utility that every patient receives when obtaining care at provider j, exclusive of price considerations. Hence, a_j captures general attributes such as comfort level, availability of advanced technologies, quality and quantity of staff and auxiliary facilities, etc. We assume that a_j is fixed and, without loss of generality, $a_1 \leq a_2$. We denote o_j the patient's out-of-pocket cost when obtaining care from provider j; for ease of exposition, we omit to make the dependence of o_j on prices and on the payment system explicit. All patients have the same price sensitivity γ. This assumption is used in related literature (e.g., Brekke et al. 2007, Truong 2014, Kouvelis et al. 2015). We relax this assumption in Section 6.2 by considering heterogeneous price sensitivity levels.

Parameter η_{ij} is the source of patient heterogeneity. It captures idiosyncratic attributes, exclusive of price considerations, that patient i receives when obtaining care from provider j, such as distance to the patient's residence and ease of access, patient's familiarity with the facility and/or doctor performing the procedure, quality of care provided by provider j as a priori perceived by patient i, etc. Because parameters η_{ij} vary from patient to patient for a given provider, our model captures heterogeneous patient preferences (Aksoy-Pierson et al. 2013). Patient i's utility from selecting an alternative treatment (i.e., choosing none of the providers) is given by $U_{i0} = u_0 + \eta_{i0}$, where u_0 is the fixed non-idiosyncratic utility of selecting an alternative treatment, and η_{i0} is the corresponding idiosyncratic added utility specific to patient i.

We assume that parameters $\eta_{ij}, i = 1, \ldots, m$ are independent and identically distributed random variables for each $j \in \{0, 1, 2\}$. We further assume that η_{ij} follows a standardized Gumbel (or type-I extreme value) distribution with cumulative distribution function form $f(x) = exp(-exp(-x))$. This form of distribution for error terms results in a multinomial logit (MNL) choice model for patients when making a selection across different providers (Train 2003, Section 3.10). Notice that the error terms η_{ij} have a constant mean that can be omitted in (3) without loss of generality (Hayashi 2011). We observe that the patient's utility from obtaining services from a given provider is influenced by the provider's characteristics (through parameter a_j) and by the unique combination of patient and provider (through parameter η_{ij}) in addition to the patient's out-of-pocket. Each patient, then, selects the utility-maximizing provider. Using the MNL model, the probability that a randomly selected patient chooses provider j is given by

$$S_j(P) = \frac{e^{a_j - \gamma o_j}}{e^{u_0} + \sum_{k=1}^{2} e^{a_k - \gamma o_k}} \in (0, 1), \quad j = 1, 2, \tag{2}$$

where $P = (p_1, p_2)$ is the vector of provider prices. The probability of seeking an alternative treatment is $S_0(P) = 1 - \sum_{j=1}^{2} S_j(P)$. The expected patient population utility is then:

$$E[U](P) = m \left(\sum_{j=1}^{2} (a_j - \gamma o_j) S_j(P) + u_0 S_0(P) \right). \tag{3}$$

3.2. Providers

We consider two competing price-setting providers in the insurer's network. At the stage that our paper focuses on, the provider network is given and does not change, i.e., providers do not drop out of the network in the phase under study (but a provider can choose to price so high that no patient would select it, effectively exiting the market). Providers incur the same treatment cost c. Indeed, reference pricing is most relevant for procedures with a uniform protocol so that variations in quality are minimal, and price comparison is easier (Fronstin and Roebuck 2014). Uniformity of protocol ensures little variation in cost of delivery. Moreover, reference pricing is used to discourage price variations that are not warranted by differences in cost. To better investigate whether reference pricing eliminates such unwarranted price variation, we focus on providers with the same treatment cost. Most of our results hold true for heterogeneous treatment costs across providers as long as the provider treatment costs are ordered according to the non-price attributes (i.e., $c_1 \leq c_2$). Such an ordering property is intuitive as improving general attributes such as comfort of the facilities, staffing level, etc. may incur increasing costs.

Given a payment system, competitive providers engage in a game, anticipating patients' reactions. Each provider j selects price p_j $(> c)$ so as to maximize its profit, given by

$$V_j(P) = m(p_j - c)S_j(P), \quad j = 1, 2. \tag{4}$$

3.3. Insurer

The insurer exerts leverage via the payment terms. In practice, the co-payment (under the fixed payment) and co-insurance rate (under the variable payment) are set in advance for *broad* categories of services (e.g., specialist visit, ER visit, hospital stay). The insurer does not adjust these reimbursement parameters on a service-per-service basis, and so it is reasonable to assume that such parameters have already been set for the considered medical procedure. However, the reference pricing system is designed specifically for a given procedure, and the insurer does have the freedom to set the reference price in an optimal way *for this procedure*. More details on the insurer's decision and its objective under reference pricing are provided in Section 4.4.

4. Payment Systems

We analyze three types of payment systems. First, we consider a fixed payment system, whereby the patient pays a fixed amount. This situation is closest to the current system in many cases. It occurs in practice when the patient is subject to a fixed co-payment. It may also occur when the patient is subject to a co-insurance with a yearly maximum out-of-pocket, and the range of prices for the procedure is high enough so the patient meets the maximum out-of-pocket regardless of the provider she selects (e.g., joint replacement surgery). Second, we investigate a variable payment, where the patient is responsible for a given fraction of the price charged by the provider. In practice, this situation occurs when the patient is subject to a co-insurance without maximum out-of-pocket. It may also occur in the presence of a yearly maximum, as long as the maximum amount is large compared to the likely patient out-of-pocket, so that the patient does not meet this yearly maximum because of the procedure. Third, we examine the reference pricing scheme, where the patient pays a fixed amount and, if selecting a provider charging above the reference price, pays in addition the entire portion above the reference price. For each of these payment models, the providers select their prices and patients then select a provider and pay the corresponding out-of-pocket amount, depending on the cost-sharing mechanism in place. In order to analyze the equilibrium decisions, we proceed by backward induction. As detailed in the proofs, we start by analyzing the patient's choice of a provider, given provider prices $p_j,\ j=1,2$; we then obtain the prices selected by the providers in equilibrium.

4.1. Fixed Payment

Under fixed payment, provider j selects a price that may not exceed $\overline{p}_j$. Each patient then selects the provider that yields maximum utility, and pays a fixed amount f regardless of the provider she selects and of the prices – namely, $o_j=f,\ j=1,2$. While patients are not sensitive to the prices charged, the insurer is, and thus the insurer negotiates the maximum price $\overline{p}_j$ with each provider in its network. (Such prices can be determined using a Nash bargaining model (Binmore et al. 1986). In contrast, under reference pricing or variable payment, the provider's market share would be negatively impacted by an excessive price. Hence, the insurer does not need to negotiate a maximum and lets market forces regulate the prices that providers select.) We consider the maximum prices $\overline{p}_j,\ j=1,2$ as given and our analysis of the fixed payment model focuses on the phase after these bounds have been set. We next determine how providers, anticipating the patients' reaction, set their prices.

Proposition 1. *Under fixed payment, at equilibrium, provider j selects $p_j^{FP}=\overline{p}_j,\quad j=1,2$.*

The result of Proposition 1 stems from the fact that when the patient pays a fixed amount, a provider's high price has no adverse effect on its market share. Since the insurer covers the portion of the charge not paid by the patient, high prices result in higher revenue with no downside for the provider. Thus, providers have no incentive to limit the price they charge. This situation illustrates the issue of moral hazard present in this context: patients make decisions without having to bear the financial consequences of these decisions. When patients have "no skin in the game," incentives are misaligned and lead to rising prices. This situation motivates the need for a different payment system, where providers would have incentives to control their prices and patients to make price-sensitive decisions.

4.2. Variable Payment

In a variable payment system, the patient is responsible for a fraction $\lambda \in (0,1]$ (referred to as the cost share) of the amount charged by the provider. Providers select their prices, and each patient then selects the provider that yields a maximum utility, where the patient out-of-pocket is $o_j = \lambda p_j,\ j = 1,2$. We next determine how providers, anticipating the patients' reaction and competing in a non-cooperative game, set their prices in equilibrium.

As a preliminary, we formalize a condition that guarantees the existence of a pure Nash equilibrium within the analysis of the variable payment model. This condition is similar to that introduced in Allon and Federgruen (2009). Let $p_j^{VP}(p_{-j})$ be provider j's best response price, when the other provider prices at p_{-j}, and let $S_j^{VP}(p_{-j})$ be provider j's corresponding market share. Also, let $\overline{p}_j^{VP} = \lim_{p_{-j}\to\infty} p_j^{VP}(p_{-j})$ and $\overline{S}_j^{VP} = \lim_{p_{-j}\to\infty} S_j^{VP}(p_{-j})$.

Assumption 1. $\overline{S}_j^{VP} \leq 50\%$ *for* $j = 1,2$.

This condition resembles the standard economics result whereby a monopolist subject to a linear price-demand function chooses to serve an optimal market share below 50%, the remainder being left unserved. We note that when the other provider sets its price at p_{-j} and p_{-j} becomes large, provider j is effectively the only relevant provider in the market, and would then gain its maximum market share. This assumption thus ensures that provider j's market share is less than 50% regardless of the competing providers' prices. Moreover, as demonstrated in the proof of Theorem 1, $\overline{p}_j^{VP}$ is an upper bound on provider j's equilibrium price under the variable payment system.

Theorem 1 shows the existence of a unique Nash equilibrium for the providers' prices in a variable payment system under Assumption 1, and describes how to obtain these prices.

Theorem 1. *At equilibrium, the providers' prices are the unique solution of the system of equations:*

$$1 - \gamma\lambda(p_j - c)(1 - S_j^{VP}(P)) = 0, \quad j = 1,2. \tag{5}$$

4.3. Reference Pricing

In the reference pricing payment system, the insurer sets a reference price p^* for the procedure and providers then select their prices. If a provider selects a price below the reference price, the provider is a "value-based" provider; otherwise it is a "non-value-based" provider. Finally, each patient selects the provider that yields a maximum utility, with $o_j = \tilde{c} + (p_j - p^*)^+ = \tilde{c} + \max\{0, p_j - p^*\},\ j = 1, 2$. Namely, patients pay a fixed co-payment ($\tilde{c}$), and, if they choose a non-value-based provider, they also pay the portion of the price above the reference price. Notice that, even though the co-payment is independent of the selected provider, it impacts the appeal of seeking treatment for the patient. We assume that the co-payment is less than the cost of treatment ($\tilde{c} < c$), which is consistent with reality. We next determine how providers, anticipating the patients' reaction, and competing in a non-cooperative game, set their prices in equilibrium.

As a preliminary, we formalize a condition that guarantees the existence of a pure Nash equilibrium within the analysis of the reference pricing system. In the following assumption, the notations are similar to those defined immediately preceding Assumption 1.

Assumption 2. $\overline{S}_j^{RP} \leq 50\%$ *for* $j = 1, 2$.

We next show how value-based providers price at equilibrium.

Proposition 2. *At equilibrium, a value-based provider prices at the reference price, p^*.*

This result is consistent with the fixed payment case and with intuition. When a patient chooses a value-based provider, she pays a fixed co-payment, regardless of the price charged by the provider. Hence, the actual price (up to the reference price) has no effect on patient choice, and thus on the provider's market share. Yet, the price has an effect on the provider's revenue. Hence, value-based providers set their prices as high as possible, that is, at the reference price, a phenomenon known as *shadow pricing* (Fronstin and Roebuck 2014). In Appendix C, we analyze a reference pricing system with *variable* cost share below the reference price, which, we show, can mitigate shadow pricing.

The following result shows how a given set of non-value-based providers jointly determine their prices in equilibrium.

Theorem 2. *Consider as given the set of non-value-based providers, $\mathcal{N}$. At equilibrium, the providers' prices are the unique solution of the system of equations:*

$$1 - \gamma(p_j - c)(1 - S_j^{RP}(P)) = 0 \quad \forall j \in \mathcal{N}, \qquad p_i = p^* \quad \forall i \notin \mathcal{N}.$$

Theorem 2 provides a way to find the equilibrium prices when the set of non-value-based providers is known. Specifically, the prices can be found by solving a system of equations (which we show has a unique solution), where the price of value-based providers is set to p^*. The ensuing results help determine the set of non-value-based providers.

Proposition 3. *If provider 1 is non-value-based, then provider 2 is non-value-based.*

Recalling that provider 2 has better non-price attributes ($a_1 \leq a_2$), Proposition 3 confirms the notion that the provider with better non-price attributes is more likely be non-value-based, as it offers patients a quality of service that could justify the higher out-of-pocket cost for patients who select it.

Below, we use the result of Proposition 3 along with Theorem 2 to obtain the set of non-value-based providers and their prices at equilibrium in at most two steps.

Algorithm 1. *Step 0. Initialize* $\mathcal{N} = \{1,2\}$ *and* $j = 1$.

Step 1. Solve the system of equations given in Theorem 2. If $p_j > p^* \quad \forall j \in \mathcal{N}$*, stop. Else, go to Step 2.*

Step 2. $\mathcal{N} \rightarrow \mathcal{N} \setminus \{j\}$, $j \rightarrow j+1$. *If* $\mathcal{N} = \emptyset$*, stop. Else, go to Step 1.*

Algorithm 1 involves solving at most two systems of equations to iteratively test possible candidates for the set of non-value-based providers. Upon completion of the algorithm we identify the set of non-value-based providers as well as the prices they select in equilibrium. This algorithm can be generalized for more than two providers.

4.4. Insurer Decision Under Reference Pricing

We now investigate the insurer's decision-making role under reference pricing.

Remark 1. *In setting the reference price, we model the insurer as aiming to maximize the social welfare, that is, the system-wide utility.*

Part of the insurer's goal is to minimize the cost of covering health care expenditures beyond the patients' out-of-pocket. However, this is not the insurer's sole objective – if it was, the insurer would simply shift the entire cost of medical care to patients (by setting the reference price at zero), leading to the worst patient welfare. Indeed, inspired by public payers such as Medicare, the literature often models the insurer's objective as that of maximizing the system-wide utility (e.g., Barros 2011, Andritsos and Tang 2018, Mahjoub et al. 2018, Guo et al. 2019, Adida 2019). This objective function ensures that the insurer considers not only its own cost of providing coverage, but also the welfare of patients under its care, as well as the providers' welfare to ensure that providers remain in-network in the long run, which maintains access to care for the population. Within the context of healthcare payment systems, for instance, Ma and Mak (2015) consider the insurer's objective to maximize a weighted sum of the social net benefit and the provider's profit. This insurer objective is also consistent with our motivating example: CalPERS is a public insurer whose mission includes delivering healthcare to its members, and can be modeled similarly to a social planner considering the utilities of all the agents of the system in its objective. Dranove (1996) notes that, "the social planner is concerned with all incremental resources associated with treatment, whether borne by patients, providers, or insurers". This is also a common structure in more traditional economic literature: for example, Baron and Myerson (1982) assume that the regulator considers the firm profit in addition to consumers. We thus model the insurer's objective as:

$$\begin{aligned}\Pi^{RP}(p^*) &= \omega_1 E[U^{RP}](P(p^*)) + \omega_2 \sum_{j=1}^{2} V_j^{RP}(P(p^*)) - W^{RP}(P(p^*)) \\ &= m \sum_{j=1}^{2} \left(\omega_1(a_j - \gamma o_j(p^*) - u_0) + \omega_2(p_j(p^*) - c) - p^*\right) S_j^{RP}(P(p^*)) + m\omega_1 u_0. \qquad (6)\end{aligned}$$

In the equation above, $P(p^*)$ are the prices that providers select in response to a reference price p^*; $W^{RP}(P) = m\sum_{j=1}^{2}(p_j - o_j)S_j^{RP}(P)$ is the insurer's cost; coefficients $\omega_1 \in [0, \frac{1}{\gamma}]$ and $\omega_2 \in [0,1]$ are the weights of the expected patient population utility and the providers' aggregated utility in the insurer's objective, respectively. We set $\omega_1 \leq 1/\gamma$ so the insurer values the patients' out-of-pocket at most as much as its own cost. Introducing weights ω_1 and ω_2 enables us to study how different types of insurers (who may value provider and patient welfare more or less relative to the insurer cost) fare under reference pricing. In particular, $\omega_1 = \omega_2 = 0$ corresponds to the case of a greedy insurer that solely considers its own cost, while $\omega_1 = 1/\gamma$, $\omega_2 = 1$ corresponds to the case of a public non-profit insurer that values patient and provider welfare as much as its own cost.

As a preliminary before analyzing the insurer's optimal decision, the following lemma illustrates how the set of non-value-based providers changes with the reference price.

Lemma 1. *As the reference price increases, the number of non-value-based providers decreases or remains constant under reference pricing.*

As the reference price increases, value-based providers gain a higher margin. A non-value-based provider may thus choose to become value-based, but not vice versa.

We assume that the insurer must set the reference price high enough to have at least one value-based provider in its network. By Proposition 3, provider 1 must thus be value-based. Past implementations of reference pricing validate this assumption (e.g., in the CalPERS joint replacement implementation, the reference price was set at the 67^{th} percentile of the prices under the fixed payment model (Robinson and McPherson 2012)). Proposition 4 describes the insurer's optimal reference price decision under this assumption.

Proposition 4. *Let* $p^*_{22} = \frac{1}{\gamma}\left(1+\frac{e^{a_2-\gamma\tilde{c}}}{e^{u_0}+e^{a_1-\gamma\tilde{c}}}\right)+c$ *and let* p^*_{11} *solve for* p^* *in* $p^* = \frac{1}{\gamma}\left(1+\frac{e^{a_1-\gamma\tilde{c}}}{e^{u_0}+e^{a_2-\gamma(p_2^{RP}(p^*)-p^*+\tilde{c})}}\right)+c$, *where* $p_2^{RP}(p^*)$ *is the best response of provider* 2 *to provider* 1 *pricing at* p^*, *i.e.* $p_2^{RP}(p^*)$ *solves*

$$e^{a_2-\gamma(p_2^{RP}(p^*)-p^*+\tilde{c})} = (\gamma(p_2^{RP}(p^*)-c)-1)(e^{u_0}+e^{a_1-\gamma\tilde{c}}). \tag{7}$$

Then $p^*_{11} < p^*_{22}$. *Moreover, if* $e^{a_2-\gamma\tilde{c}} \le (\gamma(\omega_1(a_2-\gamma\tilde{c}-u_0)-c)-1)\left(e^{u_0}+e^{a_1-\gamma\tilde{c}}\right)$ *and* $\gamma\omega_1 \le \omega_2$ *then the optimal reference price is*

$$\hat{p}^* = \underset{p^*}{argmax}\left\{\Pi^{RP}(p^*=p^*_{11}), \Pi^{RP}(p^*=p^*_{22}), \Pi^{RP}(p^*=\tilde{p}^*)\right\} = \begin{cases} p^*_{11} & \text{if } \tilde{p}^* < p^*_{11}; \\ \tilde{p}^* & \text{if } p^*_{11} \le \tilde{p}^* \le p^*_{22}; \\ p^*_{22} & \text{if } \tilde{p}^* > p^*_{22}, \end{cases}$$

and $\tilde{p}^*$ *solves for* p^* *in*

$$(\omega_1\Delta u_{21}(p^*)+\omega_2\Delta v_{21}(p^*))S_1^{RP}(P(p^*)) + (\omega_1\Delta u_{20}(p^*)+\omega_2 v_2 - p^*)S_0(P(p^*)) + \omega_1 = \frac{(1-\omega_1)S_1^{RP}(P(p^*)) + (1-\omega_2 S_2^{RP}(P(p^*)))S_2^{RP}(P(p^*))}{\gamma S_2^{RP}(P(p^*))(1-S_2^{RP}(P(p^*)))},$$

with $\Delta u_{21}(p^*) = a_2 - a_1 - \gamma(p_2^{RP}(p^*)-p^*)$, $\Delta v_{21}(p^*) = p_2^{RP}(p^*)-p^*$, $\Delta u_{20}(p^*) = a_2 - \gamma(p_2^{RP}(p^*)-p^*+\tilde{c}) - u_0$, *and* $v_2 = (p_2^{RP}(p^*)-c)$.

Conditions described in this proposition characterize situations where the insurer sets the reference price either at the minimum value that guarantees one value-based provider ($p^* = p^*_{11}$), or high enough to be indifferent between having one or two value-based providers ($p^* = p^*_{22}$), or in-between. We next focus on two special cases.

Corollary 1. *If* $\omega_1=\omega_2=0$ *(greedy insurer) then the optimal reference price is* $\hat{p}^* = p^*_{11}$. *If* $\omega_1 = \frac{1}{\gamma}$ *and* $\omega_2 = 1$ *(public non-profit insurer) then*

- *if* $(u_0-a_2+\gamma c)e^{u_0} - (a_2-a_1)e^{a_1} < 0$, *then the optimal reference price is* $\hat{p}^* = p^*_{22}$
- *if* $(u_0-a_2+\gamma c)e^{u_0} - (a_2-a_1)e^{a_1} \ge 0$, *then the optimal reference price is* $\hat{p}^* = \underset{p^*}{argmax}\left\{\Pi^{RP}(p^*=p^*_{11}), \Pi^{RP}(p^*=p^*_{22})\right\}$.

5. Comparison of Payment Models

In this section, we derive insightful properties of the equilibrium outcomes under the different payment regimes, and explore implications on different stakeholders to guide policy decisions. We focus on analytically comparing reference pricing to the variable payment system. Comparing with the fixed payment system would not yield insightful analytical results because the performance of the fixed payment system critically depends on the value of the fixed payment f and the price upper bounds $\overline{p}_j,\ j = 1,2$, which do not affect the other models. There is a consensus in the health policy community that the fixed payment model does not create the right incentives; this observation motivates us to focus on other alternatives and compare them to each other. We numerically confirm this observation in Section 7, where we compare the three payment systems to each other when parameters are calibrated according to the CalPERS implementation of reference pricing for knee and hip replacement. We first derive preliminary properties of the payment schemes.

Lemma 2. *(a) Under a variable payment system, each provider's price is decreasing in the cost share λ at equilibrium. (b) Under a reference pricing system, each provider's price is increasing in the reference price p^* at equilibrium.*

Under a variable payment scheme, as the patient cost share λ increases, patients bear a larger portion of the price and more patients are incentivized not to seek treatment, which adversely affects providers' market share. Hence, providers lower their prices to compensate for the increased cost share. Under reference pricing, increasing p^* results in value-based providers increasing their prices to keep up with the reference price, which allows any non-value-based provider to raise its price as well accordingly – or choose to become value-based without this necessitating a price decrease.

5.1. Patients

In this section, we evaluate how the payment models affect the patient utility. When the payment terms (i.e., the cost share λ and the reference price p^*) change, the patients' utility is directly affected via a change in the out-of-pocket. It is also indirectly affected via changes in the provider prices, as described in Lemma 2. The following result examines the combined net effect of a change in the payment terms on patient out-of-pocket.

Lemma 3. *(a) Under variable payment, the patient's out-of-pocket is increasing in λ. (b) Under reference pricing, the patient's out-of-pocket is non-increasing in p^*.*

Under a variable payment scheme, rising λ results, on the one hand, in higher out-of-pocket for a given price and, on the other hand, in lower provider prices, which can positively affect patients. Lemma 3 demonstrates that the direct effect of increasing λ on patient out-of-pocket dominates the indirect effect of lower prices. Under reference pricing, rising p^* has no effect for patients visiting value-based providers as their out-of-pocket remains at $\tilde{c}$. For given non-value-based providers' prices, the out-of-pocket for patients is lowered. On the other hand, rising p^* results in higher provider prices which can adversely affect patients. Lemma 3 demonstrates that the direct effect of increasing p^* on patients' out-of-pocket dominates the indirect effect of higher prices.

We now proceed to compare the payment schemes in terms of patient utility. To achieve this, we first compare the providers' equilibrium prices.

Proposition 5. *There exists $\lambda_j^* \in (0,1]$ such that provider j prices higher under the variable payment system than under reference pricing iff $\lambda < \lambda_j^*$.*

Essentially, as the cost share λ increases, by Lemma 2(b) a given provider's price under variable payment decreases (parameter λ plays no role under reference pricing). Proposition 5 shows that for a small enough cost share, the variable payment price is higher than the reference pricing price, but as the cost share increases within $(0,1]$, the variable payment price eventually becomes lower than the price under reference pricing.

Proposition 6. *Assuming that $\tilde{c} \leq \lambda c$, the patient out-of-pocket is lower under reference pricing than under a variable payment system. Moreover, the expected patient utility is higher under reference pricing than under a variable payment system at equilibrium when the outside option is weak (i.e., there exists $\hat{u}_0 > 0$ such that the expected patient utility is higher under reference pricing than under a variable payment system iff $u_0 < \hat{u}_0$).*

We assume that the co-payment is less than λc which, in practice, is often the case. Under reference pricing, value-based provider visits result in a patient out-of-pocket equal to the co-payment. Therefore, the patient out-of-pocket at non-value-based providers has to be low enough to ensure these providers remain competitive. Under variable payment, there is less pressure on providers to keep the patient out-of-pocket low. Hence, patients benefit more from reference pricing than from variable payment.

5.2. Providers

In this section we evaluate how the payment models affect the provider profit. We start by investigating how the provider profit varies as the payment parameters change.

Lemma 4. *Each provider's profit is (a) decreasing in the cost share λ under a variable payment system; (b) increasing in the reference price p^* under a reference pricing system.*

Under variable payment, as λ increases, by Lemma 3, patients bear a larger out-of-pocket and thus fewer patients choose to seek treatment. In addition, provider prices decrease, resulting in a lower profit. Similarly, under reference pricing, as p^* increases, patients bear a lower out-of-pocket, while prices increase, resulting in a higher provider profit.

Proposition 7. *There exists $\hat{\lambda}_j \in (0,1]$ such that provider j gains higher profit under variable payment than under reference pricing as a non-value-based provider iff $\lambda < \hat{\lambda}_j$.*

Under variable payment, as the cost share λ increases, by Lemma 4(b), each provider's profit decreases. Proposition 7 shows that for a small cost share, the provider profit is higher than under reference pricing, but as the cost share increases, the provider profit becomes lower than a non-value-based provider's profit under reference pricing.

5.3. Insurer

The insurer cost is the gap from the patient out-of-pocket to the provider price. We showed that the patients' out-of-pocket is in general lower under the reference pricing model (Proposition 6). We also showed that prices may be higher or lower under reference pricing (Proposition 5). The next result combines these two findings to compare the insurer cost.

Proposition 8. *There exists $\tilde{\lambda} \in (0,1]$ such that the insurer's cost under the variable payment system is larger than under the reference pricing system iff $\lambda < \tilde{\lambda}$, where $\tilde{\lambda}$ is given by the implicit equation*

$$(1-\tilde{\lambda})\sum_{k=i,j} p_k^{VP} S_k^{VP}(P^{VP}) = p^*(1 - S_0^{RP}(P^{RP})).$$

Proposition 8 states that the insurer incurs a lower cost under the reference pricing scheme for smaller values of λ (i.e., for $\lambda < \tilde{\lambda}$). Section 7 illustrates that in practice, commonly used co-insurance rates tend to be below the threshold $\tilde{\lambda}$. Hence, the insurer's cost is typically lower under reference pricing than under variable payment.

6. Extensions

6.1. Endogenous Reference Pricing

Our analysis of reference pricing in Sections 4 and 5 is based upon an exogenously-selected reference price, that is, a price that the insurer selects. In past implementations of reference pricing, there have been cases of endogenously-selected reference price – where the reference price is a result of the prices set by the providers (Brown and Robinson 2016, Antoñanzas et al. 2017). A major implementation of endogenously-selected reference price for pharmaceuticals is the external reference pricing (ERP) policy (also known as "international reference pricing"), which is used for curbing pharmaceutical spending in over 55 countries. Under ERP, the government of a country requires that the price a pharmaceutical firm charges in the country be no more than a maximum value, which is calculated based on the prices the firm charges in a well-defined set of other countries (Rémuzat et al. 2015). Under endogenous reference pricing, the providers indirectly and collectively determine what the reference price is. Hence, the insurer has less control over its spending.

In this section, we analyze the case of endogenous reference pricing for two providers. To ensure that there is at least one value-based provider, we assume that the reference price is set at the minimum of the two prices selected by the providers. Hence, when each provider selects its price, it anticipates not only what price the other provider selects, but also what the resulting reference price is, and the ensuing impact on patients' decisions.

We make a technical assumption similar to Assumptions 1 and 2.

Assumption 3. $\overline{S}_j^{ERP} \leq 50\%$ *for* $j = 1, 2$.

We next show how providers price at equilibrium.

Theorem 3. *If* $e^{u_0} + e^{a_1 - \gamma\tilde{c}} \geq e^{a_2 - \gamma\tilde{c}}$, *there exists infinitely many Nash equilibria, characterized by*

$$p_1 = p_2 \in \left(c + \frac{e^{u_0} + e^{a_1 - \gamma\tilde{c}} + e^{a_2 - \gamma\tilde{c}}}{\gamma(e^{u_0} + e^{a_1 - \gamma\tilde{c}})}, c + \frac{e^{u_0} + e^{a_1 - \gamma\tilde{c}} + e^{a_2 - \gamma\tilde{c}}}{\gamma e^{a_2 - \gamma\tilde{c}}} \right).$$

If $e^{u_0} + e^{a_1 - \gamma\tilde{c}} < e^{a_2 - \gamma\tilde{c}}$, *there exists a unique Nash equilibrium. At the equilibrium, we have* $p_1 < p_2$ *and* (p_1, p_2) *is the unique solution of the system of equations:*

$$e^{a_2 - \gamma(p_2 - p_1 + \tilde{c})} = (e^{u_0} + e^{a_1 - \gamma\tilde{c}}) \left[\gamma(p_2 - c) - 1\right] \tag{8}$$

$$\gamma(p_1 - c) - 1 = \frac{1}{\gamma(p_2 - c) - 1}. \tag{9}$$

This result indicates that when provider 2, who has attributes that are *a priori* more attractive to patients, is not *much* more attractive than provider 1 and the outside option, then both providers are value-based in equilibrium. Provider 2 is not differentiated enough to justify pricing higher than the other provider. However, when the two providers are very differentiated (a_2 much larger than a_1) and/or the value of the outside option is low, then at equilibrium provider 1 is value-based and provider 2 is non-value-based.

	$p^* < p^*_{22}$	$p^* \geq p^*_{22}$
$e^{u_0} + e^{a_1 - \gamma\tilde{c}} \geq e^{a_2 - \gamma\tilde{c}}$	(i) low p^*, little provider differentiation: endogenous: $p_1 = p_2$; exogenous: $p_1 = p^*,\ p_2 > p^*$ solves (7)	(ii) high p^*, little provider differentiation: endogenous: $p_1 = p_2$; exogenous: $p_1 = p_2 = p^*$
$e^{u_0} + e^{a_1 - \gamma\tilde{c}} < e^{a_2 - \gamma\tilde{c}}$	(iii) low p^*, high provider differentiation: endogenous: (p_1, p_2) solves (8)-(9); exogenous: $p_1 = p^*,\ p_2 > p^*$ solves (7)	(iv) high p^*, high provider differentiation: endogenous: (p_1, p_2) solves (8)-(9); exogenous: $p_1 = p_2 = p^*$

Table 1 **Comparison of endogenous and exogenous reference pricing**

Proposition 9. *Consider cases (i), (ii), (iii) and (iv) as defined in Table 1. Equilibrium pricing strategies under exogenous reference pricing (superscript 'exo') and endogenous reference pricing (superscript 'endo') compare as follows (we tested numerically that each of the possible orderings listed in Proposition 9 may indeed occur for some instance of the problem):*

- *In case (i),* $p_1^{exo} < p_2^{exo} < p_1^{endo} = p_2^{endo}$.
- *In case (ii), if* $\gamma(p^* - c) > 1 + (e^{u_0} + e^{a_1 - \gamma\tilde{c}})/e^{a_2 - \gamma\tilde{c}}$*, all endogenous Nash equilibria satisfy* $p_1^{exo} = p_2^{exo} > p_1^{endo} = p_2^{endo}$*. Otherwise, there are endogenous Nash equilibria with* $p_1^{exo} = p_2^{exo} > p_1^{endo} = p_2^{endo}$ *and others with* $p_1^{exo} = p_2^{exo} \leq p_1^{endo} = p_2^{endo}$.
- *In case (iii), there are four possible orderings: either* $p_1^{exo} < p_2^{exo} < p_1^{endo} < p_2^{endo}$ *or* $p_1^{exo} < p_1^{endo} < p_2^{exo} < p_2^{endo}$ *or* $p_1^{endo} < p_1^{exo} < p_2^{endo} < p_2^{exo}$ *or* $p_1^{endo} < p_2^{endo} < p_1^{exo} < p_2^{exo}$.
- *In case (iv),* $p_1^{endo} < p_2^{endo} < p_1^{exo} = p_2^{exo}$.

We next aim to compare the insurer's objective under the four cases defined in Table 1. In case (ii), we find that if $\omega_2 = 1$, the insurer is indifferent. If $\omega_2 < 1$, the insurer's objective is higher when the price is lower. Hence, if $\gamma(p^* - c) > 1 + (e^{u_0} + e^{a_1 - \gamma\tilde{c}})/e^{a_2 - \gamma\tilde{c}}$, the insurer's objective is higher under any of the endogenous equilibria. Otherwise, the insurer's objective under the endogenous setting may be higher or lower than under the exogenous setting, depending on which of the multiple possible endogenous equilibria occurs. In cases (i), (iii) and (iv), the comparison can be done numerically using the closed-form expressions of the insurer's objective. We obtain that in each of these cases, endogenous reference pricing may either benefit or hurt the insurer's objective depending on the specific problem instance. The following result focuses on the special case of a public non-profit insurer.

Proposition 10. *For* $\omega_1 = 1/\gamma$ *and* $\omega_2 = 1$ *(i.e., public non-profit insurer), Table 2 compares the insurer's objective under endogenous and exogenous reference pricing, where*

$$\phi \equiv \omega_1 \left((a_2 - a_1)e^{a_1 - \gamma\tilde{c}} + (a_2 - u_0)e^{u_0}\right) - \omega_2 c e^{u_0} = \frac{a_2 - a_1}{\gamma} e^{a_1 - \gamma\tilde{c}} - \left(c + \frac{u_0 - a_2}{\gamma}\right) e^{u_0}.$$

	$p^* < p^*_{22}$	$p^* \geq p^*_{22}$
$e^{u_0} + e^{a_1-\gamma\tilde{c}} \geq e^{a_2-\gamma\tilde{c}}$	(i) $\Pi^{RP}_{exo} < \Pi^{RP}_{endo}$ iff $\phi > 0$	(ii) $\Pi^{RP}_{exo} = \Pi^{RP}_{endo}$
$e^{u_0} + e^{a_1-\gamma\tilde{c}} < e^{a_2-\gamma\tilde{c}}$	(iii) $\Pi^{RP}_{exo} < \Pi^{RP}_{endo}$ iff $[(p_2^{exo} - p^*) - (p_2^{endo} - p_1^{endo})] \cdot \phi > 0$	(iv) $\Pi^{RP}_{exo} < \Pi^{RP}_{endo}$ iff $\phi < 0$

Table 2 **Comparison of endogenous and exogenous insurer objective in the special case $\omega_1 = 1/\gamma$ and $\omega_2 = 1$**

6.2. Heterogeneous Price Sensitivity

In this section we consider heterogeneous patients as either low-type or high-type, based on their price sensitivity, respectively γ_L and γ_H (with $\gamma_L < \gamma_H$). We denote ζ the proportion of the population with low price sensitivity. The results and discussions in this section can be easily extended to the case of more than two patient types, with similar insights. A patient of type $q \in \{L, H\}$ receives utility U_j^q from visiting provider j, where $U_j^q = a_j - \gamma_q \left((p_j - p^*)^+ + \tilde{c}\right)$. Note that $U_j^L > U_j^H$. Thus, the probability that a randomly selected patient of type q seeks treatment from provider j is $S_j^q(P) = e^{U_j^q}/(e^{U_0} + \sum_{k=1}^{2} e^{U_k^q})$, and provider j obtains expected profit $V_j^{HRP}(P) = m(p_j - c)\left(\zeta S_j^L(P) + (1-\zeta) S_j^H(P)\right)$ for $j = 1, 2$. We make a technical assumption similar to Assumptions 1-3.

Assumption 4. *$\overline{S}_j^q \leq 50\%$ for $j = 1, 2$ and $q = L, H$.*

The following result shows how a given set of value-based and non-value-based providers jointly determine their prices in equilibrium.

Theorem 4. *Consider as given the set of non-value-based providers, $\mathcal{N}$. At equilibrium, a value-based provider prices at the reference price, p^*. Moreover, the non-value-based providers' prices are the unique solution of the system of equations:*

$$\zeta S_j^L(P)\left(1 - \gamma_L(p_j - c)(1 - S_j^L(P))\right) + (1-\zeta) S_j^H(P)\left(1 - \gamma_H(p_j - c)(1 - S_j^H(P))\right) = 0 \;\; \forall j \in \mathcal{N}.$$

As in Section 4.4, we assume that there is at least one value-based provider (hence, $p_1 = p^*$). Similar to Lemma 6, we show that provider 2 decides to be value-based iff

$$\zeta S_2^L(p^*, p^*)\left(1 - \gamma_L(p^* - c)(1 - S_2^L(p^*, p^*))\right) + (1-\zeta) S_2^H(p^*, p^*)\left(1 - \gamma_H(p^* - c)(1 - S_2^H(p^*, p^*))\right) \leq 0. \quad (10)$$

Since $S_2^L(p^*, p^*)$ is increasing in a_2, so is the left-hand-side of inequality (10). Thus, for a given value of the reference price, provider 2 chooses to differentiate from provider 1 and become non-value-based when its non-price attribute is sufficiently more appealing to patients to justify a price premium. In this case, provider 1 serves mainly patients with high price sensitivity, and provider 2 serves mainly patients with low price sensitivity.

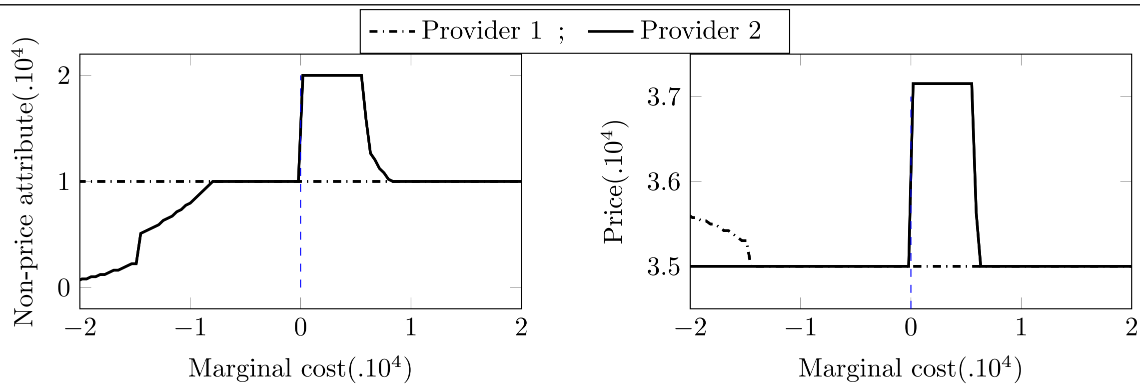


Figure 1 **Impact of the cost of obtaining a higher non-price attribute on provider differentiation (**$p^* = 3.5 \times 10^4,\ c_1 = 1 \times 10^4$**)**

Consider the case where, in a preliminary stage, provider 2 has the option to select a non-price attribute (at a cost). More precisely, in a prior stage, provider 2 decides the value of a_2. It may select a value above a_1, incurring a cost linear in a_2 (positive marginal cost), or a value below a_1, incurring a cost saving linear in a_2 (negative marginal cost). We study this problem numerically when a_2 is constrained to lie within $[a_1 - (10^4), a_1 + (10^4)]$. The optimal choice of a_2 along with the ensuing prices are illustrated in Figure 1.

Differentiation between the two providers can stem from a distinction either in non-price attribute or in price (or both). A high cost (greater than 0.84×10^4) disincentivizes provider 2 from differentiating: it chooses a_2 equal to a_1 and becomes value-based. For a low positive cost (0 to 0.6×10^4), provider 2 chooses to differentiate from provider 1 by offering a higher non-price attribute and a higher price, which results in non-value-based status (full differentiation). There also exists an intermediate range of cost (0.6 to 0.84×10^4) where provider 2 selects to offer a higher non-price attribute than provider 1 while remaining value-based (partial differentiation). Here, the benefit of attracting a higher market share through offering a higher non-price attribute outweighs the cost for provider 2, but the unit cost is too high to differentiate to an extent justifying charging above the reference price. When provider 2 can enjoy savings due to a non-price attribute lower than a_1, it chooses to become value-based. When the magnitude of these savings are small (-0.8×10^4 to 0) there is no differentiation. However, as the magnitude of cost savings increases (less than -0.8×10^4), provider 2 sacrifices market share to gain higher margins by selecting a non-priced attribute lower than a_1. Notice that for very low marginal cost (below -1.48×10^4), provider 1 differentiates from provider 2 by becoming non-value-based due to the large gap in the two providers' non-price attributes.

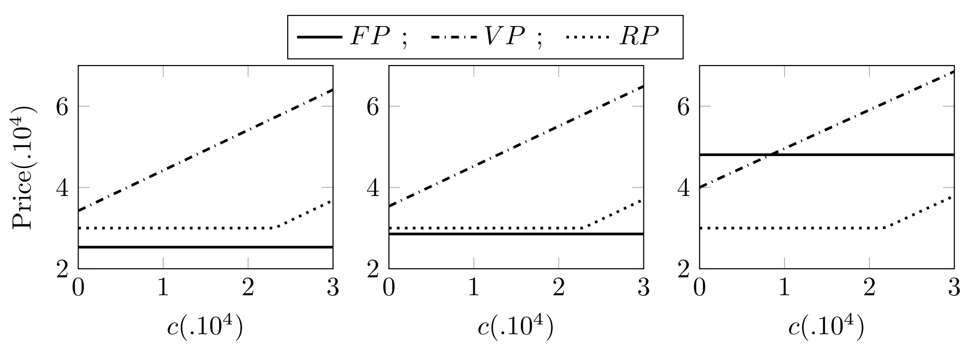
7. Numerical Study

In this section we present numerical experiments that help address policy questions by comparing outcomes for different payment mechanisms. We calibrate the base-case parameters on a joint replacement surgery, for which CalPERS implemented reference pricing in 2011 (Robinson and Brown 2013), using the medical and health economics literature. Appendix B details how we selected these parameter values, summarized in Table 4 in the Appendix. We found that the results obtained in Section 5 are robust to the presence of more than two providers in all the instances we considered.

7.1. Comparison of Payment Systems

Effect on prices. Figure 2 depicts the price selected by three of the providers (indexed 1, 5, and 10) under the different payment schemes as the treatment cost (c) varies.

Under fixed payment, providers charge the maximum allowable price, which is higher for providers with better non-price attributes. At the base-case (for $c = 2.24 \times 10^4$), the reference price is at the 67^{th} percentile of prices under fixed payment, and we find that 7 of the 10 providers choose to be value-based under reference pricing. Under variable payment, providers set higher prices as they are not limited by an upper bound and they do not compete with value-based providers. We observe that some providers with low non-price attributes increase their price under reference pricing as compared with fixed payment (Figure 2 (a) and (b)), confirming the *shadow pricing* effect. Furthermore, providers with high non-price attributes lower their prices significantly under reference pricing (Figure 2 (c)), which is consistent with observations made in practice.

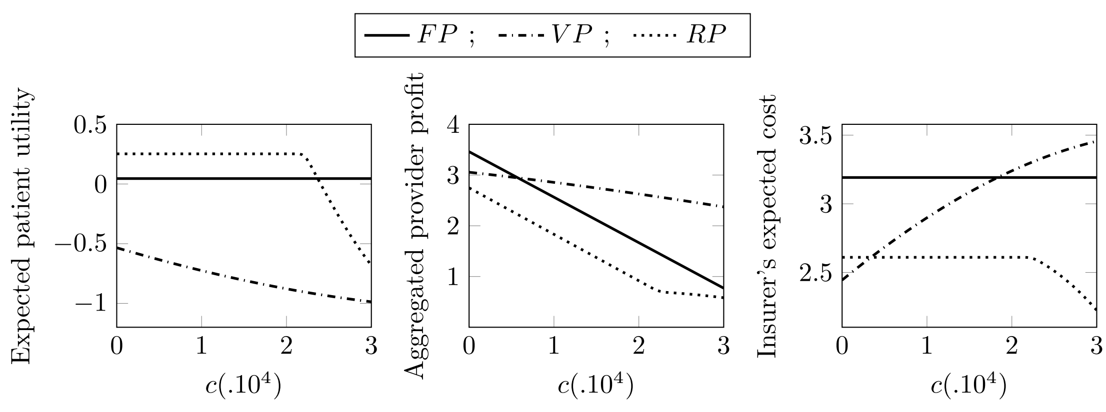


(a) Provider 1 (b) Provider 5 (c) Provider 10

Figure 2 **Effect of cost on provider prices**

We now examine the effect of varying cost c. Under fixed payment, providers charge the maximum prices $\overline{p}_j$ regardless of cost. A higher cost leads to higher prices under variable payment and, to a lesser extent, under reference pricing. Competition with value-based providers applies a downward pressure on non-value-based providers' prices, an effect that is absent under variable payment. Still, as the cost increases, value-based providers eventually choose to become non-value-based to be able to increase their prices.

Effect on patients. Figure 3(a) illustrates how the different payment systems affect the patient expected utility as the treatment cost varies. Overall, we observe that patients are worse off under variable payment over the entire range of cost. This is consistent with Proposition 6 and is due to a combination of high prices and low patient participation under variable payment (made worse as the cost increases). We observe that, unless the cost is high (i.e., above approximately $23,000 in this example, causing a lack of value-based provider), reference pricing results in higher patient expected utility than fixed payment due to a low patient out-of-pocket for value-based providers. When the cost is low relative to the reference price, a cost increase does not have a noticeable effect on the patient utility under fixed payment and reference pricing. Overall, reference pricing improves the patient benefit compared to other systems unless the cost is so high relative to the reference price that there are no value-based provider.



(a) Patient (b) Provider (c) Insurer Cost

Figure 3 **Effect of cost on the expected patient utility, aggregated provider profit and insurer cost**

Effect on providers. Figure 3(b) illustrates how different payment systems affect the aggregate provider profit as the treatment cost varies. As expected, the provider profit decreases as the cost increases. We observe that provider profits are generally highest under the variable payment system, where providers benefit from high prices which allow for higher profit margins. As expected, reference pricing lowers the aggregate provider profit as it applies a downward pressure on prices due to competition with value-based providers.

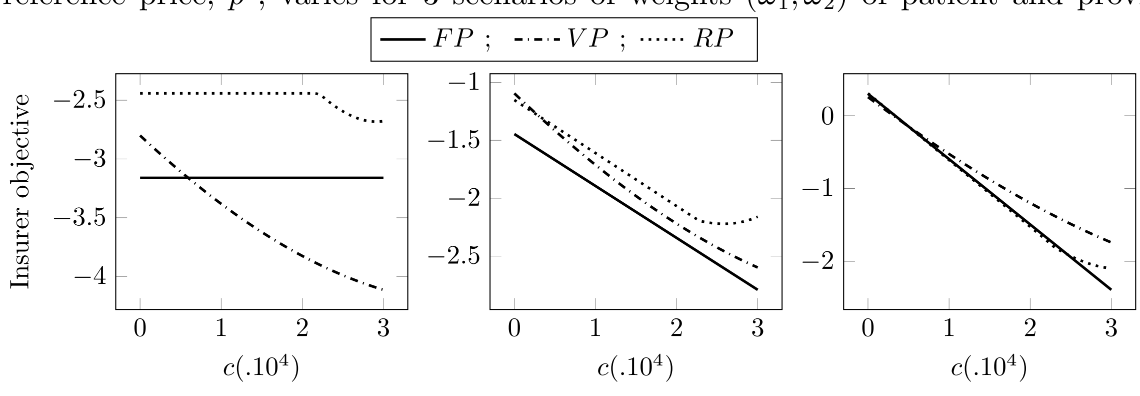
We should point out that these observations are valid for the *aggregate* provider profit; individual providers are not all impacted in the same way. In general, *lower*-indexed providers *benefit* from reference pricing because they get to price higher than under fixed payment and gain market share as value-based providers.

Effect on the insurer's cost. Figure 3(c) illustrates how the different payment systems affect the insurer's expected cost as the treatment cost varies. Overall we observe that the insurer has the lowest expected cost under reference pricing. Under reference pricing, a change in cost does not affect prices unless the cost is high. At high cost values, prices increase and there are no more value-based providers, thus fewer patients choose to seek treatment, which lowers the insurer cost.

7.2. Insurer

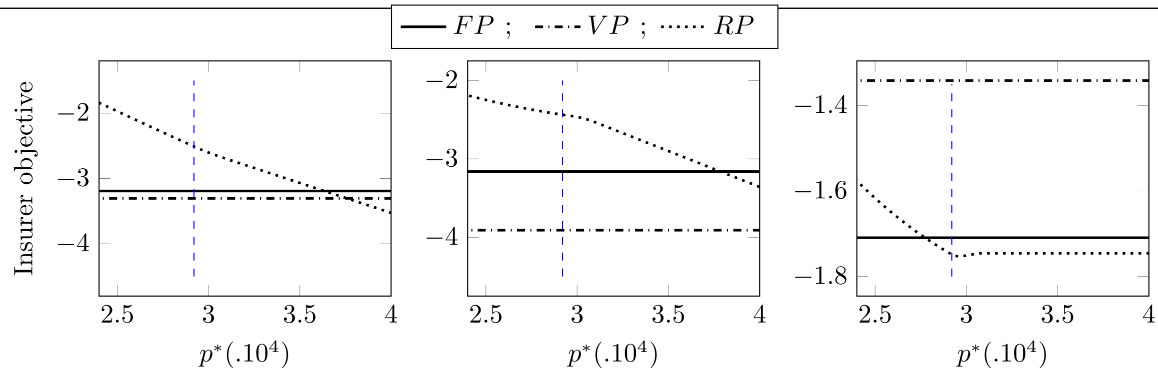
Figure 4 illustrates how the different payment systems affect the insurer's objective as the treatment cost varies for 3 scenarios of weights (ω_1, ω_2) of patient and provider utility within that objective. We observe that reference pricing results in the highest insurer's objective, unless the insurer's behavior approaches that of a public non-profit insurer. Then, the performance of reference pricing is similar to that of a fixed payment model.

Figure 5 illustrates how the different payment systems affect the insurer's objective as the reference price, p^*, varies for 3 scenarios of weights (ω_1, ω_2) of patient and provider



(a) $(\omega_1, \omega_2) = (\frac{1}{\gamma}, 0)$ (b) $(\omega_1, \omega_2) = (\frac{1}{2\gamma}, 0.5)$ (c) $(\omega_1, \omega_2) = (\frac{1}{\gamma}, 1)$

Figure 4 Effect of cost on the insurer objective ($\frac{1}{\gamma} = 0.6667$)



(a) $(\omega_1, \omega_2) = (0, 0)$ (b) $(\omega_1, \omega_2) = (\frac{1}{\gamma}, 0)$ (c) $(\omega_1, \omega_2) = (\frac{1}{\gamma}, 1)$

Figure 5 **Effect of reference price on the insurer objective ($\frac{1}{\gamma} = 0.6667$). The vertical dashed line is the minimum value of the reference price to ensure there is at least one value-based provider.**

utility within that objective. The vertical dashed line represents the minimum value of p^* that makes at least one provider value-based ($p^* = 29,200$). In this example, a reference price larger than 30,500 makes all 10 providers value-based. In general, we observe that the insurer benefits from choosing reference pricing over other payment models for a wide range of reference price, except in the case of public non-profit insurer (i.e., $(\omega_1, \omega_2) = (\frac{1}{\gamma}, 1)$). However, to ensure a reasonable balance between value-based and non-value-based providers, the insurer may select a reference price within a narrower range (i.e., $29,200 < p^* < 30,500$). In the case of public non-profit insurer, the providers' utility significantly impacts the insurers' profit and thus the variable payment model dominates.

To summarize, our analysis leads to two main observations: (a) reference pricing accomplishes its premise: it lowers prices for providers who were charging the most; and (b) if the procedure cost is relatively low (or the reference price is sufficiently high, so there is at least one value-based provider), reference pricing can indeed both benefit patients and reduce the insurer's cost. In such instances, because some providers (with high non-price attributes) would be worse off with reference pricing, it is important to ensure that providers accept to stay in the healthcare network so access to care is maintained in the long term. Finally, we note that performance of the reference pricing model varies depending on how the insurer values patients and providers. For most cases, reference pricing benefits the insurer compared to the other models. However, as the insurer's behavior approaches that of a public non-profit insurer, reference pricing may no longer be the most favored option for the insurer.

In Appendix C, we study analytically a reference pricing variant with *variable* cost share below the reference price (RV). We find numerically that, similar to reference pricing, RV can also deliver quality care at a reasonable cost to the insurer while ensuring high utility for patients. Reference pricing appears more promising than RV due to a stronger benefit for patients; however, RV mitigates the issue of shadow pricing for value-based providers.

8. Discussion and Concluding Remarks

Healthcare providers have gained sufficient market power to command high prices from insurers. Some insurers' strategies counter provider market power by either developing limited provider networks that exclude high-price providers or by requiring greater patient cost-sharing. Both co-payments and co-insurance cost-sharing schemes limit patients' financial exposure to the real cost of healthcare prices for expensive procedures (for the latter, due in part to patients' maximum out-of-pocket limits). The combination of this low consumer price-sensitivity and high provider pricing power has weakened the insurer's leverage. A recent alternative has been the implementation of reference pricing. The main objective of reference pricing is to save money by providing patients with incentives to seek treatment at low-price providers, while simultaneously using competitive forces to motivate high-price providers to lower prices in order to retain their market share.

Our analysis shows that reference pricing often leaves the patients better off and reduces the insurer's cost compared to the variable payment and the fixed payment systems, at the detriment of the highest-priced providers. However, when the procedure cost is high relative to the reference price, reference pricing can hurt the patient utility more than the status quo due to a scarcity of value-based providers and high out-of-pockets.

Reference pricing is potentially an appealing cost-saving strategy for the insurer for a number of reasons. First, rather than limiting a provider network, reference pricing maintains access to a broad network and patients may apply their insurer's contributions toward payment for any provider they choose. Second, reference pricing incentivizes the selection of lower-priced providers. This market share redistribution reduces the average price paid by the insurer, even if no provider discounts its price. In the CalPERS experiment, the increase in volume of patients choosing value-based providers by the end of the second year of implementation ranged from 8.6 percentage points for cataract removal surgery (Robinson et al. 2015) to 18.6 percentage points for laboratory tests (Robinson et al.

2016). Third, reference pricing might serve to further drive down healthcare costs if higher-priced providers respond by reducing prices. Robinson and Brown (2013) found that the introduction of reference pricing for knee and hip replacement in CalPERS resulted in a 20.2 percent decline in hospital prices. Robinson et al. (2017) report that the number of providers designated by CalPERS as value-based increased from 43 in the year of reference pricing implementation to 53 only four years later.

There are several challenges arising when considering adopting reference pricing. First, adoption of reference pricing requires both insurers and patients to have information on providers' prices. Second, an important consideration in evaluating reference pricing is to ensure quality outcomes do not diminish in value-based providers. While several evaluations of the CalPERS reference pricing experiment do not suggest quality compromises, one should acknowledge barriers to measurement of quality. Any future successful implementation of reference pricing programs should include a comprehensive quality data reporting. For instance, the Blue Cross and Blue Shield Association has developed comprehensive quality standards for joint replacements through the Blue Distinction program.

Outpatient and diagnostic procedures could be an area where reference pricing can be of great value in reducing healthcare expenditures. Such procedures tend to represent discrete services with well-defined protocols, and occur in large volumes. Imaging and lab services have little variation in quality, making them good candidates for reference pricing. It is noteworthy that the potential impact of reference pricing on such procedures alone can be quite significant. White and Eguchi (2014) identify 73 high-volume inpatient services and 90% of the most common ambulatory procedures that would be eligible for reference pricing, counting for 1/3 of the total spending for the non-elderly insured population.

While reference pricing is not a be-all and end-all solution to the shortcomings of the healthcare system, it has some clear advantages over the traditional payment methods and can flourish for the right conditions and episodes of care.

References

Adida, E. 2019. Outcome-based pricing for new pharmaceuticals via rebates. *Management Science (forthcoming)* URL `https://tinyurl.com/ydchr8wr`. Accessed September 27, 2019.

Adida, E., H. Mamani, S. Nassiri. 2017. Bundled payment vs. fee-for-service: Impact of payment scheme on performance. *Management Science* **63**(5) 1606–1624.

Aksoy-Pierson, M., G. Allon, A. Federgruen. 2013. Price competition under mixed multinomial logit demand functions. *Management Science* **59**(8) 1817–1835.

Allon, G., A. Federgruen. 2009. Competition in service industries with segmented markets. *Management Science* **55**(4) 619–634.

Anderson, S.P., A. De Palma, J.-F. Thisse. 1992. *Discrete Choice Theory of Product Differentiation*. MIT.

Andritsos, D., C.S. Tang. 2018. Incentive programs for reducing readmissions when patient care is co-produced. *Production and Operations Management* **27**(6) 999–1020.

Antoñanzas, F., C.A. Juárez-Castelló, R. Rodríguez-Ibeas. 2017. Endogenous versus exogenous generic reference pricing for pharmaceuticals. *International Journal of Health Economics and Management* **17**(4) 413–432.

Bardey, D., A. Bommier, B. Jullien. 2010. Retail price regulation and innovation: Reference pricing in the pharmaceutical industry. *Journal of Health Economics* **29**(2) 303–316.

Baron, D.P., R.B. Myerson. 1982. Regulating a monopolist with unknown costs. *Econometrica: Journal of the Econometric Society* 911–930.

Barros, P.P. 2011. The simple economics of risk-sharing agreements between the NHS and the pharmaceutical industry. *Health Economics* **20**(4) 461–470.

Binmore, K., A. Rubinstein, A. Wolinsky. 1986. The Nash bargaining solution in economic modelling. *The RAND Journal of Economics* 176–188.

Brekke, K.R., C. Canta, O.R. Straume. 2016. Reference pricing with endogenous generic entry. *Journal of Health Economics* **50** 312–329.

Brekke, K.R., I. Königbauer, O.R. Straume. 2007. Reference pricing of pharmaceuticals. *Journal of Health Economics* **26**(3) 613–642.

Brown, T.T., J.C. Robinson. 2016. Reference pricing with endogenous or exogenous payment limits: Impacts on insurer and consumer spending. *Health Economics* **25**(6) 740–749.

CMS. 2013. Center for Medicare and Medicaid Services – Hospital Compare. URL `https://www.medicare.gov/hospitalcompare/search.html`. Accessed February 7, 2019.

CMS. 2018. Center for Medicare and Medicaid Services – Fiscal Year 2019 Medicare Hospital Inpatient Prospective Payment System and Long-Term Acute Care Hospital Prospective Payment System Final Rule (CMS-1694-F). URL `https://tinyurl.com/ybfvtcnf`. Accessed February 7, 2019.

Cooper, Z., S. Craig, M. Gaynor, J. Van Reenen. 2015. The price ain't right? Hospital prices and health spending on the privately insured. URL `https://tinyurl.com/y7hdqcn6`. Accessed 02/21/2019.

Danzon, P.M., J.D. Ketcham. 2004. Reference pricing of pharmaceuticals for Medicare: Evidence from Germany, the Netherlands and New Zealand. *Frontiers in Health Policy Research / National Bureau of Economic Research* **7** 1–54.

Debreu, G. 1952. A social equilibrium existence theorem. *Proceedings of the National Academy of Sciences* **38**(10) 886–893.

Denoyel, V., L. Alfandari, A. Thiele. 2017. Optimizing healthcare network design under reference pricing and parameter uncertainty. *European Journal of Operational Research* **263**(3) 996–1006.

Dranove, D. 1996. Measuring costs. Frank A. Sloan, ed., *Valuing Health Care: Costs, Benefits, and Effectiveness of Pharmaceuticals and Other Medical Technologies*, chap. 4. Cambridge University Press.

Eijkenaar, F., M. Emmert, M. Scheppach, O. Schöffski. 2013. Effects of pay for performance in health care: A systematic review of systematic reviews. *Health policy* **110**(2-3) 115–130.

Fan, K. 1952. Fixed-point and minimax theorems in locally convex topological linear spaces. *Proceedings of the National Academy of Sciences of the United States of America* **38**(2) 121.

Fronstin, P., M.C. Roebuck. 2014. Reference pricing for health care services: A new twist on the defined contribution concept in employment-based health benefits. *EBRI Issue Brief* (398). URL `https://tinyurl.com/ybp9c348`. Accessed February 21, 2019.

Ghislandi, S. 2011. Competition and the reference pricing scheme for pharmaceuticals. *Journal of Health Economics* **30**(6) 1137–1149.

Glicksberg, I.L. 1952. A further generalization of the Kakutani fixed point theorem, with application to Nash equilibrium points. *Proceedings of the American Mathematical Society* **3**(1) 170–174.

Guo, P., C.S. Tang, Y. Wang, M. Zhao. 2019. The impact of reimbursement policy on social welfare, revisit rate, and waiting time in a public healthcare system: Fee-for-service versus bundled payment. *Manufacturing & Service Operations Management* **21**(1) 154–170.

Gupta, D., M. Mehrotra. 2015. Bundled payments for healthcare services: Proposer selection and information sharing. *Operations Research* **63**(4) 772–788.

Hayashi, F. 2011. *Econometrics*. Princeton University Press.

Healthcare Bluebook. 2019. URL `https://www.healthcarebluebook.com/`. Accessed April 17, 2019.

Jain, D.C., N.J. Vilcassim, P.K. Chintagunta. 1994. A random-coefficients logit brand-choice model applied to panel data. *Journal of Business & Economic Statistics* **12**(3) 317–328.

Kaiser, U., S.J. Mendez, T. Rønde, H. Ullrich. 2014. Regulation of pharmaceutical prices: Evidence from a reference price reform in Denmark. *Journal of Health Economics* **36** 174–187.

Kouvelis, P., Y. Xiao, N. Yang. 2015. PBM competition in pharmaceutical supply chain: Formulary design and drug pricing. *Manufacturing & Service Operations Management* **17**(4) 511–526.

Lechner, A.E., R. Gourevitch, P.B. Ginsburg. 2013. The potential of reference pricing to generate health care savings: Lessons from a California pioneer. *Center for Studying Health System Change Research Brief* **30**. URL `https://tinyurl.com/yao7tj3c`. Accessed February 21, 2019.

López-Casasnovas, G., J. Puig-Junoy. 2000. Review of the literature on reference pricing. *Health policy* **54**(2) 87–123.

Ma, C.A., H.Y. Mak. 2015. Information disclosure and the equivalence of prospective payment and cost reimbursement. *Journal of Economic Behavior & Organization* **117** 439–452.

Mahjoub, R., F. Ødegaard, G.S. Zaric. 2018. Evaluation of a pharmaceutical risk-sharing agreement when patients are screened for the probability of success. *Health economics* **27**(1) e15–e25.

Mak, H.Y. 2018. Managing imperfect competition by pay for performance and reference pricing. *Journal of Health Economics* **57** 131–146.

NBCH. 2012. Price transparency: Now more than ever. *National Business Coalition of Health Action Brief* URL `https://tinyurl.com/ycw4fwav`. Accessed February 7, 2019.

Newhouse, J.P., A.M. Garber, R.P. Graham, M.A. McCoy, M. Mancher, A. Kibria. 2013. *Variation in Health Care Spending: Target Decision Making, not Geography*. National Academies Press.

Newman, D., S.T. Parente, E. Barrette, K. Kennedy. 2016. Prices for common medical services vary substantially among the commercially insured. *Health Affairs* **35**(5) 923–927.

Rémuzat, C., D. Urbinati, O. Mzoughi, E. El Hammi, W. Belgaied, M. Toumi. 2015. Overview of external reference pricing systems in Europe. *Journal of Market Access & Health Policy* **3**(1) 27675.

Robinson, J.C. 2010. Applying value-based insurance design to high-cost health services. *Health Affairs* **29**(11) 2009–2016.

Robinson, J.C. 2016. Reference pricing in health insurance. URL `https://tinyurl.com/yagxm5or`. Accessed 2/07/2019.

Robinson, J.C., T.T. Brown. 2013. Increases in consumer cost sharing redirect patient volumes and reduce hospital prices for orthopedic surgery. *Health Affairs* **32**(8) 1392–1397.

Robinson, J.C., T.T. Brown, C. Whaley. 2015. Reference-based benefit design changes consumers' choices and employers' payments for ambulatory surgery. *Health Affairs* **34**(3) 415–422.

Robinson, J.C., T.T. Brown, C. Whaley. 2016. Association of reference pricing for diagnostic laboratory testing with changes in patient choices, prices, and total spending for diagnostic tests. *JAMA Internal Medicine* **176**(9) 1353–1359.

Robinson, J.C., T.T. Brown, C. Whaley. 2017. Reference pricing changes the 'choice architecture' of health care for consumers. *Health Affairs* **36**(3) 524–530.

Robinson, J.C., K. McPherson. 2012. Payers test reference pricing and centers of excellence to steer patients to low-price and high-quality providers. *Health Affairs* **31**(9) 2028–2036.

Rosenthal, E. 2013. The $2.7 trillion medical bill. *The New York Times.* Published June 1, 2013.

Train, K. 2003. *Discrete Choice Methods with Simulation*. Cambridge University Press.

Truong, V.-A. 2014. Optimal selection of medical formularies. *Journal of Revenue and Pricing Management* **13**(2) 113–132.

Vives, X. 1999. *Oligopoly Pricing. Old Ideas and New Tools*. MIT Press, Cambridge.

Whaley, C., T. Brown, J. Robinson. 2019. Consumer responses to price transparency alone versus price transparency combined with reference pricing. *American Journal of Health Economics* **5**(2) 227–249.

White, C., M. Eguchi. 2014. Reference pricing: A small piece of the health care price and quality puzzle. *National Institute for Health Care Reform Research Brief* (18).

Zuvekas, S.H., J.W. Cohen. 2016. Fee-for-service, while much maligned, remains the dominant payment method for physician visits. *Health Affairs* **35**(3) 411–414.

Materials for Online Appendix

Appendix A: Notations

n	number of providers
m	population size of the patients
c	treatment cost
γ	patients' price sensitivity
a_j, η_{ij}	the non-idiosyncratic, idiosyncratic payoff for patient i when visiting provider j
o_j	out-of-pocket cost for the patient obtaining care at provider j
u_0	value of outside option: patient utility when not seeking treatment
$\overline{p}_j$	maximum allowable price that provider j can set under the fixed payment model
p_j	price of the treatment charged by provider j
P	vector of provider prices
$S_j(P)$	probability that provider j is chosen by a randomly selected patient when providers price at P
$V_j(P)$	utility that provider j gains when offering a procedure when providers price at P
$W(P)$	cost of the insurer when providers price at P
p^*	reference price
f	fixed amount that patients pay under the fixed payment model
λ	portion of the payment that the patient is responsible for under variable payment

Table 3 Key Notations

Appendix B: Input Parameters for Numerical Experiments

We calibrate the base-case parameters according to the knee and hip replacement surgery, for which CalPERS implemented reference pricing in 2011, using the medical and health economics literature. We normalize the size of the population of patients seeking treatment to $m = 1$. While our analytical results were obtained in the case of two providers, in the base-case scenario of the numerical study we consider $n = 10$ providers.

We set the fixed payment f at \$3000. CalPERS normally imposes a 20% co-insurance ($\lambda = 0.2$) subject to a \$3000 maximum out-of-pocket. The amount a patient must pay as co-insurance would meet this maximum as soon as the procedure price exceeds \$15,000, which is virtually always the case for a hip and knee replacement surgery (Fronstin and Roebuck 2014). We set the reference price (p^*) at \$30,000 in the base case, consistent with the CalPERS experiment. The maximum allowable prices under the fixed-payment scheme ($\overline{p}_j$) take values within [\$20,000;\$50,000]. These values are consistent with the prices before implementation of reference pricing for CalPERS (Robinson and Brown 2013). We assign specific values of $\overline{p}_j$ so the reference price is at the 67^{th} percentile of the distribution of prices $\overline{p}_j, j = 1, \ldots, n$. The cost of treatment may be affected by many different factors. The Healthcare Bluebook estimates the *fair* price of knee replacement at about \$27,000, including anesthesia, postoperative care, implant or device, and hospital stay (Healthcare Bluebook 2019). Using this estimated price and considering a profit margin of 20% for the provider, we use $c = \$22{,}400$ as a base-case value. We use $u_0 = 0$ as the value of the outside option, but did further experiments evaluating the sensitivity of the outcome to u_0 (not presented here) and observed that the discussions in this section remain qualitatively the same.

We model the non-price attribute of provider j as $a_j = \alpha + \sigma_j\beta$, where $\sigma_j \in \{-n/2, \ldots, n/2\} \setminus \{0\}$ if n is even; and $\sigma_j \in \{-(n-1)/2, \ldots, (n-1)/2]$, if n is odd. Parameter α represents the average non-price attribute and parameter β is a measure of the level of differentiation among providers; we use $\alpha = 1000,\ \beta = 2000$ as base values. We tested the model for various values of γ and δ and set $\gamma = 1.5$, $\delta = 1/\gamma$ for the base scenario.

Variable	Base case	Sensitivity Analysis
n	10	{2,5,10,20,50,100}
m	1	
f	0.3 ($\times 10^4$)	[0.2, 0.4]($\times 10^4$)
λ	0.2	[0.1,1]
p^*	3 ($\times 10^4$)	[2.24, 4]($\times 10^4$)
$\overline{p}$	[2.5311, 2.6522, 2.7015, 2.7263, 2.8557, 2.9443, 3.3365, 4.2555, 4.6873, 4.8056] ($\times 10^4$)	
c	2.24 ($\times 10^4$)	[0.5, p^*]($\times 10^4$)
α	0.1 ($\times 10^4$)	
β	0.2 ($\times 10^4$)	[0.05, 0.4]($\times 10^4$)
u_0	0	[0,5]
γ	1.5	[0.5,3]
$\Omega = (\omega_1, \omega_2)$	$\{(0,0); (1/\gamma,1); (1/\gamma,0), (1/(2\gamma), 0.5)\}$	
$\tilde{c}$	0.15($\times 10^4$)	

Table 4 Parameter values for the numerical experiments

The calibration of parameters α, β, and γ ensures that the observable characteristics of outcomes under reference pricing (e.g., fraction of providers who choose to be value-based) match the CalPERS experiment, so our numerical findings on the agents' utilities is meaningful. Finally, in the CalPERS example, the patient fixed payment under reference pricing varied within [\$0, \$3,000], where \$3,000 was the maximum yearly out-of-pocket value per patient per year. Hence, we set $\tilde{c} = \$1,500$.

Appendix C: Extension – Reference Pricing with Variable Payment

C.1. Equilibrium analysis

In the reference pricing system with variable cost share (RV) payment system, a reference price p^* is set for the procedure. Providers select their prices.which determines whether they are "value-based" or "non-value-based". Finally, patients select a provider. All patients pay a variable payment for the portion of the payment below the reference price level and, if they choose a non-value-based provider, they also pay the portion of the price above the reference price. The patient out-of-pocket is thus $o_j = \lambda \min\{p_j, p^*\} + (p_j - p^*)^+ = \lambda p_j + (1-\lambda)(p_j - p^*)^+$ for $j = 1, 2$. Similar to the variable payment analysis, as a preliminary, we formalize a condition that guarantees the existence of a pure Nash equilibrium. In the following assumption, the notations are similar to those defined immediately preceding Assumption 1.

Assumption 5. $\overline{S}_j^{RV} \leq 50\%$ *for* $j = 1, 2$.

The following result explains how a given set of value-based and non-value-based providers jointly determine their prices at the Nash equilibrium.

Theorem 5. *Consider as given the set of non-value-based providers, $\mathcal{N}$. At equilibrium, the provider prices are the unique solution of the system of equations:*

$$\begin{cases} 1 - \gamma(p_j - c)(1 - S_j^{RV}(P)) = 0 & \forall j \in \mathcal{N} \\ 1 - \gamma\lambda(\hat{p}_j - c)(1 - S_j^{RV}(\hat{p}_j, p_{-j})) = 0 & \forall j \notin \mathcal{N} \\ p_j = \min\{\hat{p}_j, p^*\} & \forall j \notin \mathcal{N} \end{cases} \tag{11}$$

We notice that value-based providers may price below the reference under RV, in contrast with reference pricing. Hence, RV helps mitigate shadow pricing.

The ensuing result helps determine the set of non-value-based providers.

Proposition 11. *If provider 1 is non-value-based, then provider 2 is non-value-based.*

Proposition 11 confirms the notion that providers with better non-price attributes may choose to be non-value-based, just like under reference pricing. As a result, we can use an algorithm similar to Algorithm 1 to identify the set of non-value-based providers as well as the prices in equilibrium.

Finding analytically the optimal reference price under RV is not tractable. We studied numerically the effect of varying the reference price on the insurer's objective (results omitted due to space constraints, but available upon request).

C.2. Comparison of variable payment and RV

We now obtain some properties of the equilibrium under RV in the case of two providers.

Lemma 5. *As the reference price increases, the number of non-value-based providers decreases or remains constant under RV.*

Increasing the reference price motivates providers to become value-based as they can achieve improving margins and attract a higher market share.

Proposition 12. *Suppose that the insurer selects the parameters of the payment model such that there is at least one value-based provider in the system under RV. (i) If one provider is value-based and the other is non-value-based under RV, there exists $\lambda_j^* \in (0,1]$ such that provider j prices higher under the variable payment system iff $\lambda < \lambda_j^*$ for $j = 1,2$. (ii) If both providers are value-based under RV, they price higher than or the same as under the variable payment system.*

Prices tend to be higher under RV than under the variable payment if λ is high. The cost share has a more significant impact on patient out-of-pocket under the variable payment system as it is implemented on the total price of a procedure, which forces providers to limit prices.

Proposition 13. *The patient's out-of-pocket comparison between the variable payment system and RV is the same as the price comparison as stated in Proposition 12. Moreover, if $o_j^{RV} < o_j^{VP}$ for $j = 1,2$, the expected patient population utility is higher under RV than under a variable payment system at equilibrium iff the outside option is weak (i.e., u_0 smaller than a threshold $\hat{u}_0 > 0$). If $o_j^{RV} \geq o_j^{VP}$ for $j = 1,2$, the expected patient population utility is higher under RV than under a variable payment system at equilibrium iff the outside option is strong.*

When the outside option is strong, the patient benefit is aligned with the out-of-pocket. Since more patients choose not to seek treatment and take advantage of the outside option, the total patient utility improves. When the outside option is weaker, patients benefit more under variable payment than RV when they incur higher out-of-pocket under RV.

Proposition 14. *Suppose there is at least one value-based provider in the insurer's network under RV. If (i) one provider is value-based and the other is non-value-based, or (ii) both providers are value-based (either both pricing at p^* or one prices at p^* and the other prices below p^*) and the outside option is strong, then there exists $\hat{\lambda}_j \in (0,1]$ such that provider j gains higher utility under the variable payment system than under RV iff $\lambda < \hat{\lambda}_j$. If both providers are value-based and price below p^*, the providers' utilities are the same under RV and the variable payment system.*

Provider utilities tend to be higher under RV than under the variable payment if λ is high because prices are higher under RV then and the effect of market share is less strong. If both providers are value-based and price below p^*, the variable payment system is equivalent to RV.

Appendix D: Proofs

Proof of Proposition 1. Under a fixed payment, when visiting provider j, the patient out-of-pocket $o_j = f$ is independent of p_j. Therefore, each provider's market share is also independent of p_j. It follows that the provider profit is monotonically increasing in p_j, hence the optimal price is $p_j = \overline{p}_j$. □

Proof of Theorem 1. Aksoy-Pierson et al. (2013, Lemma 4.1) show that under Assumption 1, in the VP payment system, for $\lambda \in (0,1]$, the best response price of provider $j \in N$ to any competing provider prices does not exceed $\overline{p}_j^{VP}$. Where N is the set of all providers. Therefore providers only become worse off if they price above $\overline{p}_j^{VP}$. This property constructs a closed action set for providers' prices.

We have $\frac{\partial S_j^{VP}}{\partial p_j} = -\lambda\gamma S_j^{VP}(P)(1 - S_j^{VP}(P))$ and therefore, $\frac{\partial V_j^{VP}}{\partial p_j} = m S_j^{VP}(P)\left(1 - \gamma\lambda(p_j - c)(1 - S_j^{VP}(P))\right)$, and

$$\frac{\partial^2 V_j^{VP}}{\partial p_j^2} = -m\gamma\lambda S_j^{VP}(P)(1 - S_j^{VP}(P))\left(2 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)\right),$$

Where

$$2 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1) = \frac{[2 - \gamma\lambda(p_j - c)](e^{u_0} + \sum_{k\neq j} e^{a_k - \gamma\lambda p_k}) + [2 + \gamma\lambda(p_j - c)]e^{a_j - \gamma\lambda p_j}}{e^{u_0} + \sum_{k=1}^{n} e^{a_k - \gamma\lambda p_k}},$$

and the denominator is positive. The partial derivative with respect to p_j of the numerator is $-\gamma\lambda(e^{u_0} + \sum_{k\neq j} e^{a_k - \gamma\lambda p_k}) - \gamma\lambda(1 + \gamma\lambda(p_j - c))e^{a_j - \gamma\lambda p_j} \leq 0$. Therefore, $2 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)$ can change sign at most once, from positive to negative, as p_j increases. Hence, $\frac{\partial^2 V_j^{VP}}{\partial p_j^2}$ can only change sign at most once, from negative to positive, as p_j gets larger. Moreover, $\lim_{p_j\to\infty} V_j^{VP}(P) \to 0$ as a result of a disappearing market share. Thus, the provider utility is quasi-concave in p_j and provider j finds its optimal price (assuming all other prices are fixed) by solving for the first order condition

$$1 - \gamma\lambda(p_j - c)(1 - S_j^{VP}(P)) = 0. \tag{12}$$

The Debreu-Fan-Glicksberg theorem states that, if for all players (providers) the set of actions is a non-empty, convex, and compact set, and the utility of players is a continuous function which is quasi-concave on the action set, then there exists a Nash Equilibrium for the game (Debreu 1952, Fan 1952, Glicksberg 1952). Therefore, there exists a Nash equilibrium.

Based on Vives (1999), to show uniqueness we show that $\left|\frac{\partial^2 V_j^{VP}}{\partial p_j^2}\right| > \sum_{\substack{i\neq j\\ i\in N}} \left|\frac{\partial^2 V_j^{VP}}{\partial p_j \partial p_i}\right|, \quad \forall j \in N$, where

$$\left|\frac{\partial^2 V_j^{VP}}{\partial p_j^2}\right| = m\gamma\lambda S_j^{VP}(P)[1 - S_j^{VP}(P)]|2 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)|,$$

and

$$\begin{aligned}
\sum_{\substack{i\neq j\\ i\in N}} \left|\frac{\partial^2 V_j^{VP}}{\partial p_j \partial p_i}\right| &= \sum_{\substack{i\neq j\\ i\in N}} m\gamma\lambda S_j^{VP}(P) S_i^{VP}(P)|1 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)| \\
&= m\gamma S_j^{VP}(P)|1 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)|\sum_{i\neq j} S_i^{VP}(P) \\
&< m\gamma S_j^{VP}(P)|1 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)|(1 - S_j^{VP}(P)),
\end{aligned}$$

where the last inequality follows from observing that $S_j^{VP}(P) + \sum_{i \neq j} S_i^{VP}(P) < 1$. Thus, to prove uniqueness, it remains to show that

$$|2 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)| > |1 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1)|,$$

which holds as long as $1 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1) > -1/2$. We can show that

$$1 + \gamma\lambda(p_j - c)(2S_j^{VP}(P) - 1) = \gamma\lambda(p_j - c) - 1 = \frac{1}{1 - S_j^{VP}(P)} - 1 \geq 0.$$

Observing that $\sum_{\substack{i \neq j \\ i \in N}} S_i^{VP}(P) \leq 1 - S_j^{VP}(P)$, the uniqueness of the Nash equilibrium follows. Hence, the unique Nash equilibrium is the solution to the system of FOC equations. $\square$

Proof of Proposition 2. We can show that $S_j^{RP}(P)$ is continuous in p_j. Its partial derivative with respect to p_j is continuous everywhere except at p^*, and we have

$$\frac{\partial S_j^{RP}}{\partial p_j} = \begin{cases} 0 & \text{if } p_j < p^* \\ -\gamma(1 - S_j^{RP}(P))S_j^{RP}(P) & \text{if } p_j > p^*. \end{cases} \tag{13}$$

Using (13), we have

$$\frac{\partial V_j^{RP}}{\partial p_j} = mS_j^{RP}(P) + m(p_j - c)\frac{\partial S_j^{RP}}{\partial p_j} = \begin{cases} mS_j^{RP}(P) > 0 & \text{if } p_j < p^* \\ mS_j^{RP}(P)[1 - \gamma(p_j - c)(1 - S_j^{RP}(P))] & \text{if } p_j > p^* \end{cases}. \tag{14}$$

Hence, provider j's utility is monotonically increasing in p_j over the domain $p_j \leq p^*$. $\square$

Proof of Theorem 2. Using (14), we obtain that for $p_j > p^*$,

$$\frac{\partial^2 V_j^{RP}}{\partial p_j^2} = -m\gamma S_j^{RP}(P)[1 - S_j^{RP}(P)]\left[2 + \gamma(p_j - c)(2S_j^{RP}(P) - 1)\right]. \tag{15}$$

Following the same steps illustrated in the proof of Theorem 1, we have

$$\begin{aligned} 2 + \gamma(p_j - c)(2S_j^{RP}(P) - 1) &= 2 + \gamma(p_j - c)\frac{e^{a_j - \gamma(p_j - p^* + \tilde{c})} - e^{u_0} - \sum_{k \neq j} e^{a_k - \gamma(p_k - p^* + \tilde{c})^+}}{e^{u_0} + \sum_{k=1}^n e^{a_k - \gamma(p_k - p^* + \tilde{c})^+}} \\ &= \frac{[2 - \gamma(p_j - c)](e^{u_0} + \sum_{k \neq j} e^{a_k - \gamma(p_k - p^* + \tilde{c})^+}) + [2 + \gamma(p_j - c)]e^{a_j - \gamma(p_j - p^* + \tilde{c})}}{e^{u_0} + \sum_{k=1}^n e^{a_k - \gamma(p_k - p^* + \tilde{c})^+}}. \end{aligned}$$

The denominator of the expression above is positive. The partial derivative with respect to p_j of the numerator is

$$-\gamma(e^{u_0} + \sum_{k \neq j} e^{a_k - \gamma(p_k - p^* + \tilde{c})^+}) - \gamma(1 + \gamma(p_j - c))e^{a_j - \gamma(p_j - p^* + \tilde{c})} \leq 0.$$

Therefore, $2 + \gamma(p_j - c)(2S_j^{RP}(P) - 1)$ can change sign at most once, from positive to negative, as p_j increases. Hence, $\frac{\partial^2 V_j^{RP}}{\partial p_j^2}$ can change sign at most once, from negative to positive, as p_j gets larger. Moreover, as p_j approaches infinity, the provider utility V_j^{RP} approaches zero as a result of a disappearing market share. Hence, the provider profit V_j^{RP} is quasi-concave in p_j on the domain $p_j > p^*$. In particular, a non-value-based provider j finds its optimal price (assuming all other prices are fixed) by solving for the first order condition:

$$1 - \gamma(p_j - c)(1 - S_j^{RP}(P)) = 0, \tag{16}$$

under Assumption 2 and based on Aksoy-Pierson et al. (2013, Lemma 4.1). The Debreu-Fan-Glicksberg theorem states that, if for all players (providers) the set of actions is a non-empty, convex, and compact (under Assumption 2 and based on Aksoy-Pierson et al. (2013, Lemma 4.1)) set, and the utility of players is a continuous function which is quasi-concave on the action set, then there exists a Nash Equilibrium for the game (Debreu 1952, Fan 1952, Glicksberg 1952). Therefore, there exists a Nash equilibrium.

Based on Vives (1999), to show uniqueness we show that

$$\left|\frac{\partial^2 V_j^{RP}}{\partial p_j^2}\right| > \sum_{\substack{i\neq j\\ i\in N}} \left|\frac{\partial^2 V_j^{RP}}{\partial p_j \partial p_i}\right|, \quad \forall j \in \mathcal{N},$$

where, if $p_j > p^*$, from (15)

$$\left|\frac{\partial^2 V_j^{RP}}{\partial p_j^2}\right| = m\gamma S_j^{RP}(P)[1 - S_j^{RP}(P)]|2 + \gamma(p_j - c)(2S_j^{RP}(P) - 1)|.$$

Moreover, using (14) and (13), we obtain that for $i \neq j,\ i, j \in \mathcal{N}$,

$$\sum_{\substack{i\neq j\\ i\in N}} \left|\frac{\partial^2 V_j}{\partial p_j \partial p_i}\right| = \sum_{\substack{i\neq j\\ i\in N}} m\gamma S_j^{RP}(P) S_i^{RP}(P)|1 + \gamma(p_j - c)(2S_j^{RP}(P) - 1)|.$$

Observing that

$$\sum_{\substack{i\neq j\\ i\in N}} S_i^{RP}(P) \leq 1 - S_j^{RP}(P),$$

the uniqueness of the Nash equilibrium thus follows. Hence, the unique Nash equilibrium is the solution to the system of FOC equations. □

Proof of Proposition 3. We start by showing a technical lemma.

Lemma 6. *Provider j is value-based if and only if $1 - \gamma(p^* - c)(1 - S_j^{RP}(p_j = p^*, P_{-j})) \leq 0$.*

From the proof of Proposition 2 we know that a provider's utility is monotonically increasing to the left of p^*, with a slope discontinuity at p^*. Moreover, it follows from the proof of Theorem 2 that using (14), we observe that for $p_j > p^*$, the sign of $\partial V_j^{RP}/\partial p_j$ is given by the sign of $\psi(P) \equiv 1 - \gamma(p_j - c)(1 - S_j^{RP}(P))$. Taking the derivative of this expression with respect to p_j (on the domain when $p_j > p^*$), using (13), we find

$$\begin{aligned}
\frac{\partial \psi}{\partial p_j} &= -\gamma(1 - S_j^{RP}(P)) + \gamma(p_j - c)\frac{\partial S_j^{RP}}{\partial p_j} \\
&= -\gamma(1 - S_j^{RP}(P)) - \gamma^2(p_j - c)[1 - S_j^{RP}(P)]S_j^{RP}(P) \\
&= -\gamma(1 - S_j^{RP}(P))[1 + \gamma(p_j - c)S_j^{RP}(P)] \\
&\leq 0,
\end{aligned}$$

where the last inequality follows from the fact that provider j must price above its cost to make a profit. Thus ψ is monotonically decreasing in p_j. Hence it takes the value 0 at most once, and if it does, it goes from being positive to being negative on the domain $p_j > p^*$. As a result, $\frac{\partial V_j^{RP}}{\partial p_j}$ also takes the value 0 at most once, and if it does, it goes from being positive to being negative on the domain $p_j > p^*$. furthermore, it is easy to observe that $\lim_{p_j \to \infty} V_j^{RP}(P) = 0$, and thus V_j^{RP} is not monotonically increasing in p_j on the domain $p_j > p^*$. V_j^{RP} is a unimodal function of p_j: it increases in p_j on the domain $p_j < p^*$, and it is either monotonically decreasing on the domain $p_j > p^*$ (when its derivative at $(p^*)^+$ is non-positive) or it is increasing and then decreasing on the domain $p_j > p^*$ (when its derivative at $(p^*)^+$ is positive), with a derivative equal to zero at exactly one point $p_j > p^*$. Either provider j maximizes its profit by selecting $p_j = p^*$ (i.e., it is value-based); or provider j maximizes its profit by selecting $p_j > p^*$ (i.e., it is non-value-based). Since $\frac{\partial V_j^{RP}}{\partial p_j}\Big|_{p_j=(p^*)^+} = mS_j^{RP}(p_j = p^*, P_{-j})\left[1-\gamma(p^*-c)\left(1-S_j^{RP}(p_j=p^*,P_{-j})\right)\right]$, the result follows. □

We now prove the result of the Proposition. Assume that provider j is non-value-based. We want to show that any provider ranked $k > j$ is also non-value-based. By induction, it suffices to show that provider $j+1$ is non-value-based. We proceed by contradiction: suppose that provider $j+1$ is value-based, that is, $p_{j+1} = p^*$. Since provider $j+1$ is value-based, we have $1-\gamma(p^*-c)(1-S_{j+1}^{RP}(p_{j+1} = p^*, P_{-j})) = 1-\gamma(p^*-c)\frac{e^{u_0}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}{e^{u_0}+e^{a_{j+1}}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}$. This expression has the same sign as $\delta \equiv e^{u_0} + e^{a_{j+1}} + \sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+} - \gamma(p^*-c)\left(e^{u_0}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}\right)$. We obtain

$$\delta \geq e^{u_0} + e^{a_{j+1}} + \sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+} - \gamma(p^*-c)\left(e^{u_0}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}\right).$$

Provider j is non-value-based, so $p_j > p^*$ and thus

$$\delta > e^{u_0} + e^{a_{j+1}} + \sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+} - \gamma(p_j-c)\left(e^{u_0}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}\right).$$

Provider j selects its price p_j such that $1-\gamma(p_j-c)(1-S_j^{RP}(P)) = 0$, that is, $\frac{e^{u_0}+\sum_k e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}{e^{u_0}+\sum_{k\neq j} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}} = \gamma(p_j-c)$. Therefore,

$$\delta > e^{u_0} + e^{a_{j+1}} + \sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+} - \frac{e^{u_0}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}{e^{u_0}+\sum_{k\neq j} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}\left(e^{u_0}+\sum_{k} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}\right).$$

Note that the ratio in the expression above can be written as $\frac{e^{u_0}+\sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}{e^{u_0}+\sum_{k\neq j} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}} = \frac{e^{a_j-\gamma(p_j-p^*+\tilde{c})^+}+e^{u_0}+\sum_{k\neq j,j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}}{e^{a_{j+1}}+e^{u_0}+\sum_{k\neq j,j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+}} < 1$, which follows from $a_j - \gamma(p_j-p^*)^+ < a_j \leq a_{j+1}$. Therefore, we have $\delta > e^{u_0} + e^{a_{j+1}} + \sum_{k\neq j+1} e^{a_k-\gamma(p_k-p^*+\tilde{c})^+} - e^{u_0} - \sum_k e^{a_k-\gamma(p_k-p^*+\tilde{c})^+} = 0$. Hence, $1-\gamma(p^*-c)(1-S_{j+1}^{RP}(p_{j+1}=p^*,P_{-j})) > 0$, which contradicts Lemma 6 given that provider $j+1$ is value-based. Therefore, provider $j+1$ is non-value-based. □

Proof of Lemma 1. We denote the two providers as providers 1 and 2 such that $a_1 < a_2$ (without loss of generality). The proof proceeds in 3 steps. First, we determine how changes in p^* affect provider 1 when 2 is value-based. Second, we determine how changes in p^* affect provider 1 when 2 is non-value-based. Third, we determine how changes in p^* affect provider 2.

If provider 2 is value-based, based on Proposition 3, provider 1 can only be value-based since $a_1 < a_2$. In this interval both providers remain value-based as the reference price increases.

Second, consider the case when 2 is non-value-based. Using Lemma 6, provider 1 chooses to be value-based iff $e^{a_1-\gamma\tilde{c}} - (\gamma(p^*-c)-1)\left(e^{u_0}+e^{a_2-\gamma(p_2^{RP}(p^*)-p^*+\tilde{c})}\right) \leq 0$. Since we can show that $\partial p_2^{RP}(p^*)/\partial p^* > 0$, the left-hand side of this inequality is monotonically decreasing in p^*, and hence, it can change sign at most once, from positive to negative, as p^* increases, while provider 2 remains non-value-based. Since $a_1 < a_2$, from Proposition 3 provider 2 remains non-value-based at least until after provider 1 changes status to value-based as p^* increases.

Third, if provider 1 is non-value-based, provider 2 remains non-value-based. When $p^* > p^*_{11}$, which solves for p^* in the equation $p^* = \frac{1}{\gamma}\left(1 + \frac{e^{a_j-\gamma\tilde{c}}}{e^{u_0}+e^{a-j-\gamma((p-j-p^*)^+ + \tilde{c})}}\right) + c$ for $j = 1,2$, provider 1 becomes value-based. Then from Lemma 6, provider 2 is value-based iff $1 - \gamma(p^* - c)(1 - S_2^{RP}(p_2, p_1)) \leq 0$ or iff $p^* \geq p^*_{12}$. For the same reason as above, provider 2 can only change status from non-value-based to value-based as p^* increases.
□

Proof of Proposition 4. From Lemma 1, as the reference price increases non-value-based providers have incentives to become value-based. We focus on the case where at least one value-based provider is present. Since the providers are ordered so that $a_1 < a_2$, from Proposition 3, provider 1 is value-based and as p^* increases provider 2 has incentives to become value-based. Provider 1 is value-based and provider 2 is non-value-based when $p^*_{11} \leq p^* \leq p^*_{22}$, while both providers are value-based when $p^* \geq p^*_{22}$.

When the insurer is greedy $\omega_1 = \omega_2 = 0$, then it only considers its own cost which is increasing in p^*. Thus the optimal p^*, is p^*_{11}.

Taking the derivative of insurer objective (6) with respect to p^*, we can show that when both providers are value-based (i.e., for $p^* \geq p^*_{22}$) $\frac{\partial \Pi^{RP}}{\partial p^*} \leq 0$, since $\frac{\partial o_j^{RP}}{\partial p^*} = 0$ for $j = 1,2$. On this interval the optimal reference price is p^*_{22}.

When provider 1 is value-based and provider 2 is non-value-based (i.e., for $p^*_{11} \leq p^* \leq p^*_{22}$), with a public non profit insurer ($\omega_1 = \frac{1}{\gamma}$ and $\omega_2 = 1$), there are two scenarios to consider.

1. If $(u_0 - a_2 + \frac{c}{\delta})e^{u_0} - (a_2 - a_1)e^{a_1} < 0$: $\frac{\partial \Pi^{RP}}{\partial p^*} > 0$. Thus the optimal p^* $(\hat{p}^*)$, is p^*_{22}.

2. If $(u_0 - a_2 + \frac{c}{\delta})e^{u_0} - (a_2 - a_1)e^{a_1} \geq 0$: $\frac{\partial \Pi^{RP}}{\partial p^*} < 0$. Thus the optimal p^* is p^*_{11}. The overall optimal reference price then is $\hat{p}^* = \underset{p^*}{Argmax}\left\{\Pi^{RP}(p^* = p^*_{11}), \Pi^{RP}(p^* = p^*_{22})\right\}$.

For general ω_1 and ω_2, the optimal reference price is only tractable when $\gamma\omega_1 \leq \omega_2$ and $p^*_{22} \leq \omega_1(a_2 - \gamma\tilde{c} - u_0)$. In which case, we can show that the insurer objective function can only change sign from positive to negative resulting in an optimal solution either on boundaries or an intermediate point in (p^*_{11}, p^*_{22}). This intermediate point is the solution to the first order condition as stated in Proposition 4. □

Proof of Lemma 2. (a) Taking the derivative of provider 2's FOC with respect to λ and using (4) and (12) we have $-\left(p_2^{VP} + \lambda\frac{\partial p_2^{VP}}{\partial \lambda}\right) + c(1 - S_2^{VP}(P)) + \left(p_1^{VP} + \lambda\frac{\partial p_1^{VP}}{\partial \lambda}\right)\frac{S_1^{VP}(P)S_2^{VP}(P)}{1 - S_2^{VP}(P)} = 0$. Similarly, the derivative with respect to λ of provider 1's FOC can be calculated and replaced in the previous expression. Since $p_2^{VP} \geq c$, after simplifications, it follows that $\partial p_2^{VP}/\partial\lambda \leq 0$.

(b) Suppose that provider 2 is value-based. Then, by Proposition 2, provider 2 prices at p^*, and so the price is continuously increasing in p^* while the provider remains value-based (based on Lemma 1). Now suppose that provider 2 is non-value-based. If provider 1 is value-based, we established in the proof of Lemma 1 that in this case $\partial p_2^{RP}/\partial p^* > 0$. We thus now focus on the case when provider 1 is also non-value-based. Taking the derivative of provider 2's FOC and its market share with respect to p^*, and using $\gamma(p_2 - c) = 1/(1 - S_2^{RP}(P))$ at equilibrium, it follows that $\frac{\partial p_2^{RP}}{\partial p^*} = \frac{S_2^{RP}(P)\left(1 - S_2^{RP}(P) + S_1^{RP}(P)\left(\frac{\partial p_1^{RP}}{\partial p^*} - 1\right)\right)}{1 - S_2^{RP}(P)}$. Hence, $\partial p_2^{RP}/\partial p^* > 0$. Finally, from the proof of Lemma 1, the price of a provider remains continuous as the provider transitions from non-value-based to value-based. □

Proof of Lemma 3. (a) Under VP, the patient out-of-pocket from visiting provider 2 is $o_2^{VP} = \lambda p_2$. Using the proof of Lemma 2, we can show that $\frac{\partial o_2^{VP}}{\partial \lambda} \geq 0$.

(b) Under RP, the patient out-of-pocket from visiting a value-based provider is $\tilde{c}$. The patient out-of-pocket from visiting non-value-based provider 2 is $o_2^{RP} = p_2 - p^* + \tilde{c}$. If provider 1 is value-based, it is easy to see that $\frac{\partial p_2}{\partial p^*} < 1$, and thus $\frac{\partial o_2^{RP}}{\partial p^*} \leq 0$. If provider 1 is non-value-based, we can show that $\frac{\partial o_2^{RP}}{\partial p^*} \leq 0$.

Proof of Proposition 5. Lemma 2(b) establishes that the provider prices under VP are decreasing in λ. The prices under RP are indifferent to λ. Moreover, as λ approaches zero, p_j^{VP} must become infinitely large so the FOC has a solution. Hence, it suffices to show that, as λ approaches 1, each of the provider prices under VP, approaches a value lower than its RP counterparts. We examine three cases, depending on whether providers 1 and/or 2 are value-based or not.

Case 1: providers 1 and 2 are value-based. Then $p_1^{RP} = p_2^{RP} = p^*$. Using the expression for value-based providers in Lemma 6, assuming $\tilde{c} \leq c$ and assuming without loss of generality that $p_2^{VP} \geq p_1^{VP}$, $\gamma(p_2^{VP} - c) = \frac{e^{u_0} + e^{a_1 - \gamma p_1^{VP}} + e^{a_2 - \gamma p_2^{VP}}}{e^{u_0} + e^{a_1 - \gamma p_1^{VP}}} < \frac{e^{u_0} + e^{a_1 - \gamma \tilde{c}} + e^{a_2 - \gamma \tilde{c}}}{e^{u_0} + e^{a_1 - \gamma \tilde{c}}} \leq \gamma(p^* - c)$, It follows that $\gamma(p_1^{VP} - c) \leq \gamma(p_2^{VP} - c) < \gamma(p^* - c)$, and thus $p_1^{VP} \leq p_2^{VP} < p^*$.

Case 2: providers 1 and 2 are non-value-based. First, suppose that $p_2^{VP} < p_2^{RP}$ is already established. Let $p = p_1^{RP}$ be the equilibrium price under RP solving the FOC equation $e^{a_1 - \gamma(p - p^* + \tilde{c})} - (\gamma(p - c) - 1)\left(e^{u_0} + e^{a_2 - \gamma(p_2^{RP} - p^* + \tilde{c})}\right) = 0$. We can show that the left hand side above is decreasing in p. Therefore, to show that $p_1^{VP} < p_1^{RP}$, it suffices to show that this left-hand-side evaluated at $p = p_1^{VP}$ is positive. This result follows by using providers 1's expression for price at equilibrium under VP and under the assumption that $p_2^{VP} < p_2^{RP}$ and knowing that $\tilde{c} < p^*$. To complete the proof, it remains to show that $p_2^{VP} < p_2^{RP}$. We first show a preliminary lemma.

Lemma 7. *Let* $g(p_2) = e^{a_2 - \gamma p_2} - (\gamma(p_2 - c) - 1)\left(e^{u_0 - \gamma(p^* - \tilde{c})} + e^{a_1 - \gamma p_1^{RP}(p_2)}\right)$ *and* $f(p_2) = e^{a_2 - \gamma p_2} - (\gamma(p_2 - c) - 1)\left(e^{u_0} + e^{a_1 - \gamma p_1^{VP}(p_2)}\right)$, *where* $p_1^{RP}(p_2)$ *is provider 1's best response price to provider 2's price* p_2 *under RP and* $p_1^{VP}(p_2)$ *is provider 1's best response price to provider 2's price* p_2 *under VP. Then* $f(.)$ *and* $g(.)$ *are decreasing at* p_2 *solving for* $f(p_2) = 0$ *and* $g(p_2) = 0$ *respectively and for* $p_2 > c + 1/\gamma$. *Moreover, we have* $g(p_2) > f(p_2)$ $\forall p_2 > c + 1/\gamma$.

Proof of Lemma 7. If provider i is value-based, its price is p^* and the monotonicity result is clear. We thus focus on the case when provider i is non-value-based. We have $g'(p_2) = -\gamma e^{a_2 - \gamma p_2} - \gamma\left(e^{u_0 - \gamma(p^* - \tilde{c})} + e^{a_1 - \gamma p_1^{RP}(p_2)}\right) + (\gamma(p_2 - c) - 1)\gamma \frac{\partial p_1^{RP}}{\partial p_2} e^{a_1 - \gamma p_1^{RP}(p_2)}$. We can show that $\frac{\partial p_1^{RP}}{\partial p_2} > 0$ using the FOC equation for provider 1. Moreover, when $g(p_2) = 0$, $\gamma(p_2 - c) - 1 = \frac{e^{a_2 - \gamma p_2}}{e^{u_0 - \gamma(p^* - \tilde{c})} + e^{a_1 - \gamma p_1^{RP}(p_2)}}$ resulting in a unique solution for p_2. Hence $g'(p_2)|_{p_2 = g^{-1}(0)} < 0$. Similarly, we calculate the expression for $f'(p_2)$ and show that $\frac{\partial p_1^{VP}}{\partial p_2} > 0$. Thus, $f(.)$ is decreasing at p_2 that solves $f(p_2) = 0$. With some algebra we can show that $g(p_2) - f(p_2) \geq 0$. That is, that $p_1^{RP}(p_2) > p_1^{VP}(p_2)$.

We now return to the proof of Proposition 12. From Lemma 7, $g(p_2^{VP}) > f(p_2^{VP}) = 0$. Because $g(.)$ is decreasing at the unique value of price that sets $g(.)$ to zero, $p_2^{VP} < p_2^{RP}$.

Case 3: provider 2 is non-value-based, provider 1 is value-based. Since 1 is value-based, from Lemma 6, we have $e^{a_1 - \gamma \tilde{c}} + (1 - \gamma(p^* - c))\left(e^{u_0} + e^{a_2 - \gamma(p_2^{RP}(p^*) - p^* + \tilde{c})}\right) \leq 0$. If p^* is also chosen under the variable payment for provider 1, $p_2^{RP}(p^*) > p_2^{VP}(p^*)$ and $f(p_1 = p^*) < g(p_1 = p^*) \leq 0$. Since $f(p_1 = p^*) < 0$ and $f(.)$ is decreasing at the price that sets $f(.)$ to zero, we can conclude p_1^{VP} which makes $f(p_1^{VP}) = 0$ is such that $p_1^{VP} < p^*$. □

Proof of Proposition 6. Under the reference pricing scheme, if the provider is value-based, the patient out-of-pocket is $\tilde{c}$ and assuming $\tilde{c} \leq \lambda c$, is always less than that of the variable payment regardless of the value of λ. Let's suppose that provider 2 is non-value-based. We first consider the case when provider 1 is also non-value-based. Let $\tilde{g}(o_2) = e^{a_2-\gamma o_2} - (\gamma(o_2 + p^* - \tilde{c} - c) - 1)\left(e^{u_0} + e^{a_1-\gamma o_1^{RP}(o_2)}\right)$ and $\tilde{f}(o_2) = e^{a_2-\gamma o_2} - (\gamma(o_2 - \lambda c) - 1)\left(e^{u_0} + e^{a_1-\gamma o_1^{VP}(o_2)}\right)$, where $o_1^{RP}(o_2) = p_1^{RP}(o_2 + p^* - \tilde{c}) - p^* + \tilde{c}$ and $o_1^{VP}(o_2) = \lambda p_1^{VP}(o_2/\lambda)$. Observe that $\tilde{g}(o_2) = e^{\gamma(p^*-\tilde{c})} g(o_2 + p^* - \tilde{c})$ and $\tilde{f}(o_2)$ is similar to $f(o_2/\lambda)$ after modifying $f(.)$ with a co-insurance rate λ not necessarily equal to 1. By Lemma 7, $\tilde{g}(.)$ and $\tilde{f}(.)$ are decreasing at the value of out-of-pocket that sets these functions equal to zero for $o_2 > c + 1/\gamma - p^* + \tilde{c}$ and $o_2 > \lambda(c + 1/\gamma)$, respectively. Following the same steps as Proposition 5 we can show that Because $\tilde{f}(.)$ is decreasing at the unique value of out-of-pocket that sets it equal to zero, and assuming that $\tilde{c} \leq \lambda c$, $o_2^{RP} < o_2^{VP}$. When provider 1 is value-based, $o_1^{RP}(o_2) = \tilde{c}$. Then, $\tilde{g}(.)$ is decreasing at the value of out-of-pocket that sets it equal to zero and we have $o_1^{RP}(o_2) = \tilde{c} < o_1^{VP}(o_2)$. The rest of the proof for the case with 1 non-value-based is valid.

We now focus on the expected patient population utility, $E[U] = m\left(\sum_{j=1,2}(a_j - \gamma o_j)S_j + u_0 S_0\right)$ (we omit the dependence on price vector P and we denote $u_j \equiv a_j - \gamma o_j$ for clarity of exposition). Since $o_j^{RP} < o_j^{VP}$, we have $u_j^{RP} > u_j^{VP}$. Thus, $S_0^{VP} > S_0^{RP}$. Using these inequalities and with some algebra we next show that $\sum_{j=1,2} u_j^{RP} S_j^{RP} > \sum_{j=1,2} u_j^{VP} S_j^{VP}$. Therefore, $E[U^{RP}] > E[U^{VP}] \Leftrightarrow u_0 < \frac{\sum_{j=1,2}(a_j - \gamma o_j^{RP})S_j^{RP} - \sum_{j=1,2}(a_j - \gamma o_j^{VP})S_j^{VP}}{S_0^{VP} - S_0^{RP}}$, where the above threshold on u_0 is positive. □

Proof of Lemma 4. (a) Using Theorem 1, under VP, the provider profit is $V_j^{VP} = m(p_j^{VP} - c)\left(1 - \frac{1}{\gamma\lambda(p_j^{VP} - c)}\right)$. Taking the derivative of this expression with respect to λ and with some algebra we can show that $\mathrm{V}_j^{VP}/\partial\lambda < 0$.

(b) Under RP, the provider profit is $V_j^{RP}(P) = m(p_j^{RP} - c)\frac{e^{a_j - \gamma(p_j^{RP} - p^* + \tilde{c})^+}}{e^{u_0} + e^{a_j - \gamma(p_j^{RP} - p^* + \tilde{c})^+} + e^{a_-j - \gamma(p_{-j}^{RP} - p^* + \tilde{c})^+}}$ for $j = 1, 2$. If both providers are value-based, provider profit is increasing in p^*.

If provider 1 is value-based and provider 2 is non-value-based, then observing that, from the proof of Lemma 1, p_2^{RP} increasing in p^*, $p_2^{RP} - p^*$ is decreasing in p^*, it follows that $V_2^{RP}(P)$ is increasing in p^*.

If both providers are non-value-based, from Lemma 2, p_2^{RP} is increasing in p^* and $S_2^{RP}(P)$ is increasing in p^* as well. Therefore, the provider profit is increasing in p^*.

Proof of Proposition 7. As shown in the proof of Proposition 5, as λ approaches zero, the price under VP becomes arbitrarily large. Notice that as λ approaches zero, S_j^{VP} remains within $[0, 1]$, so λp_j^{VP} remains bounded and S_j^{VP} does not approach zero for $j = 1, 2$. Therefore, for a small enough value of λ, the provider profit under VP exceeds that under RP ($V_j^{RP} < V_j^{VP}$). Lemma 4(b) shows that the provider profit under VP decreases in λ (under RP, the provider profit is independent of λ). Hence, it suffices to show that, as λ approaches 1, the provider profit under VP at equilibrium is lower than that under RP. As λ approaches 1, the provider profit under VP approaches $m(p_j^{VP} - c - 1/\gamma)$. When provider j is non-value-based, from Theorem 2, and Proposition 5, $p_j^{RP} > p_j^{VP}$ when λ approaches 1. Therefore, $V_j^{RP} > V_j^{VP}$. □

Proof of Proposition 8 The insurer's expected cost under the variable payment is $W^{VP} = m(1-\lambda)\sum_{k=i,j} p_k^{VP} S_k^{VP}(P)$. We then have,

$$\frac{1}{m}\frac{\partial W^{VP}}{\partial \lambda} = \sum_{k=i,j}\left[\frac{\gamma\lambda(p_k^{VP}-c)-1}{\gamma\lambda(p_k^{VP}-c)}\left((1-\lambda)\frac{\partial p_k^{VP}}{\partial\lambda} - p_k^{VP}\right) + \frac{(1-\lambda)p_k^{VP}}{\gamma\lambda(p_k^{VP}-c)}\left(\frac{\partial p_k^{VP}}{\partial\lambda}\frac{1}{(p_k^{VP}-c)} + \frac{1}{\lambda}\right)\right].$$

which can be shown to be decreasing in λ. As λ approaches 1, the insurer share of the cost approaches zero, and thus becomes lower than the insurer payment under RP. As λ approaches zero, $S_k^{VP} = 1 - 1/(\gamma\lambda(p_k^{VP}-c))$ remains within $[0,1]$, so λp_k^{VP} remains bounded. Therefore, the insurer cost, becomes arbitrarily large. Hence, for a small enough co-insurance rate λ, the insurer cost under VP is larger than that under RP. Thus follows, with the value of the co-insurance rate yielding equal insurer costs under the two payment models. □

Proof of Theorem 3. After straightforward calculations, we obtain

$\frac{\partial^2 V_i}{\partial p_i^2} = -m\gamma S_i S_j (2+\gamma(1-2S_j)(p_i - c))$ (<0 under Assumption 3); $\frac{\partial^2 V_j}{\partial p_j^2} = -m\gamma S_j(1-S_j)(2-\gamma(1-2S_j)(p_j-c))$.

For p_2 fixed, we find the best response $p_1^*(p_2)$ using the FOC. For $p_1 \in [c, p_2]$: if $p_2 < c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma e^{a_2-\gamma\tilde{c}})$, then $p_1^* = p_2$; else, $p_1^* \le p_2$ is the unique solution to the equation

$$e^{u_0} + e^{a_1-\gamma\tilde{c}} = (\gamma(p_1-c)-1)e^{a_2-\gamma(p_2-p_1+\tilde{c})}. \tag{17}$$

For $p_1 \in (p_2, \infty)$, similar to the proof of Theorem 2, V_1 is quasi-concave and tends to zero as p_1 becomes large. Hence, if $p_2 > c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma(e^{u_0} + e^{a_2-\gamma\tilde{c}}))$, then $p_1^* = p_2$; else, $p_1^* > p_2$ is the unique solution to the equation

$$(e^{u_0} + e^{a_2-\gamma\tilde{c}})(\gamma(p_1-c)-1) = e^{a_1-\gamma(p_1-p_2+\tilde{c})}. \tag{18}$$

Finally, since $c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma e^{a_2-\gamma\tilde{c}}) > c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma(e^{u_0} + e^{a_2-\gamma\tilde{c}}))$,

- if $p_2 \le c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma(e^{u_0} + e^{a_2-\gamma\tilde{c}}))$, then $p_1^* = \bar{p}$ $(> p_2)$ where $\bar{p}$ solves (18);
- if $c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma(e^{u_0} + e^{a_2-\gamma\tilde{c}})) < p_2 < c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma e^{a_2-\gamma\tilde{c}})$, then $p_1^* = p_2$;
- else (i.e., if $p_2 \ge c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma e^{a_2-\gamma\tilde{c}})$), then $p_1^* = \tilde{p}$ $(\le p_2)$ where $\tilde{p}$ solves (17).

$p_2^*(p_1)$ is obtained similarly by symmetry. Since the Nash equilibrium is the intersection of the best responses, we find that when $c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma(e^{u_0} + e^{a_1-\gamma\tilde{c}})) \le c + (e^{u_0} + e^{a_1-\gamma\tilde{c}} + e^{a_2-\gamma\tilde{c}})/(\gamma e^{a_2-\gamma\tilde{c}})$, the Nash equilibrium is $p_1 = p_2$. Otherwise, the unique Nash equilibrium is $p_1 = \tilde{p}(p_2),\ p_2 = \bar{p}(p_1)$. □

Proof of Proposition 9. In case (i), the endogenous price equilibrium $p_1 = p_2$ is above $p_{22}^*(> p^*)$. Moreover, $\gamma(p_2^{\text{exo}} - c) - 1 < \gamma(p_{22}^* - c) - 1$. Hence, we have $p_1^{\text{exo}} = p^* < p_2^{\text{exo}} < p_{22}^* < p_1^{\text{endo}} = p_2^{\text{endo}}$. In case (ii), $p^* \ge p_{22}^*$ implies that p^* is above the lower end of the interval of possible Nash equilibria under endogenous RP. Hence, if p^* is above the upper limit of the interval, all endogenous equilibria lie below the exogenous equilibrium. Otherwise, the endogenous price may be either below or above the exogenous price. In case (iii), we have $\gamma(p_2^{\text{endo}} - c) - 1 = \frac{e^{a_2-\gamma(p_2^{\text{endo}} - p_1^{\text{endo}} + \tilde{c})}}{e^{u_0} + e^{a_1-\gamma\tilde{c}}}$, $\gamma(p_2^{\text{exo}} - c) - 1 = \frac{e^{a_2-\gamma(p_2^{\text{exo}} - p^* + \tilde{c})}}{e^{u_0} + e^{a_1-\gamma\tilde{c}}}$. Hence, $p_2^{\text{exo}} > p_2^{\text{endo}}$ iff $p_2^{\text{exo}} - p^* < p_2^{\text{endo}} - p_1^{\text{endo}}$. In case (iv), the endogenous prices satisfy $p_1^{\text{endo}} < p_2^{\text{endo}}$ and $\gamma(p_2^{\text{endo}} - c) - 1 = \frac{e^{a_2-\gamma(p_2-p_1)}}{e^{u_0} + e^{a_1-\gamma\tilde{c}}} < \frac{e^{a_2-\gamma\tilde{c}}}{e^{u_0} + e^{a_1-\gamma\tilde{c}}} = \gamma(p_{22}^* - c) - 1$, hence, $p_1^{\text{endo}} < p_2^{\text{endo}} < p_{22}^*$. Since, $p_{22}^* < p^*$, the result follows. □

Proof of Proposition 10 The result follows immediately from comparing expressions of the insurer's objective pairwise. □

Proof of Theorem 4. a) We can show that

$$\frac{\partial V_j^{HRP}}{\partial p_j} = \begin{cases} m\left(\zeta S_j^L(P) + (1-\zeta)S_j^H(P)\right) > 0 & \text{if } p_j < p^* \\ m\zeta S_j^L(P)[1-\gamma_L(p_j-c)(1-S_j^L(P))] + m(1-\zeta)S_j^H(P)[1-\gamma_H(p_j-c)(1-S_j^H(P))] & \text{if } p_j > p^* \end{cases}. \tag{19}$$

Hence, provider j's utility is monotonically increasing in p_j over the domain $p_j \leq p^*$.

b) Following the same steps as those illustrated in the proof of Theorem 2, we can show that a unique Nash equilibrium exits where a non-value-based provider j finds its optimal price by solving the first order condition:

$$\zeta S_j^L(P)\left(1-\gamma_L(p_j-c)(1-S_j^L(P))\right) + (1-\zeta)S_j^H(P)\left(1-\gamma_H(p_j-c)(1-S_j^H(P))\right) = 0 \tag{20}$$

□

Proofs of the results in Appendices C.1 and C.2 are similar to the proofs of the analogous results in Sections 4.3 and 5. Detailed derivations are available upon request.