The Impact of *Custom Contracting* on the Key Information Roles of Group Purchasing Organizations (GPOs) in the Healthcare Supply Chain

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Abstract: Manufacturers and distributors of expensive implants and other medical supplies often require buyers to sign non-disclosure agreements treating negotiated prices as trade secrets. Such agreements make it difficult for hospitals to obtain accurate pricing benchmarks. In order to save on procurement costs and also obtain pricing benchmarks, most hospitals in the United States join group purchasing organizations (GPOs). GPOs are believed to lower procurement costs by aggregating hospitals' demands. Some hospitals buy using the GPO contract, and some further improve on prices available via GPO contracts, negotiating *custom contracts* directly with the GPO vendors. Whether GPOs indeed add value to the healthcare supply chain and whether they produce actual savings for hospitals are frequently debated issues, as evidenced by the ongoing discussions on the topic in the U.S. Congress. In order to understand the important role of *custom contracting* in the hospitals' supply chain, we developed a game-theoretic model where the decisions by the Hospitals and the Vendor are all endogenous. With this model, we can explain how GPOs that allow *custom contracting* benefit smaller hospitals through demand aggregation, while larger hospitals gain primarily from having access to the GPO pricing information as a benchmark for further negotiations. Our model supports the proposition that purchasing through a GPO results in savings for hospitals; we explain however, why the savings are always lower when the GPOs allow *custom contracting*.

Key words: group purchasing; Group Purchasing Organizations (GPOs); healthcare supply chain; information intermediaries; custom contracts

1. Introduction

The New York Times (NYT) reported on August 3, 2013, "…*device makers typically require doctors' groups and hospitals to sign nondisclosure agreements about prices, which means institutions do not know what their competitors are paying. This secrecy erodes bargaining power*…." (Rosenthal, 2013). In another article on August 25, 2013 the NYT reported, "…*it is secrecy that helps keep prices high: hidden in the underbrush of transactions among multiple buyers and sellers, and in the hieroglyphics of hospital bills. At every step from manufacturer to patient, there are confidential deals among the major players, including drug companies, purchasing organizations and distributors, and insurers. These deals so obscure prices and profits that even participants cannot say what the simplest component of care actually costs, let alone what it should cost*" (Bernstein, 2013). Supplies claim a significant proportion of costs at U.S. hospitals, second only to labor: While labor costs constitute two-thirds of total hospital expenses, supply costs account for approximately one-fourth (MHA, 2010). The demand for healthcare services is geographically fragmented, but hospitals' materials requirements overlap substantially. Thus, as early as 1910, several hospitals in New York City formed a group purchasing organization (GPO) to lower the cost of procured laundry services (Rooney, 2011). Over time, the number of GPOs has grown, and most hospitals use them now. In the U.S. in 2007, there were approximately 5,000 hospitals and more than 600 healthcare GPOs, both for- and not-for-profit. However, healthcare group purchasing is a concentrated industry. The combined purchase volume of the six largest GPOs[1] accounts for almost 90% of all hospital GPO contracts (GAO-10-738, 2010).

In the past decade, GPOs have come under significant governmental scrutiny. A 1986 bill passed by Congress permitted GPOs to cover operating costs by collecting revenue shares from vendors rather than membership fees from the hospitals. The intent of the *Safe Harbor* bill, that exempted GPOs from the anti-kickback provisions in Medicare law, was to help the struggling hospitals. Yet, as the result, GPOs' revenues became tied to the revenues of the suppliers that they were supposed to be pressing for lower prices (Blake, 2010). A 2002 series of articles in The New York Times (Bogdanich, 2002; Walsch, 2002; Walsch & Meier, 2002) exposed GPO practices that limited hospitals' access to innovative medical devices. The series also supplied some anecdotal evidence that cost savings with GPOs may be illusory. The New York Times exposé led to an investigation by the U.S. Government Accountability Office (GAO) into the practices of healthcare GPOs. Control of healthcare costs is important for the U.S. government, which is a significant stakeholder in the sector through its VA hospitals, Medicare and Medicaid programs. A small GAO study (GAO-02-690T, 2002) found that GPO prices for specialized

[1] Some of the prominent national GPOs are Premier, Novation, MedAssets, Amerinet, Health Trust, Consorta, Healthcare Purchasing Partners, GNYHA, and Innovatix.

items such as safety syringes and pacemakers were in fact higher than the prices outside. Following this congressional investigation, many GPOs adopted a voluntary code of conduct that promised to eliminate conflicts of interest in their product and vendor selection decisions.

Nevertheless, ten years later, the question whether purchasing through GPOs saves hospitals money remains unanswered. In 2010, the U.S. Senate Finance Committee issued a minority report entitled "Empirical Data Lacking to Support Claims of Savings with Group Purchasing Organizations" (Senate, 2010). The report noted that empirical studies (Burns & Lee, 2008; Chapman, Gupta, & Mango, 1998; Goldenberg & King, 2009; Schneller, 2009) claiming that GPOs generate savings for members were based on surveys of hospitals' procurement specialists; furthermore, only one of the studies (Burns & Lee, 2008) had been peer-reviewed. In their study, Burns and Lee (Burns & Lee, 2008) observed a quizzical practice: Hospitals sometimes used the GPO price as a starting point and negotiated a lower price with the same vendor (the vendor selling through the GPO), making a direct contracting effort on their own.

Shortly after the release of the Senate minority report, Litan and Singer (2010) published a study commissioned by the Medical Device Manufacturers Association (MDMA). The study examined a database of aftermarket medical device transactions from MEMdata, a firm that conducts auctions for GPO member hospitals that seek to improve upon the prices offered by the incumbent suppliers on the GPO contract. In examining nine years' worth of data, Litan and Singer found that GPOs often failed to secure the best prices for their members and that hospitals were able to save, on average, 18 percent in aftermarket negotiations. Earlier, the methodology of such cost-savings studies had been criticized by the Health Industry Group Purchasing Association.[2] It pointed to the failure to consider savings resulting from the additional services provided by GPOs, as well as "*the fact that hospitals that obtain better pricing outside their GPO often use the GPO contract as a starting point for their negotiations with vendors, much in the same way that non-union workers may use union contracts as a benchmark for their own negotiations*" (Cowie, 2011).

Our paper is a result of several years of close observation of the contracting practices of a number of multi-national healthcare vendors, leading American GPOs, and large-scale academic medical centers. Our goal is to add an objective and analytical contribution to the current debate on the ways in which GPOs add value to the medical supply chain. In particular, we explore the difference between arrangements that allow member hospitals to establish direct *custom contracts* with GPO vendors at a *custom price*, and situations in which such contracts are forbidden. In both cases, when a member hospital purchases an item from a GPO vendor, the GPO collects from the vendor a percentage of the revenue in

[2] Now Healthcare Supply Chain Association.

the form of contract administration fees. We investigate who benefits when custom contracting is allowed, who loses, and the extent of the gains and losses. Earlier studies cited above seem to indicate that allowing GPO members the flexibility to renegotiate has an unambiguous effect of savings for the hospitals, but the extent of the savings from such flexibility is not clear. The collateral effects on other hospitals, GPOs, and GPO vendors are even less clear, given that an increase in the purchase volume may or may not offset a decrease in the negotiated prices.

To answer these questions, we create a novel analytical model of three-way business-to-business (B2B) procurement contracting that reflects the healthcare supply chain structure, involving vendors, hospitals and a GPO. We capture the salient characteristics of the healthcare market, where hospitals' demand for many products is inelastic, and hospitals have a fair idea of the quality of each product they need to purchase but face significant uncertainty about the price (in contrast to the well-known "market for lemons" phenomenon). The price uncertainty exists because manufacturers of many medical supplies require buyers to sign gag clauses promising not to disclose purchase prices. This secrecy hinders comparison-shopping (Bernstein, 2013; Blake, 2010; Rosenthal, 2013). Since the market prices of numerous medical products are uncertain, vendors and hospitals have to engage in a drawn-out price-discovery process (negotiation, request for quotes, reverse auction, etc.) to establish purchase prices. The price-discovery process is costly for both hospitals and vendors. By joining a GPO, hospitals get access to the GPO-negotiated group purchase prices and save on the cost of price discovery for numerous SKUs. Vendors join a GPO to reduce their own negotiating costs and to gain access to a larger pool of customers. We analyze the impact of allowing custom contracting from the perspective of hospitals, the GPO vendor, and the GPO, all operating under the typical healthcare setting. Our analysis confirms that procurement via a GPO contract results in savings; however, the overall cost savings from GPO membership are lower when custom contracting is allowed. More surprisingly, we find that even big hospitals, which seem to generate additional savings over the GPO price through custom contracting, could have been better off if the provision for custom contracting did not exist. We show that, allowing custom contracting benefits vendors and GPOs at the expense of the member hospitals. This unexpected outcome occurs because vendors behave strategically. A GPO vendor that does not expect GPO hospitals to renegotiate offers a price that results in a lower total cost of acquisition than the cost obtained via custom contracts. We also explain why allowing custom contracting may not always be socially desirable. To the best of our knowledge, our work is the first analytical study addressing this issue.

2. Literature review

The concept of group purchasing exists in different industries under many different names, e.g., group buying, cooperative purchasing, or collaborative purchasing. Schotanus (2007) has an extensive list of

terms that are used to refer to the practice and the alliances that engage in group purchasing. Our focus is on B2B procurement. Thus, our work differs from a number of studies (Anand & Aron, 2003; Chen, Chen, Kauffman, & Song, 2009; Chen, Chen, & Song, 2007; Chen, Kauffman, Liu, & Song, 2010; Kauffman, Lai, & Lin, 2010; Kauffman & Wang, 2001) that examine procurement costs and buyer and vendor strategies for Internet-based group buying in a business-to-consumer (B2C) context.

The extant literature on B2B *group purchasing* in healthcare and in other industries broadly falls into three categories: 1) competition and anti-trust issues of healthcare GPOs, 2) formation and stability of purchasing alliances, and 3) the impact of group buying on buyers' procurement costs and vendors' profitability.

Competition and anti-trust issues with group purchasing:

This stream of literature studies the role of GPOs in driving vendor competition. The GAO employed structured interviews with GPO representatives, customers, and medical product vendors to study business practices of GPOs, examining contract mechanisms, product selection, fee structure, service provided, code of conduct, etc. (GAO-03-998T, 2003; GAO-10-738, 2010). Other important work in this category includes the study of exclusive contracts or sole sourcing by a GPO (Dana, 2009; Elhauge, 2002) and model-based analysis of anti-trust issues related to collecting administration fees from vendors (Hu & Schwarz, 2011; Hu, Schwarz, & Uhan, 2012; Sethi, 2006) and of vendor competition in the presence of GPOs (Hu & Schwarz, 2011; Hu et al., 2012; Marvel & Yang, 2008).

Formation and stability of purchasing alliances:

In a purchasing consortium, member commitment and compliance play a critical role in the stability and the performance of the group. Although the practice of custom contracting cannot be labeled an absolute failure of an alliance, it is certainly an instance of defection from the existing GPO contract. There are several survey-based studies of drivers of successes and of failures of purchasing alliances. For example, stability is seen as dependent on the level of trust and member commitment (Doucette, 1997), the level of enforcement of written contracts, the nature of benefits, etc. (Nollet & Beaulieu, 2003).

The closest theory that may partially explain the practice of custom contracting comes from the literature that studies the mechanism of allocating cost savings among members of group-buying alliances (Heijboer, 2002; Nagarajan, Sosic, & Zhang, 2010; Schotanus, 2004; Schotanus , Telgen, & de Boer, 2008). However, from these studies it is not clear why vendors and buyers (hospitals in our case) would negotiate further after the hospitals have already joined the GPO. It is also not clear how the price negotiated directly by a GPO member can be lower than what the GPO has already negotiated for the (larger) group with the same vendor. We examine the economic rationale behind the practice of custom contracting and draw further insights into the implications of this practice for different players in the

supply chain. We discuss whether GPOs would be willing to allow custom contracting, and, if allowed, who benefits, and who loses, from such practices.

The impact of group buying on buyers' procurement costs and vendors' profitability:

As noted in the introduction, most empirical studies investigating savings through GPO-mediated procurement are based on surveys of purchasing managers in the U.S. healthcare industry (Burns & Lee, 2008; Chapman et al., 1998; Goldenberg & King, 2009; Schneller, 2009). Schotanus (2005) and Tella and Virolainen (2005), who examine B2B group purchasing in non-healthcare industries outside the U.S., also employ surveys of purchasing managers. Analysis of a database of aftermarket transactions for medical devices leads Litan and Singer (2010) to conclude that GPOs fail to consistently secure the best prices for their members, and GPO member hospitals time and again obtain significant savings by making use of "after-market agreements" such as custom contracting.

Two analytical models of group purchasing (Chipty & Snyder, 1999; Inderst & Wey, 2007) focus on how a buyer's bargaining position is affected by the seller's cost structure. Chipty and Snyder (1999) show that mergers among buyers enhance buyers' bargaining position whenever the seller's gross surplus is concave in the total purchase quantity. Inderst and Wey (2007) conclude that larger buyers will obtain more favorable terms whenever suppliers are capacity constrained or have strictly convex cost functions. Broadly, we contribute to the literature on B2B contracting in the specific context of group purchasing for healthcare supplies. One important aspect of our study is that we show how the strategic behavior of vendors unexpectedly affects the payoffs of the three stakeholders groups—vendors, GPOs, and hospitals—when they resort to custom contracting. Our study sheds additional light on the multifaceted role of GPOs in the U.S. healthcare supply chain.

Supply chain intermediaries:

The GPOs serving hospitals are a special case of trade intermediaries. So another relevant stream of literature deals with supply chain intermediaries. The theory of supply chain intermediation including the reasons for existence of intermediaries are extensively covered in (Wu, 2004). Wu (2004) categorizes intermediaries in two broad types: transactional intermediaries and informational intermediaries. Transactional intermediaries reduce uncertainty by setting and stabilizing prices, reduce costs associated with searching and matching, and aggregate supply and demand to achieve economies of scale. Informational intermediaries synthesize dispersed information to reduce information asymmetry, and in some instances create a trusted institution reducing the need for direct negotiations. Subsequent work such as (Adida, Bakshi, & DeMiguel, 2013; Belavina & Girotra, 2012; Yang & Babich, 2013) examines other reasons to use or to avoid intermediaries. Yang and Babich (2013) investigate how intermediaries should be used when suppliers are unreliable, while Belavina and Girotra (2012) identify the benefits of intermediaries when product preferences of the downstream entities change over time. In a recent paper

Adida et al. (2013) examine how the market power of the downstream entities affects the profitability of supply chain intermediaries, and of the overall supply chain profit. GPOs are unlike most other supply chain intermediaries: while they do aggregate demand, they do not hold inventory; they operate in a highly regulated environment; and their markup margins are determined externally.

3. The GPO Purchasing and Contracting Model

We focus on studying the impact of allowing custom contracts through an analysis of the GPO vendor's pricing strategy for the GPO's member hospitals in the presence of the GPO as an intermediary. To focus on our primary issue, i.e., the impact of allowing custom contracts, we limit the scope of our analysis to the strategic interaction between the GPO vendor and member hospitals. It is assumed that the hospitals are already part of the GPO, and their membership choice is outside the scope of this paper; likewise, we assume that there are several vendors for the product, but one of the vendors, henceforth referred to as the *GPO vendor*, is the only one selling through the GPO. Member hospitals have the option to buy the product from the GPO vendor or from vendor(s) outside the GPO. As most of the higher-end medical supplies are procured individually, we focus on the procurement of a single SKU type.

The sequence of events is shown in Figure 1: In the first stage of the game, the GPO vendor declares the *GPO price*, P_g $[\$/unit]$, the uniform unit price the vendor offers exclusively to all GPO members, irrespective of their individual demands for the product. Then the GPO makes the pricing information available exclusively to member hospitals. In the second stage of the game, each member hospital, after learning this price, chooses to buy the product from the GPO vendor at the GPO price, or seeks a better price on its own. Pursuing a better price involves negotiating further with other vendors. The hospital can also negotiate with the same GPO vendor, if custom contracting with the GPO vendor is permitted.

We assume that member hospitals are heterogeneous with respect to their purchase quantities for the product, and the purchased quantity does not depend on the final price. Below we formalize these assumptions.

Assumption 1 (demand heterogeneity among the GPO's member hospitals): *We assume that hospitals vary in their demands, and without loss of generality we label them by their demand sizes. The distribution of demand sizes has the density function* $g(x)$ *with* $\int_0^\infty g(x)dx = 1$. *Further, a hospital procures the needed quantity irrespective of the price.*

In an efficient market, buyers know both the quality and the price of a product. In a "market for lemons," buyers know the price of the product but do not know the quality of the product with certainty. In health

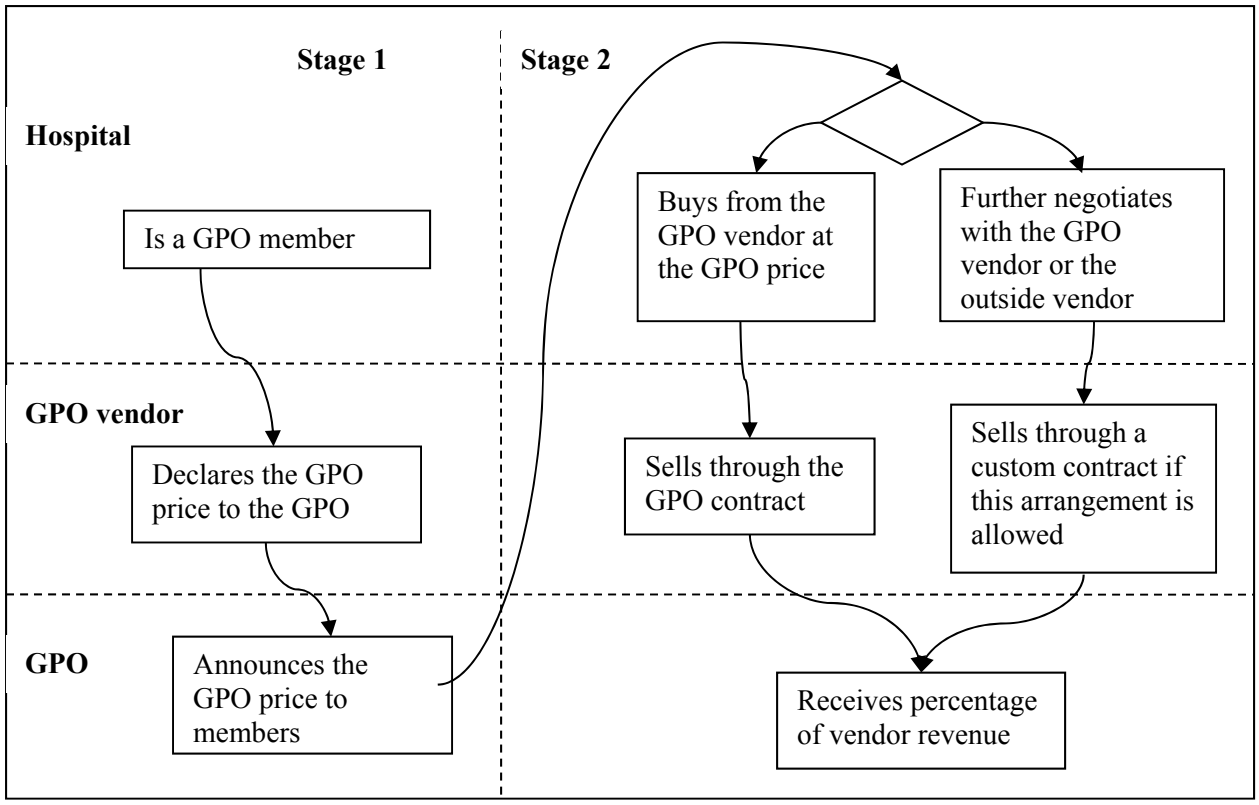

Figure 1. Timeline for the model

care, on the other hand, hospitals have a fair idea of the quality of the product, but price information is not readily available to them. With some particularly expensive supplies, such as physician-preferred medical devices, there can be significant uncertainty prior to purchasing negotiations (Lerner, Fox, Nelson, & Reiss, 2008). There have been some efforts by policy makers to promote price transparency in health care. The Transparency in Medical Device Pricing Act of 2007 (S. 2221) in the U.S. requires manufacturers to report their national mean and median prices for Physician Preferred Items (PPIs) quarterly to the Secretary of Health and Human Services. It further requires that the Centers for Medicare and Medicaid Services maintain and publish disclosed price data on their website; however, the act does not call for disclosing any price ranges or any local pricing information. Vendors often charge some buyers more than they charge others. Medical device vendors, for instance, argue that the prices negotiated with individual customers are trade secrets. They often design contracts that forbid hospitals from disclosing the negotiated price to other hospitals, or even to physicians, patients, or insurers. While ostensibly this is done to prevent prices from playing a role in product selection by physicians (DeJohn, 2006; Mantone, 2006), it also limits comparison-shopping. In the past, some healthcare consulting firms

(e.g., Aspen Healthcare Metrics,[3] ECRI) collected price information across the market and shared it with hospitals that used the firms' services. However, vendors started to enforce nondisclosure provisions in court (e.g., device maker Guidant Corporation brought suit against Aspen and ECRI in 2004) or by using implicit threats to rescind hospital contracts and revert back to list price (Pauly & Burns, 2008). As a result, prospective buyers face significant uncertainty about the prices they will have to pay on numerous SKUs if they purchase these products on their own, going outside the GPO arrangement. We model this lack of transparency while buying from outside vendors by using a distribution of reservation prices of the vendors for the product. Below we formalize our assumption on the distribution of the reservation prices.

Assumption 2 (assumption on reservation prices): *Reservation prices are private information to the vendors. However, the distribution of reservation prices is a common knowledge among vendors and hospitals. The distribution is formulated as follows: The unit reservation price is random, but contingent on the size of an individual hospital's demand. The unit reservation price is denoted as* $\tilde{P}(q)$*, where* q *is the hospital's demand for the product under consideration;* $\tilde{P}(q)$ *is stochastically decreasing in the purchase volume q.*

In the presence of price uncertainty, the exact price of each product is established between the hospital and the vendors through different price-discovery mechanisms, such as negotiation, requests for quotes, reverse auctions, etc. Engaging in any of these processes is costly for hospitals, which are contracting for thousands of high-priced SKUs annually. It is also costly for the vendors. We assume that the costs associated with price discovery are fixed and are incurred per SKU, rather than per unit, for both the hospital and the vendor. For the sake of simplicity, we use the term *negotiation* for any price-discovery mechanism. We refer to all costs associated with price discovery collectively as the *cost of negotiation*. The assumptions with respect to the cost of negotiation are formalized below:

Assumption 3 (assumption on the cost of negotiation): *The cost of negotiation,* C_H*, per SKU, is fixed and the same for all hospitals irrespective of their demand and the vendors it negotiates with. It is incurred when a hospital negotiates with a vendor on its own. The cost of negotiation,* C_V*, is fixed for the vendor. It is incurred when the vendor participates in direct negotiations with a hospital.*

[3] Currently a MedAssets company.

After learning the GPO price the hospitals use that price as a benchmark for negotiation. So, the expected price after negotiation cannot be higher than the GPO price. We denote the expected price after negotiation as $E\left[\tilde{P}(q)|P_g\right]$.

Lemma 1: *The expected price after negotiation is bounded by the expected price in the absence of the information on the GPO price, i.e.,* $E\left[\tilde{P}(q)|P_g\right] \leq E[\tilde{P}(q)]$. *The change in the expected price after negotiation, given a change in* P_g *is bounded by the change in* P_g*, that is,* $0 \leq \partial E\left[\tilde{P}(q)|P_g\right]/\partial P_g \leq 1$.*The expected price after negotiation is decreasing in* q*, that is,* $\partial E\left[\tilde{P}(q)|P_g\right]/\partial q \leq 0$.

Proofs of all lemmas and propositions are included in the Appendix.

The objective of each hospital is to minimize its total cost of procurement, and the objective of the GPO vendor is to maximize its profit. The GPO earns its revenue by collecting contract administration fees from the GPO vendor. The contract administration fee is typically a percentage of the sales revenue of the GPO vendor. In the United States, the percentage that the GPO can collect from the GPO vendor is regulated by the S*afe Harbor* provision enacted by Congress. That provision states: "*GPOs may be allowed to provide goods or services to a hospital or health care provider as long as both of the following two standards are met – (1) The GPO must have a written agreement with each hospital or health care provider, that provides for either of the following agreements: (a) The vendor from which the hospital or health care provider will purchase goods or services will pay a fee to the GPO of 3 percent or less of the purchase price of the goods or services provided by that vendor, and (b) In the event the fee paid to the GPO is not fixed at 3 percent or less of the purchase price of the goods or services, the agreement specifies the exact percentage or amount of the fee. (2) The GPO must disclose in writing to the hospital or health care provider at least annually, the amount received from each vendor with respect to purchases made by or on behalf of the hospital or health care provider.*"[4] Given the nature of current regulations governing the structure of contract administration fees, we model the percentage collected by the GPOs as exogenous. The next assumption defines the strategic positions of the market participants.

Assumption 4 (assumption on hospitals, the GPO, and the GPO vendor): *We assume that hospitals and the GPO vendor are strategic and risk-neutral. The objective of each hospital is to minimize its expected cost of procurement, and the hospital selects the purchase channel that results in the lowest*

[4] http://www.supplychainassociation.org/resource/resmgr/research/safe_harbor.pdf (last accessed June 14, 2012)

procurement costs. The objective of the GPO vendor is to maximize its expected profit; the vendor's strategic variable is the GPO price. The GPO earns its revenue by collecting a fraction of the sales revenue from the GPO vendor. We assume that this fraction is exogenous and equals λ*, where* $0 < \lambda < 1$.

Table 1 summarizes the hospital's expected procurement cost, the GPO vendor's expected profit, and the GPO's expected revenue for a transaction volume of q units.

Table 1: Cost and revenues corresponding to a transaction volume of q units

	Expected procurement cost incurred by the hospital	Expected profit of the GPO vendor (the marginal cost of the product is m)	Expected revenue of the GPO
Hospital buys the product at the GPO price, (P_g)	qP_g	$(1-\lambda)(qP_g)$ $-qm$	$\lambda(qP_g)$
Hospital negotiates further after the GPO price (P_g) is announced	$qE[\tilde{P}(q)\|P_g] + C_H$	$(1-\lambda)(qE[\tilde{P}(q)\|P_g])$ $-qm - C_V$	$\lambda(qE[\tilde{P}(q)\|P_g])$

To analyze the marginal impact of custom contracts, we compare the equilibrium outcomes, the GPO vendor's profitability and the member hospitals' procurement costs, under two different pricing regimes—one where custom contracting is allowed, and another where it is not. In the next section we illustrate why some hospitals prefer to buy at the GPO price while other hospitals choose to negotiate using the framework discussed above.

4. Heterogeneity in Hospitals' Purchasing Behavior

The heterogeneity in hospitals' purchasing behavior is primarily driven by their different demand sizes, the presence of price uncertainty in the market, and the positive cost of negotiation. Once GPO members learn the GPO price, they face a tradeoff between potential additional savings through further negotiation and the additional cost of such negotiation.

Lemma 2: *Let* $f(q) = qP_g - \left(qE[\tilde{P}(q)|P_g] + C_H\right)$ *be the difference between the total cost of buying through the GPO at price* P_g *and the expected cost of buying directly from the GPO vendor after negotiation. The function* $f(q)$ *is increasing in* q.

Lemma 2 implies segmentation: for a certain range of parameters P_g and C_H there exists a hospital with demand $\hat{q}(P_g, C_H)$, such that hospitals with smaller demand levels, $q < \hat{q}(P_g, C_H)$, purchase through the GPO, and hospitals with higher demand levels, $q > \hat{q}(P_g, C_H)$, purchase directly from the vendor. Any hospital with a demand level $q = \hat{q}(P_g, C_H)$ is indifferent between purchasing through the GPO and purchasing directly from the vendor; that is $f\big(\hat{q}(P_g, C_H)\big) = 0$.

Figure 2 illustrates how the purchasing behavior varies across members with different demand per SKU, for a given level of price uncertainty, cost of negotiation, and GPO price. In general, the same hospital can be at the left side of this volume heterogeneity curve for certain products and on the right side of the curve for others—all purchased through the same GPO. Several factors drive these variances, including the size of the hospital, its mix of procedures, and regional differences in clinical best practices. In Figure 2, hospitals' purchase volumes for an SKU are plotted along the horizontal axis. The leftmost point on the axis represents the hospital with the lowest demand, and the rightmost the highest. $P_L(.)$ and $P_H(.)$ depict the band of reservation prices of the vendors for hospitals with different demands. For example, the price at which a hospital with demand q may be able to procure is uncertain and uniformly distributed in the interval $[P_L(q), P_H(q)]$. The interval is illustrated by the line segment $\overline{AB}$ in the figure. $E[\tilde{P}(.)]$ depicts the expected prior on the market price. The GPO price, P_g, is drawn as a horizontal straight line. It is not dependent on an individual member's demand, and it is deterministic. $E[\tilde{P}(.)|P_g]$ depicts the expected market price conditional on P_g; that is, $E[\tilde{P}(.)|P_g]$ is the expected posterior price once the members are informed of the GPO price.

Hospitals in Region A, those with very low demand, do not expect to get a lower price through further price exploration. They buy using the GPO contract and pay the GPO price $\big(P_g\big)$.

Hospitals with intermediate demands, those in Regions B and C, expect to get a lower price than the GPO price through further negotiations. However, these hospitals face the tradeoff between getting a lower price and incurring additional costs for these negotiations. Hospitals in Region B, whose demands and expected cost savings are lower than those of hospitals in Region C, still buy at the GPO price $\big(P_g\big)$. from the GPO vendor. For these hospitals, *the expected cost savings* from further negotiation (the expected savings is determined by the hospital's demand and the difference between the horizontal line and the dashed line) do not justify the additional cost of negotiation (C_H); i.e., for a hospital in Region B with demand q,

$$qE\big[\tilde{P}(q)\big|P_g\big] + C_H \geq qP_g. \tag{1}$$

Hospitals in Region C negotiate further and use the GPO price as a benchmark for negotiations. For a hospital in this region with demand q, custom contracting is beneficial because

$$qE\left[\tilde{P}(q)\middle|P_g\right] + C_H \leq qP_g. \tag{2}$$

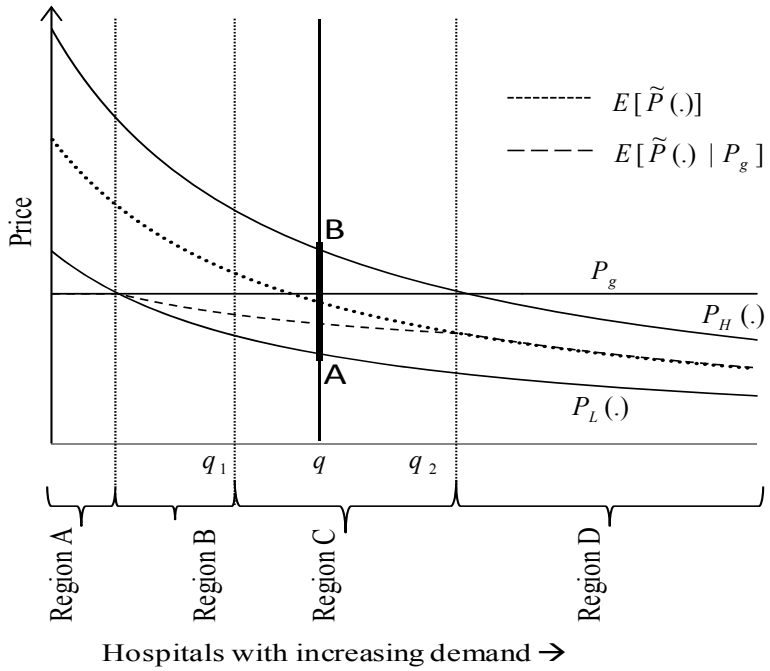

Figure 2. Heterogeneity in hospitals' purchasing behavior

For hospitals in Region D, $E\left[\tilde{P}(q)\middle|P_g\right]$ is the same as $E[\tilde{P}(q)]$. In this region, hospitals do not seem to realize any direct benefit from GPO membership for procuring that product, so their GPO membership may seem counter-intuitive. In practice, this group may not always exist. Even when it does, the larger hospitals are likely to be GPO members for a variety of structural reasons: these hospitals may use the GPO membership to buy other products that are available more economically through the GPO, and GPOs already impose various contractual obligations on their members, offering package deals that bundle products together. To get the best price on knee implants, a hospital might have to agree to buy everything from pacemakers to stethoscopes from the GPO's preferred vendors. The larger hospitals may also be GPO members in order to obtain other purchasing-related services from the GPO; the GPO has incentives to get those hospitals on board for free (in practice, we indeed observe GPOs waiving some of the membership fees for the larger hospitals) or sometimes even offer additional rebates based on their purchase volume so that the GPO can earn a positive net profit by collecting administration fees from the GPO vendor every time any of these hospitals makes a purchase from the GPO vendor. Part of these fees may be "rebated" back to the procuring hospital.

Lemma 3: *Let* $\hat{q} = \hat{q}(P_g, C_H)$ *denote the demand of the hospital that is indifferent between buying at the GPO price* (P_g) *and exploring the price further with the GPO vendor or with an outside vendor. Then the following are true:* $\frac{\partial \hat{q}}{\partial P_g} \leq 0,\ \frac{\partial \hat{q}}{\partial C_H} \geq 0.$

Lemma 3 implies that *ceteris paribus* fewer hospitals buy at the GPO price P_g when that price increases, and more hospitals will buy at the GPO price when the cost of negotiation, C_H , increases.

In the next section we analyze the broader consequences of allowing custom contracting.

5. Custom contracts and the Intermediary Role of GPOs

We begin by characterizing the equilibrium with and without custom contracts. In Section 5.3 we present a comparative analysis of the two equilibrium outcomes to gain insight into the impact of custom contracts on the GPO vendor's profitability and the hospitals' expected cost of procurement. We also quantify the cost savings for the hospitals from GPO membership with and without custom contracts in comparison with having no membership. In Section 5.4 we discuss the intermediary role of the GPO.

5.1 Equilibrium outcomes when custom contracting is not allowed

Here, we present the case in which either the GPO vendor does not offer custom contracts or the GPO does not allow custom contracting between the GPO vendor and member hospitals once the GPO price has been established. We use this case as a benchmark in order to find the marginal impact of allowing custom contracting. The game sequence is as described in Figure 1, except that custom contracting is not allowed between any hospital and the GPO vendor. A hospital buys from the GPO vendor at the GPO price, or it procures from an outside vendor.

The GPO vendor does not incur any additional cost of negotiation for any number of hospitals that buy from it at the GPO price. A hospital does not incur any additional cost of negotiation while buying from the GPO vendor at the GPO price; it does incur a cost of negotiation if it buys from an outside vendor. The GPO collects contract administration fees based on the revenue received by the GPO vendor. When a hospital expects to save more than the cost of negotiation, it chooses not to buy from the GPO vendor and will explore vendors outside the GPO.

Recall that $\hat{q}(P_g, C_H)$ denotes the demand of the hospital that is indifferent between buying at the GPO price (P_g), and exploring the price further with an outside vendor. The vendor's expected profit is a function of the price it sets, and it is given as follows (the superscript *NC* denotes *No* Custom contracting):

$$V^{NC}(P_g; C_H, \lambda, m) = \int_0^{\hat{q}(P_g, C_H)} \Big(x\big((1-\lambda)P_g - m\big)\Big) g(x)dx. \tag{3}$$

We denote the GPO vendor's maximum profit as

$$\Pi_v^{NC}(C_H, \lambda, m) = \max_{P_g} V^{NC}(P_g; C_H, \lambda, m), \tag{4}$$

the profit-maximizing price set by the GPO vendor as

$$P_g^{NC} = \operatorname{argmax}_{P_g} V^{NC}(P_g; C_H, \lambda, m), \tag{5}$$

and the indifferent hospital as

$$\hat{q}^{NC} = \hat{q}(P_g^{NC}, C_H). \tag{6}$$

The GPO's resulting revenue is given as

$$R^{NC}(C_H, \lambda, m) = \int_0^{\hat{q}^{NC}} \big(x\lambda P_g^{NC}\big) g(x)dx. \tag{7}$$

Clearly, the profit of the GPO vendor is decreasing in λ and m. In Section 5.4, we discuss the effect of C_H on the vendor's profit. The effect of λ and C_H on the optimal GPO price is not necessarily unidirectional. The following lemma establishes that, when custom contracting is not allowed, the optimal GPO price is increasing in the marginal cost of the product.

Proposition 1: *When custom contracting is not allowed, the optimal GPO price is increasing in the marginal cost of the product; that is,* $\frac{d}{dm}\big(P_g^{NC}\big) \geq 0$.

A GPO vendor lowers the GPO price to sell to an additional hospital so long as it makes a positive profit over the marginal cost of the product, since it incurs no additional cost of negotiation to sell to an extra hospital. The higher marginal cost prevents the GPO vendor from selling at a lower GPO price.

5.2 Equilibrium outcomes when custom contracting is allowed

In this case, the member hospitals and the GPO vendor are allowed to engage in custom contracting after the GPO price has been made available. The game sequence is as described in Figure 1. In the second stage of the game, hospitals either buy the product at the GPO price or choose to explore the price further. The hospitals in this case are not barred from negotiating directly with the GPO vendor.

Neither the GPO vendor nor any of the hospitals incurs any additional cost of negotiation if a transaction occurs at the GPO price; however, both do if they engage in further price negotiations. A hospital that expects to generate more savings than the cost of negotiation will engage in further negotiations with the GPO vendor, or with outside vendors. From our discussions with purchasing managers, it became evident that even when member hospitals negotiate with outside vendors, it is more often the incumbent GPO vendor that wins the business. The GPO vendor is likely to win for several reasons: 1) it may have a business account and logistical supply interfaces with the hospital already, so it can avoid significant setup costs and offer a lower price than what outside vendors can; 2) it may have earned extra credibility by virtue of going through the process of product and vendor evaluation that is typically conducted by the GPO; or 3) information about the GPO vendor may be readily available from the GPO as well as other member hospitals. Thus, from a practical perspective we ignore the possibility of an outside vendor winning the business of a GPO member. Assuming that a certain fraction of business will be won by outside vendors will only shift our results marginally, without changing any of the insights qualitatively. We do not model the GPO vendor as a monopoly. The distribution of the reservation prices, the nature of which is captured in Assumption 2, acts as a proxy for outside vendors. The nature of the expected price after negotiation in such a competitive scenario has been formalized in Lemma 1.

The vendor's expected profit is a function of the GPO price it sets and the expected prices after custom contracting with some of the larger hospitals, and is given as follows (the superscript *C* denotes Custom Contracting):

$$
\begin{aligned}
&V^C\left(P_g; C_H, \lambda, m, C_V\right) \\
&\quad = \int_0^{\hat{q}\left(P_g, C_H\right)} \left(x\left((1-\lambda)P_g - m\right)\right) g(x)dx \\
&\quad + \int_{\hat{q}\left(P_g, C_H\right)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{P}(x)\middle|P_g\right] - m\right) - C_V\right) g(x)dx.
\end{aligned} \tag{8}
$$

We denote the GPO vendor's maximum profit as

$$\Pi_v^C(C_H, \lambda, m, C_V) = \max_{P_g} V^C\left(P_g; C_H, \lambda, m, C_V\right), \tag{9}$$

the profit-maximizing GPO price as

$$P_g^C = \operatorname*{argmax}_{P_g} V^C\left(P_g; C_H, \lambda, m, C_V\right), \tag{10}$$

and the indifferent hospital as

$$\hat{q}^C = \hat{q}(P_g^C, C_H). \tag{11}$$

The GPO's resulting revenue is given as

$$R^C(C_H, \lambda, m, C_V) = \int_0^{\hat{q}^C} \left(x\lambda P_g^C\right) g(x)dx + \int_{\hat{q}^C}^{\infty} \left(x\lambda E\left[\tilde{P}(x)\middle|P_g^C\right]\right) g(x)dx. \tag{12}$$

The optimal GPO price in either case, with or without custom contracting, is expected to depend on the demand heterogeneity and on the aggregate demand of the member hospitals. The exact solutions of the above optimization problems have been omitted due to their intractability. However, cardinal insights on the outcomes are derived by analyzing the nature of the solution.

Clearly, the profit of the GPO vendor is decreasing in λ and m. In Section 5.4, we discuss the effect of C_H on the vendor's profit. The effect of λ and C_H on the optimal GPO price is not necessarily unidirectional. The following lemma establishes that, when custom contracting is allowed, the GPO price is decreasing in the cost of negotiation for the GPO vendor but doesn't depend on the marginal cost of the product.

Proposition 2: *When custom contracting is allowed, the optimal GPO price is decreasing in the cost of negotiation for the GPO vendor; that is,* $\frac{d}{dC_V}\left(P_g^C\right) \leq 0$. *The GPO price doesn't depend on the marginal cost of the product beyond the fact that* $(1-\lambda)P_g^C$ *is bounded below by the marginal cost of the product.*

We expect that the potential outside options for the member hospitals drive their respective reservation prices for a product. If the GPO vendor's cost of negotiation (C_V) were zero, it would try to sell to every hospital directly at their respective reservation prices through negotiating individually with each one of them, aiming at first degree price discrimination. Given that (C_V) is not zero, the vendor does not want to negotiate directly with all of the smaller hospitals; the expected profit from selling to them directly is not large enough to compensate for the cost of negotiation. The way to discourage small hospitals from negotiating directly is to offer a GPO price low enough that it is acceptable to those hospitals. So the higher the (C_V), the lower the GPO price will be.

5.3 Analyzing the impact of custom contracts

In this section, we present a detailed comparative analysis of the two policy regimes—with and without custom contracting. In addition to analytically proving our primary results on the marginal impact of custom contracting, we use a numerical example to further illustrate our analytical findings and present additional managerial insights.

Proposition 3: *When custom contracting is allowed, (i) the GPO price, the GPO vendor's profit, and the GPO revenue are all higher, that is,* $P_g^C \geq P_g^{NC}$, $\Pi_v^C(C_H, \lambda, m, C_V) \geq \Pi_v^{NC}(C_H, \lambda, m)$, $R^C(C_H, \lambda, m, C_V) \geq R^{NC}(C_H, \lambda, m)$; *(ii) fewer hospitals buy at the GPO price, that is,* $\hat{q}^C \leq \hat{q}^{NC}$.

Proposition 3 shows that with the added possibility of custom contracting, the GPO vendor does not lower the GPO price any further to get an additional member hospital when the marginal revenue from selling the product to that hospital at the GPO price is less than what the GPO vendor can expect to earn through direct negotiation. Thus, in this situation, the GPO vendor sets a *higher GPO price*, anticipating that some member hospitals will eventually renegotiate. As a result, the GPO price and the GPO vendor's total revenue and profit are *all higher* with custom contracts than what they would have been if custom contracting were not a possibility.

We illustrate the finding with the example detailed in Table 2. The example lists 40 hospitals sorted based on their purchase volumes. For each hospital, we specify the pair of minimum and maximum unit reservation prices to expect from vendors based on the purchase volume; both are decreasing in volume. For the purpose of the numerical illustration, we assume the realized price is uniformly distributed between the minimum $P_L(q)$ and the maximum $P_H(q)$, so that the expected price is $E[\tilde{P}(q)] = \frac{P_L(q)+P_H(q)}{2}$. This satisfies Assumption 2. We further assume, again for the sake of numerical illustration only, that the expected price after the negotiation is given by:

$$E\left[\tilde{P}(q)|P_g\right] = \begin{cases} P_g, & when\ P_g \leq P_L(q) \\ \frac{P_L(q)+P_g}{2}, & when\ P_L(q) \leq P_g \leq P_H(q). \\ same\ as\ E[\tilde{P}(q)] = \frac{P_L(q)+P_H(q)}{2}, & when\ P_g \geq P_H(q) \end{cases} \quad (13)$$

Note this satisfies Lemma 1. We assume that the cost of negotiation is \$20,000, and it is the same for the hospital and the GPO vendor. We assume a 3% fee collected by the GPO from the vendor. Finally we assume that the marginal cost of production is \$5,000.

Table 3 presents a summary of the equilibrium outcomes corresponding to the numerical example in Table 2, while Table 4 has the details. Columns (1) & (2) in Table 4 are the same as Columns (1) & (2) in Table 2. Columns (3) & (4) in Table 4 detail expected price and expected cost when hospitals have no

Table 2: Numerical Example

$C_H = C_V = \$20{,}000;\ \lambda = 3\%; m = \$5{,}000.$

1	2	3	4		1	2	3	4
Hospital ID	**Purchase volume q**	**Min unit price $P_L(q)$**	**Max unit price $P_H(q)$**		**Hospital ID**	**Purchase volume q**	**Min unit price $P_L(q)$**	**Max unit price $P_H(q)$**
1	17	$8,176.00	$9,406.00		21	40	$ 6,501.00	$ 7,480.00
2	18	$8,054.00	$9,267.00		22	49	$ 6,468.00	$ 7,442.00
3	19	$7,822.00	$9,000.00		23	49	$ 6,468.00	$ 7,442.00
4	19	$7,822.00	$9,000.00		24	50	$ 6,243.00	$ 7,183.00
5	20	$7,672.00	$8,827.00		25	55	$ 6,207.00	$ 7,141.00
6	21	$7,525.00	$8,658.00		26	55	$ 6,207.00	$ 7,141.00
7	22	$7,446.00	$8,567.00		27	56	$ 6,162.00	$ 7,090.00
8	23	$7,302.00	$8,402.00		28	57	$ 6,135.00	$ 7,059.00
9	24	$7,300.00	$8,400.00		29	58	$ 6,066.00	$ 6,979.00
10	26	$7,098.00	$8,167.00		30	59	$ 6,026.00	$ 6,923.00
11	27	$7,035.00	$8,094.00		31	59	$ 6,026.00	$ 6,923.00
12	28	$6,906.00	$7,946.00		32	60	$ 5,979.00	$ 6,879.00
13	29	$6,804.00	$7,828.00		33	61	$ 5,911.00	$ 6,801.00
14	30	$6,786.00	$7,807.00		34	62	$ 5,874.00	$ 6,758.00
15	30	$6,786.00	$7,807.00		35	63	$ 5,859.00	$ 6,740.00
16	31	$6,786.00	$7,807.00		36	72	$ 5,755.00	$ 6,622.00
17	32	$6,734.00	$7,748.00		37	74	$ 5,734.00	$ 6,597.00
18	33	$6,669.00	$7,673.00		38	79	$ 5,691.00	$ 6,548.00
19	35	$6,567.00	$7,556.00		39	84	$ 5,645.00	$ 6,494.00
20	37	$6,536.00	$7,519.00		40	107	$ 5,518.00	$ 6,348.00

Table 3: A summary of the equilibrium outcomes when implementing c*ustom contracting*

	Equilibrium outcomes		
	Without custom contracting	**With custom contracting**	**Percentage change**
GPO Price (P_g)	$6,493.92	$7,777.05	20% ↑
GPO vendor's profit (Π_v)	$1,758,985.19	$2,360,954.15	34% ↑
GPO's profit (R)	$263,783.05	$360,338.79	37% ↑
Purchase volume of the indifferent buyer (q)	63	33	48% ↓

GPO membership; Columns (5) to (8) detail the equilibrium results when custom contracting is not allowed; Columns (9) to (14) detail the equilibrium results when custom contracting is allowed.

When custom contracting is not allowed, Hospitals 1 to 35 (hospitals with purchase volumes up to 63 units) buy from the GPO vendor, at a GPO price of \$6,493.92 per unit, while Hospitals 36 to 40 buy from an outside vendor. When custom contracting is allowed, Hospitals 1 to 18 (hospitals with purchase volumes up to 33 units) buy from the GPO vendor at a GPO price of \$7,777.05 per unit, while Hospitals 19 to 40 buy through custom contracts. With custom contracting the GPO price is almost 20% higher (it increases from \$6,493.92 per unit to \$7,777.05 per unit); the GPO vendor's profit increases almost 34% (from \$1,758,985 to \$2,360,954); and the revenue collected by the GPO increases by almost 37% (from \$263,783 to \$360,339).

Interestingly, with custom contracting the GPO vendor is not enjoying an additional profit uniformly from all hospitals served. It enjoys an increase in profit of \$558,843 from Hospitals 1 to 18, because they pay higher prices per unit and do not negotiate further with the GPO vendor. Similarly, it has an added profit of $\$274{,}031$ from selling to Hospitals 36 to 40, which otherwise would not have bought from it. With custom contracting, Hospitals 19 to 35 will indeed pay a higher per unit price, but because they engage in further negotiations, the GPO vendor has a \$230,905 reduction in profit in dealing with the hospitals in the middle. Consider, for instance, Hospital 20. The GPO vendor's net profit from selling to this hospital without custom contracting is $\$48{,}067 = 37 \times [(1.00 - 0.03) * \$6{,}493.92 - \$5{,}000]$.

GPO membership has multiple impacts on hospitals' procurement cost. Table 4 shows that Hospital 11, for instance, faces an estimated stochastic price ranging from $P_L(27) = \$7{,}035.00$ to $P_H(27) = \$8{,}094.00$. This leads to an expected unit price of $(\$7{,}035.00 + \$8{,}094.00)/2 = \$7{,}564.50$ per unit purchased outside the GPO, as shown in column (3) of Table 4. Hence, without GPO membership, the cost of buying 27 units from an outside vendor, with the needed negotiation costs, is $(\$7{,}564.50 \times 27 + \$20{,}000) = \$224{,}242$. When custom contracting is not allowed, the GPO price is \$6,493.92. It is easy to verify using Equation (13) that $E[\tilde{P}(27)|P_g] = \$6{,}493.92$, and Hospital 11's total purchasing cost from an outside vendor is $(\$6{,}493.92 \times 27 + \$20{,}000) = \$195{,}336$. Just learning about the GPO price, and not even buying from the GPO vendor, saves the hospital $\$28{,}906 (= \$224{,}242 - \$195{,}336)$. This cost reduction highlights the "information access value" of the GPO. It implies that with GPO membership even the cost of buying from an outside vendor goes down significantly. The cost of buying from the GPO vendor is even more attractive, and it amounts to $(\$6{,}493.92 \times 27) = \$175{,}336$, representing a 22% savings for that hospital thanks to its GPO membership. With custom contracting, the GPO price is $\$7{,}777.05$, and $E[\tilde{P}(27)|P_g] = \frac{\$7{,}035.00+\$7{,}777.05}{2} = \$7{,}406.02$. Hospital 11's total

Table 4: Analysis of cost savings

1	2	3	4		5	6	7	8		9	10	11	12	13	14
		No GPO membership			Custom contracting is **not** allowed					Custom contracting is allowed					
Hospital ID	Purchase volume, q	Expected price ($)	Expected cost of buying without GPO membership ($)		Cost of buying at GPO price ($)	Expected cost of buying from outside vendor ($)	Buy at GPO price? Y/N	Effective percentage savings from GPO membership (%) (Col. 4 – Min(Col. 5, Col. 6))/Col. 4		Cost of buying at GPO price ($)	Expected price conditional on GPO price ($)	Expected cost of buying through custom contract ($)	Buy at GPO price? Y/N	Percentage savings over GPO price through custom contract (%) (Col. 9 – Min(Col. 9, Col. 11))/Col. 9	Effective percentage savings from GPO membership (%) (Col. 4 – Min(Col. 9, Col. 11))/Col. 4
1	17	$8,791.00	$169,447		$110,397	$130,397	Y	35%		$132,210	$7,777.05	$152,210	Y	0%	22%
2	18	$8,660.50	$175,889		$116,891	$136,891	Y	34%		$139,987	$7,777.05	$159,987	Y	0%	20%
3	19	$8,411.00	$179,809		$123,384	$143,384	Y	31%		$147,764	$7,777.05	$167,764	Y	0%	18%
4	19	$8,411.00	$179,809		$123,384	$143,384	Y	31%		$147,764	$7,777.05	$167,764	Y	0%	18%
5	20	$8,249.50	$184,990		$129,878	$149,878	Y	30%		$155,541	$7,724.53	$174,491	Y	0%	16%
6	21	$8,091.50	$189,922		$136,372	$156,372	Y	28%		$163,318	$7,651.03	$180,672	Y	0%	14%
7	22	$8,006.50	$196,143		$142,866	$162,866	Y	27%		$171,095	$7,611.53	$187,454	Y	0%	13%
8	23	$7,852.00	$200,596		$149,360	$169,360	Y	26%		$178,872	$7,539.53	$193,409	Y	0%	11%
9	24	$7,850.00	$208,400		$155,854	$175,854	Y	25%		$186,649	$7,538.53	$200,925	Y	0%	10%
10	26	$7,632.50	$218,445		$168,842	$188,842	Y	23%		$202,203	$7,437.53	$213,376	Y	0%	7%
11	27	$7,564.50	$224,242		$175,336	$195,336	Y	22%		$209,980	$7,406.03	$219,963	Y	0%	6%
12	28	$7,426.00	$227,928		$181,830	$201,830	Y	20%		$217,757	$7,341.53	$225,563	Y	0%	4%
13	29	$7,316.00	$232,164		$188,324	$208,324	Y	19%		$225,535	$7,290.53	$231,425	Y	0%	3%
14	30	$7,296.50	$238,895		$194,818	$214,818	Y	18%		$233,312	$7,281.53	$238,446	Y	0%	2%
15	30	$7,296.50	$238,895		$194,818	$214,818	Y	18%		$233,312	$7,281.53	$238,446	Y	0%	2%
16	31	$7,296.50	$246,192		$201,312	$221,312	Y	18%		$241,089	$7,281.53	$245,727	Y	0%	2%
17	32	$7,241.00	$251,712		$207,805	$227,805	Y	17%		$248,866	$7,241.00	$251,712	Y	0%	1%
18	33	$7,171.00	$256,643		$214,299	$234,299	Y	16%		$256,643	$7,171.00	$256,643	Y	0%	0%
19	35	$7,061.50	$267,153		$227,287	$247,287	Y	15%		$272,197	$7,061.50	$267,153	N	2%	0%
20	37	$7,027.50	$280,018		$240,275	$260,275	Y	14%		$287,751	$7,027.50	$280,018	N	3%	0%
21	40	$6,990.50	$299,620		$259,757	$279,757	Y	13%		$311,082	$6,990.50	$299,620	N	4%	0%
22	49	$6,955.00	$360,795		$318,202	$337,567	Y	12%		$381,076	$6,955.00	$360,795	N	5%	0%
23	49	$6,955.00	$360,795		$318,202	$337,567	Y	12%		$381,076	$6,955.00	$360,795	N	5%	0%
24	50	$6,713.00	$355,650		$324,696	$338,423	Y	9%		$388,853	$6,713.00	$355,650	N	9%	0%
25	55	$6,674.00	$387,070		$357,166	$369,275	Y	8%		$427,738	$6,674.00	$387,070	N	10%	0%
26	55	$6,674.00	$387,070		$357,166	$369,275	Y	8%		$427,738	$6,674.00	$387,070	N	10%	0%
27	56	$6,626.00	$391,056		$363,660	$374,366	Y	7%		$435,515	$6,626.00	$391,056	N	10%	0%
28	57	$6,597.00	$396,029		$370,153	$379,924	Y	7%		$443,292	$6,597.00	$396,029	N	11%	0%
29	58	$6,522.50	$398,305		$376,647	$384,238	Y	5%		$451,069	$6,522.50	$398,305	N	12%	0%
30	59	$6,474.50	$401,996		$383,141	$389,338	Y	5%		$458,846	$6,474.50	$401,996	N	12%	0%
31	59	$6,474.50	$401,996		$383,141	$389,338	Y	5%		$458,846	$6,474.50	$401,996	N	12%	0%
32	60	$6,429.00	$405,740		$389,635	$394,188	Y	4%		$466,623	$6,429.00	$405,740	N	13%	0%
33	61	$6,356.00	$407,716		$396,129	$398,350	Y	3%		$474,400	$6,356.00	$407,716	N	14%	0%
34	62	$6,316.00	$411,592		$402,623	$403,406	Y	2%		$482,177	$6,316.00	$411,592	N	15%	0%
35	63	$6,299.50	$416,869		$409,117	$409,117	Y	2%		$489,954	$6,299.50	$416,869	N	15%	0%
36	72	$6,188.50	$465,572		$467,562	$460,961	N	1%		$559,948	$6,188.50	$465,572	N	17%	0%
37	74	$6,165.50	$476,247		$480,550	$472,433	N	1%		$575,502	$6,165.50	$476,247	N	17%	0%
38	79	$6,119.50	$503,441		$513,020	$501,304	N	0%		$614,387	$6,119.50	$503,441	N	18%	0%
39	84	$6,069.50	$529,838		$545,489	$529,835	N	0%		$653,272	$6,069.50	$529,838	N	19%	0%
40	107	$5,933.00	$654,831		$694,849	$654,831	N	0%		$832,145	$5,933.00	$654,831	N	21%	0%

purchasing cost through custom contracting is $(\$7{,}406.02 \times 27 + \$20{,}000) = \$219{,}963$, and through buying at the GPO price it is $(\$7{,}777.05 \times 27) = \$209{,}980$. With custom contracting, then the "information access value" is $\$4{,}279\ (= \$224{,}242 - \$219{,}963)$ and, the total savings from GPO membership is 6% $\left(= \frac{\$224{,}242 - \$209{,}980}{\$224{,}242}\right)$.

We now analytically assess the value of GPO membership and the impact of custom contracting from the hospitals' point of view. Absent any information on the GPO prices, the expected cost of procurement for a hospital with demand q that is not a GPO member is $\left(qE[\tilde{P}(q)] + C_H\right)$. The expected savings from GPO membership for a hospital with demand q through having access to the GPO price is given as

$$\text{(Cost without GPO membership} - \text{Cost with GPO membership)}$$

$$= \begin{cases} \left(qE[\tilde{P}(q)] + C_H\right) - \left(qE\left[\tilde{P}(q)\middle|P_g\right] + C_H\right) \\ \text{when the member hospital uses information on } P_g \text{ to negotiate directly with the vendor} \\ \\ \text{or} \\ \\ \left(qE[\tilde{P}(q)] + C_H\right) - qP_g \\ \text{when member hospital buys at the GPO price, } P_g. \end{cases}$$

Proposition 4: *The expected cost savings from GPO membership for all member hospitals are non-negative, with or without custom contracts. However, these cost savings are always lower when custom contracting is allowed.*

The results in Proposition 4 are primarily driven by the fact that the GPO price is higher with custom contracts. However, what is more interesting about the result is that large hospitals, even after improving on the GPO price through custom contracting, end up incurring higher procurement costs. When custom contracting is allowed, the GPO vendor strategically offers a higher price through the GPO, anticipating that some of the larger hospitals will then renegotiate. As a result, the hospitals are worse off, facing higher overall procurement costs. Smaller hospitals are worse off because they pay a higher GPO price; the larger hospitals are worse off because the expected price after negotiation is the same, or even higher, and on top of that, they cannot avoid the negotiation cost.

Table 4 details the comparative savings for all hospitals in the example discussed earlier. The values in columns (8) and (14) in Table 4 are all non-negative, meaning that GPO membership offers cost savings to all hospitals. Not surprisingly, the percentage savings in columns (8) and (14) are monotonically non-increasing in the purchase volume, conforming to the correct common belief that the smaller hospitals benefit proportionally the most from their GPO membership.

Comparing the values in columns (8) and (14), we find that for all hospitals here the values in column (8) are either higher or the same as those in (14). That is a clear illustration of Proposition 4, namely that all hospitals are better off when custom contracting is not allowed. It is interesting to note that despite the added flexibility of negotiating directly with the GPO vendor, no single hospital is better off when custom contracting is permitted. The most striking observation comes from analyzing the cost savings of the relatively larger hospitals, which in practice strongly believe they save a significant amount through renegotiating with GPO vendors. The authors of this research have heard it repeatedly from senior executives at several of the larger medical centers. These executives even expressed gratitude to GPO leadership for allowing them to leverage their larger size and to engage in custom contracting negotiations with GPO vendors after the GPO prices have been established. The evidence is clear that when custom contracting is allowed, Hospitals 19-40 seem to attain additional cost savings over the GPO price through renegotiation, as shown by column (13), but column (14) shows that their effective savings are zero when custom contracting is allowed, and could have been higher in the absence of custom contracting, as depicted in column (8). Take, for example, Hospital 32, which buys 60 units. The expected procurement cost of that hospital without the information on the GPO price is $405,740. When the hospital is a GPO member and custom contracting is not allowed, its procurement cost goes down to $389,635. When custom contracting is allowed, the GPO unit price increases from $6,493.92/unit to $7,777.05/unit. Hospital 32 then wants to buy at a price lower than $7,777.05/unit, and in fact is expected to negotiate a further discounted price of $6,429.00/unit. This is an impressive discount of almost 17% per unit. The total expected cost of procurement for Hospital 32, however, factoring in the added cost of negotiation, is $60 \times \$6{,}429 + \$20{,}000 = \$405{,}740$. The buying cost here is the same, as without a GPO. Besides, this total cost is higher than $389,635, but the leadership of that hospital wrongly believes that, through renegotiation, it gets almost a 17% discount over the GPO price and 13% on the total procurement cost, still making its purchasing manager look highly valuable. The hospital typically fails to realize that the GPO price itself would have been lower if custom contracting were not allowed. Hospitals should be aware of the pricing strategies of the GPO vendors and should not be misled by measuring their savings with reference to the cost of buying at the GPO price. As we saw above, the savings from further negotiations could be significantly lower than they appear.

Analyzing the comparative savings in Table 4 provides good intuition for these unexpected results. There are basically three types of hospitals: "small" hospitals (Hospitals 1-18, with purchase volumes up to 33 units), the "mid-size" hospitals (Hospitals 19-35, with purchase volumes above 33 and up to 63 units), and the "large" hospitals (Hospitals 36-40, with volume above 63 units). The small hospitals buy at the GPO price in either case, paying a higher GPO price when custom contracting is allowed. Custom contracting increases the aggregate procurement cost for hospitals in this category by $576,127; this

increase translates directly into additional profits for the GPO vendor and the GPO. For that group the net gain in social surplus from custom contracting is zero. The "mid-size" hospitals negotiate further when custom contracting is allowed; when it is not, they buy at the GPO price. These hospitals incur the additional cost of negotiation and have a higher expected cost of procurement. These "mid-size" hospitals will use custom contracting to negotiate a price lower than the GPO price, but the aggregate total cost for the hospitals in this category increases by $452,470. In this case the net gain in social surplus from custom contracting is negative, because of the additional negotiation costs incurred by both the hospitals and the GPO vendor. The "large" hospitals leverage their size and negotiate in either case. Yet they do not do any better (in expectation) with custom contracting, since their expected price after the negotiations is not any lower than what it would be if custom contracting were not allowed. In this case, the net gain in social surplus from custom contracting remains at zero. We find that small hospitals are hurt the most by the practice of custom contracting. For these small hospitals, the range of percentage savings from GPO membership goes down from 16-35% to 0-22%, as seen in Table 4. Considering all the hospitals as a group, the GPO vendor and the GPO benefit at the expense of the hospitals when custom contracting is allowed, and a significant amount of social surplus is lost in the form of the added costs of negotiation.

5.4 The intermediary role of the GPO

In the absence of custom contracting, Hospitals 1-35 buy at the GPO price, and only a few hospitals (Hospitals 36-40) use the GPO price for benchmarking purposes. When custom contracting is allowed, Hospitals 1-18 buy at the GPO price, and the rest of the hospitals buy through custom contracting while using the GPO price as benchmark price. Clearly, with custom contracting the GPO plays the role of demand aggregator for fewer hospitals and benefits the rest of the hospitals indirectly by giving them access to the GPO price, which they then use as a benchmark in the negotiation process; it mitigates the price uncertainty of certain medical supplies to some extent. This means that with custom contracting, GPOs are playing a smaller role as demand aggregators and an increasing role as (pricing) information providers for the membership.

The GPO vendor's revenue is higher when custom contracting is allowed. Higher revenue with custom contracts has further implications for the GPO's policy. We anticipate that a GPO that earns its revenue by sharing a percentage of the GPO vendor's revenue will be more likely to encourage custom contracts, and its vendors would welcome custom contracting as well.

GPOs and GPO vendors can also have an impact on the profitability of the GPO vendor, if they can manipulate the hospitals' cost of negotiation. We state the result, first.

Proposition 5: *The GPO vendor's profit is non-decreasing in the cost of negotiation for the hospitals,* C_H*, that is,* $\frac{d}{dC_H}(\Pi_v^C) \geq 0$ *and* $\frac{d}{dC_H}(\Pi_v^{NC}) \geq 0$.

As the cost of negotiation rises, hospitals are less likely to generate a surplus through further negotiations with the GPO vendor, or with outside vendors. The GPO vendor can increase its profit by exploiting this factor. Indeed, the GPO vendor would want to make the cost of negotiation for the hospitals as high as possible to benefit itself in the game. Over the years we have observed how vendors have added more "features" to their hospital contracts as a way to drive up the negotiating costs, C_H. These added features include complex accrued rebates, funding of clinical trials, multi-year contracts, or the conditional delivery of continued medical education programs for the medical staff of the contracting hospital.

The above result has another implication on GPOs' role. When a hospital is uncertain whether any outside vendor is able to charge less than the GPO price, this uncertainty increases the probability that the hospital has to bargain with multiple vendors before it receives a reasonable deal and thus increases the hospital's expected cost of negotiation. The GPO has an informational advantage because it has access to its members' past transactions. As a result, the GPO can play a significant role in reducing the price uncertainty of a product. As mentioned earlier, GPOs may be barred from sharing price information on individual transactions with any member hospital, but they can still provide statistical analyses of past price information and share aggregate price information analytics with their members. These efforts to reduce price uncertainty are highly desirable for the GPO's member hospitals, but they may not be welcomed by the GPO vendor, since Proposition 5 proves that the GPO vendor's profit increases with the hospital's cost of negotiation.

6. Conclusions

While the general role of GPOs has been well established in the supply chain literature, there is still an ongoing political debate concerning whether GPOs actually add value in the healthcare marketplace. Our study sheds more light on this economic and political controversy by analyzing GPOs' multifaceted role in the U.S. healthcare supply chain. Some hospitals buy using the GPO contract, while others follow the common wisdom that suggests that they can further improve on the prices available via their GPO contracts by negotiating custom contracts directly with the GPO vendors. Surprisingly, we find that this common wisdom is incorrect when vendors behave strategically. We use game theory to show how the strategic behavior of vendors unexpectedly affects the payoffs of the three stakeholder groups—vendors, GPOs, and hospitals—when they resort to custom contracting.

Our initial results prove that the absolute difference between the total cost of buying through the GPO at price P_g and the expected cost of buying directly from the GPO vendor after price negotiation is an increasing function of the purchase quantity q. These results imply monotone market segmentation, where the purchasing behavior varies across members with different demands for a given level of price uncertainty, cost of negotiation, and GPO price. Some hospitals purchase via the GPO; others use the GPO price as a benchmark and seek a lower price outside the GPO contract. Assuming that all variables except those under immediate consideration are held constant, we have proved that fewer hospitals buy at the GPO price when that price increases, but more hospitals buy at the GPO price when a hospital's cost of negotiation, C_H, increases.

When custom contracting is permitted, it leads to some unexpected results. For example, the GPO price and the GPO vendor's total revenue and profits are all higher, and fewer hospitals buy at the GPO price. Our other salient result is that the expected cost savings from GPO membership for all member hospitals are non-negative, with or without custom contracts, but we prove that these cost savings are always lower when custom contracting is allowed. Thus, member hospitals, in fact, do not benefit from the added flexibility promised by custom contracting. Rather, the practice yields positive returns to the GPO vendor and the GPO, as the GPO vendor strategically offers a higher price through the GPO, thus raising the costs for small hospitals, which must pay the GPO price, and larger hospitals as well, whether or not they pursue further negotiations.

As GPO vendors realize higher revenues and profits with custom contracts, both for-profit GPOs that receive a percentage of the vendor's revenues as fees and GPO vendors are likely to encourage this practice. However, when the cost of negotiation for the vendor (C_V) is very high, the vendor may not always welcome renegotiation. We show that, when custom contracting is allowed, the GPO price offered by the GPO vendor decreases in the vendor's cost of negotiation. When custom contracting is not allowed, the GPO price doesn't depend on the vendor's cost of negotiation; it depends on the marginal cost of production of the product, and it is increasing in the marginal cost of production of the product. Since the profits of the GPO vendors are non-decreasing in the costs of negotiation for the hospitals (C_H), the GPO vendors may try to increase their profits by exploiting this factor and making those costs as high as possible.

Our numerical example shows that vendors realize higher revenues (37% higher) and profits (34% higher) with custom contracts. Small hospitals lose out more than the larger ones, as they incur much higher costs than they would have without custom contracting. The "mid-size" hospitals negotiate further when custom contracting is allowed; when it is not, they buy at the GPO price. These hospitals incur the additional cost of negotiation and have a higher expected cost of procurement. In this case the net gain in social surplus from custom contracting by the "mid-size" hospitals is negative, because of the additional

negotiation costs incurred by both the hospitals and the GPO vendor. Moreover, although larger hospitals may be able to negotiate a good price on their own, they are not better off with custom contracting, as their additional negotiations on price impose additional costs as well.

Healthcare providers may be ignoring the fact that GPO vendors do not offer the same prices when custom contracts are permitted. Large member hospitals, which engage in further negotiation after the announcement of the GPO price, are likely to be under the impression that a discount off the GPO price means a better deal for them. What we observed in practice can be explained by a phenomenon similar to the "prisoner's dilemma," where players (in this case hospitals) make choices that prevent them from attaining the desired outcome where all players collectively would be better off. In the Nash equilibrium outcome, the vendor manages to achieve higher profits by protecting the negotiated price with each individual hospital as a trade secret, thereby enticing large hospitals with a promise of cost savings through custom contracting. We find that collectively prohibiting custom contracts leads to an even lower price up front, making renegotiation unnecessary. Large hospitals need to rethink the benefits of custom contracting, as they often have the bargaining power necessary to convince their GPOs, which profit from custom contracts, to forgo them. In fact, when the hospitals realize the price they need to pay to have the flexibility to renegotiate, GPOs need to reconsider their policies on allowing custom contracting in order to prevent hospitals from joining competitive GPOs that do not allow custom contracting.

Our analysis identifies a significant shift in the GPO's role. When custom contracting is allowed, the GPO's role shifts from group purchasing intermediary, or volume aggregator, to information intermediary. Given this shift, the emergence of Integrated Delivery Networks (IDNs), mostly comprising larger regional hospitals, is more likely. As part of an IDN, a hospital does not wholly forgo the benefit of group purchasing; at the same time, it may not suffer from the so-called "free-rider" problem, where small hospitals are believed to benefit more from cooperative purchasing.

Our current research does have some limitations: For example, we focus on the strategic interactions between the GPO vendor and GPO members and do not incorporate into our model the vendors' selling decisions or bundling choices or hospitals' membership decisions. We anticipate that a hospital's decision to join a GPO is driven by the expected cost savings across all the products it intends to buy through the GPO. On the other hand, the vendor's decision whether to sell through the GPO depends on a reservation profit, taking into consideration a portfolio of products—as opposed to our single product case here. Additionally, sales to larger hospitals can supply "clinical reputation" value to the vendor, which, in turn, can pass on added cost savings back to hospitals, above and beyond the plain vanilla GPO contract. Our results are also driven by the assumption that the hospitals are heterogeneous in their purchase volumes. If hospitals are similar enough in their purchase volumes, either all will buy at the GPO price or all will renegotiate further with the GPO vendor, reaching equilibrium with a corner solution.

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Appendix A: Notations

Table 5: Notations

Expected price per unit for a hospital with demand q	$E[\tilde{P}(q)]$
Price uncertainty	$\tilde{P}(q) \sim U[P_L(q), P_H(q)]$
The vendor's marginal cost of production	m
Cost of negotiation per transaction for the vendor	C_V
Cost of negotiation per transaction for any hospital	C_H
Contract administration fee	λ fraction of sales revenue, $0 \leq \lambda \leq 1$
GPO price	P_g
Expected unit price after negotiation for a hospital with demand q conditional on the GPO price	$E\left[\tilde{P}(q)\middle\|P_g\right]$

Appendix B: Proofs of lemmas and propositions

Proof of Lemma 1:

$E\left[\tilde{P}(q)|P_g\right] = \int_0^{P_g} \tilde{P}(q)d\tilde{P}(q) + Pr\{\tilde{P}(q) > P_g\}P_g \leq \int_0^{\infty} \tilde{P}(q)d\tilde{P}(q) = E[\tilde{P}(q)]$.

In addition, when$\Delta \geq 0$,

$E\left[\tilde{P}(q)|P_g + \Delta\right] - E\left[\tilde{P}(q)|P_g\right]$

$= \left(\int_{P_g}^{P_g+\Delta} \left(\left(P_g + \Delta\right) - \tilde{P}(q)\right) d\tilde{P}(q)\right) + Pr\{\tilde{P}(q) \geq P_g + \Delta\}\Delta$

$\leq \left(\int_{P_g}^{P_g+\Delta} \Delta d\tilde{P}(q)\right) + Pr\{\tilde{P}(q) \geq P_g + \Delta\}\Delta$

$\leq Pr\{\tilde{P}(q) \leq P_g + \Delta\}\Delta + Pr\{\tilde{P}(q) \geq P_g + \Delta\}\Delta$

$\leq \Delta$.

Therefore, $0 \leq \frac{\partial E\left[\tilde{P}(q)|P_g\right]}{\partial P_g} \leq 1$.

Furthermore,

$E\left[\tilde{P}(q + \Delta)|P_g\right] - E\left[\tilde{P}(q)|P_g\right]$

$= \left(\int_0^{P_g} \tilde{P}(q + \Delta)d\tilde{P}(q + \Delta)\right) + Pr\{\tilde{P}(q + \Delta) \geq P_g\}P_g - \left(\int_0^{P_g} \tilde{P}(q)d\tilde{P}(q)\right) - Pr\{\tilde{P}(q) \geq P_g\}P_g$

≤ 0, since $Pr\{\tilde{P}(q + \Delta) \geq P_g\} \leq Pr\{\tilde{P}(q) \geq P_g\}$ following Assumption 2.

Therefore, $\frac{\partial E\left[\tilde{P}(q)|P_g\right]}{\partial q} \leq 0$. (QED)

Proof of Lemma 2:

Differentiating $f(q)$, we have

$$f'(q) = \left(P_g - E\left[\tilde{P}(q)|P_g\right]\right) - q\frac{\partial E\left[\tilde{P}(q)|P_g\right]}{dq}.$$

The quantity in the brackets is positive because $E\left[\tilde{P}(q)|P_g\right] \leq P_g$. The last term is positive as well because $\partial E\left[\tilde{P}(q)|P_g\right]/\partial q$ is negative. (QED)

Proof of Lemma 3:

The function $\hat{q} = \hat{q}(P_g, C_H)$ satisfies the equations

$$\hat{q}\left(P_g - E\left[\tilde{P}(\hat{q})\middle|P_g\right]\right) = C_H. \tag{14}$$

From the implicit function theorem we have:

$$\frac{\partial \hat{q}}{\partial P_g} = \frac{-\hat{q}\left(1 - \frac{\partial E\left[\tilde{P}(\hat{q})\middle|P_g\right]}{\partial P_g}\right)}{\left(P_g - E\left[\tilde{P}(\hat{q})\middle|P_g\right]\right) - \hat{q}\frac{\partial E\left[\tilde{P}(\hat{q})\middle|P_g\right]}{\partial \hat{q}}}, \tag{15}$$

$$\frac{\partial \hat{q}}{\partial C_H} = \frac{1}{\left(P_g - E\left[\tilde{P}(\hat{q})\middle|P_g\right]\right) - \hat{q}\frac{\partial E\left[\tilde{P}(\hat{q})\middle|P_g\right]}{\partial \hat{q}}}. \tag{16}$$

Following Lemma 1, the denominator in both (15) and (16) are positive, because $E\left[\tilde{P}(\hat{q})\middle|P_g\right] \leq P_g$ and $\partial E\left[\tilde{P}(q)|P_g\right]/\partial q \leq 0$; the numerator in (15) is negative because $\partial E\left[\tilde{P}(q)|P_g\right]/\partial P_g \leq 1$. (QED)

Proof of Proposition 1:

$$\frac{\partial^2}{\partial m \partial P_g}\left(V^{NC}(P_g; C_H, \lambda, m)\right)$$

$$= \frac{\partial}{dm}\left(\frac{\partial}{\partial P_g}\left(\int_0^{\hat{q}(P_g, C_H)}\left(x\left((1-\lambda)P_g - m\right)\right)g(x)dx\right)\right)$$

$$= \frac{\partial}{\partial m}\left(\frac{\partial \hat{q}(P_g, C_H)}{\partial P_g}\left(\hat{q}(P_g, C_H)\left((1-\lambda)P_g - m\right)\right)g\left(\hat{q}(P_g, C_H)\right) + \int_0^{\hat{q}(P_g, C_H)} x(1-\lambda)g(x)dx\right) \text{ (using}$$

Leibniz Integral Rule)

$$= -\frac{\partial \hat{q}(P_g, C_H)}{\partial P_g}\left(\hat{q}(P_g, C_H)\right)g\left(\hat{q}(P_g, C_H)\right) \geq 0, \text{ since } \frac{\partial \hat{q}(P_g, C_H)}{\partial P_g} \leq 0.$$

The optimal GPO price thus is increasing in the marginal cost of the product. (QED)

Proof of Proposition 2:

$$\frac{\partial}{\partial P_g}\left(V^C\left(P_g; C_H, \lambda, m, C_V\right)\right)$$

$$= \frac{\partial}{\partial P_g}\left(\int_0^{\hat{q}(P_g, C_H)} \left(x\left((1-\lambda)P_g - m\right)\right) g(x)dx \right.$$

$$\left. + \int_{\hat{q}(P_g, C_H)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{P}(x)\middle|P_g\right] - m\right) - C_V\right) g(x)dx \right).$$

So, $\frac{\partial^2}{\partial C_V \partial P_g}\left(V^C\left(P_g; C_H, \lambda, m, C_V\right)\right)$

$= \frac{\partial}{\partial C_V}\left(A - \frac{\partial}{\partial P_g}\left(\int_{\hat{q}(P_g, C_H)}^{\infty} C_V g(x)dx\right)\right)$ (where A is not a function of C_V)

$= \frac{\partial}{\partial C_V}\left(A + \frac{\partial \hat{q}(P_g, C_H)}{\partial P_g} C_V g\left(\hat{q}\left(P_g, C_H\right)\right)\right)$ (using Leibniz Integral Rule)

$= \frac{\partial \hat{q}(P_g, C_H)}{\partial P_g} g\left(\hat{q}\left(P_g, C_H\right)\right) \leq 0$, since $\frac{\partial \hat{q}(P_g, C_H)}{\partial P_g} \leq 0$.

The optimal GPO price thus is decreasing in C_V.

In addition, $\frac{\partial^2}{\partial m \partial P_g}\left(V^C\left(P_g; C_H, \lambda, m, C_V\right)\right)$

$= \frac{\partial}{\partial m}\left(B - \frac{\partial}{\partial P_g}\int_0^{\hat{q}(P_g, C_H)} mxg(x)dx - \frac{\partial}{\partial P_g}\int_{\hat{q}(P_g, C_H)}^{\infty} mxg(x)dx\right)$ (where B is not a function of m)

$= \frac{\partial}{\partial m}\left(B - m\frac{\partial \hat{q}(P_g, C_H)}{\partial P_g}\hat{q}\left(P_g, C_H\right) g\left(\hat{q}\left(P_g, C_H\right)\right) + m\hat{q}\left(P_g, C_H\right) g\left(\hat{q}\left(P_g, C_H\right)\right)\frac{\partial \hat{q}(P_g, C_H)}{\partial P_g}\right)$ (using Leibniz Integral Rule)

$= 0$.

The optimal GPO price thus doesn't depend on m. (QED)

Proof of Proposition 3:

Suppose that without custom contracts the optimal GPO price is P_g^{NC}, and hospitals with demand up to q^{NC} buy at the GPO price; with custom contracts, the optimal GPO price is P_g^C, and hospitals with demand up to q^C buy at the GPO price.

The optimal profit of the GPO vendor without custom contracting with GPO price P_g^{NC}

$$= \int_0^{q^{NC}} x\left((1-\lambda)P_g^{NC} - m\right) g(x)dx$$

$$\leq \int_0^{q^{NC}} x((1-\lambda)P_g^{NC} - m)g(x)dx + \int_{q^{NC}}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right] - m\right) - C_V\right) g(x)dx$$

= The profit with custom contracting with GPO price P_g^{NC}

≤ The optimal profit with custom contracting with GPO price P_g^C.

Therefore, the GPO vendor's profit without custom contracting is lower than the GPO vendor's profit with custom contracting.

Now,

$$\left(\int_0^{\hat{q}\left(P_g^{NC},\, C_H\right)} x\left((1-\lambda)P_g^{NC} - m\right) g(x)dx\right) \geq \left(\int_0^{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)} x((1-\lambda)(P_g^{NC}-\Delta) - m)g(x)dx\right), \quad \forall \Delta \geq 0, \text{ since } P_g^{NC} \text{ is the optimal GPO price without custom contracting.} \tag{17}$$

Therefore,

$$\left(\begin{array}{c} \int_0^{\hat{q}\left(P_g^{NC},\, C_H\right)} x\left((1-\lambda)P_g^{NC} - m\right) g(x)dx \\ + \int_{\hat{q}\left(P_g^{NC},\, C_H\right)}^{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right] - m\right) - C_V\right) g(x)dx \end{array}\right) \geq \left(\int_0^{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)} x\left((1-\lambda)\left(P_g^{NC}-\Delta\right) - m\right) g(x)dx\right), \quad \forall \Delta \geq 0 \text{ (follows from Lemma 3: } \hat{q}\left(P_g^{NC}-\Delta,\, C_H\right) \geq \hat{q}\left(P_g^{NC},\, C_H\right), \forall \Delta \geq 0\text{).} \tag{18}$$

In addition,

$$\left(\int_{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right] - m\right) - C_V\right) g(x)dx\right) \geq \left(\int_{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|\left(P_g^{NC}-\Delta\right)\right] - m\right) - C_V\right) g(x)dx\right), \tag{19}$$

$\forall \Delta \geq 0$ (follows from Lemma 1: $E\left[\tilde{p}(x)\middle|P_g^{NC}\right] \geq E\left[\tilde{p}(x)\middle|\left(P_g^{NC}-\Delta\right)\right], \forall \Delta \geq 0$).

Error! Reference source not found. and (19) together imply

$$\left(\begin{array}{c}\int_0^{\hat{q}\left(P_g^{NC},\, C_H\right)} x\left((1-\lambda)P_g^{NC}-m\right)g(x)dx \\ +\int_{\hat{q}\left(P_g^{NC},\, C_H\right)}^{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)}\left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right]-m\right)-C_V\right)g(x)dx \\ +\int_{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)}^{\infty}\left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right]-m\right)-C_V\right)g(x)dx\end{array}\right)$$

$$\geq\left(\begin{array}{c}\int_0^{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)} x\left((1-\lambda)\left(P_g^{NC}-\Delta\right)-m\right)g(x)dx \\ + \\ \int_{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)}^{\infty}\left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}-\Delta\right]-m\right)-C_V\right)g(x)dx\end{array}\right) \quad (20)$$

$$\forall\Delta \geq 0.$$

Therefore,

$$\left(\begin{array}{c}\int_0^{\hat{q}\left(P_g^{NC},\, C_H\right)} x\left((1-\lambda)P_g^{NC}-m\right)g(x)dx \\ +\int_{\hat{q}\left(P_g^{NC},\, C_H\right)}^{\infty}\left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right]-m\right)-C_V\right)g(x)dx\end{array}\right)$$

$$\geq\left(\begin{array}{c}\int_0^{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)} x\left((1-\lambda)\left(P_g^{NC}-\Delta\right)-m\right)g(x)dx \\ +\int_{\hat{q}\left(P_g^{NC}-\Delta,\, C_H\right)}^{\infty}\left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}-\Delta\right]-m\right)-C_V\right)g(x)dx\end{array}\right) \quad (21)$$

$$\forall\Delta \geq 0.$$

So, the profit with custom contracting at GPO price P_g^{NC} is greater than or equal to the profit with custom contracting at GPO price $\left(P_g^{NC}-\Delta\right)$.

As a result, P_g^C cannot be less than P_g^{NC}. Also, $P_g^C \geq P_g^{NC}$ implies $q^C \leq q^{NC}$.

Therefore, the GPO price is higher with custom contracting, and fewer hospitals buy at the GPO price when custom contracting is permitted.

Now, the revenue of the GPO vendor without custom contracting is $\int_0^{q^{NC}}\left(xP_g^{NC}\right)g(x)dx$

Clearly,

$$\int_0^{q^{NC}}\left(xP_g^{NC}\right)g(x)dx \leq \int_0^{q^{NC}}\left(xP_g^{NC}\right)g(x)dx + \int_{q^{NC}}^{\infty}\left(xE\left[\tilde{p}(x)\middle|P_g^{NC}\right]\right)g(x)dx.$$

To prove that the revenue with custom contracting is higher than the revenue without custom contracting, it suffices to prove that

$$\int_0^{q^{NC}} \left(xP_g^{NC}\right) g(x)dx + \int_{q^{NC}}^{\infty} \left(xE\left[\tilde{p}(x)\middle|P_g^{NC}\right]\right) g(x)dx \leq \text{Revenue with custom contracting}$$

$$= \int_0^{q^C} \left(xP_g^C\right) g(x)dx + \int_{q^C}^{\infty} \left(xE\left[\tilde{p}(x)\middle|P_g^C\right]\right) g(x)dx$$

Since, the GPO vendor's profit with custom contracting at GPO price P_g^C is greater than or equal to the profit with custom contracting at GPO price P_g^{NC},

$$\begin{pmatrix} \int_0^{q^C} x\left((1-\lambda)P_g^C - m\right) g(x)dx \\ + \int_{q^C}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^C\right] - m\right) - C_V\right) g(x)dx \end{pmatrix} \geq$$

$$\begin{pmatrix} \int_0^{q^{NC}} x\left((1-\lambda)P_g^{NC} - m\right) g(x)dx \\ + \int_{q^{NC}}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{NC}\right] - m\right) - C_V\right) g(x)dx \end{pmatrix}.$$

Simplifying further we get,

$$\left(\int_0^{q^C} xP_g^C g(x)dx + \int_{q^C}^{\infty} xE\left[\tilde{p}(x)\middle|P_g^C\right] g(x)dx - \frac{C_V}{1-\lambda}\int_{q^C}^{\infty} g(x)dx\right)$$

$$\geq \left(\int_0^{q^{NC}} xP_g^{NC} g(x)dx + \int_{q^{NC}}^{\infty} xE\left[\tilde{p}(x)\middle|P_g^{NC}\right] g(x)dx - \frac{C_V}{1-\lambda}\int_{q^{NC}}^{\infty} g(x)dx\right).$$

Therefore,

$$\left(\int_0^{q^C} xP_g^C g(x)dx + \int_{q^C}^{\infty} xE\left[\tilde{p}(x)\middle|P_g^C\right] g(x)dx\right) \geq$$

$$\left(\int_0^{q^{NC}} xP_g^{NC} g(x)dx + \int_{q^{NC}}^{\infty} xE\left[\tilde{p}(x)\middle|P_g^{NC}\right] g(x)dx\right), \text{ since } \frac{C_V}{1-\lambda}\int_{q^C}^{\infty} g(x)dx \geq \frac{C_V}{1-\lambda}\int_{q^{NC}}^{\infty} g(x)dx.$$

So, the GPO vendor's revenue without custom contracting is less than or equal to the GPO vendor's revenue with custom contracting.

Therefore, the GPO's revenue without custom contracting is less than or equal to the GPO's revenue with custom contracting (as GPOs collect a percentage of GPO vendors' revenue). (QED)

Proof of Proposition 4:

Suppose that, without custom contracts, hospitals with demand up to q^{NC} buy at the GPO price P_g^{NC}, and the rest buy from vendor(s) outside the GPO at price $E\left[\tilde{P}(x)|P_g^{NC}\right]$; with custom contracts, hospitals with demand up to q^C buy at the GPO price P_g^C, and the rest negotiate further with the GPO vendor and contract at a price $E\left[\tilde{P}(x)|P_g^C\right]$.

Following Proposition 3, $P_g^C \geq P_g^{NC}$ and $q^C \leq q^{NC}$.

We segregate the hospitals into three categories based on their demand and purchasing behavior, and analyze the cost savings for each category separately.

Category I: Hospitals with demand x $(0 < x \leq q^C)$ buy at the GPO price irrespective of whether custom contracting is allowed:

Expected procurement cost

$$= \begin{cases} \text{with no GPO membership: } \left(xE[\tilde{P}(x)] + C_H\right) \\ \text{with GPO membership: } \begin{cases} custom\ contracting \text{ is allowed: } \left(xP_g^C\right) \\ custom\ contracting \text{ is not allowed: } \left(xP_g^{NC}\right) \end{cases} \end{cases}.$$

We have that $\left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right) \geq xP_g^C \geq xP_g^{NC}$, since $P_g^C \geq P_g^{NC}$.

Therefore, $\left(xE[\tilde{P}(x)] + C_H\right) \geq xP_g^C \geq xP_g^{NC}$, since $E[\tilde{P}(x)] \geq E\left[\tilde{P}(x)|P_g^C\right]$.

Category II: Hospitals with demand x $(q^C \leq x \leq q^{NC})$ buy at the GPO price in the absence of custom contracting, but they renegotiate when custom contracting is allowed:

Expected procurement cost

$$= \begin{cases} \text{with no GPO membership: } \left(xE[\tilde{P}(x)] + C_H\right) \\ \text{with GPO membership: } \begin{cases} custom\ contracting \text{ is allowed: } \left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right) \\ custom\ contracting \text{ is not allowed: } \left(xP_g^{NC}\right) \end{cases} \end{cases}.$$

We have that $E\left[\tilde{P}(x)|P_g^C\right] \leq E[\tilde{P}(x)]$. Therefore, $\left(xE[\tilde{P}(x)] + C_H\right) \geq \left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right)$.

In addition, $E\left[\tilde{P}(x)|P_g^C\right] \geq E\left[\tilde{P}(x)|P_g^{NC}\right]$, since $P_g^C \geq P_g^{NC}$. Therefore, $\left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right) \geq \left(xE\left[\tilde{P}(x)|P_g^{NC}\right] + C_H\right)$. As a result, $\left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right) \geq xP_g^{NC}$, since $\left(xE\left[\tilde{P}(x)|P_g^{NC}\right] + C_H\right) \geq xP_g^{NC}$.

Category III: Hospitals with demand x $(q^{NC} \leq x < \infty)$ do not buy at the GPO price irrespective of whether custom contracting is allowed:

Expected procurement cost

$$= \begin{cases} \text{with no GPO membership: } \left(xE[\tilde{P}(x)] + C_H\right) \\ \text{with GPO membership: } \begin{cases} custom\ contracting \text{ is allowed: } \left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right) \\ custom\ contracting \text{ is not allowed: } \left(xE\left[\tilde{P}(x)|P_g^{NC}\right] + C_H\right) \end{cases} \end{cases}.$$

We have that $E[\tilde{P}(x)] \geq E\left[\tilde{P}(x)|P_g^C\right] \geq E\left[\tilde{P}(x)|P_g^{NC}\right]$

Therefore, $\left(xE[\tilde{P}(x)] + C_H\right) \geq \left(xE\left[\tilde{P}(x)|P_g^C\right] + C_H\right) \geq \left(xE\left[\tilde{P}(x)|P_g^{NC}\right] + C_H\right)$. (QED)

Proof of Proposition 5:

Say that the optimal prices are P_g^* and $P_g^{*\prime}$, with the costs of negotiation for the hospitals C_H and C_H', respectively, and $C_H < C_H'$.

The vendor profit without custom contracting when the cost of negotiation for the hospitals is C_H

$$= \int_0^{\hat{q}\left(P_g^*, C_H\right)} x\left((1-\lambda)P_g^* - m\right) g(x)dx$$

$$\leq \int_0^{\hat{q}\left(P_g^*, C_H'\right)} x\left((1-\lambda)P_g^* - m\right) g(x)dx \quad \left(\text{since } \frac{\partial \hat{q}}{\partial C_H} \geq 0, \text{ from Lemma 3}\right)$$

$$\leq \int_0^{\hat{q}\left(P_g^{*\prime}, C_H'\right)} x\left((1-\lambda)P_g^{*\prime} - m\right) g(x)dx \quad \left(\text{since } P_g^{*\prime} \text{ is the optimal price when the cost of negotiation is } C_H'\right)$$

= The vendor profit without custom contracting when the cost of negotiation for hospitals is C_H'.

The profit with custom contracting when the cost of negotiation for the hospitals is C_H

$$= \int_0^{\hat{q}\left(P_g^*, C_H\right)} x\left((1-\lambda)P_g^* - m\right) g(x)dx + \int_{\hat{q}\left(P_g^*, C_H\right)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^*\right] - m\right) - C_V\right) g(x)dx$$

$$\leq \int_0^{\hat{q}\left(P_g^*, C_H'\right)} x\left((1-\lambda)P_g^* - m\right) g(x)dx + \int_{\hat{q}\left(P_g^*, C_H'\right)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^*\right] - m\right) - C_V\right) g(x)dx \text{ (since}$$

$\hat{q}\left(P_g^*,\ C_H'\right) \geq \hat{q}\left(P_g^*,\ C_H\right)$, following Lemma 3; $E\left[\tilde{p}(x)\middle|P_g^*\right] \leq P_g^*$, following Lemma 1)

$$\leq \int_0^{\hat{q}\left(P_g^{*\prime}, C_H'\right)} x\left((1-\lambda)P_g^* - m\right) g(x)dx + \int_{\hat{q}\left(P_g^{*\prime}, C_H'\right)}^{\infty} \left(x\left((1-\lambda)E\left[\tilde{p}(x)\middle|P_g^{*\prime}\right] - m\right) - C_V\right) g(x)dx$$

(since $P_g^{*\prime}$ is the optimal price when the cost of negotiation is C_H')

= The profit with custom contracting when the cost of negotiation for the hospitals is C_H'. (QED)