Essays on Economics of Technology-Enabled Intermediaries

by

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The author was born in India on December 13, 1977. He attended Indian Institute of Technology, Kharagpur from 1996 to 2000, and graduated with Bachelor of Technology (Honours) degree in Computer Science and Engineering in 2000. Thereafter he worked in the information technology industry for 5 years and worked for organizations such as Oracle India Private Ltd., Novell Software Development (I) Ltd., Cal2Cal India Ltd. before coming to Rochester. He joined the William E. Simon Graduate School of Business Administration, University of Rochester in the summer of 2005 and began graduate studies in Computers and Information Systems. He researched on the dynamics of technology-enabled intermediaries, in general, under the supervision of professor Ravi Mantena, and a more specific kind of supply chain intermediaries, known as Group Purchasing Organizations (GPOs) in the United States healthcare industry, under the supervision of Professors Abraham Seidmann and Vera Tilson. He received the Master of Science degree in Business Administration from the University of Rochester in 2008.
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Abstract

The dissertation consists of three essays that examine a number of economic aspects of technology-enabled intermediaries. The first essay studies the effect of asymmetry in platform-technology on competition and collaboration between intermediaries in two-sided markets. I find that collaboration between rivals in the form of direct or indirect inter-network access can lead to Pareto improvements in profits, with or without monetary transfers between them. Such improvements are most likely when the technological asymmetry between rivals is large, or the incumbent has a large installed base. Technology licensing deals are not possible without a pre-existing installed base for the inferior technology platform, but these too become more attractive with larger installed bases and technological asymmetry. The second and third essays focus on issues related to a specific kind of procurement intermediaries, known as Group Purchasing Organizations (GPOs). Hospitals in the United States join GPOs to improve procurement efficiencies and get deeper group discounts contracted for by GPOs. Some members further negotiate directly with the same vendors. The common perception is that hospitals benefit from such directly-established “custom contracts” as they yield prices lower than the GPO-negotiated prices. In the second essay, using a game-theoretic model, I find that allowing custom contracts benefits vendors at the expense of hospitals. I show how, with the provision for custom contracts, GPOs act as demand aggregators for small hospitals, and information intermediaries for the rest. The third essay explores the economic rationale behind compliance-based pricing in GPO contracts. The common perception is that higher purchase volume leads to lower unit price. I show that a vendor’s fixed cost of managing an active B2B account and the heterogeneity in product preferences within the hospital can largely drive such compliance-based pricing. Interestingly, I find that it is possible for a hospital to get a lower price even when it buys fewer units, as compared to another hospital which is buying more from the same vendor but not fulfilling its entire demand from that vendor. I also show that, in certain cases, such pricing may not only decrease procurement cost but also increase social surplus.
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Foreword on Collaboration

This dissertation consists of three essays—chapters 2, 3, and 4. The first essay is a joint work with Professor Ravi Mantena. The second essay is a joint work with Professors Avi Seidmann and Vera Tilson. The third essay is a solo work by me.

Chapter 2: Competition and Strategic Partnership between Intermediary Platforms in the Presence of Heterogeneous Technologies

Prof. Mantena provided me with valuable directions in defining the scope of this research and formulation of the model. I carried out the analysis, and developed the lemmas and propositions presented in this chapter. The preliminary results of this work have been presented in 2008 Workshop on Information Systems and Economics and 2009 INFORMS Conference on Information Systems and Technology. I have published an initial version of this work in the proceedings of the 2012 Hawaii International Conference on System Sciences jointly with Prof. Mantena. We have coauthored a version of the paper that has been submitted in the Journal of Management Information Systems in February 2012.

Chapter 3: Custom Contract and the Role of Group Purchasing Organizations (GPOs) as Information Intermediaries

Prof. Seidmann and Prof. Tilson provided me with valuable directions in defining the scope of this research and formulation of the model. I carried out the analysis, and developed the lemmas and propositions presented in this chapter. The preliminary results of this work have been published in the proceedings of the 2011 Hawaii International Conference on System Sciences jointly with Prof. Seidmann and Prof. Tilson. The current set of results have also been presented in 2011 INFORMS Conference on Information Systems and Technology and 2011 Workshop on Information Systems and Economics. We plan to collaborate on publishing the final version of the work.

Chapter 4: Compliance Trumps Volume

I carried out the research and analysis on this chapter myself. This is a solo work by me.
1. Introduction

Intermediaries exist to facilitate transactions between two parties who benefit from interacting or trading with each other. Rapid advances in technology over the last two decades, especially the Internet and other networks that facilitate intra- and inter-organizational information exchange and collaboration, have not only given rise to a new generation of intermediaries, but also significantly altered the value propositions of the existing intermediaries. In some cases technology has completely replaced human intervention in mediation, whereas in others, the added technological capability has reshaped the economic value addition by the intermediaries. Either ways, the technology has impacted the economic benefits of the interacting agents in the market as well as that of the intermediaries. The list of these technology-enabled intermediaries includes, but is not limited to, electronic job markets (Monster), ecommerce sites (Amazon), online advertising platforms (Google, Yahoo), Group Purchasing Organizations (MedAssets, Novation), online auction platforms (eBay), group buying platforms on the web, etc.

Markets with intermediaries consist of three types of strategic players: two distinct groups of agents and one or more intermediaries/platforms. The platform’s strategic decisions primarily relate to—how to price its services for agents on the two sides (price level and price structure based on the asymmetry in two sides of the market, tradeoff between usage- and subscription- based pricing, etc.), platform’s policy on openness and competition (e.g., whether to offer proprietary or standard interface to agents, whether to collaborate with competitors), platform’s policy on contract mechanisms among agents, etc. The agents’ decisions typically concern such issues as which platform(s), if any, to join, how to utilize the platform (use the platform for discovering feasible transactions as well as conducting the transaction or use the platform for discovering feasible transactions alone), choice of contractual terms for interaction with agents on the other side, etc. The market structure and the utility of platforms depend on platform’s decisions as well as the type of platform sponsorship/ownership (buyer or seller-sponsored, or independent), type of agents
and their heterogeneity, asymmetry in size and externality between the two sides of
the market, legal framework, and competition. An agent’s surplus depends on the
agent’s decisions as well as the network size, platform pricing, platform policy, and
technology of the platform.

In this dissertation I analyze a number of economic aspects concerning
technology-enabled intermediaries. My study broadly adds to the literature on
intermediaries. Evans and Schmalensee [36] classify these markets with
intermediaries into four different kinds—exchanges, advertising-supported media,
transaction systems, and software platforms. The first essay is more generic and
contributes directly to the literature on two-sided markets, and most directly applies
to exchanges (as classified by [36]), but to a lesser extent, also to software platforms
(especially mobile and video game platforms) and transaction systems (such as
mobile payment systems). The second and third essays focus on a specific type of
healthcare supply chain intermediaries known as Group Purchasing organizations or
GPOs. The GPOs fall under the category of exchanges (following the classification in
[36]). In addition to the literature on intermediaries, the second and third essays
contribute to the literature on group purchasing and B2B pricing in general.

In two-sided markets with technology-enabled intermediaries (e.g., Google,
Yahoo, and Microsoft in online advertising, Amazon and eBay in electronic
marketplace), the technology of the platform can improve network effects
experienced by the agents, by increasing the number of successful transactions and
improving the quality of each transaction. So, the technology of the platform is
expected to play a strategic role in the interactions between such platforms. In my
first essay (chapter 2), I seek to understand the effect that technological asymmetry
between platforms has on competitive outcomes, and answer the following questions.
Should technology based platform intermediaries collaborate with their rivals? If so,
what form should this collaboration take? I add to the literature on two-sided markets
by analytically studying the effect of platform technology on competition, division of
surplus, and its role on the strategic partnership between platforms. I find that these
Markets are characterized by extremely lop-sided outcomes. Under open competition, the superior technology platform strongly dominates the market, and surprisingly, this domination persists even as the technology gap between the two platforms vanishes. Collaboration between rivals in the form of direct or indirect inter-network access can lead to Pareto improvements in profits, with or without monetary transfers between them. Such improvements are most likely when the technological asymmetry between rivals is large, or the incumbent has a large installed base. Technology licensing deals are not possible without a pre-existing installed base for the inferior technology platform, but these too become more attractive with larger installed bases and technological asymmetry.

In the second and third essays (chapters 3 and 4), I focus on a particular kind of healthcare supply chain intermediaries, known as Group Purchasing Organization or GPOs. The healthcare supply chain with GPOs consists of hospitals as buyers, medical device manufacturers and distributors as vendors, and GPOs as intermediaries. GPOs do not buy or sell products; instead, they establish contracts with vendors on behalf of member hospitals. The GPOs can be buyer or seller-sponsored or independent, and can operate as either for-profit or non-profit organizations. Many hospitals in the United States join GPOs with an objective to lower their procurement costs by availing GPO-negotiated group discounted price. The strategic decisions that are very specific to GPOs are—how to price their services to vendors and hospitals (the price is usually in the form of contract administration fees to vendors, membership fees and loyalty rebates to hospitals, etc.); what information to share with vendors and/or hospitals. The strategic decisions that are very specific to hospitals are—whether to join a GPO or buy directly from the vendor; which GPO(s) to join, if any; and if they join, whether to buy at the GPO price or negotiate further with the vendor directly in an attempt to get additional discounts. The vendor’s decisions lie in offering an optimal price schedule; it also faces the tradeoff between selling through the GPO and pay the contract
administration fees, and selling directly and incurring the cost of separately establishing contracts with hospitals.

Typically, hospitals become members of a GPO; the GPO negotiates product prices with vendors on behalf of all its member hospitals in order to get deeper volume discounts. However, savings through GPO contracts are often debated. There is evidence that member hospitals often contract at a price lower than the GPO price, with the same vendor, through direct negotiation. Such contracts established directly between the same GPO vendor and member hospitals are commonly known as custom contracts. In the second essay, I contribute to the literature on group purchasing by analytically studying the impact of custom contracting, from vendors’, hospitals’, and GPOs’ perspective. The common perception is that hospitals benefit from custom contracting as it yields additional savings over GPO prices. Using a game-theoretic model, I surprisingly find that exactly the opposite is true: the provision for custom contracts benefits vendors at the expense of hospitals. I illustrate how measuring savings against GPO price could be misleading. I also find that an increase in the cost of negotiation for hospitals increases the profit of the GPO vendor. So, any effort by the GPO to reduce hospital’s cost of negotiation will be desirable by the hospitals but will not be welcome by the vendors. I show how with the provision for custom contracts, GPOs act as demand aggregators for relatively small hospitals, while they play the role of information intermediaries for the rest.

In the third essay, I contribute to the literature on group purchasing, and also pricing in general, through an analysis of compliance-based pricing that is offered by the vendors through GPOs. The common perception is that a higher purchase volume leads to a lower unit price. However, a close study of GPO contracts reveals that the price a hospital is offered by the GPO vendor depends on not only the purchase quantity but also the monetary volume of the purchase and the compliance level of the individual hospital. I explore how the compliance level of a hospital can be an important driver in vendor’s pricing strategy and why a hospital may not always fulfill the entirety of its demand from a single vendor despite the reward on
compliance level. I show that a vendor’s fixed cost of managing an active account with a hospital and the heterogeneity in product preferences within the hospital can largely drive such compliance-based pricing. Interestingly, I find that it is possible for a hospital to get a lower price even when it buys fewer units, as compared to another hospital which is buying more from the same vendor but not fulfilling its entire demand from that vendor. I also show that such compliance-based pricing, in certain cases, may not only increase vendor’s profit but also decrease hospital’s procurement cost and increase social surplus. I further show how the heterogeneity in product preferences within a hospital can impact the vendor’s profit and the hospital’s procurement cost.
2. Competition and Strategic Partnership between Intermediary Platforms in the Presence of Heterogeneous Technologies

Technology-enabled platforms that mediate interactions between multiple sets of agents are ubiquitous in the modern economy—from PC and mobile operating systems (platforms between application developers and application users), online advertising networks (between web properties and advertisers), job boards (between job seekers and recruiters), real-estate brokerages (between property buyers and sellers), to electronic marketplaces and payment card systems (between merchants and consumers) and more recently, mobile payments platforms. These platforms facilitate gainful interactions between two or more groups of customers, where such interactions may otherwise have been difficult, inefficient, too costly, or even impossible without the platform. Their economic prominence has drawn wide attention from researchers (e.g., [29, 36, 49, 50, 69, 72, 73]) in economics, information systems and marketing, who often label these markets as two-sided markets or two-sided networks. Each customer’s utility in these markets is typically an increasing function of the number of customers of the other type available to interact with on the platform, thereby creating cross-market network effects. Evans and Schmalensee [36] classify these markets into four different kinds – exchanges, advertising supported media, transaction systems, and software platforms. Our analysis in this paper most directly applies to exchanges (as classified by [36]), but to a lesser extent, also software platforms (especially mobile and video game platforms) and transaction systems (such as mobile payment systems).

In all these two-sided networks, platform providers typically perform two primary functions. First, they match agents on the two sides, enabling transactions between them; and second, they add to the quality of transactions in different ways. The utility that an agent on each side gets depends on not only the number of agents on the other side of the platform (cross-market network effects), but also how well the platform facilitates the transactions (effectiveness of the platform technology). Take for example, Google’s advertising platform. The platform enables online advertisers to
display ads on content providers’ websites. It has two components—Adwords and Adsense. Adwords is targeted towards online advertisers, while the Adsense component targets content providers (media sites, retail sites, blogs, etc.). Ads are placed on the Google content network (Google and its partner sites) and advertisers pay for clicks.

![Figure 2.1: Google’s advertising platform](image)

The utility to advertisers in this case will generally depend not only on the number of content sites available on the ad network but also on the click-through rates and the fit between their service and advertising vehicle (the content sites). These, in turn, depend on the effectiveness of Google’s contextual mapping technology and its matching algorithms. Google also provides advertisers with placement performance reports, which enable them to measure the effectiveness of their ads and fine-tune their strategies. On the content side, Google provides tools to its partner sites to format the ads, filter inappropriate ads (including competitors’ ads, and ads that may hurt the site’s image), track performance, etc. These technologies provided by Google are a significant part of its value proposition to clients (advertisers and partner sites), and along with the size of its network, a significant reason for its dominance in this space.

Similar value propositions from platform technologies are common across many two-sided markets. For example, better technology from an electronic job board improves efficiency of the search process and the quality of the match between job seekers and recruiters, thereby creating value for both employers and employees. The
bigger the recruiter, the larger the net benefit from such improved efficiency. Superior technology in a video game platform provides better tools for game developers and improves the players’ experience. A more stable and secure operating system reduces user frustration and development time for application developers. Improvement in the technology of the platform provided by real-estate brokers enables sellers to showcase their properties better and buyers to more efficiently find and assess properties of interest.

In this chapter, we seek to understand the effect that technological asymmetry between players has on competitive outcomes, and also answer the following questions—Should technology based platform intermediaries collaborate with their rivals while competing for the same market? If so, what form should this collaboration take? Should they share their networks or should they share their platform technology? To answer these questions, we use a simple analytical framework with two rival platforms endowed with heterogeneous levels of technology to study competition and collaboration between them. The framework incorporates many of the key features of these markets, such as heterogeneity in customers’ value from transactions, presence of technology influenced network effects, different forms of collaboration between platforms, installed bases for incumbents, etc. in a tractable setting. The primary insights from our analysis are: (i) Even small disadvantages in technology levels can translate into large disparities in outcomes; (ii) Collaboration between rivals through direct or indirect network sharing can be mutually beneficial, and may even arise as a natural outcome; (iii) Licensing one’s technology to an inferior rival, while potentially beneficial in some cases, is less likely to be so when compared to network sharing; and (iv) Opportunities for collaboration are most pronounced when one platform has a significant technology disadvantage and/or an incumbent with a large installed base faces a superior entrant.

The rest of the paper is structured as follows: we start with a brief overview of the extant literature in §2.1; in §2.2 we describe the basic model of utility; in §2.3 we analyze a monopoly scenario, which introduces the basic analytical approach; in §2.4
we analyze open duopoly competition with no collaboration between platforms. The results in §2.4 serve as baseline comparisons for the analysis in §2.5, where we study incentives for strategic partnership between rival platforms. In §2.6 we extend the analysis to an incumbent/entrant setting, and we conclude in §2.7 with a discussion of the key results and implications.

2.1 Literature review

The role of platform intermediaries, and competition among them, has received considerable academic attention over the last decade (e.g., [29, 36, 49, 50, 68, 69, 72, 73]). This literature is fundamentally concerned with the role that cross-market network effects play in these markets, and the attempts of platform owners to coordinate the actions of agents on the two sides of the platform and internalize some of the externalities (e.g., [1, 36, 40, 72]). Price structure and level are usually the primary focus of the analysis. Other significant issues of interest include the difference between these markets and one-sided networks (e.g., [73, 86]), competitive strategies and anti-trust issues (e.g., [4, 13, 14, 68, 69, 71]), and the effects of multi-homing (e.g., [7, 24, 39]).

However, these markets exhibit many rich characteristics beyond network effects and unique pricing strategies. For instance, Lin et al. [56] investigate how platform pricing can impact seller-side pricing and innovation. They endogenize the creation of cross-market network effects through pricing and innovation on the seller-side, and analyze the effect of these on the platform’s pricing strategies on both sides. Anderson et al. [3] study trade-offs that platforms face between investing in their core technology, and the development of complements that improve network effects. Interestingly, they find that significant improvements in core technology may not necessarily be beneficial to platforms, as compared to investments in complements, a finding that is qualitatively similar to one of our own.

A key variable, especially for technology based intermediaries that are so common in the current economy, is the level of technology incorporated into the platform which potentially influences both the number and quality of successful
interactions in these markets. However, despite the undeniable importance of technology in creating value, and influencing competition between platforms, very little of the literature has focused on this issue. Significant exceptions are papers by Eisenmann et. al [30, 31] and one by Katsamakas and Bakos [50]. Eisenmann et al. [30] provide a rich discussion of the role of technology in creating value on the platform and the importance of managing it optimally to appropriate that value. The paper by Katsamakas and Bakos [50] also recognizes the significance of platform quality. They focus on the neutrality of the platform with respect to the two sides of the market in a single platform scenario. In our research, we focus on the effect of platform technology on competition, division of industry profits, and its role on the strategic partnership between technology-enabled intermediaries. The model we analyze is similar to that in [39] where agents are considered to be heterogeneous on both sides of the market and network effects are captured within a vertical differentiation framework, although technology does not play a role in their analysis.

Our study is also close to the literature on platform competition that studies different aspects of platform compatibility (e.g., [29, 68, 74]). Parker and Van Alstyne [68] focus on the complementarity and substitutability aspects of the platforms in a two-sided market. They show that while a free strategic complement can raise a firm’s profits, free strategic substitutes can lower the profit of the competitors. Their model explains market behavior such as free goods, upgrade paths, split versioning, and strategic information substitutes. Schiff [74] presents a comparative study of different market structures—monopoly and duopoly, with and without compatibility. The paper shows that duopoly with compatibility is socially preferable to the other regimes, while monopoly is socially preferable to duopoly without compatibility. Our own focus is substantially more on the feasibility of “compatibility” in a competitive market, than on its social impact. Economides and Katsamakas [29] develop a framework to characterize the optimal two-sided pricing strategies for proprietary and open-source platforms, and analyzes the structure of competition and industry implications in terms of pricing, sales, profitability, and
social welfare. We contribute to this stream of literature on platform competition by introducing heterogeneity in platform technologies and showing how the level of technologies of competing platforms can create motives for strategic partnership through technology and/or network sharing.

Our study also contributes to the literature on interconnection between competing platforms. The early literature in this area has mostly focused on firm’s choice of interconnection and the interconnection fee thereafter in the context of one-sided networks. Armstrong [5] analyzes the competition between rivals in the context of telecommunication industry. The paper shows that in an unregulated industry symmetric rivals agree to set interconnection charge above associated cost in order to achieve joint profit-maximizing outcome. The paper also derives welfare maximizing interconnection fee for a dominant incumbent in a regulated industry. Foros and Hansen [38] analyzes competition between Internet Service Providers where customers benefit form an increase in network size. They show that rival firms prefer to interconnect with high level of compatibility (a measure they use to indicate the extent of network utility a customer gets from rival’s network) to ease competition in future periods, however, if interconnection is costly, firms overinvest as compared to the welfare maximizing investment level. Hermalin and Katz [45] analyze interconnection between messaging and communication platforms and derive that the socially optimal interconnection charge is independent of the direction of the message. We contribute to this literature by analyzing interconnection choice between heterogeneous platforms in two-sided markets that consist of two distinct networks and agents in one network derive utility from interacting with agents on the other. Our focus in this paper is on the choice of interconnection and not interconnection pricing. We show how technological disparity between platforms, cross-platform technology experience, and size of installed base can drive the decision to interconnect.
2.2 The basic model of utility

Consider a two-sided market with heterogeneous customers on both sides. For ease of exposition we refer to customers on one side as sellers \((s)\) and the other side as buyers \((b)\). Transactions between buyers and sellers are facilitated by one or two platforms. As noted, the use of the terms sellers and buyers is purely expositional, and “transactions” can generically be any type of gainful interactions between the two sets of agents including trade, social interaction, information transmission, etc. Details of the transactions are abstracted away, and the net benefit of these interactions to the buyers and sellers are represented by the reduced form utility function described below. The platforms are independently owned, and serve as both platform sponsors and providers [30].

Sellers and buyers are denoted respectively by their types \(\theta_s\) and \(\theta_b\) respectively. A customer’s type represents the ability of that customer to extract value from a transaction, and customers are assumed to be heterogeneous in this regard. For instance, in the context of the Google advertising platform, different advertisers may have different click-through rates and conversion ratios, and hence derive different values from an ad impression. We assume that \(\theta_s\) and \(\theta_b\) are uniformly distributed over the range \([0,1]\). We further assume that there are \(N_s\) sellers and \(N_b\) buyers who are potentially interested in interacting over the platforms. However, as will become clear in the next two sections, not all potential customers may join a platform. The actual number who join is endogenously determined by the prices chosen by the platforms.

The net utility to a customer on side \(i = \{s, b\}\), from joining a platform \(j = \{1,2\}\) is given by the following reduced form utility function in (2.1):

\[
U_{ij}(\theta_i; n_{ij}) = \theta_i t_j n_{ij} - p_{ij},
\]

(2.1)

where \(n_{ij}\) is the number of customers joining Platform \(j\) on side \(\hat{i} = \{s, b\}; \hat{i} \neq i\); \(p_{ij}\) is the membership price charged by Platform \(j\) to customers on side \(i\), and \(t_j\) is the level of technology provided by Platform \(j\). The customers do not incur any other
costs beyond the price of membership and platforms are assumed to have zero marginal costs associated with serving customers. The utility function reflects the presence of cross-market network effects, i.e., each customer’s utility is affected by the number of members she can interact with on the “other” side of the platform. Moreover, the multiplicative form of the utility function implies that network effects are both type and technology dependent.

The simple multiplicative form of the utility function defined in (2.1), and the assumption of uniform distribution of customer types help us focus on the role that technology plays in platform markets, and enable us to derive explicit closed form solutions in most of the cases. These solutions clearly do not generalize in a straightforward fashion to arbitrary distributions or utility functions. However we do believe that the qualitative intuition does extend to more general distributions and utility functions. The reasons for this belief are discussed in the final section of this chapter. In the next section we will analyze a scenario with a monopoly platform, before turning to an in-depth examination of platform competition in the sections that follow.

2.3 Monopoly analysis

The monopoly analysis in this section helps illustrate the basic analytical approach and serves as a baseline for comparing the competitive results that follow. We consider a monopoly platform, with a technology level $t$. The monopolist chooses a pair of membership prices, $p_b$ and $p_s$ for the buyers’ and sellers’ sides respectively. Customers join the platform if the net utility (as given by (2.1)) from doing so is non-negative, i.e., their Individual Rationality (IR) constraint is satisfied. Assessing utility, however, requires knowledge of the number of members on the other side of the platform, which is not known until the customers make their choices. To get around this circularity, we follow the network effects literature in assuming that customers form rational expectations about future network sizes, and make choices accordingly.
The structure of the game is as follows: In stage 1, given the level of platform technology, the monopolist chooses prices for both sides of the market. Following that, in stage 2, the customers form rational expectations about the platform’s equilibrium network sizes on both sides. We do not consider the details of how these beliefs are formed, but only beliefs that are fulfilled in equilibrium are considered rational. In stage 3, the customers make their membership decisions based on their expectations of network sizes and the monopoly prices. The expectations are assumed to be fulfilled in equilibrium. The equilibrium concept used is the Fulfilled Expectations Equilibrium (FEE) employed by Katz and Shapiro [51] and Economides [26] in the network externalities literature.

Following the choice of prices by the monopolist, let \( n_s^e \) and \( n_b^e \) respectively be the buyers’ and sellers’ expectations about how many customers from the other side join the platform. Let \( D_b(.) \) and \( D_s(.) \) be the corresponding monopoly demands on the two sides. The monopolist’s choice problem is, therefore,

\[
\max_{p_b, p_s} \pi_M = p_b D_b(p_b, p_s; n_s^e, n_b^e, t) + p_s D_s(p_b, p_s; n_s^e, n_b^e, t). \tag{2.2}
\]

The following lemma establishes the unique monopoly equilibrium with positive membership prices and positive demands on both sides of the market. We will refer to such outcomes, where all prices and demands are positive, as interior outcomes. In addition to such outcomes, there will often be outcomes where at least one of the prices and/or demands is zero. Such outcomes will be referred to as boundary outcomes.

**Lemma 2.1:** Optimal monopoly prices, demands, the platform profit, the consumer surplus, and the total surplus under the unique interior equilibrium are given by,

\[
p_b^* = \frac{t N_s}{4}; \quad p_s^* = \frac{t N_b}{4}; \quad D_b = \frac{N_b}{2}; \quad D_s = \frac{N_s}{2};
\]

\footnote{1 Later in this section, we will impose one more condition on the beliefs to rule out some unlikely outcomes.}
From Lemma 2.1 it is clear that the price on each side depends on the size of the network on the other, which follows from the presence of cross-market network effects. Further, while the price structure is generally asymmetric (unless $N_b = N_s$), the monopoly platform otherwise behaves similar to a regular monopolist facing a linear demand curve in a non-network market, covering half the market on each side.

Note that, in addition to the above interior equilibrium, two other boundary equilibriums also exist. The first boundary equilibrium involves customer expectations of zero demands on both sides of the market. Since platform membership in our model is a pure network good, with no inherent value, i.e., no value if there are no members on the other side of the market to transact with, expectations of zero network size are always rational, and they will always be fulfilled in equilibrium. While acknowledging this, going forward, we will ignore this outcome due to two reasons. First, if multiple sets of rational expectations exist, it is common in the network externalities literature (e.g., [26, 28]), to assume that customers co-ordinate on the set that is Pareto efficient from their perspective, i.e., they co-ordinate on the set of expectations that gives a higher benefit to the customers. The consumer surplus in the zero network size equilibrium is zero, and hence it is Pareto dominated. Second, if the platform has positive standalone value, however small it is, then the monopolist can always find a set of positive prices, where zero network size is not a rational expectation. Even where the platform value derives purely from transactions, such standalone value may exist if the platform has a pre-existing installed base (from an earlier time period), even if no customers join the platform in the current period. We will consider this explicitly in Section 2.6.

A second set of boundary FEE also exist. These outcomes involve the monopolist pricing platform access at a price of zero on one side ($p_i = 0, i = b \ or \ s$, but not both), and a positive price on the other ($p_i = \frac{t_{N_i}}{2}$). The corresponding
expectations are that all customers on the free (zero price) side join the platform, while half the customers on the other side join. Access could be free on either side, and thus there are two similar (identical except for the permutation in sides) outcomes. The resulting monopoly profits in both cases equal \( \pi_M^* = \frac{t N_B N_S}{4} \), the same as the profit under the outcome specified in Lemma 2.1. It is straightforward to show that this set of prices and expectations constitutes an FEE. Going forward, for convenience, we refer to this outcome as the asymmetric equilibrium to distinguish it from the interior outcome specified in Lemma 2.1.

Returning to our analysis in Lemma 2.1, a direct consequence of that result is,

**Proposition 2.1:** Under the unique interior equilibrium, improvements in platform technology increase prices, monopoly profits, consumer surplus, and total surplus but do not affect equilibrium network size, i.e., \( \frac{d\pi_M}{dt} > 0, \frac{dp_i}{dt} > 0, \frac{d(CS)}{dt} > 0, \frac{dW}{dt} > 0, \frac{dD_i}{dt} = 0 \) for \( i = b, s \).

Improvements in technology make the platform more valuable to customers. So, the increases in monopoly price and profits are not surprising. The lack of impact on demand is not that straightforward, and in fact turns out to be a consequence of the linearity of demand curves. The result holds for more general forms of utility than that specified in (2.1), so long as it yields a linear monopoly demand curve, i.e., so long as the utility increases linearly in customer type, and the type distribution is uniform. Thus, for instance, the result would hold even if customer value increases non-linearly in technology or if the product were to have a non-zero inherent value. Comparative statics similar to those described in Proposition 2.1 also hold for the asymmetric equilibrium.

### 2.4 Open duopoly competition

Here, we consider open competition between two platforms, characterized by technology levels \( t_1 \) and \( t_2 \). Without loss of generality, assume \( t_1 > t_2 \), i.e. Platform
1’s technology is superior, and define \( r = t_2/t_1 \) where \( r \in (0, 1) \). We further assume that the technologies employed by the two platforms are proprietary, and that there is no collaboration of any form between the platforms.\(^2\) We also assume that the customers single-home, that is, they join no more than one platform. Therefore, members of one platform cannot transact with members of the other.

The structure of the game is very similar to the monopoly case. In stage 1, with knowledge of each other’s technologies, the two platforms simultaneously choose membership prices on both sides. In stage 2, customers form rational expectations about the equilibrium network sizes of the two platforms. In stage 3, the customers make platform adoption decisions based on their expectations, platform prices, and the Individual Rationality (IR) and Incentive Compatibility (IC) constraints. In equilibrium, the expectations are assumed to be fulfilled. Finally, when multiple sets of rational expectations are feasible, we assume that customers coordinate on the Pareto efficient set, i.e., the set of expectations where the resulting equilibrium provides the largest consumer surplus. Formally, the Fulfilled Expectations Nash Equilibrium (FENE) is defined as:

**Definition:** A Fulfilled Expectations Nash Equilibrium (FENE) is defined by two sets of prices \( \{p_{b,j}^*, p_{s,j}^*\}, j = 1, 2 \), and two sets of expectations \( \{n_{i1}^e, n_{i2}^e\}, i = b, s \), such that:

(i) Given the expectations, \( \{n_{i1}^e, n_{i2}^e\}, i = b, s \), the choices of Platform \( j \), \( \{p_{b,j}^*, p_{s,j}^*\} \), are best responses to the choices of platform \( j; j, \hat{j} = 1, 2; j \neq \hat{j} \).

(ii) Given the two sets of prices, \( \{p_{b,j}^*, p_{s,j}^*\}, j = 1, 2 \), customer expectations are rational, i.e., demands \( D_{ij} \left( \{p_{b,j}^*\}, \{n_{ij}^e\}\right) = n_{ij}^e \) for all \( i = b, s; j = 1, 2 \).

(iii) The customer expectations \( \{n_{i1}^e, n_{i2}^e\}, i = b, s \), Pareto dominate all other sets of expectations satisfying conditions (i) and (ii) from the customer perspective.

The above definition requires that sets of prices constitute a Nash equilibrium of the overall game, as well as a Nash equilibrium in each market looked at in isolation.

---

\(^2\) We explore collaboration in the next section.
It also implies that if multiple sets of expectations are rational for a given set of prices, then the one corresponding to that set that is most beneficial from the customer perspective is the focal one.

The decision problem facing each platform is similar to the monopolist’s decision problem defined in (2.2). Each platform seeks to maximize its total profit (profit from the buyers side + profit from the sellers side) given the choices of the other platform and the corresponding rational expectations. Given the prices and expectations, each customer makes a choice to maximize her net surplus subject to her IR and IC constraints. Thus, a customer of type $\theta_i$, joins Platform $j$ if the following two conditions are satisfied.

$$\text{IR: } \theta_i t_j n_{ij}^e - p_{ij} \geq 0, \quad (2.3)$$

$$\text{IC: } \theta_i t_j n_{ij}^e - p_{ij} \geq \theta_i t_j n_{ij}^e - p_{ij}. \quad (2.4)$$

If the first condition is not satisfied, then the customer does not join any platform. The demand for each platform on each side is given by the measure of the set of $\theta_i$ satisfying the above two conditions, i.e.,

$$D_{ij}\left(\{p_{ij}^*\}, \{n_{ij}^e\}\right) = N_i \int_\Theta d\theta_i, \text{ such that } \Theta$$

$$= \{\text{all } \theta_i \text{ that satisfy Equations (2.3) and (2.4)}\}$$

The resulting FENE could either have both platforms active in the market (each with positive demands on both sides), or have only a single active platform. Note that a platform cannot have positive demand only on one side (and zero demand on the other) since a platform with zero network size has no value, and hence if a platform has no demand on one side, no customer would adopt that platform on the other side as well. Expectations of zero network sizes for both platforms are rational with any set of price choices, but are ignored here for the same reason as in the monopoly case—they are Pareto inefficient from the customer perspective.

Figure 2.2 illustrates the structure of any equilibrium where both platforms are active. The customers on the upper end of both sides join one platform, while the
customers in the middle join the second one. The lower end of the market in each side is typically left uncovered. It is easy to show that all possible equilibriums with both firms active necessarily have this structure. Equilibriums where customer sets crisscross (i.e., each platform serves the top end of one side and the middle part of the other), or are non-contiguous, are not feasible. However, it is possible for either of the platforms to be the one serving the top end of the market. If the top end is served by the superior technology platform (Platform 1), we call this case the Superior-on-Top outcome, and the other case, the Inferior-on-Top outcome.

Lemma 2.2 characterizes the FENEs where both platforms are active.

![Figure 2.2: Structure of platform membership when both platforms are active](image)

**Figure 2.2:** Structure of platform membership when both platforms are active

**Lemma 2.2:** Under any FENE with both platforms active, and Platform $j$ on top, the equilibrium platform prices, demands, profits, the consumer surplus and the total surplus are given by ($i, i' = \{b, s\}; i \neq i', (j, j' = \{1, 2\}; j \neq j)$:

\[
p_{ij}^* = \frac{8N_t(t_j^2 - t_j)}{(8t_j - t_j)^2}; \quad D_{ij} = \frac{4N_t}{(8t_j - t_j)}; \quad \pi_j = \frac{64N_bN_s t_j^3 (2t_j - t_j)}{(8t_j - t_j)^3};
\]

\[
p_{i'j}^* = \frac{2N_t t_j (2t_j - t_j)}{(8t_j - t_j)^2}; \quad D_{ij} = \frac{2N_t t_j}{(8t_j - t_j)}; \quad \pi_{j'} = \frac{8N_bN_s t_j^3 t_j (2t_j - t_j)}{(8t_j - t_j)^3};
\]

\[
CS = \frac{8N_bN_s t_j^3 (8t_j + 5t_j)}{(8t_j - t_j)^3};
\]
While there are two possible FENEs where both platforms are active, Lemma 2.3 establishes that the *Inferior-on-Top* outcome is only feasible for a limited range of technology asymmetry (\(r\)) values when Platform 2 is not significantly inferior to Platform 1.

**Lemma 2.3:** While the *Superior-on-Top* FENE is feasible for any value of \(r \in (0, 1)\), the *Inferior-on-Top* FENE is only feasible for \(r \geq 1/2\).

In the standard vertical differentiation models (e.g., [10, 81]), the higher quality firm always serves the top end of the market. In our model, the effective “quality” is a function both of the exogenous technology level as well as the endogenous network size. Under the right set of expectations, the inferior technology firm can, therefore, become the “higher quality” firm if it has a larger network, thereby leading to the Inferior-on-Top FENE. However, this gets increasingly difficult as Platform 2’s technology disadvantage increases, and Lemma 2.3 establishes that it is not feasible when \(r < 1/2\). Even where it is feasible, the Inferior-on-Top FENE always results in a smaller industry (Platform 1 + Platform 2) profit than the Superior-on-Top outcome.

Therefore, the Inferior-on-Top FENE is feasible, and non-Pareto-dominated, only for a subset of the parameter range (for higher values of \(r\)). Further, from a practical perspective, while it is certainly possible for an inferior technology platform to create expectations of a larger network size, we believe that in most markets, the superior technology platform is better placed to do so. Therefore, going forward, we will focus our analysis only on the Superior-on-Top FENE. This also enables us to maintain consistency, as we explore potential collaboration in the next section. As will be discussed later, collaboration is generally only feasible at the lower range of \(r\) values,
and the Inferior-on-Top FENE is not feasible at all in the collaboration scenarios analyzed.

Before concluding our discussion of possible outcomes, it is important for the sake of completeness to state that a FENE with only a single active platform (the superior technology one) is also possible at low values of $r$. Lemma 2.4 establishes this result. However, from a practical perspective, this outcome is once again less interesting because it effectively negates any significant effect of competition, and therefore, scope for collaboration, which is our primary focus in this paper.

**Lemma 2.4**: For $r \leq 1/2$, there also exists a FENE where only the superior technology platform is active, with the equilibrium outcomes in this case corresponding to those of the asymmetric monopoly equilibrium.

### 2.4.1 Analysis of the competitive equilibrium

In this subsection we examine the competitive outcomes more closely. As stated earlier, our sole focus going forward will be the Superior-on-Top FENE where both platforms are active. In the resulting equilibrium, described in Lemma 2.2 with $j = 1$ and $\hat{j} = 2$, the superior technology platform charges much higher prices to both sides than the inferior technology platform ($p_{11}^*/p_{12}^* = 4t_1/t_2$), but still has twice the market share, and makes substantially more profits ($\pi_{11}^*/\pi_{22}^* = 8t_1/t_2$). Thus, while the outcome may not be a “winner-take-all” in terms of market shares, it is perilously close to that in terms of profit shares. Compared to the monopoly case, the overall market coverage is higher ($D_{11} + D_{12} > D_{IM}$), the overall combined platform profit is lower ($\pi_{11}^* + \pi_{22}^* < \pi_{M}^*$), the consumer surplus and the total surplus both are lower.

Comparative statics of market shares, equilibrium prices, and profits are described in the following proposition.
**Proposition 2.2:** With both platforms active, and Superior-on-Top, as $t_2/t_1$ increases:

a) Equilibrium demands of both platforms increase on both sides of the market. In the limit, as $t_2 \to t_1$, the total coverage approaches $6/7^{th}$ of the total market, but relative market shares remain unchanged.

b) Prices decrease for the superior platform, while they increase for the inferior platform.

c) Profits decrease for the superior platform, while they increase for the inferior platform. However, for any value of $t_2/t_1 \in (0,1)$, $\pi_1^* / \pi_2^* > 8$ and $\pi_1^* / \pi_M^* = 256/343 > 0.7464$.

d) The consumer surplus and the total surplus both increase.

A decrease in technological asymmetry, i.e., an increase in $(t_2/t_1)$, reduces Platform 1’s differentiation vis-à-vis Platform 2. To mitigate this effect, Platform 1 decreases its price, and also increases the endogenous source of differentiation—its network size. Nevertheless, Platform 1 suffers some profit erosion, while Platform 2 improves its profits, thereby reducing the profit ratio between the two platforms. Despite this improvement in profit of Platform 2, the profit difference continues to be large, and Platform 1’s profit share remains $8/9^{th}$ of the total platform profit even as $t_2 \to t_1$. Further, as $t_2 \to t_1$, $\pi_1^* / \pi_M^* \to 256/343 \approx 0.7464$, that is, even when the difference in the two platform technologies is negligible, the ‘superior’ platform makes almost 75% of the profits of a monopoly platform.

The relative resilience of the superior platform’s profits to changes in the inferior platform’s technology is interesting. As $t_2 \to t_1$, the two platforms are more or less homogeneous from a technological perspective, making the network size the only meaningful differentiator. This disparity in network sizes enables the superior platform to convert a very small technological advantage into a dramatic asymmetry in profit shares. This result is consistent with similar observations in the literature of
one-sided network markets [27], and highlights the importance of managing expectations in network markets. With very similar technologies, the platform with a slight technological advantage, which can credibly create expectations of a larger network, ends up dominating the market and captures the bulk of the profits. In fact, as the proposition shows, in this case, the dominant duopoly platform is not much worse off than it would be in the absence of competition.

2.5 Platform collaboration

Having analyzed open platform competition in the previous section, we now turn to an exploration of the potential for collaboration between platforms. Three different forms of collaboration are considered. The first two involve the platforms sharing/interconnecting their networks, thereby enabling members of one platform to transact with members of the other. Both direct and indirect access to each other’s networks will be considered. The third form of collaboration involves the superior technology firm licensing its technology to its rival. In all of these cases, we will investigate if collaboration increases the overall industry profits, thereby providing opportunities for mutual benefit through appropriate contracting. We should emphasize, however, that collaboration in our analysis does not mean collusion, as the firms continue to play a non-cooperative game in prices even when they collaborate along other dimensions.

2.5.1 Collaboration through network sharing

In this section, we consider the case of network sharing/interconnection where members of one platform can access members of the second. For instance, in 2009, Microsoft and Yahoo reached an agreement to share their advertising platforms. Advertisers on each site can access the other’s properties. (They also agreed that Bing, which had the superior search technology at that point, would serve as the search service provider for the Yahoo site as well, but we consider technology sharing in the next section. For now, the technologies of the two platforms still remain independent.)
In the absence of an external mandate, interconnection generally requires the consent of both platforms. Here, we start by assuming that the platforms are interconnected, and analyze the resulting equilibrium in order to identify conditions under which platforms have an incentive to interconnect. With interconnection, while the utility from a transaction between two members of the same platform remains the same as before, the utility from a cross-platform transaction (i.e., transaction between members of different platforms), may in general depend on the technologies of both platforms. In particular, we use \( \gamma_1(t_1, t_2) \) and \( \gamma_2(t_1, t_2) \) to represent the “effective” cross-platform technologies experienced by members of platforms 1 and 2, respectively. The utility to a customer on side \( i \) on platform \( j \) \( (j,j \in \{1,2\}; j \neq j; i \neq i) \) is given by:

\[
U_{ij}(\theta_i; n_{t1}, n_{t2}) = \theta_i t_j n_{ij} + \theta_i \gamma_j(t_1, t_2)n_{ij} - p_{ij}.
\] (2.5)

In the absence of interconnection, \( \gamma_1 = \gamma_2 = 0 \), and (2.5) is identical to (2.1). Lemma 2.5 characterizes the equilibrium outcomes assuming that the platforms are interconnected. Note that \( \gamma_1(t_1, t_2) \) and \( \gamma_2(t_1, t_2) \) have been shortened here to \( \gamma_1 \) and \( \gamma_2 \) respectively to simplify notation.

**Lemma 2.5:** When the platforms are interconnected, the equilibrium prices and demands for side \( i \), \( (i, i \in \{b, s\}; i \neq i) \), overall platform profits, the consumer surplus, and the total surplus are given by:

\[
p^*_i = \frac{2(N_i)(2t_1 + \gamma_1)^2(2t_1 - t_2 + \gamma_1 - 2\gamma_2)}{(8t_1 - t_2 + 4\gamma_1 - 2\gamma_2)^2}; \quad D_i = \frac{2N_i(2t_1 + \gamma_1)}{(8t_1 - t_2 + 4\gamma_1 - 2\gamma_2)};
\]

3 If one party unilaterally interconnects (say through the development of a one-way converter), the other can typically take recourse to legal action or alter its technology to make the converter ineffective. Apple took the latter path when Real Networks developed a converter enabling iPod owners to access its music store (http://money.cnn.com/2004/07/29/technology/apple_real/)
Lemma 2.5 establishes that, in equilibrium, the platform with the superior technology continues to serve a larger share of the market (directly) than the inferior platform \((D_{l1} = 2D_{l2})\), generally sets a higher price \((p_{l1}/p_{l2} = 2(2t_2 + \gamma_1)/(2\gamma_2 + t_2) > 1\) unless \(\gamma_1 \ll \gamma_2\)), and earns a larger profit \((\pi_1/\pi_2 = 4(2t_2 + \gamma_1)/(2\gamma_2 + t_2) > 1\) unless \(\gamma_1 \ll \gamma_2\)).

In the next two subsections, we consider the cases of direct and indirect interconnection respectively. In the indirect access case, the cross-platform interaction experience is potentially affected by both technologies. Different cases of how the cross-platform experience is determined by the two technologies are considered and incentives for strategic partnership are explored. The general conclusion from these analyses is that access to a larger network increases the value to customers, but its profitability depends on the platforms ability to differentiate themselves.

2.5.1.1 Platforms share networks only—direct access to network

Here, we consider direct interconnection. With direct interconnection, each platform shares its database of customers with its competitor and provides them direct
(non-mediated) access to their networks. For example, this would be the case if Yahoo and Microsoft were to share with each other their advertisers’ network and the content providers’ network, but, they did not share the technology that matches the advertisement with the content site or any other technology related to contextual advertising. In this case, the cross-platform experience is unaffected by the other platform’s technology. Therefore, this is equivalent to specifying \( \gamma_j(t_1, t_2) = t_j \) for \( j = 1, 2 \) in Lemma 2.5.

**Lemma 2.6:** When platforms provide direct access to each other’s customers, the equilibrium prices and demands for side \( i \), \( (i, \bar{i} = \{b, s\}; i \neq \bar{i}) \), overall platform profits, the consumer surplus, and the total surplus are given by:

\[
\begin{align*}
p^*_i &= \frac{6N_i t_1^2 (t_1 - t_2)}{(4t_1 - t_2)^2}; \\
D_{i1} &= \frac{2N_i t_1}{(4t_1 - t_2)}; \\
p^*_{i2} &= \frac{3N_i t_1 t_2 (t_1 - t_2)}{(4t_1 - t_2)^2}; \\
D_{i2} &= \frac{N_i t_1}{(4t_1 - t_2)}; \\
\pi^*_i &= \frac{24N_b N_s t_1^3 (t_1 - t_2)}{(4t_1 - t_2)^3}; \\
\pi^*_2 &= \frac{6N_b N_s t_1^2 t_2 (t_1 - t_2)}{(4t_1 - t_2)^3}; \\
CS &= \frac{8N_b N_s t_1^3 (8t_1 + 5t_2)}{(8t_1 - t_2)^3}; \\
TS &= \frac{8N_b N_s t_1^2 (24t_1^2 - t_1 t_2 - t_2^2)}{(8t_1 - t_2)^3}.
\end{align*}
\]

**Proposition 2.3:** When platforms provide direct access to each other’s customers, higher values of \( t_2 / t_1 \) are associated with:

(a) higher equilibrium demands for both platforms on both sides of the market,

(b) lower prices for the superior platform, but a non-monotonic change in price for the inferior platform (prices for the inferior platform initially increase, but decline thereafter),

(c) a non-monotonic change in profit for the inferior platform (it initially increases, but declines thereafter), and
(d) increase in both the consumer surplus and the total surplus.

Figure 2.3 depicts the equilibrium prices and profits as \( r = \frac{t_2}{t_1} \) is varied over \((0, 1)\). The comparative statics of demand with respect to \( r \) are similar to those in the open competition case (Proposition 2.2), but the effect on prices and profits is different and interesting. As the tech asymmetry between platforms decreases, the inferior platform’s prices and profit initially rise before dropping. Unlike the case of open competition, here the platforms are substitutes as well as complements, as a larger network size for each also benefits the other. With direct interconnection, the two platforms are undifferentiated in terms of network sizes leaving technology as the only differentiator. As parity increases, at some point, the gain in price and profits due to improved value is overpowered by the pricing pressure due to reduced differentiation, leading Platform 2’s price and profit to be non-monotonic. Higher tech parity beyond a point pushes the platforms closer towards undifferentiated Bertrand competition causing the prices to fall to their marginal costs, i.e., zero.

![Figure 2.3: Comparative statics of equilibrium prices and profits under direct access](image)

The results derived above, along with those in Section 2.4, can now be used to identify opportunities for fruitful collaboration between platforms. To do so, we compare the equilibrium profits in the network sharing case, with the corresponding ones in the open competition case, and identify conditions under which profits can be
improved through collaboration. This general methodology will be followed in the rest of this section (and the next one). Further, to make such comparisons analytically feasible, we fix the value of $t_1$ at 1 and allow $t_2$ to vary over $(0, 1)$. Details of specific contracts written to implement the strategic partnerships are beyond the scope of this paper, and we limit ourselves to identifying conditions under which such contracting may be feasible. Proposition 2.4 identifies these conditions for the direct interconnection case.

**Proposition 2.4:** Collaboration through direct interconnection is:

(a) *pareto optimal*, for $(t_2/t_1) \in (0, 0.67)$,
(b) *feasible*, through transfers from Platform 2 to Platform 1, for $(t_2/t_1) \in [0.67, 0.71]$,
(c) *not feasible* for $(t_2/t_1) > 0.71$.

[Note that the values specified are rounded to the 2nd decimal place]

Figure 2.4 compares the corresponding platform profits with and without direct network sharing and establishes the intuition for the result. The horizontal axis depicting technology asymmetry is broadly split into three regions. In the first region, both platforms’ profits under direct sharing are higher than the corresponding profits under open competition. Therefore, sharing is a dominant strategy for both platforms in this region. The additional profits from network sharing are due to increased customer value through the added network effects from accessing each other’s networks. In Region 2 (Regions 2A and 2B combined), while Platform 2’s profit under sharing is still higher, Platform 1’s profit is lower than the open competitive case. Network sharing between the platforms cannot happen unless Platform 1 is compensated through appropriate transfers. Within Region 2, the total combined profits (of both platforms) in the sharing case are higher than the open competition case in Sub-Region 2A, while they are lower in Sub-Region 2B. Therefore, contracting for direct network sharing through appropriate transfers from Platform 2 to Platform 1 can result in Pareto improvement in Region 2A, and is hence feasible.
there. Such contracting is infeasible in Region 2B and in Region 3 (where both platforms’ profits under sharing are lower than the corresponding ones under direct competition). Although voluntary sharing in Region 2B is not feasible, here the inferior platform has an incentive to unilaterally build a converter of some kind. However, this arrangement generally poses both technological and legal (related to intellectual property) problems as noted earlier.

In summary, direct network sharing is most feasible when the degree of asymmetry between the technologies is high. In industries where the technology is maturing, the leader might find it difficult to sustain a significant superiority. Therefore, in such industries, network sharing might be time limited.
Figure 2.4: Profit comparison between direct access sharing and open competition
2.5.1.2 Collaboration through mediated/indirect network Access

We now turn to the case where the platforms interconnect, but do not allow the members of one platform to access the other’s members directly; rather, cross-platform transactions are routed through both platforms. Consequently, the utility of agents on each platform potentially depends on the technologies of both platforms. We consider three prototypical cases for the cross-platform technology experience function, \( \gamma_j(t_1, t_2) \). Our assumption in considering these cases is that the cross-platform technology experience is likely to be no worse than the experience provided by the inferior technology alone, and no better than that provided by the superior technology alone. Clearly, these are not the only possible cases, but we believe that this set provides a good representation for analysis. The three cases we analyze are:

\[
\begin{align*}
\gamma_j(t_1, t_2) &= \text{Min}(t_1, t_2), \\
\gamma_j(t_1, t_2) &= \text{Avg}(t_1, t_2), \\
\gamma_j(t_1, t_2) &= \text{Max}(t_1, t_2).
\end{align*}
\]

Analysis follows a path similar to that in the previous subsection, and conditions for profitable indirect network sharing are identified. Proposition 2.5 specifies these conditions for the different cases of the cross-platform technology experience. (As before the value of \( t_1 \) is fixed at 1).

**Proposition 2.5:** Collaboration through indirect network sharing is:

(a) pareto optimal,

\[
\{(t_2/t_1) \in (0,0.30) \text{ when } \gamma_j(t_1, t_2) = \text{Min}(t_1, t_2) \}
\]

\[
\{(t_2/t_1) \in (0,0.09) \text{ when } \gamma_j(t_1, t_2) = \text{Avg}(t_1, t_2) \}
\]

(b) feasible, through transfers from Platform 2 to Platform 1,

\[
\{(t_2/t_1) \in [0.30, 0.45] \text{ when } \gamma_j(t_1, t_2) = \text{Min}(t_1, t_2) \}
\]

\[
\{(t_2/t_1) \in [0.09, 0.30] \text{ when } \gamma_j(t_1, t_2) = \text{Avg}(t_1, t_2) \},
\]

\[
\{(t_2/t_1) \in (0 , 0.01) \text{ when } \gamma_j(t_1, t_2) = \text{Max}(t_1, t_2) \}
\]

(c) not feasible other values for \( t_2/t_1 \).

(Note: All values are rounded off to 2 decimal places)
The structure of the results here is similar to that depicted in Figure 2.4, although the specifics are a little different, and the results in this case qualitatively mirror those in the direct network access case—interconnection is most likely when the platform technologies are significantly asymmetric, and opportunities for collaboration decrease with increasing tech parity. Potential for collaboration also decreases as the cross-platform technology experience improves (from Min, through Avg to Max), and collaboration is almost impossible when the cross-platform experience closely mirrors that of the superior technology platform’s intra-platform experience.

In deriving the results in Proposition 2.5 we deliberately kept the cross-platform experience symmetric for both platforms to avoid complicating the parameter space. However, some numerical analyses we conducted revealed that asymmetries in the cross-platform experience can affect the results. A better cross-platform technology experience for members of Platform 1 makes interconnection more likely, whereas, the same for members of Platform 2 makes it less likely. This finding is consistent with our earlier results because an improvement in $\gamma_1$ increases Platform 1’s differentiation vis-à-vis Platform 2, while an increase in $\gamma_2$ decreases it.

2.5.2 Technology licensing—technology sharing without network sharing

In this section, we consider the case where platforms do not share their networks but the superior technology platform licenses its technology to the inferior platform. The customers of both platforms experience the better of the two technologies, but can only interact with customers on their own platform. The equilibrium outcomes can be obtained by evaluating the equilibrium outcomes of the open competition case specified in

Lemma 2.2 for $t_2 = t_1$.

Lemma 2.7: When platforms do not share network and the platform with superior technology licenses its technology to the other platform, the equilibrium platform prices and demands for side $i$, $(i, \hat{i} = \{b, s\}; i \neq \hat{i})$, overall platform profits, the consumer surplus, and the total surplus are given by:
The equilibrium outcomes are similar to those of open competition with no network sharing, except for the fact that members of both platforms enjoy the better of the two technologies. Note that even though both platforms have identical technologies, the outcome is not symmetric. This is because, although there is no ex-ante (exogenous) differentiation between the two platforms, the different network sizes (driven by different expectations) create an endogenous source of differentiation. To derive the results here, we assume that Platform 1, which is the licensor, is expected (by consumers) to have the larger network leading to an asymmetric outcome.

To check for the possibility of a technology licensing agreement of this sort, we compare the total profits of the two platforms with technology licensing to those without it.

Proposition 2.6: When platforms do not share network, technology licensing by the platform with the superior technology to the platform with the inferior technology is not optimal.

The comparative statics of the total industry profits with and without tech licensing are depicted in Figure 2.5. First of all, note that the industry profits under technology licensing are unaffected by $t_2/t_1$ since both platforms now incorporate $t_1$. Further, total profits under licensing are always lower than those under open competition, and therefore, Pareto improvements for the platforms are impossible with tech licensing. This outcome is not surprising since tech licensing decreases platform differentiation to the lowest level of all the cases we have considered and is
hence most destructive to industry profits. It is possible that licensing can in some cases work as a price coordination mechanism, enabling firms to mitigate competition in that fashion, but that is outside the scope of our current analysis.

![Figure 2.5: Total profits of Platforms 1 and 2, with and without technology licensing](image)

2.6 Competition in the presence of an installed base

The model we have analyzed thus far is a static model, one that focuses on outcomes in a single time period, while most real-world platform markets are dynamic, i.e., they evolve over time. Despite this nature of two-sided markets, dynamic models are rare in the literature because they pose severe tractability problems. In this section we extend our model through the introduction of an additional parameter to study some of the dynamic issues. While not truly a dynamic model, our analysis nevertheless helps highlight the key issues as they relate to platform competition and partnership.

The most significant difference between a single-period and long-run analysis in network markets is the presence of an installed base. These are customers who have joined the platform in a previous period, but are still active, and therefore, contribute to the network effects associated with platform membership. To focus on this aspect, we consider competition between a platform which has a pre-existing installed base
(of size $n$ on each side), which we call the *incumbent*, and one which does not, which we call the *entrant*. In reality, all competing platforms could have installed bases. However, in those cases, it is typically the *difference between the sizes of the installed bases*, rather than the installed bases themselves, that typically drives competitive outcomes. In that sense our model can be considered a special case where the installed base of the smaller platform has been normalized to zero, and $n$ represents the difference. In general it is also possible for the sizes of the installed bases to be different on the two sides, but we have chosen to keep it symmetric to reduce parameter creep.

Issues of entry into network markets have long been of interest. A key question is when an entrant may be able to overcome incumbent inertia, and successfully enter a network market. For instance, in a recent paper, Zhu and Iansiti [87] find that an entrant may be able to enter a platform market even with a slight technological advantage if the network effects are not too strong. Our focus in this paper is not the feasibility of entry. Rather, we are interested in the effect that installed base has on competition (along with technology) and how it alters the incentives to partner with rival platforms. In general, while it may be possible for an entrant to enter the market with an inferior technology, much of the literature considers this outcome unlikely. Further, even if it were to happen, our analysis in the previous sections provides us with reasonably good intuition for that situation, since from an analytical perspective, the outcomes in that case would be similar to those in the previous sections with the “effective technology” of the entrant adjusted downward to account for the installed base disadvantage. Thus, the profit outcomes in this case would be more asymmetric than those in a situation with no installed base, and potential for platform interconnection would be correspondingly higher. Going forward, therefore, we focus on the case where the entrant has a technology advantage, i.e., the entrant will be the superior technology platform.

Since platform value is determined by both network size and technology, technological superiority of the incumbent implies that either platform could have a
higher “effective quality,” and therefore, the effect of the installed base on outcomes is non-obvious. Following the terminology from Section 2.4, both Entrant-on-Top and Incumbent-on-Top outcomes are feasible. The next two Lemmas specify the conditions under which these two equilibriums are feasible under open competition without collaboration, and the corresponding market outcomes. In arriving at these equilibriums, we assume that while the installed base contributes to customer utility through network effects, it does not directly contribute to the current period revenues of the platform. Further, maintaining the assumption in Section 2.5, we normalize \( t_1 \) to 1, and therefore, \( r = t_2/t_1 \in (0,1) \). We also normalize \( N_b, N_s \) to 1 to simplify the expressions. This normalization has no qualitative effect on the results beyond scaling the potential market sizes on each side to 1.

**Lemma 2.8:** Entrant-on-Top equilibrium is only feasible when \( n \leq \frac{2-r}{3r} \); The corresponding equilibrium prices and demands for side \( i \), \((i = \{b, s\})\), and overall platform profits, are:

\[
p^*_E = \frac{4(2 + nr)(2 - r - 3nr)}{(8 - r)^2}; \quad D^*_E = \frac{2(2 + nr)}{8 - r};
\]

\[
\pi^*_E = \frac{16(2 + nr)^2(2 - r - 3nr)}{(8 - r)^3};
\]

\[
p^*_I = \frac{2(1 + 4n)r(2 - r - 3nr)}{(8 - r)^2}; \quad D^*_I = \frac{2 + nr}{8 - r};
\]

\[
\pi^*_I = \frac{4(1 + 4n)r(2 + nr)(2 - r - 3nr)}{(8 - r)^3}.
\]

In the above, \( E \) stands for Entrant, and \( I \) for incumbent. Thus, when the incumbent’s installed base is sufficiently small, the entrant can obtain larger market and profit shares than the incumbent. Both market shares increase with the size of the installed base. Further, the threshold \( \left( \frac{2-r}{3r} \right) \) is decreasing in \( r \), which implies that a larger installed base for the incumbent will require a greater technological superiority from the entrant to be on top.
Lemma 2.9: Incumbent-on-Top equilibrium is only feasible when $n \geq \frac{1-2r}{3r}$ or $r > \frac{1}{2}$; The corresponding equilibrium prices and demands for side $i$, $(i = \{b, s\})$, and overall platform profits, are:

\[
\begin{align*}
\pi_E^* &= \frac{(r - 2nr + A)B}{C}; \\
\pi_i^* &= \frac{2rDB}{C}; \\
D_i &= \frac{2r - 2nr + A}{8r - 1}; \\
\pi_i^* &= \frac{8r^2D^2B}{C}; \\
\end{align*}
\]

where $A = \sqrt{r(1 + 2n)^2 - nr}$; $B = (2 + 4n)r^2 - A + r(n - 1 + 2A)$; $C = (8r - 1)^3(r + 2nr + A)^2$; $D = (n(4r - 1) + 2(r + A))$; $E = (5 + 40r - 96r^2 + 256r^3)$; $F = (6n^2 + 2r(5 + 8r))$.

As before, $E$ = Entrance, $I$ = Incumbent. The Lemma implies that it is possible for the incumbent to maintain a dominant position in the market when the entrant does not offer a sufficiently superior technology or when the existing installed base is sufficiently large. Here, the additional network effect from the installed base compensates for the technological inferiority.

Combining conditions from the two Lemmas (Lemma 2.8, Lemma 2.9), the following parameter set provides the space where both types of equilibriums are feasible: \(\left\{ (n, r): \left(\text{Max}(0, \frac{1-2r}{3r}) \leq n \leq \frac{2r}{3r}\right) \right\}\). Qualitatively this is the region where neither the entrant’s tech superiority, nor the incumbent’s installed base, is sufficiently high to provide a decisive advantage.

2.6.1 Analyzing the potential for partnership

The analysis in this section parallels that in Section 2.5. When the incumbent’s and entrant’s networks are interconnected, either directly or indirectly, the utility to a customer of type $\theta_i$ on side $i$, $(i, i = \{b, s\}; i \neq i)$, on the incumbent (Platform 2) and entrant (Platform 1) platforms are respectively given by (Recall: $t_1 = 1; r = t_2/t_1 \in (0, 1)$):
When customers on each platform can access members of the other platform, the network sizes of both platforms are identical, and the only source of differentiation is the access technology. Therefore, so long as the cross-platform experience of the superior technology platform (the entrant) is no worse than that of the inferior technology platform (the incumbent), an incumbent-on-top equilibrium is not feasible. The following Lemma formalizes this insight.

**Lemma 2.10:** An Incumbent-on-Top equilibrium is not feasible with network interconnection.

Note that Lemma 2.10 does not negate Lemma 2.9. Even though the incumbent-on-top equilibrium cannot arise with interconnection, it can still be the outcome in the open competition case when the necessary conditions are satisfied. Solutions corresponding to those in Lemma 2.8 can be derived for the only feasible equilibrium under interconnection, the Entrant-on-Top equilibrium. The expressions specifying the outcomes are algebraically very cumbersome and devoid of any intuition. So, they are omitted here; however, we provide an outline to compute the equilibrium outcomes in the appendix under the subsection “Entrant-on-top equilibrium with network interconnection.” Conditions supporting network sharing are identified by comparing the profits under the interconnection and open competition in different cases, and are graphically illustrated in Figure 2.6. The primary insight is summarized in the following observation.

**Observation 1:** A larger installed base for the incumbent platform, and high degree of technology asymmetry, make network sharing, both direct and indirect, more likely.
Since there are two possible equilibriums in the open competition case, the appropriate sets of profits are used for comparison with the interconnection case, based on their regions of feasibility. In our discussion below, we focus on the case of indirect network access, where the cross-platform technology experience is equivalent to the average technology level of the two platforms. The qualitative insights carry over to the other cases discussed in Section 2.5. The results are presented in Figure 2.6. Tech asymmetry parameter $r$ is varied along the x-axis, and the installed base parameter along the y-axis. Note that the installed base is scaled by the value of the total current market size to yield a value between 0 and 1.

Let’s start with Regions 4, 5, and 6 in the figure. Together, these represent the region where $n \geq \frac{2-r}{3r}$, i.e., the part of the parameter space where Incumbent-on-Top is the only feasible equilibrium under open competition. Comparing these profits with the corresponding ones under interconnection, we find that interconnection results in no improvement in profits for the incumbent in any of the Regions 4, 5, or 6. In
Regions 4 and 5, however, the entrant makes higher profit under interconnection. In Region 4, the combined profit of the two platforms is higher with interconnection. Taken together, these imply that: (i) Interconnection is never Pareto optimal in Regions 4, 5 and 6; (ii) it can be implemented through transfers from the entrant to the incumbent in Region 4; and (iii) it is infeasible in Regions 5 and 6. Region 4 has the right sweet spot in terms of a high installed base, as well as sufficient technological asymmetry for mediated network interconnection to improve overall industry profits without completely dissipating them through increased competition.

Regions 1, 2A, 2B, and 3 represent the part of the parameter set where the Entrant-On-Top equilibrium is feasible in the open competition case. These profits are compared to those under interconnection to establish potential for network sharing. Focusing first on the horizontal axis, where $n = 0$, the boundaries between Regions 1, 2A, 2B and 3 correspond exactly to those in Figure 2.4 in Section 2.5 with a similar interpretation. (i) In Region 1 network sharing is Pareto optimal; (ii) In Region 2A, network sharing is feasible with appropriate transfers from the incumbent to the entrant; (iii) In Regions 2B and 3, network sharing is not feasible even with transfers. Figure 2.6 further shows that the boundaries of Regions 1 and 2A curve to the right with an increase in $n$, the incumbent’s installed base, thus making network sharing more likely even for higher values of $r$. This outcome is not surprising, since utility increases more with interconnection in the presence of a larger installed base.

Turning now to the possibility for collaboration through technology licensing, the following observation establishes the primary insight. Details are once again messy and hence excluded.

**Observation 2:** The likelihood of technology licensing increases with the incumbent’s installed base.

The outcome following a technology licensing partnership is almost always an incumbent on top equilibrium (unless the installed base is very low, in which case,
either equilibrium is feasible). If the corresponding equilibrium under open competition is also incumbent-on-top, then technology licensing is Pareto optimal. If the open competition outcome is entrant-on-top, then technology licensing may be feasible with transfers from the incumbent to entrant, but is not guaranteed. As the installed base increases, the chances of an incumbent-on-top outcome increases in the open competition case, and hence the likelihood of technology licensing also increases.

2.7. Conclusion and discussion

In this paper, we have focused on the role that technology plays in shaping competition between platforms, and their incentives for collaboration. A number of clear and interesting insights were derived which find good anecdotal support in real platform markets, especially the online advertising network market, which has been one of our main motivating examples. In concluding this paper, we highlight the main results, discuss some of their implications, and robustness of our results, and identify some potential extensions.

Outcomes under open competition are lop-sided with respect to demands and prices, but even more so with respect to profit shares. Even small technology advantages can translate to a near order-of-magnitude difference in profits. Such outcomes, while not uncommon in the literature on network markets, throw useful light on why Google has been such a dominant player in the online advertising market despite significant technological advances by Yahoo, its nearest competitor. By some counts Google gets about 75 to 80% of the profit share in this market. Interestingly, our results on collaboration suggest that acknowledging its inferiority and playing ball might be more beneficial to the less valuable platform, than taking the leader head on.

Collaboration through network sharing, whether direct or indirect, seems to be the most likely form of partnership in these markets. Between these two, direct network sharing, which preserves technology based differentiation, seems to have the most potential to arise as a “natural” outcome, where both parties have unambiguous
incentives to enter into a sharing relationship, so long as there is a reasonable degree of tech asymmetry between the platforms. In this context, tech parity, either because of improvements by the inferior platform, a maturing of the industry or due to a move to standardization, is likely to reduce such opportunities. Opportunities are also lower when network sharing involves mediation by both platforms. Direct and indirect network sharing also seems to arise spontaneously when a significantly technologically superior neophyte enters the industry with a large incumbent. The partnership between Microsoft and Yahoo in online advertising networks may be an instance of this tendency in action. It may also make the incumbent more accommodating of market entry, although this aspect has not directly been analyzed in our model.

Our analysis of technology licensing indicates that it is unlikely to be observed in the early stages of platform markets (when no platform has an installed base). The superior technology firm has little incentive, monetary or strategic, to bring its rival up to parity in these cases. Licensing has most potential, when a significantly technologically superior entrant faces an incumbent with a large installed base. Licensing its technology, while potentially denying the entrant a chance to become the leading player, can have some benefits. It can soften competition with the dominant firm, and potentially ease financial burdens through upfront licensing fee receipts. By enabling the large number of incumbent platform members to enjoy the superior technology, this arrangement can also create customer (and social) value.

While the simple analytical framework, and our sharp focus on the role of technology and its impact on competition and collaboration, have enabled us to derive interesting results, they have also limited our analysis in many ways. First, our results have been derived in the context of a very specific utility function, and customer distribution, which give rise to linear demand curves. Despite this assumption, we are confident that our insights will qualitatively extend to more general, but regular, demand functions as none of our results are knife-edged or particularly sensitive to small changes in assumptions. Further, our analysis of the model with an installed
base (which has an effect similar to an inherent, non-network, value to some extent), reveals that our assumption of a pure network good is not particularly problematic. However, the static nature of our model may limit the applicability of our results in multi-period scenarios as extensions to dynamic settings sometimes change the results significantly. Our attempts to extend the setting to a truly dynamic setting quickly became intractable. However, our analysis of the incumbent/entrant setting in Section 2.6 gives us reasonable confidence in the robustness of our insights. We believe that the most likely outcome of successfully analyzing a dynamic extension, if it were possible, would be to moderate the asymmetry of the outcomes, and perhaps, a reduction in the possibility for technology licensing, as the shadow of the future makes this strategy less appealing to the superior firm. Finally, multiplicity of equilibriums is always a problem with these kinds of models. While we have enumerated the different kinds of equilibriums that can arise, we focused the analysis on what we thought was the most reasonable to be realized. However, we acknowledge that expectation formation (detailed analysis of the formation of which was outside the scope of our analysis) can have a huge effect on the equilibrium selected.

A number of fruitful extensions to our analysis can be pursued. We restricted our attention to pure membership pricing by platforms. More complicated pricing schemes including transaction pricing or some combination of the two could be considered. However, our explorations in this regard suggest that this analysis could also get intractable quite quickly. Due to our focus on identifying the potential for collaboration, we have also abstracted away from details of the mechanisms/contracts through which such collaboration can be implemented. Such contracts, apart from effecting monetary transfers, can also potentially serve as price coordination devices possibly increasing the gain from collaboration, but at the same time possibly calling the legality of such relationships into question.
3. Custom Contract and the Role of Group Purchasing Organizations (GPOs) as Information Intermediaries

The concept of group purchasing has existed for decades. The practice initially started with buyers forming a consortium to strengthen their negotiation position using collective bargaining power and aggregate demand, and to save on miscellaneous transaction costs associated with product and vendor search and evaluation, logistics, contract management, etc. Group purchasing is now widely adopted in different forms in a variety of industries, e.g., power and utility sector, construction, healthcare, restaurant supplies, home furnishings, etc. Anand and Aron [2] provide an extensive list of supplier and buyer-sponsored group purchasing entities.

From the procurement perspective, the healthcare industry is highly fragmented, while at the same time hospitals’ materials requirements overlap substantially. The complexity in procurement, potential benefits from economies of scale, and the lack of price transparency in the market made the practice of group purchasing more likely in this industry. In the US healthcare industry, group purchasing is facilitated by the supply chain intermediaries popularly known as Group Purchasing Organizations (GPOs). GPOs do not take direct part in product and payment exchange between hospitals and vendors. These organizations establish contracts with suppliers on behalf of a group of hospitals and act as intermediaries for managing contracts between hospitals and suppliers.4 Healthcare Supply Chain Association (HSCA)

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4 There is another kind of intermediaries that are often talked about in the context of healthcare supply chain are Pharmacy Benefit Managers (PBMs). PBMs act as intermediaries between drug vendors and payors of the drug (patients as well as insurance companies/plan sponsors). Many health plan sponsors offer their members prescription drug insurance and hire PBMs to manage these pharmacy benefits on their behalf. As part of the management of these benefits, PBMs assemble networks of retail and mail-order pharmacies so that the plan sponsor’s members can fill prescriptions easily and in multiple locations. PBMs are believed to negotiate volume discount when more patients/insurance companies enroll with them. PBMs’ service also include automatic checks on whether: (a) there will be interactions with other pharmaceutical products the consumer may be taking, (b) a generic version of the prescribed drug is available, and (c) enough days have passed before a prescription can be refilled, etc. PBM may or may not be pure intermediary as a PBM may own a pharmacy of its own or be owned by a pharmacy. PBMs could be independent (Medco Health Solutions, Inc., Express Scripts, Inc., and Caremark Rx, Inc.), Insurer-owned (Aetna Inc., Cigna Corporation,
estimates that about 98 percent of U.S. hospitals use GPOs to purchase products.\textsuperscript{5} In 2007 there were over 600 for-profit and non-profit GPOs in the United States. The list of some of the prominent national level GPOs includes Premier, Novation, MedAssets, Amerinet, Health Trust, Consorta, Healthcare Purchasing Partners, GNYHA, Innovatix, etc. In 2008, the combined purchase volume of the six largest GPOs totaled over $108 billion, accounting for almost 90 percent of all hospital GPO contracts (GAO-10-738, August 2010).

The economics of volume discounting and collective bargaining power suggest that larger aggregate demand would imply lower product prices. They also imply that an individual buyer is better off purchasing supplies as part of a group rather than on its own. A number of empirical studies based on surveys of hospitals’ procurement specialists claim that GPOs indeed generate cost savings for members (e.g., [12, 16, 41, 75]). However, there is also evidence to the contrary, showing that GPO contracts do not always offer the most competitive prices to member hospitals, and that member hospitals do not always purchase their supplies using GPO contracts. For example, a study by the Government Accountability Office (GAO) in 2002 (GAO-02-690T, April 2002) found that GPO prices for items like safety syringes, pacemaker models were in fact higher than the prices outside. A recent study by Litan and Singer \textsuperscript{57} commissioned by the Medical Device Manufacturers Association (MDMA) empirically shows that GPOs fail to secure best prices for their members. Litan and Singer examined a database of aftermarket medical device transactions between 2001 and 2010 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.

A study conducted by Burns and Lee [12] indicated that hospitals sometimes use the GPO price as a starting point and negotiate a lower price with the same GPO vendor making a direct contracting effort on their own. Such contracts established directly between the GPO vendor and the hospitals are commonly known as *custom contracts* where a vendor offers a *custom price* to a particular hospital going below the GPO price. Typically, hospitals become members of a GPO; the GPO negotiates product prices with suppliers on behalf of its member hospitals; member hospitals buy product from vendors as per the contracts established by the GPO. When a member hospital uses a GPO negotiated contract to buy an item from a vendor, the GPO collects from the vendor a percentage of the revenue as contract administration fees. The fee is designed primarily to cover the GPO’s operating expenses. Interestingly, when a new contract is established between the hospital and the GPO vendor through *direct* negotiation, the GPO does not forfeit its revenue entirely, instead, the GPO collects contract administration fees based on the newly negotiated price. The report by the US Government Accountability Office (GAO-10-738, August 2010) states that all of the 6 largest GPOs in the United States assist their members in establishing custom contracts for some products.

The arrangement of custom contracts raises several questions: first, what role is GPO playing if direct negotiations (custom contracting) are allowed between the GPO vendor and the hospitals? Second, should GPOs allow such practice of custom contracting? Third, who benefits/loses if custom contracting is allowed? To answer these questions, we create an analytical model of B2B procurement. We analyze and present, in detail, the impact of allowing custom contracting from hospitals’, the GPO vendor’s, and the GPO’s point of view when there is uncertainty in the price of a product in the market. We also show how the cost of negotiation for hospitals influences market outcomes. Finally, we comment on GPOs’ new role as information intermediaries in the context of our analysis.
We find that the GPO membership generates non-negative cost savings for all hospitals with as well as without custom contracting. However, overall savings are lower when custom contracting is allowed. Our analysis suggests that, the provision for custom contracts between GPO’s member hospitals and the GPO vendor benefits both the GPO vendor and the GPO. While it may appear that the mechanism allowing all hospitals the flexibility to renegotiate has a potential of additional cost savings by yielding a price lower than the GPO price, the GPO vendor anticipates hospitals’ incentive to renegotiate, and sets a higher GPO price up front. We illustrate how measuring cost savings against GPO price could be misleading.

We model the market price of a product as uncertain, where vendors and hospitals have to engage in a price discovery process (negotiation, request for quotes, reverse auction, etc.) to establish a purchase price. This price discovery process is costly to both hospitals and vendors. By joining a GPO, hospitals get access to the GPO negotiated group purchase price and also save on the cost of price discovery. Some GPO members further explore the market on their own for better price if the expected cost savings from doing so exceed the additional cost of price discovery on their own. Thus, the GPO membership that allows custom contracts provides hospitals with an “option” to buy at the GPO price. Hospitals can either exercise the option or do better through negotiating further on their own. Typically, only small hospitals buy at the GPO price, whereas, hospitals with large demand use the GPO price as a starting point for further negotiation with the GPO vendor. The GPO vendor who anticipates further negotiation sets a high price. As a result, small hospitals end up paying a higher GPO price and large hospitals, even after renegotiation, end up incurring higher cost than what they would have if the provision for custom contracts did not exist.

We also show that an increase in the cost of negotiation for hospitals increases the profit of the GPO vendor. The implication of that is: the GPO vendor would want the cost of negotiation for hospitals to remain high, whereas, any effort by the GPO that
reduces cost of negotiation for the hospitals would be desirable by the GPO’s member hospitals.

The paper is structured as follows: in §3.1 we present a brief overview of the literature; In §3.2 we describe the model; In §3.3 we illustrate the drives of heterogeneity in purchasing behavior among hospitals; In §3.4 we present the analysis on custom contracts and comment on the role of GPOs as information intermediaries; In §3.5 we conclude by summarizing our main results.

3.1 Literature review

The concept of group purchasing exists in different industries under many different names, e.g., group buying, purchasing consortia, cooperative purchasing, collaborative purchasing, etc. The paper by Schoranus [78] has an extensive list of terms that are used to refer to the practice of group purchasing and the alliances that engage in group purchasing. The extant literature on group purchasing broadly falls into three categories: 1) the impact of group purchasing on buyers’ procurement costs and vendors’ profitability 2) formation and stability of purchasing alliances 3) competition and anti-trust issues with group purchasing.

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

There are several works that study procurement cost and vendor strategy for Internet-based group purchasing in a business-to-consumer context (e.g., [2, 17-19, 52, 53]). Kauffman and Wang [53] study bidder behavior in an instance of dynamic pricing where product prices drop as more buyers place their orders. The study finds the presence of positive participation externality effect and significant ending effect in bidding behavior. Anand and Aron [2] explore how sellers may use group-buy mechanism to respond to uncertainty in demand and shows that group-buy scheme is often dominated by simple posted pricing. Chen et al. [18] present a comparative analysis of the seller’s performance under group buying auction and fixed price mechanism. The study shows that group buying auction outperforms fixed price mechanism when there exist economies of scale or the seller is risk seeking. Chen et
al. [17] show how online group-buying auction mechanism on the internet can produce higher welfare for participants. Kaufmann et al. [52] experimentally study the bidders’ behavior toward uncertainty and risk involved in group-buying auctions. The study indicates that positive textual comments made by the participants about sellers in past auctions and larger number of existing bids enhances perceived trust in the auction initiator and reduce financial risk.

Our focus is on the business-to-business (B2B) procurement. Several aspects of group purchasing in the B2B context have been investigated empirically as well as analytically in the past. By examining data from an action research project of establishing consortium sourcing among several companies, Essig [35] empirically showed that consortium sourcing helps lower transaction costs as well as the number of transactions, and enables members to share a common benefit from lower purchasing prices and better usage of purchasing resources. Schotanus [76] studied practices of cooperative purchasing by different members within the United Nations. Through surveying the members of the United Nations Inter Agency Procurement Working Group, the study finds lower prices and transaction costs, sharing information, and learning to be the most important factors for cooperative purchasing. The study also identifies the lack of opportunity and lack of priority to purchase cooperatively as reasons for not buying together. Tella and Virolainen [83] studied the Finnish machine manufacturing industry and identified cost savings and collection of information on supply markets as two main motives behind purchasing consortia.

Empirical studies of GPO-mediated procurement in the US healthcare industry were conducted by Chapman et al. [16], Burns and Lee [12], Schneller [75], Goldenberg and King [41], Litan and Singer [57], as well as by the Government Accountability Office (GAO). The study by the GAO in 2002 (GAO-02-690T, April 2002) focused on the aspect of cost savings through GPO contracts. Through analyzing prices paid by hospitals, and interviewing hospital, GPO officials and manufacturers, the study concluded that purchasing through GPOs reduced costs; however cost savings were not uniform across all products; price savings differed by
the size of the hospitals but it had no relationship with the size of the GPOs. The study by the GAO in 2003 (GAO-03-998T, July 2003) and 2010 (GAO-10-738, Aug 2010) particularly focused on understanding GPOs’ business practices (contract mechanism, product selections, fee structure, service provided, code of conduct, etc.) of major national GPOs in the US through structured interviews of GPO representatives, GPO customers, and medical product vendors. Analyzing survey data, Burns and Lee [12] found that hospital purchasing group alliances succeed in reducing healthcare costs by lowering procurement costs particularly for commodity and pharmaceutical items. The commodity products are more standardized and hence can be sourced in larger quantities from fewer manufacturers leading to lower unit prices and transaction costs. Schneller [75], and Goldenberg and King [41] surveyed hospitals’ purchasing managers and the latter attributed cost savings primarily to volume discounts through demand aggregation, lowering of administrative costs through economies of scale, savings from the avoidance of duplication of purchasing resources, etc. On the contrary, Litan and Singer [57], by examining aftermarket transactions on medical devices, shows that GPOs fail to secure best prices for their members and GPO member hospitals consistently secure significant savings in aftermarket transactions.

Analytical models include papers by Chipty and Snyder [20] and Inderst and Wey [48]. Both papers focus on how buyers’ bargaining position is affected by the seller’s cost structure. Chipty and Snyder [20] show that buyer merger can enhance buyers’ bargaining position if seller’s gross surplus is concave in total purchase quantity. Inderst and Wey [48] show that if suppliers are capacity constrained or have strictly convex costs, large buyers can obtain more favorable terms from their suppliers. We contribute to this stream of literature by presenting an analytical study of a specific supply chain practice, known as custom contracts, in the context of group purchasing in healthcare in the US. We primarily focus on studying the marginal impact of allowing custom contracts on the cost of procurement and the profitability of the GPO
vendor, and discuss the role of GPOs in this context. To the best of our knowledge our work is the first analytical study on the issue.

**Formation and stability of purchasing alliance:** In a purchasing consortium, member commitment and compliance play a critical role in the stability and the performance of the group. While the practice of custom contracting cannot be labeled as an absolute failure of an alliance, it is certainly an instance of defection from existing GPO contract. There are several survey-based works that study what drives the success or failure of purchasing alliances. The stability is attributed to level of trust and member commitment [25], sensitivity of competitive information among buyers and anti-trust issues [44], level of enforcement of written contracts [21], nature of benefits and supplier relationship [65], etc. The closest theory that may partially explain the custom contracting comes from the literature that studies the mechanism of allocating cost savings among group buying members (e.g., [43, 63, 77, 79]). Schotanus [77] identifies the unfair allocation of cost savings among members as one of the important reasons behind the failure of some consortia. The paper analytically demonstrates different fairness aspects of existing allocation mechanisms (equal pricing, proportional saving, Shapely values, etc.) and presents a case based recommendation for which allocation mechanism to use. Schotanus et al. [79] recognize that equal pricing policy ignores the marginal contribution of each member to other members of the purchasing group. So, it is likely that a member dissatisfied with the allocation of cost savings may find better price elsewhere. However, from these studies it is not clear why buyers (hospitals in our case) would join a GPO despite having an intention to bypass the GPO contract and buy later directly through custom contract from the same vendor. It is also not clear how the price negotiated directly by a GPO member can be lower than what the GPO has negotiated for the group with the same vendor. We contribute to this stream of literature by providing economic rationale behind the practice of custom contracting and draw further insights on GPOs’ role.
**Competition and anti-trust issues with group purchasing:** This stream of literature studies the role of the GPO in driving vendor competition. It includes the study of exclusivity contract or soul sourcing by the GPO (e.g., [22, 32]), anti-trust issues related to collecting administration fees from vendors (e.g., [46, 80]), vendor competition (e.g., [46, 60]), etc. While Marvel and Yang [60] and Hu and Schwarz [46] study duopoly competition between GPO vendors, we study the strategic interactions between single GPO vendor with GPO members when GPO members are faced with a price uncertainty that prevails in the market.

**Supply chain intermediaries and information transparency:** We also contribute to the literature on the role of supply chain intermediaries in influencing information transparency in the supply chain. This issue got more attention with the advent of information technology that made availability, processing, and transmission of information more feasible. Several of the studies focus on the role of Internet or more specifically electronic marketplace as an intermediary between buyers and sellers. Bakos [8] shows how an electronic marketplace can reduce the ability of the sellers to extract monopolistic profits by lowering buyer’s search cost to acquire product and price information in the market. Internet-based digital marketplaces are considered to have the potential to reduce transaction costs, add product and pricing transparency, generate market liquidity, and facilitate bidding by a broad spectrum of potential suppliers in a standardized platform [88]. By studying 19 electronic market places (EMPs), that survived the dotcom crash, Soh et al. [82] found that all EMPs pursuing a low cost strategy had high price transparency and performed poorly; All EMPs that performed well pursued strategies of differentiation, but, interestingly, not all successful EMPs avoided price transparency: Some EMPs succeeded despite enabling high price transparency. Zhu [89] shows that information may not always be beneficial to participants of B2B exchanges, and thus, explain the slower adoption of B2B exchanges. We particularly focus on the B2B procurement. We contribute to this literature by identifying the informational role of GPOs as intermediaries in the healthcare supply chain. We show that, in healthcare B2B purchasing where prices
are not readily available in the marketplace and there is a cost associated with establishing a price, an increase in the cost of negotiation can increase the profit of the GPO vendor. Thereafter, we discuss how uncertainty in product prices can lead to higher expected cost of negotiation and how GPOs can reduce price uncertainty in the market through collecting and aggregating product and price information.

3.2 Model

We consider a single GPO with a number of hospital members, and focus on the procurement of a single product. 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. Hospitals have the option to buy the product from the GPO vendor as well as from vendor(s) outside the GPO. To focus on our primary research question, 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 both the vendor and the hospitals are already part of the GPO, and their membership choice is outside the scope of this paper. In this paper, 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.

The sequence of events, in general, is as follows (also shown in Figure 3.1): In the first stage of the game, the GPO vendor declares the GPO price, \( P_g \), to the GPO (the GPO price is the unit price that the GPO vendor is willing to offer exclusively to GPO members, irrespective of their individual demands.), and then the GPO makes that information available to GPO members; In the second stage of the game, each GPO member, after learning the GPO price, chooses to either buy the product from the GPO vendor at the GPO price, or explore for a better price on their own. Exploring better price could be renegotiating further with the same GPO vendor or it could be buying from the outside vendor if custom contracting with the GPO vendor is not permitted.
We assume that member hospitals are heterogeneous with respect to their purchase quantities for the product. Purchased quantity does not depend on the final price as hospitals must buy their clinical supplies, however hospitals buy from the channel that minimizes their total cost of procurement. The assumptions on the characterization of hospitals’ purchase volumes are formalized below:

**Assumption 3.1 (demand heterogeneity among GPO’s member hospitals):** We assume that hospitals vary in their demands and without loss of generality we label them by their demand sizes. Demands across hospitals range from $q$ to $\bar{q}$. The distribution of demand sizes has the density function $g(x)$ with $\int_{\underline{q}}^{\bar{q}} g(x)dx = 1$. Further, a hospital must procure the needed quantity irrespective of the price.
In an efficient market, buyers know both quality and price of a product. In the market for lemons, buyers know the price of the product but do not know the quality of the product with certainty. However, in healthcare, hospitals have a fair idea of the quality of the product but price information is not readily available to them. Vendors frequently charge some buyers more than they charge others. Besides price discriminating, medical device vendors claim each and every individual medical device price to be a trade secret and often design contracts forbidding hospitals from disclosing the negotiated price to other hospitals, or even to physicians, patients or insurers ([23, 59]) in order to limit comparison shopping by hospitals and also make physicians make device selection without regard to the price. Vendors may not reveal price information publicly, and some require hospitals to sign contracts to not share price information with others hospitals and also not to share the information with surgeons who use the devices. In the absence of strict enforcement of the contract, some third party organizations (e.g., Aspen Healthcare Metrics, ECRI) do collect such price information across the market and share it with hospitals which subscribed to them. However, lately vendors have been enforcing disclosure provision of the contracts either through litigating directly with these third party organizations that collect and disseminates price information (e.g., device maker Guidant Corporation brought lawsuit against Aspen and ECRI in 2004) or using implicit threats to rescind hospital contract and revert back to list price [70]. As a result, the information on current prices is not readily available to prospective buyers. With some particularly expensive supplies such as physician preferred medical devices there can be significant price uncertainty prior to purchasing negotiations [55]. There have been some efforts by the policy makers to promote price transparency in healthcare. Transparency in Medical Device Pricing Act of 2007 (S. 2221) requires manufacturers to report their national mean and median prices for Physician Preferred Items (PPIs) quarterly to the Secretary of Health of Human Services, and further requires Centers for Medicare and Medicaid Services to maintain and publish
disclosed price data on their website; however the act doesn’t call for any price ranges or local information on prices to be disclosed. So, prospective buyers face significant uncertainty about the price they would have to pay if they purchase the product on their own, going outside the GPO arrangement. We model this lack of transparency in the price of a product by specifying a pricing schedule that is stochastically decreasing in volume. Below we formalize our assumptions on uncertainty in the market price of a product.

**Assumption 3.2 (assumption on price uncertainty):** The price uncertainty is a common knowledge to all players. The unit price of a product is random, but contingent on demand size of an individual hospital; let the unit price be \( \tilde{P}(q) \), where \( q \) is the hospital’s demand for the product under consideration; we assume, \( \tilde{P}(q) \) is uniformly distributed with support \([P_L(q), P_H(q)]\), where \( P_L(q) \leq P_H(q) \), and both \( P_L(q) \) and \( P_H(q) \) are decreasing in purchase volume \( q \).

Figure 3.2 depicts the price uncertainty faced by the hospitals. Hospitals are plotted along the horizontal axis in the increasing order of their demands from left to right. The dotted line denotes the expected prices. \( P_H(. ) \) and \( P_L( . ) \) denote the band of uncertainty around the expected price.
In the presence of price uncertainty, the price of a product is established between the hospital and the vendor through different price discovery mechanisms, such as negotiation, request for quotes, reverse auction, etc. Engaging in any of these processes is not costless for the hospitals. Nor is it costless for the vendor to participate in these processes. We assume that these costs associated with price discovery are fixed, and are incurred per transaction, rather than on per item, basis for both the hospital and the vendor. For the sake of simplicity, we generally use the term negotiation to refer to any or all of the above possible mechanisms of price discovery and also 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 3.3 (assumption on the cost of negotiation):** The cost of negotiation is fixed and equals $C_H$ for all hospitals irrespective of their demands, and is incurred
only when a hospital negotiates with the vendor on its own. The cost of negotiation is fixed and equals $C_V$ for the vendor and is incurred only when the vendor participates in a negotiation with the hospital.

The objective of each hospital is to minimize its total cost of procurement, while the objective of the GPO vendor is to maximize its profit. The GPO earns its revenue by collecting contract administration fees from the 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 is regulated by the Safe Harbor provision enacted by the congress. The Safe Harbor 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.” So, given the nature of regulation on the structure of contract administration fees, it would not be too unrealistic to assume that the percentage collected by the GPO is exogenous. Besides, we primarily intend to model the strategic interactions between the member hospitals and the GPO vendor. So, we assume that the percentage value is exogenous and given. The following is our assumption on hospitals’, the GPO’s, and the GPO vendor’s strategic positions.

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6 http://www.supplychainassociation.org/resource/resmgr/research/safe_harbor.pdf (last accessed Feb 13, 2011)
Assumption 3.4 (assumption on hospitals, the GPO, and the GPO vendor): We assume that hospitals as well as the GPO vendor are strategic and risk-neutral. The objective of each hospital is to minimize its expected cost of procurement, whereas, the objective of the GPO vendor is to maximize its expected profit. The GPO earns its revenue by collecting a fraction of the sales revenue from the GPO vendor. We assume the fraction value is exogenous and equals $\lambda$, where $0 < \lambda < 1$.

We assume that after learning the GPO price, hospitals, that use the GPO price or $P_H(\cdot)$, whichever is lower, as a benchmark for negotiation could get a price that uniformly lies between the $\text{Min}\{GPO \text{ Price}, P_H(\cdot)\}$ and $P_L(\cdot)$. We make the following assumption on the expected price, given that the GPO price is known.

Assumption 3.5 (assumption on the expected price after the GPO price is known): We define $E[\tilde{P}(q)|P_g]$ as,

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

The following table summarizes the hospital’s expected procurement cost, the GPO vendor’s expected profit, and the GPO’s expected revenue corresponding to transaction volume $q$.

<table>
<thead>
<tr>
<th>Table 3.1: Costs and revenues corresponding to transaction volume $q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected procurement cost of the hospital</td>
</tr>
</tbody>
</table>
To analyze the marginal impact of custom contracts, we compare the equilibrium outcomes, GPO vendor’s profitability and member hospitals’ procurement costs, under two different pricing regimes—one where custom contracting is allowed, another where it is not. However, before presenting the marginal analysis, we illustrate, in the next section, what drives the heterogeneity in purchasing behavior of hospitals (some hospitals buy at the GPO price and some hospitals renegotiate) using the framework discussed above through an exemplary scenario.

3.3 Illustration of the heterogeneity in hospitals’ purchasing behavior

The heterogeneity in purchasing behavior of hospitals 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 cost savings through further negotiation and the additional cost of such negotiation.

**Lemma 3.1:** Let $f(q) = qP_g - (qE[\bar{P}(q)|P_g] + C_H)$ be the difference between the cost of buying through the GPO at price $P_g$ and of buying directly through renegotiation. The function $f(q)$ is increasing in $q$. 

<table>
<thead>
<tr>
<th>Hospital buys the product at the GPO price, $P_g$</th>
<th>$qP_g$</th>
<th>$(1 - \lambda)(qP_g) - qm$</th>
<th>$\lambda(qP_g)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital negotiates further after the GPO price ($P_g$) is known</td>
<td>$qE[\bar{P}(q)</td>
<td>P_g] + C_H$</td>
<td>$(1 - \lambda)(qE[\bar{P}(q)</td>
</tr>
</tbody>
</table>
Lemma 3.1 implies segmentation: for a certain range of parameters $P_g, C_H$ there exists a hospital with demand $\hat{q}(P_g, C_H) \in [q, \overline{q}]$ such that hospitals with smaller demand levels $q < \hat{q}(P_g, C_H)$ purchase through the GPO, while hospitals with larger demand levels, $q > \hat{q}(P_g, C_H)$ purchase directly from the vendor.

Figure 3.3 illustrates how the purchasing behaviors differ across members of different demand sizes for a given level of price uncertainty, cost of negotiation, and GPO price. Hospitals’ purchase volumes are plotted along the horizontal axis. The leftmost point on the axis represents the hospital with the lowest demand, which is $q$, and the rightmost the highest, which is $\overline{q}$. $L(.)$ and $H(.)$ depict the band of price uncertainty 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 $[P_L(q), P_H(q)]$ given in Figure 3.3 by the line segment $AB$. $E[\bar{P}(.)]$ depicts the expected prior on market price. The GPO price ($P_g$) is the unit price that the GPO vendor agrees to offer to all GPO members without further negotiation and irrespective of their individual demand. $P_g$ is drawn as a horizontal straight line as it is not dependent on the demand of an individual GPO member, and it is deterministic. $E[\bar{P}(.)|P_g]$ depicts the expected market price conditional on $P_g$, that is $E[\bar{P}(.)|P_g]$ is the expected posterior price once the members are informed of the GPO price. As we will see, purchasing behavior of hospitals with different demands vary extensively.
Hospitals in Region A, those with very low demands, will buy using the GPO contract and pay the GPO price ($P_g$) as they do not expect to get a lower price from the outside market (the lowest price they can expect from the market, while buying directly, is still higher than the GPO price).

Hospitals with intermediate demands, those in Regions B and C, expect to get a lower price than the GPO price through further negotiation. However, these hospitals face the tradeoff between getting a lower price through further negotiation and incurring the additional cost of negotiation. It is easy to see that hospitals in Region B, whose demands and expected cost savings are lower than that of hospitals in Region C, will buy at the GPO price ($P_g$), as well, from the GPO vendor. For these hospitals, expected cost savings from further negotiation (the expected savings is
determined by, 1) the demand of the hospital and 2) 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 $q$,

$$qE[\bar{P}(q)|P_g] + C_H \geq qP_g. \quad (3.1)$$

Hospitals in Region C display the most interesting purchasing behavior. These hospitals choose to negotiate further and use the GPO price only as a starting point for negotiations. For a hospital in this region with demand $q$,

$$qE[\bar{P}(q)|P_g] + C_H \leq qP_g. \quad (3.2)$$

For hospitals in Region D, $E[\bar{P}(q)|P_g]$ is same as $E[\bar{P}(q)]$. In this region, hospitals do not seem to realize any direct benefit from GPO membership. So, their GPO membership may seem counter intuitive. However, in practice, such high volume hospitals are likely to be GPO members for the following reasons: 1) the GPO has incentives to get those hospitals on board for free (in practice, we indeed observe GPOs waiving the membership fee for large hospitals) or sometimes even offer additional rebates based on purchase volume so that the GPO can earn a positive net profit through collecting administration fee from the GPO vendor every time any of these hospitals makes a purchase from the GPO vendor, 2) these hospitals may be members of the GPO to buy other products sold through the GPO, 3) these hospitals may also be GPO members in order to obtain other purchasing related services from the GPO, etc.

**Lemma 3.2:** Let $\hat{q}(P_g, C_H)$ denote the demand of the hospital which is indifferent between buying at the GPO price ($P_g$) and exploring price further, then the following are true: $\frac{\partial \hat{q}}{\partial P_g} \leq 0$, $\frac{\partial \hat{q}}{\partial C_H} \geq 0$. 
Lemma 3.2 implies that, ceteris paribus, 1) fewer hospitals buy at the GPO price when the GPO price increases 2) more hospitals buy at GPO prices when the cost of negotiations increases.

In the next section we use equilibrium analysis to get insights into the marginal impact of allowing custom contracts.

3.4 Custom contracts and the role of the GPO as an information intermediary

To analyze the impact of custom contracts on hospitals, the GPO vendor, and the GPO, we first characterize the equilibrium with and without custom contracts. Thereafter, in Section 3.4.1 we present a comparative analysis of the two sets of outcomes to gain insight into the marginal impact of custom contracts on the GPO vendor’s profitability and hospitals’ cost of procurement. We also quantify cost savings for hospitals from GPO membership, with and without custom contracts in comparison to no GPO membership. In Section 3.4.2 we discuss the informational role of the GPO.

Equilibrium outcomes when custom contracting is not allowed

Here, we present the case in which the GPO vendor does not offer custom contracts and/or the GPO does not allow the practice of custom contracting between the GPO vendor and the GPO members once the GPO price has been established. We use this as a benchmark case in order to find the marginal impact of allowing custom contracting. The game sequence is as described in Figure 3.1, except for the fact that the custom contracting is not allowed between any hospital and the GPO vendor in the second stage of the game. A hospital either buys from the GPO vendor at the GPO price or does not buy from the GPO vendor at all.

The GPO vendor does not incur any additional cost of negotiation for any number of hospitals that buy from the GPO vendor at the GPO price. On the other hand, a hospital does not incur any additional cost of negotiation while buying from the GPO vendor at the GPO price but does so while buying from outside vendor(s). The GPO collects contract administration fees based on the revenue received by the
GPO vendor. It is expected that a hospital, that expects to generate more cost saving than the cost of negotiation, will choose not to buy from the GPO vendor and will explore vendor(s) outside the GPO.

The vendor’s expected profit is a function of the price he sets, and is found as

$$V(P_g; C_H, \lambda, m, C_V) = \int_{q}^{\bar{q}} \left( x \left( (1 - \lambda) P_g - m \right) \right) g(x) dx,$$

subject to \( \bar{q} \leq C_H \leq \bar{q} \), so that the maximum profit is

$$\Pi_v(C_H, \lambda, m, C_V) = \max_{P_g} V(P_g; C_H, \lambda, m, C_V),$$

and the profit maximizing price is,

$$P_g^* = \arg\max_{P_g} V(P_g; C_H, \lambda, m, C_V).$$

Hospitals with demand up to \( q^* = \bar{q}(P_g^*, C_H) \) buy from the GPO vendor at price \( P_g^* \).

Hospitals with demand \( x \), where \( q^* \leq x \leq \bar{q} \), do not buy from the GPO vendor.

The resulting GPO revenue is given by,

$$R(C_H, \lambda, m, C_V) = \int_{q}^{\bar{q}} \left( x \lambda P_g^* \right) g(x) dx.$$

**Equilibrium outcomes when custom contracting is allowed**

Here, we present the case in which member hospitals and the GPO vendor are allowed to engage in custom contracting after the GPO price has been made available to member hospitals. The game sequence is as described in Figure 3.1. In the second stage of the game, hospitals either buy the product at the GPO price or choose to explore price further. The hospitals in this case are not barred from negotiating directly with the GPO vendor.

Neither the GPO vendor nor hospitals incur any additional cost of negotiation if transaction occurs at the GPO price; however, both do if they engage in further price negotiation. A hospital, which expects to generate more cost saving than the cost of negotiation, would engage in further negotiation with the GPO vendor or outside
vendor(s). From our discussion with purchasing managers it became evident that even when member hospitals engage in negotiating with outside vendor(s), it is more likely that the GPO vendor wins the business. The GPO vendor usually wins the business for several reasons: 1) the GPO vendor may have a business account with the hospital already; As a result, the GPO vendor will be able to avoid a significant setup cost and will be able to offer a lower price than what outside vendors can, 2) the GPO vendor may have earned extra credibility as it may have gone through product and vendor evaluation done by the GPO, 3) the information on product and vendor assessment regarding the GPO vendor may be readily available to the hospital members from the GPO as well as other GPO members giving the GPO vendor an extra marketing mileage over outside vendors, 4) GPOs often offer rebates to loyal members which makes a certain level of their total purchases form GPO vendors; this rebates create additional incentive for the hospitals to buy from the GPO vendor. So, from a practical perspective we ignore the possibility of outside vendor(s) winning the business of a GPO member. Assuming a certain fraction of business to be won by outside vendor(s) will only shift our results marginally without changing any of the insights qualitatively. However, it is to be noted that we are not ignoring the existence of the outside vendor(s). The existence of market price, the nature of which is captured in Assumption 3.2, acts as a proxy for the outside vendor(s) and forces the GPO vendor to participate in further price negotiation and not stick to the GPO price if a negotiation is initiated by the hospital.

The vendor’s expected profit is a function of the price he sets, and is found as

\[
V(P_g; C_H, \lambda, m, C_V) = \int_{-\infty}^{\hat{q}(P_g, C_H)} \left( x \left( 1 - \lambda \right)P_g - m \right) g(x) dx + \int_{\hat{q}(P_g, C_H)}^{\hat{q}} \left( x \left( 1 - \lambda \right)E[\tilde{P}(x)|P_g] - m \right) - C_V \right) g(x) dx
\]
subject to $\hat{q}(P_g, C_H) \in [q, \bar{q}]$, so that the maximum profit is,

$$\Pi_v(C_H, \lambda, m, C_V) = \max_{P_g} V(P_g; C_H, \lambda, m, C_V), \quad (3.8)$$

and the profit maximizing price is,

$$P_g^* = \arg\max_{P_g} V(P_g; C_H, \lambda, m, C_V). \quad (3.9)$$

Hospitals with demand up to $q^* = \hat{q}(P_g^*, C_H)$ buy from the GPO vendor at price $P_g^*$. Hospitals with demand $x$, where $q^* \leq x \leq \bar{q}$, engage in further price negotiation and buy directly from the GPO vendor with an expected price of $E[\tilde{P}(x)|P_g^*]$. The resulting GPO revenue is,

$$R(C_H, \lambda, m, C_V) = \int_q^{q^*} (x\lambda P_g^*) g(x) dx + \int_{q^*}^{\bar{q}} (x\lambda E[\tilde{P}(x)|P_g^*]) g(x) dx. \quad (3.10)$$

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

**Proposition 3.1:** With as well as without the provision for custom contracting, the profit of the GPO vendor is higher when the cost of negotiations for the hospitals ($C_H$) is higher.

With higher cost of negotiations for the hospitals, hospitals are less likely to generate surplus through further negotiation with the GPO or non-GPO vendors. The GPO vendor can increase its profit by exploiting this factor. In fact, the GPO vendor would want to make the cost of negotiation for the hospitals as much as possible to benefit itself in the game.
3.4.1 Marginal impact of custom contracts

In this section, we present a comparative analysis of the two policy regimes, with and without custom contracts, discussed above. When custom contracting is allowed, we expect the GPO vendor to sell to only very small hospitals at the GPO price. Because, for the GPO vendor, isolated revenues from selling directly to small hospitals may not be large enough to compensate for the cost of negotiating directly. However, we expect that the GPO vendor would set the GPO price only low enough to discourage these small hospitals from negotiating further. The GPO vendor would prefer to offer custom contracts to the rest of the hospitals through direct negotiation as direct negotiation would facilitate the vendor to price discriminate hospitals of different sizes more effectively.

**Proposition 3.2:** The GPO price, the GPO vendor’s total revenue and profit, are all higher when custom contracting is allowed. With the provision for custom contracting fewer hospitals buy at the GPO price.

With the availability of custom contracts, the GPO vendor would want to sell to every hospital directly if the cost of negotiation for the vendor ($C_V$) were negligible. Given that the cost of negotiation for the vendor ($C_V$) is often significant, the revenue from selling to small hospitals is not large enough to compensate for the cost of negotiation. The existence of $C_V$ explains why the GPO vendor offers a GPO price such that relatively small hospitals (Regions $A$ and $B$ in Figure 3) would find it optimal to not renegotiate and buy at the GPO price. However, the GPO vendor would set the GPO price low enough only to get those small hospitals to buy at the GPO price. With the added possibility for custom contracting the GPO vendor would not lower the GPO price any further to get an additional member when the marginal revenue from selling the product to that member at the GPO price is less than what the GPO vendor can expect to earn through direct negotiation. So, with the availability of custom contracts, the GPO vendor sets a higher price anticipating that
some members will eventually renegotiate. As a result, the GPO price, the total revenue as well as the profit of the GPO vendor are all higher with custom contracts than what they would have been if custom contracting was not a possibility.

The finding has a significant implication on GPOs’ policy as well as GPO vendors’ attitude towards custom contracting. As custom contracting increases GPO vendors’ profitability and GPOs’ revenue, revenue sharing GPOs are more likely to encourage custom contracting and vendors would welcome it.

Clearly, the expected cost of procurement for a hospital with demand \( q \) would have been \( (qE[\tilde{P}(q)] + C_H) \) if the hospital did not have access to the GPO price and always needed to negotiate with some vendor on its own. So, the expected cost saving from having access to the GPO price for that hospital can be expressed as,

\[
\text{Expected cost saving from the GPO membership} = \text{cost without GPO membership} - \text{cost with GPO membership} \\
= \begin{cases} 
(qE[\tilde{P}(q)] + C_H) - (qE[\tilde{P}(q)|P_g] + C_H) \geq 0 \\
\text{when member hospital goes with custom contracting} \\
(qE[\tilde{P}(q)] + C_H) - qP_g \geq 0 \\
\text{when member hospital buys at the GPO price}
\end{cases} 
\]

Proposition 3.3: Expected cost savings from GPO membership for all hospital members are non-negative, with as well as without custom contracts. However, the cost savings are lower with the availability of custom contracts.

We find that the GPO membership offers non-negative cost savings to hospitals. After all, GPO membership saves, at least, the cost of negotiations for those hospitals which buy at the GPO price, and enables the rest to negotiate at a price lower, than what they would have negotiated on their own without knowing the GPO price. However, the cost savings are lower when custom contracting is practiced. This outcome is primarily driven by the fact that the GPO price is higher with custom
contracts. When custom contracting is allowed, the GPO vendor offers a higher price through the GPO anticipating that hospitals would renegotiate. As a result, small, as well as large, hospitals are worse off with higher procurement costs—small hospitals are worse off because they pay a higher GPO price; large hospitals are also worse off because the expected price after negotiation is the same if not higher. There are basically three types of hospitals: “small” hospitals which buy at the GPO price in either case, with or without custom contract, pay a higher GPO price when custom contracting is allowed; “mid-size” hospitals which negotiate further when custom contracting is allowed but would have bought at the GPO price in the absence of it, incur not only the additional cost of negotiation but also a higher expected cost of procurement, even after negotiating at a price lower than the GPO price; “large” hospitals, which would negotiate in either case, with or without custom contracting, at least, do not do any better with custom contracting as their expected price after negotiation is not any lower than what they could have negotiated without custom contracting.

From hospitals’ point of view, it is interesting to note that despite having the added flexibility of negotiating directly with the GPO vendor, no hospital is better off with the availability of custom contracts. Here, flexibility comes at a hefty price. Hospitals should be aware of the pricing strategies of the GPO vendor and shouldn’t be misled by the cost savings, measured with reference to the cost at buying at the GPO price. Savings from renegotiation are lower than what they would have been with lower GPO price if renegotiation wasn’t allowed in the first place.

### 3.4.2 Role of the GPO

When custom contracting is allowed, the GPO plays the role of demand aggregator for small hospitals (Regions A & B in Figure 3.3), whereas, it indirectly benefits the rest of the hospitals (Regions C & D in Figure 3.3) by giving access to the GPO price which is used primarily for benchmarking by these large hospitals. We have seen in the previous section, the GPO vendor’s revenue is higher with the availability of custom contracts. Higher revenue with custom contracts has further implications on the policy of the GPO. Although, GPOs claim to reducing
procurement cost for the hospitals as their primary objective, we anticipate that a for-profit, independently-owned GPO, that earns its revenue through sharing a percentage of the GPO vendor’s revenue, would be more likely to encourage custom contracts, and vendors would welcome it. We also anticipate that a buyer-sponsored GPO would be more likely to discourage custom contracting.

We also observed that the GPO vendor’s profit increases with the increase in the cost of negotiation for hospitals. One of the ways the cost of negotiation for hospital could be higher is when there is high uncertainty in the price of a product. When a hospital is uncertain whether any other outside vendor is able to charge less than the GPO price, more uncertainty would increase the probability that the hospital has to visit multiple vendors before it receives a reasonable bargain, thereby increasing the expected cost of negotiation for the hospitals. The GPO has the informational advantage through having access to all past transactions that its members were part of. As a result the GPO can play a significant role in influencing the price uncertainty of a product. Even though the GPO may be barred from sharing price information of individual transactions with any member, it can still influence the price uncertainty through statistical analysis of past price information and sharing aggregate price information with GPO members. The GPO typically maintains a repository of product and price information from past transactions. Each time a new transaction takes place through the GPO, the GPO member uploads the product and price information onto GPO’s database. The GPO analyzes the information across all transactions and shares the aggregate price information with members. As we observed that the profit of the GPO vendor decreases with a decrease in the cost of negotiation with as well as without custom contracting, the GPO’s effort in reducing the price uncertainty may not be welcome by the GPO vendors but would be desirable by the GPO member hospitals. The GPO will be able to benefit hospitals by collecting more product and price information, investing more on statistical analysis of the collected data, and sharing as much information as possible with the members.
In summary, GPOs’ value proposition has shifted over time from mere demand aggregating to demand aggregating for some and acting as information intermediaries for the rest. With the provision for custom contracts, GPOs act as demand aggregators only for small hospitals, whereas, they benefit large hospitals through offering GPO price for benchmarking purposes, and aggregating information on products and product prices.

3.5 Conclusion and discussion

Group Purchasing Organizations (GPOs) constitute a significant part of the healthcare supply chain in the United States. GPOs operate as intermediaries between hospitals and medical suppliers. They do not directly participate in product and payment exchange between two sides. However, they establish contracts with vendors on behalf of hospitals and thereafter facilitate by managing contracts between the two parties. The primary economic rationale behind the existence of GPOs is the lower cost of procurement attained through volume discounting—usually hospitals become members of a GPO, then the GPO aggregates the demand of all of its members and negotiates a lower price with a vendor. The GPO also reduces the operational cost of procurement through economies of scale, and it earns most of its revenue by collecting a percentage of the sales revenue from the vendor.

Our research was motivated by an interesting phenomenon in the supply chain—despite the economic rationale of volume discounting through group buying, some hospital members of a GPO often negotiate directly with the GPO vendor and contract at a price which is even lower than what the GPO negotiated for the group. Such a contract established directly between the supplier and the GPO member is commonly known as a custom contract. While the practice of custom contracting is common and well-documented, its economic impacts have not been critically examined. Our research seeks to fill this vacuum.

Using game theory, we analyze the impact of custom contracts on hospitals, the GPO vendor, and the GPO. We assume that the GPO members are heterogeneous in their demand sizes. We also assume that the price of a product cannot be known for
certain, and it is stochastically decreasing in purchase quantity. We model the strategic interaction between the GPO vendor and the GPO members in two different scenarios—with and without the availability of custom contracts. We find the marginal impact of allowing custom contracts through a comparative analysis of the two cases. We also present a sensitivity analysis on the equilibrium outcomes with respect to the cost of negotiations for the hospital.

Despite the added flexibility and apparent attractiveness of custom contracts to large hospitals, it turns out that, in reality, the availability of custom contracts leaves all hospitals worse off. The practice of custom contracting, in fact, benefits both the GPO vendor and the GPO. We find that, when custom contracting is allowed, the GPO vendor, anticipating larger hospitals to renegotiate, offers a higher price to the GPO. With the availability of custom contracts, small hospitals, which procure through the GPO, therefore, pay a higher price than what they would have paid otherwise. The large hospitals, which end up paying separately negotiated price, also pay more than what they would have paid if custom contracting wasn’t permitted: their negotiations with the GPO vendor lead to discounts off the GPO price, but these discounts are smaller than the gap between what they would have paid with and without custom contracting. In summary, all hospitals lose with custom contracting despite the flexibility to renegotiate. Interestingly, with the availability of custom contracts, the GPO plays the role of demand aggregator only for small hospitals, whereas, it indirectly benefits the rest of the hospitals through giving access to the GPO price only. This insight also implies that averaging cost savings all over the hospital industry would not reflect the real picture as different hospital gets benefited differently by the GPO. This is a tremendous shift in GPO’s role from group purchasing intermediaries to information intermediaries.

One implication of the practice of custom contracting is that vendors realize higher revenues and profits with custom contracts, and they, therefore, are likely to encourage this practice. Another is that healthcare providers are potentially ignoring the unexpected outcome that GPO vendors do not offer the same prices in the
presence of the provision for custom contracts as they do in its absence. Large hospital members, who engage in further negotiation after the announcement of the GPO price, are likely under the impression that a discount off the GPO price means a better price. However, what we find is that not having the provision for custom contracts leads to an even lower price up front and renegotiations may not be necessary. These large members need to seriously rethink the benefits of custom contracting—they often have the bargaining power necessary to convince their GPOs, who also profit from the provision for custom contracts, to forgo the provision.

We also find that the profit of the GPO vendor increases with an increase in the cost of negotiations for hospitals. GPOs have access to an enormous repository of price and product information from past transactions and the statistical capability to analyze the same, and they can indirectly reduce the expected cost of negotiation by reducing the price uncertainty in the market through providing hospitals with more information on product prices across the market. A for-profit GPO however may do so only in exchange for a fee from the hospitals as it may not directly benefit from the reduction in cost of negotiation.

Some of the limitations of our current research are: we focus only on the strategic interactions between the GPO vendor and GPO members; we do not incorporate in our model vendors’ selling decision or buyers’ membership choice with the GPO. We anticipate that buyers’ joining decisions would be driven by their expected cost savings from not just buying a single product but a group of products they intend to buy through the GPO. On the other hand, vendors’ joining decisions would depend on a reservation profit which is the profit they could make without selling through the GPO, and that too considering a portfolio of products as opposed to a single product. So, it wouldn’t have been justified to incorporate vendors’ selling and hospitals’ membership decision with the GPO in our model, as we were studying pricing strategy for a single product. We also limited our analysis to a single GPO vendor scenario. However, if more than one vendor is allowed to sell through the GPO the nature of competition within the GPO is expected to further influence vendors’
pricing strategy and hospitals purchasing behavior. In one hand, more competition within the GPO is expected to drive down the GPO price, on the other hand, lower economies of scale is expected to drive it upward. Further analysis is necessary to draw more insights on the dynamics of such competition. We also assumed demands of hospitals to be inelastic. So, the insights we got can potentially be applied to other industries where demands are at least fairly inelastic. However, if the buyers’ demands were elastic the results may not directly hold.
4. Compliance Trumps Volume

Hospitals in the United States join Group Purchasing Organizations (GPOs) in order to get deeper volume discount through demand aggregation. The common perception is that a higher purchase volume leads to a lower unit price. However, a close study of the GPO contracts reveals that the price a member hospital is offered by the vendor through the GPO depends on not only the purchase quantity but also the monetary volume of the purchase and the *compliance level* (the percentage of its total demand the hospital is procuring from that particular vendor) of the individual hospital. Pricing based on compliance level is quite common in other industries, as well. The discounts that are based on the buyer’s share of purchase are also known as market-share discounts, and the contracts that give rise to them are known as market-share contracts. Lately, market-share contracts across industries has received considerable attention from researchers (e.g., [22, 34, 47, 54, 58, 61]). Most of the existing works focus on how market-share contracts can influence vendor profitability. They also study the implication of such contracts on consumer surplus, welfare, market foreclosure, etc. My primary objective in this research is to show how cost structure of buyers and sellers, and product preferences of the buyers can lead to such contracts, and how such contracts explain the incidence of a low-volume, fully-compliant buyer getting a lower price than what a high-volume, partially-compliant buyer gets from the same vendor. In healthcare GPOs, market-share contracts exist in different forms. As the report by the US Government Accountability Office (GAO-03-998T, July 2003) indicates, volume and compliance level are both important for a hospital to get favorable pricing from the vendor; some contracts require hospitals to commit to a certain percent of their total purchase, through the GPO; others offer differential pricing for those who commit to a certain percentage and those who don’t; some contracts offer tiered commitment levels so that hospitals can choose from a range of commitment levels and obtain price discounts accordingly. When tiered commitment levels are available, a member hospital is typically put into a tier based on its purchase volume as well as compliance level, and the price it gets
depends on the tier it belongs to (this pricing practice in healthcare GPOs is commonly known as tier pricing). There are two types of discounts that are based on compliance level: 1) discount from the GPO itself for making a certain level of purchase through the GPO (buying from any vendor that the GPO has established contract with falls into this category); discounting is typically implemented through sharing a part of the administration fees, that are collected from the vendors, with the hospitals; 2) discount from a particular GPO vendor for making a certain level of purchase with that GPO vendor. In this paper, I focus on the latter type of discount that comes directly from the vendor.

In the past, such pricing practices by medical suppliers have attracted a lot of negative attention from anti-trust watchdogs. Offering rebates on bundles of unrelated items or bundling with an intention to keep the competitors out of the market has been found problematic in several court rulings. For example, in a class-action lawsuit (Spartanburg Regional Healthcare System v Hillenbrand Industries, Inc. et al.) in the United States District Court for the district of South Carolina, Spartanburg alleged that beginning in 1990, Hillenbrand engaged in an anti-competitive practice by offering discounts on its standard beds and in-room products to customers who also agreed to rent Hillenbrand or SSI specialty beds. The hospital system alleged that Hillenbrand attempted to monopolize the market for specialty beds by using its market power in standard beds and in-room products. The contract was through Premier, one of the national level GPOs in the US. The case ended with a $337.5 million settlement in 2005. Ever since GPOs have always been under the radar of the US congress and consumer press, and their practices concerning sole-sourcing from vendors and allowing contracts that are potentially anti-competitive have been scrutinized by the US Government Accountability Office (GAO) several times in the past. In the Australian Competition and Consumer Commission v Baxter Healthcare Pty Ltd case, Baxter Healthcare Pty Ltd was fined $4.9 million in 2010 by the

8 Australian Competition and Consumer Commission v Baxter Healthcare Pty Ltd [2010] FCA 929;
Federal Court of Australia for bundling sterile fluids (used for re-hydration and cleaning wounds) and peritoneal dialysis fluids (used to treat chronic failure). Baxter offered to supply sterile and peritoneal dialysis fluids on an item-by-item basis at high prices. As an alternative, it would supply the products at discounted prices, so long as the hospital acquired all or most of its requirements from Baxter for a long time period. At the time of offering the bundle, Baxter was the sole Australian manufacturer of sterile fluids and faced very limited competition from imports. It was also the main manufacturer of peritoneal dialysis products in Australia, although it faced import competition. Hence the practice was found to be anti-competitive.

However, not all practices that came under scrutiny were found anti-competitive. In August 2010, the Eight Circuit Court of the US issued a ruling addressing bundled rebates and the law surrounding exclusionary contracts. The judgment in the Southeast Missouri Hospital v. C.R. Bard, Inc. case⁹ essentially dismissed a hospital’s (plaintiff: Southeast Missouri Hospital) challenge against several aspects of the vendor’s (defendant: C.R. Bard, Inc.) contract with the GPO: 1) a “sole source” provision that established the defendant’s catheters as the only catheters available to the hospital under the GPO contract; 2) tiered pricing that granted discounts to hospitals purchasing a substantial percentage of certain products from the defendant; and 3) bundled rebates that offered discounts to hospitals purchasing multiple product lines from the defendant. The Eighth Circuit affirmed dismissal because the plaintiff failed to show that the defendant’s discounts resulted in below-cost pricing. The court reached the conclusion regarding Bard’s share-based discounts, specifically noting that, in order to receive the discounts, hospitals were not required either to purchase 100% of their catheter needs from Bard or to refrain from purchasing from other competitors, and the GPO agreements did not contractually obligate hospitals to purchase anything from Bard, instead, if a hospital purchased less than the agreed

http://www.claytonutz.com/publications/news/201009/02/baxter_fine_a_warning_for_those_who_bundle_products_or_services.page (last accessed on Dec 21, 2011)

⁹ Southeast Missouri Hospital v. C.R. Bard, Inc. No. 09-3325;
upon percent, it simply lost its negotiated discount. As is evident, vendors run the risk of exposing themselves to anti-trust issues when they try to monopolize a market through tying, or offering a bundle or compliance-based pricing. As a consequence of such anti-trust lawsuits, GPOs as well as vendors have been more careful in offering bundle or compliance-based pricing. "We make it a point never to bundle unrelated products," said Rosalind McLeod, general counsel for Novation, Irving, Texas, at the 2006 VHA Leadership Conference in St. Louis. "There’s been so much scrutiny of GPOs over the last five or six years, and the bundling issue plays into healthcare law and antitrust issues. We do allow for bundling in related product categories, but when we do, we look at it very carefully."¹⁰

So, it is evident that compliance-based pricing does exist in healthcare despite the likelihood of some forms of it being considered anti-competitive. In this paper, I do not intend to evaluate whether the existing pricing practices on certain product(s) conform to trade laws or not. Instead, I analyze the nature of compliance-based pricing, purely from an economic perspective. Using a game theoretic model, I study how competition between vendors, is driven by the cost structure of the vendors, the demand of the hospital, and the heterogeneity in product preferences within the hospital. I explore how hospitals allocate demand between vendors, and how the level of compliance by the hospital can be an important drive in vendor’s pricing strategy. I find that the heterogeneity in product preferences within the hospital and the vendor’s as well as hospital’s high fixed cost of managing a B2B account can drive compliance-based pricing. I show that it is possible to get a lower price with higher compliance level despite buying fewer units, as compared to another hospital, which buys from the same vendor but doesn’t fulfill its entire demand from that vendor. In this context, I also discuss the role that GPOs play in facilitating the implementation of such compliance-based pricing. I draw further insights on the impact of hospitals’ product preferences on the profitability of vendors and procurement cost of hospitals. I also show that compliance-based pricing can increase social surplus in certain cases.

The paper is structured as follows: in §4.1 I present a brief overview of the extant literature; In §4.2 I describe the model; In §4.3 I analyze duopoly competition and the nature of pricing; In §4.4 I analyze the impact of a hospital’s product preferences on profitability of vendors and procurement costs of hospitals; In §4.5 I conclude by summarizing the main results.

4.1 Literature review

Discounts of any nature are designed primarily to encourage loyal buying behavior that potentially benefit sellers. The economic literature on loyalty discounts studies different mechanisms that are prevalent in the industry, e.g., tying and bundling (e.g., [6, 11, 42, 64]), where rebates are given conditional on buying multiple products that are part of a bundle; nonlinear pricing in the form of quantity discounts (e.g., [15, 66]), where a buyer is offered a price schedule based on purchase quantity; all units discounts (AUD) (e.g., [37, 54]), where quantity discount takes a special form, and a buyer is offered a lower price on all units purchased once the purchase quantity crosses a threshold; market share discounts (e.g., [47, 58, 62, 84, 85]), where a buyer is offered a price schedule based on the fraction of total demand the buyer fulfills from the respective seller; exclusionary contracts (e.g., [9, 22]), where a buyer is contractually obligated to fulfill all its demand from a single seller and not buy anything from the rival seller(s). The literature in this area mostly focuses on vendor profitability, buyer surplus, and anti-competitive aspects of the above mentioned pricing mechanisms for single product as well as product bundle. My analysis concerns pricing of a single product. Here, I present an overview of the extant literature that focuses on different forms of discounting mechanisms in the pricing of a single product scenario and my contribution to the literature.

One of the primary factors that increases the discount is considered to be purchase volume. The list of other factors includes, but is not limited to, competition among suppliers, buyers’ loyalty, exclusivity commitment, etc. Ellison and Snyder [34] empirically find that large drugstores receive a modest discount for antibiotics produced by competing suppliers but no discount for antibiotics produced by
monopolists, and thereby suggests that supplier competition, in addition to the buyer size, is a pre-requisite for countervailing power (the ability of large buyers to extract discounts from suppliers) of the buyer. A recent work by Marvel and Yang [60] models the competitive effects of nonlinear tariffs in a market where the preferences of the buyers are horizontally differentiated. They show that while nonlinear tariffs are an effective way for a monopolist to extract consumer surplus, when two suppliers compete using such schedules, the results are far more competitive in comparison to simple Bertrand–Nash competition with linear tariffs. Non-linear pricing can exist in different forms, e.g., two-part tariffs, quantity discounts, menu pricing, etc. One of the special forms of quantity discounts that are observed in the industry is All-Units Discounts or AUDs, where a buyer is offered a discount on all units purchased once the purchase quantity exceeds a pre-established threshold. Kolay et al. [54] show that AUDs eliminate double marginalization in a complete information setting, and extract more profit than a menu of two-part tariffs would in the standard incomplete information setting with two types of buyers. Another special form of nonlinear pricing that exists in the market is market-share discounts, where discounts are offered based on, not absolute purchase quantity, but the share of the buyer’s total purchase from the respective vendor. Inderst and Shaffer [47] model competition between two suppliers, who are selling to two downstream retailers. They show that, unlike contracts that only depend on how much a retailer purchases, market-share contracts give the dominant firm the ability to influence not only the quantity sold of its own product but also the quantity sold of its rival’s products; they also show that market-share contracts increase the dominant supplier’s profit, and if demand is linear, lowers consumer surplus and welfare even though rivals are not completely foreclosed. Majumdar and Shaffer [58] show that, when a dominant firm and competitive fringe supply substitute goods to a retailer who has private information about demand, it is profitable for the dominant firm to condition payment on how much the retailer buys from the fringe. They show that the dominant firm can create countervailing incentives for the retailer and, in some cases, obtain the full-
information outcome using market-share contracts. The main difference between the models in [47] and [58] and my model is that both [47] and [58] assume that the supplier, whose pricing strategy is under question, is the dominant firm; I consider the case, where both suppliers are strategic, neither is dominant, and they sell their products to a downstream buyer (hospital) which is characterized by its demand as well as product preference. Using a vertical model with linear differentiated demand, Vassallo [85] shows that the welfare effects of market share discount plans can often be positive as optimal market share discount plans can mimic vertical integration between the manufacturer and the retailer, and can potentially eliminate the double marginalization problem and achieve the outcome of joint profit maximization.

All of these price mechanisms are believed to have some potential for market foreclosure even when exclusionary contracts are not directly pursued by vendors. Ordover and Shaffer [67] consider a two-period model with two sellers and one buyer in which the efficient outcome calls for the buyer to purchase one unit from each seller in each period. The paper shows that when the buyer's valuations between periods are linked by switching costs and at least one seller is financially constrained, there are plausible conditions under which exclusion arises as the unique equilibrium outcome. Mills [62] claims that, even though market-share discounts may have exclusionary effects under certain circumstances when a seller has significant market power, there exist other plausible non-exclusionary reasons, e.g., rent extraction and inducing downstream selling effort for offering market-share discounts. Kolay et al. [54] show that AUDs may profitably arise absent any exclusionary motives. Using a setting of a single upstream manufacturer selling products to a downstream retailer, they also show that AUDs can eliminate double marginalization when demand is known by both manufacturer and the retailer; the manufacturer can earn higher profits with AUDs than with optimal menu of two-part tariffs when demand information is private to the retailer.

There also exist contracts where exclusivity commitment is explicitly asked for by the vendors, or is offered by buyer(s) in order to get additional discounts. Dana
models competition among multiple sellers to sell to a continuum of buyers each with at most unit demand. The study shows that even small groups composed of buyers with heterogeneous preferences can increase price competition among rival sellers by committing to purchase exclusively from one seller. O'Brien and Shaffer [66] show that the buyer can obtain a lower price through an exclusive commitment however the exclusive commitment comes with inefficiency in that, the buyer does not receive its desired allocation of the suppliers' goods. They show that, by providing a manufacturer with increased flexibility (beyond linear pricing) to extract a retailer’s surplus, nonlinear pricing may instead have the effect of reducing the incidence of observed market foreclosure.

A significant part of this literature are debates on costs and benefits, and the anti-competitive nature of such pricing practices. Marx and Shaffer [61] study the economics of rent-shifting using a three-party sequential contracting environment in which two sellers negotiate with a common buyer and demonstrates that the division of surplus depends on the set of feasible contracts, the relationship between the sellers’ products, and the bargaining power of the firms. Calzolari and Denicolo [15] analyze the competitive effects of quantity discounts in an asymmetric duopoly. They find that for a sizeable set of parameter values, quantity discounts harm the smaller firm and reduce consumers' surplus, and can even decrease social welfare. Using a two-period model, where an incumbent faces second-period competition by entrants, Feess and Wohlschlegel [37] show how AUDs can be abused to shift rents from entrants. Elhauge [33] proves that loyalty discounts can create anti-competitive effects not only because they can impair rival efficiency but also because loyalty discounts can perversely discourage discounting even when they have no effect on rival efficiency. Tom et al. [84] argue that (1) market-share discounts structured to produce total or partial exclusivity should be judged according to the same economic principles that govern exclusive dealing; and (2) the case law, properly construed, permits such discounts to be condemned under the Sherman Act or FTC Act if they produce anticompetitive effects without counterbalancing procompetitive effects.
Bernheim and Whinston [9] demonstrate that exclusionary contractual provisions may be irrelevant, anti-competitive, or efficiency-enhancing, depending on different market settings.

My study was primarily motivated by price contracts in the healthcare industry. However, parallel insights can be drawn in other industries, too, that are of similar nature. I model duopoly competition, where vendors with symmetric cost structures offer horizontally differentiated product. Transactions are facilitated, to some extent, by GPOs. I analyze the pricing strategy of the vendors who are competing to make a sale to a hospital. Hospitals are characterized by their demands and product preferences. I do not consider any of the vendors to be dominant, and assume their cost structure to be symmetric. I also assume the demand of the hospital to be inelastic. I contribute to the literature by showing how fixed cost of managing an active account, both for the hospital and the vendor, in B2B transactions and heterogeneity in product preferences within a hospital drive vendors’ compliance-based pricing strategy, and how a hospital can get a lower price based on full compliance despite buying a smaller quantity than another hospital. I also show how heterogeneity in product preferences within a hospital drive profitability of the vendor and procurement cost of the hospital.

4.2 The model

I analyze duopoly competition between vendors competing to sell a product to hospitals with different tastes and demand levels. I model the strategic interactions among different players in the game using a variation of the Hotelling model. First, I make the following assumptions on vendors.

Assumption 4.1 (assumption on vendors): There are two vendors, selling horizontally differentiated products, one located at each end of a unit-length linear market. The linear market space is denoted by \( x, x \in [0,1] \). Vendor 1 is located at \( x = 0 \), and vendor 2 is located at \( x = 1 \).
Purchasing transactions in B2B markets typically occur over a prolonged period of time. During this period, vendors need to actively manage accounts with buyers, and also maintain a business relationship to support prospective sales in the future. This engagement with the buyers incurs an account management cost on the part of the vendors, which is largely fixed and generally quite insensitive to the quantity of sale. Such account management costs may include, but are not limited to, contract monitoring costs, any fixed cost associated with shipping, cost of procedural or other changes required to accommodate the buyer, personnel cost (e.g., cost of assigning account manager, travel related costs), cost of buyer-specific product customization, etc. I assume that vendors have symmetric cost structures for both product and account management costs. I formalize the cost structure of vendors in the following assumption.

**Assumption 4.2 (assumption on vendors’ cost structure):** Vendors are symmetric in terms of their cost structures. Cost for selling $q$ units of product to a buyer is given by, \(mq + F_V * 1_{(q>0)}\), where \(m\) is the marginal cost of production and \(F_V\) the fixed cost of account management for the vendor (incurred only when \(q > 0\)).

Partly for the reasons similar to those that apply to the vendor, the hospital’s purchasing department also incurs an additional fixed cost to maintain a business relationship with a vendor. The cost of maintaining business with a new vendor is not limited to the purchasing department alone. When a hospital purchases medical devices from a new vendor, there is an indirect cost associated with the time invested in learning and getting familiar with new devices and instruments. Sometimes, the hospital incurs additional cost in training the staff in using new devices. So, there is a fixed cost associated with each additional vendor that the hospital purchases from. I refer to these costs collectively as the cost of account management for the hospital.
Assumption 4.3 (assumption on hospital’s fixed cost of account management): A hospital incurs a fixed cost of account management, $F_H$, per each vendor it procures from.

In a B2B scenario buyers typically have demand for multiple units. However, the demands originate from several entities that make up the buyer and the entities vary in their product preferences. A hospital or an IDN (group of hospitals) is a classic example of such a buyer. Hospitals’ demand and taste characteristics stem partly from their missions (teaching versus nonteaching) and size (high versus low volume procedure). In most cases, the buying decision is influenced by physicians who have a range of preferences for devices. These preferences may be shaped by patients’ preferences (perhaps by direct-to-consumer advertising) but more likely reflect physicians’ familiarity with a particular device model, judgments of relative product features and clinical attributes, preferences for specific vendors, and close ties with vendors’ sales representatives [12]. I capture the heterogeneity in product preferences within a hospital by assuming that a hospital is located on an arc of positive length as opposed to a single point, and the demand originates uniformly along the arc. I also assume the demand to be inelastic, which is typically true for hospitals. A hospital is parameterized by its demand $Q$, fit cost $t$ per unit distance ($t$ is usually product as well as hospital specific; as I’m modeling competition considering a single product, $t$ can be taken as hospital specific only), fixed account management cost $F_H$ per vendor, and an arc of length $l$ centered at the location $c$, i.e., the linear segment $[c - l/2, c + l/2]$, i.e., hospitals are defined by the set $(Q, t, F_H, c, l)$. The parameter $l$ can be interpreted as the measure of heterogeneity in product preferences within the hospital, and $c$ can be interpreted as the collective product preference for the hospital. The set of all possible hospitals is denoted as:

$$H := \{(Q, t, F_H, c, l): Q > 0, t > 0, F_H > 0, 0 \leq c \leq 1, 0 \leq l/2 \leq \min\{c, 1 - c\}\}$$

The assumption that captures the heterogeneity in a hospital’s demand is formalized below.
Assumption 4.4 (assumption on buyer’s demand and taste): The buyer, i.e., the hospital, is located on a line segment of positive length along the linear market, and has a demand that is inelastic. If the hospital has a total demand $Q$ and is located on $[c - l/2, c + l/2]$, I assume that the demand density is \( \frac{Q}{l} \) on $[c - l/2, c + l/2]$, and 0 elsewhere.

The above assumption ensures that the demand over the segment $[c - l/2, c + l/2]$, where the hospital is located, sums up to \( \int_{(c-l/2)}^{(c+l/2)} \left( \frac{Q}{l} \right) dx = Q \). I illustrate this assumption using the diagram below.

![Diagram](image)

**Figure 4.1: Location of a hospital/IDN in reference to the vendors**

I assume that the hospital’s preferences are common knowledge. This is a reasonable assumption since such information is not very difficult to obtain for the vendors. For example, solely from the market knowledge it can be deduced that research hospitals’ preferences are more varied and wider (large $l$) than that of the community hospitals as research hospitals are more likely to try or can afford to try new products. Regional units of a vendor are expected to be aware of the preferences of the hospitals in the region. Besides, since hospitals are members of a GPO, the GPO can further assess a hospital’s taste-span ($[c - l/2, c + l/2]$) by analyzing the
past purchases of the hospital. Similarly, the total demand of a hospital for the current period can also be fairly estimated by observing the demands in the previous periods. So, I believe that it is reasonable to assume that both the location (line segment representing the hospital on the linear market) and the demand of the member hospital are known to the GPO, and vendors are equally aware of the same through their own market research and/or learning from GPOs.

One of the implications of the hospital’s demand coming from physicians with heterogeneous preferences is that, the hospital may not want to buy all of its units from a single vendor despite being offered a discounted price schedule. To focus on product preferences, and the resulting demand allocation, I abstract away from other considerations that might go into demand allocation, such as suppliers’ capacity constraints and hospital’s risk minimization through second sourcing, etc. Hospitals allocate demand between vendors to minimize their total cost of procurement, i.e., the sum of their payments to vendor(s), the aggregate cost of disutility, and the fixed account management cost(s). Sellers offer different kind of non-linear pricing/loyalty discounts in order to increase their profitability. The list of such mechanisms includes: tying and bundling, where rebates are given conditional on buying multiple products that are part of a bundle; nonlinear pricing in the form of quantity discounts, where a buyer is offered a price schedule based on purchase quantity; All-Units discounts (AUD), where quantity discount takes a special form, and a buyer is offered a lower price on all units purchased once the purchase quantity crosses a threshold; market share discounts, where a buyer is offered a price schedule based on the fraction of total demand the buyer fulfills from the respective seller; exclusionary contracts, where a buyer is contractually obligated to fulfill all its demand from a single seller and not buy anything from the rival seller(s). Any pricing mechanism that incorporates a hospital’s compliance level (share of purchase with the respective vendor) will require the compliance level to be monitored. Here, the mediation of the GPO in purchasing saves both vendors from making any extra effort to monitor hospital’s purchase activity. GPOs can monitor purchases of any of its member
hospitals at no marginal cost when the hospital buys through GPO contracts, whereas, in other cases GPOs make a conscious effort to monitor their members’ purchases from GPO as well as non-GPO vendors. Consequently separate efforts by vendors to audit a hospital’s purchases are not necessary to enforce compliance-based pricing schedules in the presence of a GPO. The following assumption summarizes the information structure of the model.

**Assumption 4.5 (assumption on the GPO):** Each hospital’s parameters \( \{Q, t, F_H, c, l\} \), and purchases, are common knowledge (to the vendors and the GPO) and no separate cost is incurred in monitoring compliance.

### 4.3 Duopoly competition and the nature of pricing

Pricing in healthcare industry is notoriously opaque. Vendors frequently price discriminate between hospitals, and pricing is typically customized for individual hospitals based on the demand and taste characteristics of the hospital. Since vendors often have good information on a hospital’s demand characteristics, such as physicians’ product preferences, vendor allegiances, physician power in the hospital, and total volume of purchases, vendors leverage this information to price discriminate, hospitals with strong product preferences and modest volume typically pay higher prices [70]. Given such customized pricing, competition for each hospital’s business can be analyzed in isolation, and I take this approach, where a hospital is parameterized by the parameter set described earlier.

I analyze the following two-stage game of complete information. In stage 1, vendors simultaneously furnish price schedules to the hospital based on common knowledge about its price and cost characteristics. In stage 2, the hospital allocates its demand between the two vendors to minimize total procurement cost. The equilibrium concept employed is the sub-game perfect Nash equilibrium.
Figure 4.2: Game Sequence

The hospital’s cost minimization problem can be defined as,

$$
\min_{(c-l/2) \leq k \leq (c+l/2)} \left[ \int_{c-l/2}^{k} (p_1 + xt) \left( \frac{Q}{l} \right) dx + F_H \cdot 1_{(c-l/2 < k)} + \int_{k}^{c+l/2} (p_2 + (1-x)t) \left( \frac{Q}{l} \right) dx + F_H \cdot 1_{(k < c+l/2)} \right] \quad (4.1)
$$

where: $\frac{k-(c-l/2)}{l}$ is the fraction of the demand that is procured from vendor 1 and the rest from vendor 2; $t$ is the fit cost per unit distance from the ideal product; $p_1$ and $p_2$ are prices offered by vendors 1 and 2, respectively; the hospital incurs a fixed of $2F_H$ when it buys from two vendors (in that case $k$ strictly lies between $(c-l/2)$ and $(c+l/2)$); $F_H$ when it buys from one vendor. Further, I denote the fraction of demand bought from vendor $i$ as $f_i$. Therefore,

$$
f_1 = \frac{k-(c-l/2)}{l}; \quad f_2 = 1 - f_1 = \frac{(c + l/2) - k}{l}. \quad (4.2)
$$

Vendor $i$’s problem is to decide price $p_i$, that maximizes its profit. Vendor $i$’s profit maximization problem is defined as:

$$
\max_{p_i} \left( (p_i - m)Qf_i - F_V \cdot 1_{(Qf_i>0)} \right). \quad (4.3)
$$

**Lemma 4.1:** Price reaction curves of vendors 1 and 2, while selling to a hospital $\{Q, t, F_H, c, l\}$, are given by.
Price reaction curves, $p_{1R}(p_2)$ and $p_{2R}(p_1)$, following Lemma 4.1, are shown in Figure 4.3.

When vendor 1 sets a price below $p_{1L}$, vendor 2 cannot make a sale profitably and when vendor 2 sets a price below $p_{2L}$, vendor 1 cannot make a sale profitably.
Vendors’ pricing strategy: Whenever profits at $C$ are positive for both vendors, vendors 1 and 2 make their “regular” price offers, $p_{iC}, (i = 1,2)$, to the hospital without asking for any commitment on the level of compliance from the hospital. When compliance-based pricing is allowed, in addition to the regular price, both vendors make their “discounted” price offers, $p_{id}, (i = 1,2)$, requiring 100% compliance level from the hospital. Any discounted price below $p_{IL}$ is dominated by $p_{IL}$ for vendor $i$. The discounted price, conditional on 100% compliance as offered by vendor $i$ is given as,

$$p_{id} = \arg\max_{p_{IL} \leq p \leq p_{iC}} (Q(p - m) - F_Y),$$

such that, $(Q(p - m) - F_Y) \geq \Pi_i(p_{IL}, p_{iL}).$

However, it is clear from the reaction curves that a discounted price offer $p_{id}$ doesn’t constitute an equilibrium if $p_{id}$ strictly lies in between $p_{IL}$ and $p_{iC}$. So, there are three probable equilibriums: A) vendor 2 is inactive and the hospital procures from vendor 1 only at price $p_{1L}$, B) vendor 1 is inactive and the hospital procures from vendor 2 only at price $p_{2L}$, and C) the hospital allocates its demand between vendors 1 and 2.

Lemma 4.2: The equilibrium price(s) and profit(s) of the vendor(s), the aggregate disutility and the total procurement cost of the hospital at A, B, and C are given by:
The existence of equilibrium C implies that, even if a hospital may get a lower price through making its entire purchase from a single vendor, it is not optimal for the hospital to do so as it leads to higher disutility cost. In such cases, the hospital minimizes its total cost of procurement by allocating its demand between vendors.

The total cost of procurement for the hospital across these probable price offers determine which of the price offer(s) is accepted, i.e., which of the three scenarios (A, B, or C) is an equilibrium. The following section lays out the conditions for A, B, or C to be an equilibrium:
A is the equilibrium if 1) the profit of vendor 1 at A is positive and higher than that at C, 2) either vendor 1’s profit at C is negative or the procurement cost for the hospital at C is higher than that at A, 3) either vendor 2’s profit at B is negative or the procurement cost for the hospital at B is higher than that at A, i.e.,

\[
\left\{(\Pi_{1A} \geq 0) \text{ AND } (\Pi_{1A} \geq \Pi_{1C})\right\} \cup \left\{\Pi_{1C} \leq 0 \text{ OR } (C_A \leq C_C)\right\} \cup \left\{\Pi_{2B} \leq 0 \text{ OR } (C_A \leq C_B)\right\}.
\]

B is the equilibrium if 1) the profit of vendor 2 at B is positive and higher than that at C, 2) either vendor 2’s profit is negative at C or the procurement cost for the hospital at C is higher than that at B, 3) either vendor 1’s profit at A is negative or the procurement cost for the hospital at A is higher than that at B, i.e.,

\[
\left\{(\Pi_{2B} \geq 0) \text{ AND } (\Pi_{2B} \geq \Pi_{2C})\right\} \cup \left\{\Pi_{2C} \leq 0 \text{ OR } (C_B \leq C_C)\right\} \cup \left\{\Pi_{1A} \leq 0 \text{ OR } (C_B \leq C_A)\right\}.
\]

C is the equilibrium if 1) Profits of both vendors are positive at C 2) either vendor 1’s profit at C is higher than that at A or the procurement cost for the hospital at A is higher than that at C 3) either vendor 2’s profit is higher at C than that at B or the procurement cost for the hospital at B is higher than that at C, i.e.,

\[
\left\{(\Pi_{1C} \geq 0) \text{ AND } (\Pi_{2C} \geq 0)\right\} \cup \left\{(\Pi_{1C} \geq \Pi_{1A}) \text{ OR } (C_C \leq C_A)\right\} \cup \left\{(\Pi_{2C} > \Pi_{2B}) \text{ OR } (C_C \leq C_B)\right\}.
\]

When a hospital buys all its units from a single vendor it could be due to one or all of the following reasons: 1) the entire hospital (all users of the product within the hospital) prefer one vendor over the other and hence the hospital cuts on aggregate disutility through buying from the preferred vendor only 2) it saves on payment as the vendor may be offering a discount conditional on full compliance 3) the hospital saves on the fixed cost with one less vendor. The following proposition states a
necessary condition for the full compliance (equilibrium A or B) by the hospital to be equilibrium.

**Proposition 4.1:** A hospital procure its entire demand from a single vendor if the following inequality is satisfied: \( \frac{18l}{(3l+2d-1)^2} \leq \frac{qt}{F_V} \leq \frac{2592l^3}{(3l+2d-1)^2(9l+2d-1)^2} \), where \( d \) is the distance of the center of the hospital’s location from the vendor’s location.

The above proposition implies that the full compliance is not an equilibrium, if the hospital’s demand is very large, or the hospital has a high fit cost for the product, or the account management cost for the vendor is low, \( \left( \frac{qt}{F_V} > \frac{2592l^3}{(3l+2d-1)^2(9l+2d-1)^2} \right) \). The explanation is as follows: 1) the fit cost may be too high for a vendor to entice the hospital to buy all units from it; when the fit cost of the product is not high, a hospital can be incentivized to buy all its units with a reasonable discount, 2) the total purchase volume of the hospital may be large enough to compensate the vendors’ account management cost. When total purchase volume of the hospital is not large enough \( \left( Q \leq \frac{2592F_V l^3}{t(3l+2d-1)^2(9l+2d-1)^2} \right) \), it is optimal for the disadvantaged vendor (in terms of product preferences within the hospital) to stay off the market and let the other vendor make the entire sale to the hospital. On the other hand, if the purchase volume of the hospital is too low \( \left( Q \leq \frac{18F_V l}{t(3l+2d-1)^2} \right) \), the discounted price \( p_{td} \) will not be as low as \( p_{UL} \), since any additional discount for full compliance depends on the total demand of the hospital and is decreasing in total demand. The discounted price, \( p_{td} \), being higher than \( p_{UL} \) will not be realized in equilibrium.

The result in Proposition 4.1 further leads to the possibility that a hospital with lower absolute purchase volume may be offered a lower price, as compared to that of another hospital, merely for maintaining full compliance level with the vendor.
Proposition 4.2: It is possible that full compliance on the part of a hospital can lead to a lower price, as compared to another buying more from the same vendor but not fulfilling all of its demand from that vendor, i.e., there exists pair of hospitals, $H^S := \{Q^S,t^S,F_H^S,c^S,l^S\}$ and $H^L := \{Q^L,t^L,F_H^L,c^L,l^L\}$, (read the superscripts ‘L’ as “Large” and ‘S’ as “Small”) such that in equilibrium either

1) $H^S$ buys all units from vendor 1 paying a unit price of $p_{1A}^S$,
2) $H^L$ buys $f_{1C}^L$ fraction of its demand from vendor 1 paying a unit price of $p_{1C}^L$,
3) $(p_{1A}^S \leq p_{1C}^L)$ despite the fact that $(Q^S \leq Q^L f_{1C}^L)$,

or

1) $H^S$ buys all units from vendor 2 paying a unit price of $p_{2B}^S$,
2) $H^L$ buys $f_{2C}^L$ fraction of its demand from vendor 2 paying a unit price of $p_{2C}^L$,
3) $(p_{2B}^S \leq p_{2C}^L)$ despite the fact that $(Q^S \leq Q^L f_{2C}^L)$.

The above result is counterintuitive and interesting because it contradicts the common perception that high volume always leads to deeper discount. The above proposition shows that it is possible for a hospital to enjoy favorable price through making all its purchase from a single vendor despite buying lower volume compared to some other hospital. It is possible because, in such a case, where it is optimal for the hospital to make its entire purchase from single vendor, the saved fixed cost of account management through keeping the competing vendor out of the market is getting distributed to not only the winning vendor but also the hospital.

Vendors reward hospitals with lower prices through such exclusivity contracts. Vendors do so because it increases vendor’s profit; hospitals accept such offers because it lowers hospitals’ total cost of procurement. In the past, exclusivity contracts have attracted negative attention due to its anti-competitive nature in several occasions. However, I show that, there exist cases, where such contracts may not only increase the social surplus but also decrease the social cost.

The social surplus is defined as:
The social cost is defined as:

\[
\text{aggregate cost from disutility for the hospital} \\
+ \text{fixed account management cost for the vendor(s)} \\
+ \text{fixed account management cost for the hospital}
\]

**Proposition 4.3:** It is possible that a price based on full compliance can not only increase the profit of the vendor and decrease the procurement cost for the hospital but also increase the social surplus and decrease the social cost, i.e., there exists hospital \( H := \{Q, t, F_H, c, l\} \), such that, in equilibrium:

1) either \( H \) buys all units from vendor 1, incurs a disutility cost of \( D_A \) and a total cost of \( C_A \), the vendor makes a profit of \( \Pi_{1A} \), or \( H \) buys all units from vendor 2, incurs a disutility cost of \( D_B \) and a total cost of \( C_B \), the vendor makes a profit of \( \Pi_{2B} \).

2) regular prices without requiring full compliance are offered by both vendors, and if the hospital bought from both vendors it would have incurred a total cost of \( C_C \), and the two vendors would have made profits of \( \Pi_{1C} \) and \( \Pi_{2C} \), respectively.

3) \text{(increase in social surplus)} \( \Pi_{1A} \geq \Pi_{1C} \) AND \( C_A \leq C_C \) AND \( \Pi_{1A} - C_A \geq \Pi_{1C} + C_C \) if \( H \) bought all units from vendor 1; \( \Pi_{2B} \geq \Pi_{2C} \) AND \( C_B \leq C_C \) AND \( \Pi_{2B} - C_B \geq \Pi_{1C} + C_C \) if \( H \) bought all units from vendor 2.

4) \text{(decrease in social cost)} \( \Pi_{1A} \geq \Pi_{1C} \) AND \( C_A \leq C_C \) AND \( D_A + F_H + F_V \leq D_C + 2F_H + 2F_V \) if \( H \) bought all units from vendor 1; \( \Pi_{2B} \geq \Pi_{2C} \) AND \( C_B \leq C_C \) AND \( D_B + F_H + F_V \leq D_C + 2F_H + 2F_V \) if \( H \) bought all units from vendor 2.

Improvement in social surplus and decrease in social cost are achieved here through saving one vendor’s fixed cost of account management as well as the fixed cost of the hospital with one less vendor across the supply chain. However, the improvement in social surplus achieved or the decrease in social cost through full
compliance contracts is not expected to be as much as the saved fixed cost of account management through keeping one vendor out of the market. Part of the savings is lost in the transaction as the hospital incurs higher aggregate disutility due to buying from a single vendor; the other part is realized through increase in profit for the vendor, and lower payment and fixed cost for the hospital.

### 4.4 Impact of a hospital’s product preference on vendor profitability and procurement cost

The profitability of either vendor depends on not only their own cost structure and the demand of the hospital but also the heterogeneity in product preferences within the hospital. The heterogeneity is captured by specifying the location of the hospital in the linear market as $(c, l)$, where $c$ and $l$ are, respectively, the center and the length of the line segment representing the location of the hospital. I denote the distance of the center of the hospital’s location from that of the respective vendor as $d$; $d$ equals $c$ for vendor 1 and $(1 - c)$ for vendor 2.

The following proposition summarizes the sensitivity of vendor’s profit and hospital’s cost to the taste parameters (location) of the hospital.

**Proposition 4.4:** For a hospital $\{Q, t, F_H, c, l\}$,

1) If either of $A$ or $B$ is the equilibrium (i.e., the hospital procures from one vendor only):

   a) the total cost of the hospital as well as the profit of the vendor, the hospital buys from, is concave in $l$, and reaches maximum at $l = \frac{2F_V}{Qt}$,

   b) the total cost of the hospital as well as the profit of the vendor, the hospital buys from, is decreasing in $d$;

2) If $C$ is the equilibrium (i.e., the hospital procures from both vendors):

   a) the total cost of the hospital is increasing in $l$,

   b) the total cost of the hospital is concave in $c$, and it maximizes at $c = 1/2$,.
c) vendor profit is increasing in l if $d \geq 1/2$; convex in l, and reaches minimum at $l = \frac{1}{3} (1 - 2d)$, otherwise,

d) the profit of either vendor decreases in d.

**Vendors’ profits with respect to d:** It is not so surprising that the vendor’s profit is always decreasing in d irrespective of which one of the A, B, or C is the equilibrium. A vendor would always want the hospital’s product preference to be as close as possible to what it has to offer such that it can generate higher values for the hospital and extract as much surplus as possible from the hospital.

**Hospitals’ procurement costs with respect to d:** When it is optimal for a hospital to buy all its units from a single vendor (either A or B is the equilibrium), a longer distance between the center of the hospital’s location and the vendor the hospital is buying from (large d) works against the vendor and for the hospital, as the vendor will have to lower the price to meet the lowest reservation price for the physician located at the furthest point $(d + l/2)$. However, when it is optimal for the hospital to buy from both vendors (C is the equilibrium), among hospitals of the same level of heterogeneity $(l)$, a hospital with its center closer to one of the vendors (away from $c = 1/2$) is better off than another centered at $c = 1/2$. Ceteris paribus, the total cost for the hospital is maximum if it is located at $c = 1/2$.

**Hospitals’ procurement costs with respect to heterogeneity in product preferences within the hospital (l):** When it is optimal for a hospital to buy all its units from a single vendor (either A or B is the equilibrium), the profit of the vendor and the procurement cost of the hospital are concave in l, and they reach maximum value at $l = \frac{2F_V}{q_t}$. When the hospital buys from both vendors (C is the equilibrium), as expected, a higher level of heterogeneity in preferences (large $l$) hurts the hospital.
Vendors’ profits with respect to heterogeneity in product preferences within the hospital: Vendors’ profits are not always monotone in \( l \). If the hospital’s collective preference is more inclined to one vendor than the other \((c \neq 1/2)\), the profit of the disadvantaged vendor, \((d \geq 1/2)\), increases in \( l \), because with an increase in \( l \), it can not only charge a higher price but also gets to sell a larger fraction of the total demand. For the advantaged vendor \((d \leq 1/2)\), the profit is convex, and it reaches minimum at \( l = \frac{1}{3}(1 - 2d) \), since with an increase in \( l \), initially the profit decreases as the demand gradually shifts to the competing vendor; however, with further increase in \( l \), profit starts increasing as the vendor charges a higher price.

4.5 Conclusion and discussion

Hospitals in the United States join Group Purchasing Organizations (GPOs) in order to get deeper volume discount through demand aggregation. A close study of GPO contracts reveals that the price a member hospital is offered by the vendor through the GPO in fact depends on not only the purchase quantity but also the monetary volume of the purchase and the compliance level of the individual hospital.

I model a duopoly competition, where two vendors with similar cost structures offer horizontally differentiated products. I analyze the pricing strategy of the vendors for a scenario in which they compete to sell to a hospital; the hospital is characterized by its total demand and heterogeneity in product preferences. I find that the heterogeneity in product preferences within the hospital and the vendor’s as well as the hospital’s fixed cost of account management in B2B transaction can lead to compliance-based pricing. I derive conditions for the full compliance by the hospital to be equilibrium. Thereafter, I show that it is possible for a small hospital to enjoy a lower price compared to another hospital which is buying from the same vendor a higher quantity but, unlike the small hospital, is not fulfilling its demand entirely from that vendor. I also show that such exclusivity contract may increase not only the profit of the vendor but also the social surplus. I also analyze the sensitivity of the vendor profitability and procurement cost to hospital’s preference. As expected, the
vendors’ profits are higher when the hospital’s preference is “more” inclined to what they offer. Further, a higher degree of heterogeneity in preferences within a hospital, which procures from both vendors, often leads to a higher cost of procurement. Interestingly, a vendor’s profitability may not always be monotone in the hospital’s heterogeneity in product preferences.

In this paper, I have derived several interesting insights on vendor’s pricing strategy, and hospitals’ purchasing behavior. The results have been derived in the context of the healthcare industry where many transactions are mediated by GPOs. GPOs can facilitate vendors by providing better estimates of hospitals’ demands and product preferences. However, if that’s not the case, some surplus will be lost in the uncertainty of information (unless vendors adopt other means to gather more accurate information on demand and preference parameters of a hospital). GPOs also facilitate vendors through monitoring purchase level of hospitals. In the absence of a GPO, vendors will have to bear that cost themselves, resulting in a higher cost of account management, making compliance-based pricing more likely. The current analysis has been done with the assumption that cost structures are symmetric between vendors. Introducing asymmetry in cost structure will make the desirability of compliance-based pricing even higher for the vendor that has higher cost of account management. This study was restricted to analyzing compliance-based discounting that only comes from the vendor. Incorporating GPOs’ own discounting mechanism and service pricing into the game may provide more insights into vendors’ pricing strategies and hospitals’ procurement decisions.
5. Conclusion

Technology intermediaries play a critical role in mediating interactions between the two sides of the market with the level of technology playing an important role in the strategic decisions of competing intermediaries.

In the first essay, using a game theoretic model, I have studied the effect of platform technologies on competition, and identified conditions under which rival platforms would want to engage in strategic partnerships. I find that these markets are characterized by extremely lop-sided outcomes. Under open competition, the superior technology platform strongly dominates the market, and surprisingly, this domination persists even as the technology gap between the two platforms vanishes. Collaboration between rivals in the form of direct or indirect inter-network access can lead to Pareto improvements in profits, with or without monetary transfers between them. Such improvements are most likely when the technological asymmetry between rivals is large, or the incumbent has a large installed base. Technology licensing deals are not possible without a pre-existing installed base for the inferior technology platform, but these too become more attractive with larger installed bases and technological asymmetry. The insights have significant implications on the collaboration strategies of technology-based platforms. This study also increases the understanding of the nature of competition between technology-based platforms.

The study can be further extended to analyze platform’s investment decision in its own technology vs. technology that improves cross-platform technology experience. More sophisticated platform pricing schemes including transaction pricing or some combination of membership and transaction pricing could be considered. The primary focus of this study was identifying the potential for collaboration between rival platforms. Analyzing the mechanisms/contracts through which such collaboration can be implemented may provide more insights into the collaboration. Such contracts, apart from monetary transfers, can also potentially serve as price coordination devices possibly increasing the gain from collaboration, but at the same time possibly calling the legality of such relationships into question.
In the second and third essays, I focused on issues in the context of a specific kind of healthcare supply chain intermediaries, known as Group Purchasing Organizations (GPOs). I also discussed GPOs’ new role as information intermediaries in the context of my analysis.

In the second essay, I have analyzed the impact of custom contracts on hospitals’ procurement costs and the GPO vendor’s profitability. The insights from this study have significant implication on GPO policies, vendors’ pricing and hospitals’ procurement strategies. I find that, when custom contracting is practiced, the GPO vendor, anticipating larger hospitals to renegotiate, offers a higher price to the GPO; small hospitals, who procure through the GPO, therefore, pay a higher price. Large hospitals, which renegotiated further, also pay more than what they would have paid if custom contracting wasn’t permitted: their negotiations with the GPO vendor lead to discounts off the GPO price, but these discounts are smaller than the gap between the GPO prices with and without custom contracting. One implication is that vendors realize higher revenues and profits with custom contracts, and they, therefore, are likely to encourage this practice. Another is that hospitals are potentially ignoring the unexpected outcome that GPO vendors do not offer the same prices in the presence of the provision for custom contracts as they do in its absence. Large hospital members, who engage in further negotiation after the announcement of the GPO price, are likely under the impression that a discount off the GPO price means a better price. However, what I find is that not having the provision for custom contracts leads to an even lower price up front and renegotiations are unnecessary. I also find that the profit of the GPO vendor increases with the cost of negotiations for hospital. A higher cost of negotiations may arise from higher level of price uncertainty in the market. GPOs have access to an enormous repository of price and product information from past transactions and the statistical capability to analyze the same. GPOs can reduce the price uncertainty by providing information on product prices across the market. Any effort by the GPO to reduce price uncertainty may not be welcome by the vendors but would be desirable by the hospitals.
A number of fruitful extensions to our analysis can be pursued. The study was limited to analyzing the strategic interactions between the GPO vendor and GPO members. Analyzing vendors’ selling decision or hospitals’ membership choice with the GPO may offer more insights into the interactions between GPO vendors and GPO members. Analyzing competition among multiple GPO vendors within the GPO may provide further insights into the game. Considering more sophisticated pricing scheme in the GPO contracts could be an interesting extension to this work.

In the third essay I have studied the aspect of compliance-based pricing contracts that are offered by vendors through GPOs. I find that the heterogeneity in product preferences within the hospital and the vendor’s as well as the hospital’s high fixed cost of account management in B2B transaction can drive compliance-based pricing. I first derive the conditions for the full compliance by the hospital to be equilibrium. Thereafter, I show that it is possible for a small hospital to enjoy a lower price compared to another hospital which is buying from the same vendor a higher quantity but, unlike the small hospital, is not fulfilling its demand entirely from that vendor. I also show that such exclusivity contract may not always be socially undesirable as it may increase not only the profit of the vendor but also the social surplus. I also analyze the sensitivity of the profitability of the vendor and the procurement cost of the hospital to the hospital’s product preference. As expected, vendors’ profits are higher when hospital’s preference is “more” inclined to what vendors have to offer. Higher heterogeneity in preferences within a hospital that buys product from multiple vendors incurs higher cost of procurement. Interestingly, vendor profitability may not always be monotonic in hospital’s heterogeneity in product preferences. The study has a significant implication on vendor’s pricing policies and hospitals’ procurement decision.

The primary focus of the current study was on the compliance-based discounting mechanism of the vendor. Incorporating GPO’s own discounting mechanism into the game may shed more lights into vendors’ pricing strategies and hospitals’ price savings through GPOs. More sophisticated form of tier pricing could be analyzed.
Bibliography


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Appendices
A. Appendix to Chapter 2

A.1 Notations

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A.2 Proofs of lemmas and propositions

**Proof of Lemma 2.1:** Given the prices \( p_b, p_s \) chosen by the monopolist and expectations \( n_s^e, n_b^e \), the indifferent customer type on each side is given by, \( \theta_i^* = p_i/tn_i^e \), \( (i, i \in \{b, s\}; i \neq i) \) leading to a monopoly platform profit of:

\[
\pi_M = p_s(1 - \theta_s^*)N_s + p_b(1 - \theta_b^*)N_b
\]

The profit function is concave in prices and hence yields a unique solution. Profit maximization by the monopolist gives FOCs: \( p_i = tn_i^e/2 \). Imposing the FEE condition, by equating the equilibrium demands to expectations, gives marginal
customer types on each side as $\theta_b = \theta_s = 1/2$. Substituting back into the FOCs and profit function, we have,

$$p_b^* = \frac{tN_s}{4}; \quad p_s^* = \frac{tN_b}{4}; \quad D_b = \frac{N_b}{2}; \quad D_s = \frac{N_s}{2}; \quad \pi^*_M = \frac{tN_bN_s}{4}$$

Consumer surplus is given by,

$$CS = N_b \int_{1/2}^1 (xtD_s - p_b^*)dx + N_s \int_{1/2}^1 (xtD_b - p_s^*)dx = \frac{N_bN_s t}{8}$$

Total surplus is given by,

$$TS = \pi^*_M + CS = \frac{3N_bN_s t}{8}$$

**Proof of Proposition 2.1:** Follows directly from the analytical expressions for prices and profits in Lemma 2.1.

**Proof of Lemma 2.2:** Assume that Platform $j$ is the one serving the top end. Let, on side $i$, $\theta^*_{ij}$ be the customer type, who is indifferent between the two platforms, and $\theta^*_{ij}$ the customer type, who is indifferent between joining platform $j$ and not joining at all. We have:

$$\text{IR: } t_j \theta^*_{ij} n_{ij}^e = p_{ij},$$

$$\text{IC: } t_j \theta^*_{ij} n_{ij}^e - p_{ij} = t_j \theta^*_{ij} n_{ij}^e - p_{ij}.$$  

This implies $\theta^*_{ij} = p_{ij}/t_j n_{ij}^e$ and $\theta^*_{ij} = (p_{ij} - p_{ij})/(t_j n_{ij}^e - t_j n_{ij}^e)$. The platform profits are then given by:

$$\pi_j = p_{bj} (1 - \theta^*_{bj})N_b + p_{sj} (1 - \theta^*_{sj})N_s,$$

$$\pi_j = p_{bj} (\theta^*_{bj} - \theta^*_{bj})N_b + p_{sj} (\theta^*_{sj} - \theta^*_{sj})N_s.$$  

The profit functions are concave, and therefore, the FOCs are sufficient and yield a unique solution. Solving the four FOCs and fulfilled expectations condition, we get:

$$\theta^*_{ij} = \frac{4t_j - t_j}{8t_j - t_j}; \quad \theta^*_{ij} = \frac{2t_j - t_j}{8t_j - t_j}.$$  

Substituting back into the FOCs, and calculating the equilibrium prices, demands and profits we obtain the stated result.
Consumer surplus is given by,

\[ CS = \sum_{i=\{b,s\}} N_i \left( \int_{\theta_{ij}^*}^1 (x_t D_{ij} - p_{ij}) dx + \int_{\theta_{ij}^*} (x_t D_{ij} - p_{ij}) dx \right) \]

\[ = \frac{8N_b N_s t_j^3 (8t_j + 5t_j)}{(8t_j - t_j)^3}. \]

Total surplus is given by,

\[ TS = \pi^*_M + CS = \frac{8N_b N_s t_j^2 (24t_j^2 - t_j t_j - t_j^2)}{(8t_j - t_j^3)}. \]

**Proof of Lemma 2.3:** For this equilibrium to be feasible, the total market coverage must not exceed 100%. i.e. \( \frac{4N_t t_j}{(8t_j - t_j)} + \frac{2N_t t_j}{(8t_j - t_j)} \leq N_i \). This yields, \( \frac{t_j}{t_j} \geq \frac{1}{2} \). This condition is always satisfied when the Superior platform is on top, but when the Inferior platform is on top, this is only true when \( \frac{t_j}{t_j} \geq 1/2 \). The condition can also be derived from the non-negativity of prices.

**Proof of Lemma 2.4:** We only provide a sketch of the proof here, but it suffices to show the general nature of the argument. To start with, the asymmetric equilibrium established in the monopoly case (with zero price on one side, and half market coverage on the other) is also a “feasible FEE” here if the associated demands are the expectations that the customers start with. Assume that Platform1 is the potentially active platform, and that the buyers side is priced at zero. The corresponding sellers side price \( p_{31} = \frac{rN_b}{2} \) results in it serving half the market on that side. This outcome would result in zero profits for Platform 2, since it is not active. However, it is easy to show that for all values of \( r > 1/2 \), Platform 2 can choose a positive price on the sellers side, while choosing a zero price on the buyers side, such that, this is a feasible FEE, which results in a positive profit for Platform 2 and a higher consumer surplus. Therefore, the above choice of prices by Platform 1 is not a FENE. In response, while continuing to maintain a zero price on the buyers’
Proof of Lemma 2.5: Given network size expectations $n_{i1}^0$ and $n_{i2}^0$, and prices $p_{i1}$, $p_{i2}$; let, on side $i$, $\theta^*_1$ be the customer type who is indifferent between joining the two platforms, and $\theta^*_2$ the customer type who is indifferent between joining Platform 2 and not participating at all. These two indifferent types on side $i$ are specified by the following the IR and IC constraints.

Proof of Proposition 2.2: After putting $j = 1$ and $\hat{j} = 2$ in Lemma 2.2

(a) $D_{i1} = \frac{4N_i}{8 - (t_2/t_1)} \Rightarrow \frac{dD_{i1}}{dt_2} > 0$; $D_{i2} = \frac{2N_i}{8 - (t_2/t_1)} \Rightarrow \frac{dD_{i2}}{dt_2} > 0$; $D_{i1} + D_{i2} = \frac{6N_i}{8 - (t_2/t_1)} \Rightarrow \lim_{(t_2/t_1) \to 1} (D_{i1} + D_{i2}) = \frac{6N_i}{7}$

(b) $-\frac{dp_{i1}}{d(t_2/t_1)}|_{t_2} = \frac{dp_{i1}}{dt_2}.t_1 = -\frac{8(N_i)t^2_1(4t_1 + t_2)}{(8t_1 - t_2)^3} < 0$; $-\frac{dp_{i2}}{d(t_2/t_1)}|_{t_2} = \frac{dp_{i2}}{dt_2}.t_1 = \frac{4(N_i)t^2_1(8t_1 - 7t_2)}{(8t_1 - t_2)^3} > 0$

(c) $\frac{d\pi_1}{d(t_2/t_1)} = \frac{d\pi_1}{dt_2}.t_1 = -\frac{128N_bN_s t^4_1(t_1 + t_2)}{(8t_1 - t_2)^4} < 0$

$\frac{d\pi_2}{d(t_2/t_1)} = \frac{d\pi_2}{dt_2}.t_1 = \frac{8N_bN_s t^3_1(16t^2_1 + 12t_1t_2 - t^2_2)}{(8t_1 - t_2)^3} > 0$

$\lim_{(t_2/t_1) \to 1} \frac{\pi^*_1}{\pi^*_2} = \lim_{(t_2/t_1) \to 1} \frac{8t_2}{t_1} = 8$; $\lim_{(t_2/t_1) \to 1} \frac{\pi^*_1}{\pi^*_M} = \lim_{(t_2/t_1) \to 1} \frac{256(2 - (t_2/t_1))}{(8 - (t_2/t_1))^3} = \frac{256}{343} \approx 0.7464$

(d) $\frac{d(CS)}{d(t_2/t_1)} = \frac{d(CS)}{dt_2}.t_1 = \frac{16N_bN_s t^4_1(32t_1^2 + 5t_2)}{(8t_1 - t_2)^4} > 0$

$\frac{d(TS)}{d(t_2/t_1)} = \frac{d(TS)}{dt_2}.t_1 = \frac{8N_bN_s t^3_1(64t_1^2 - 18t_1t_2 - t^2_2)}{(8t_1 - t_2)(8t_1 - 2t^2_2)} > 0$
Proof of Lemma 2.6: Substituting \( \gamma_j(t_1, t_2) = t_j \) into Lemma 2.5 and simplifying, we obtain the result.

Proof of Proposition 2.3: Based on the outcomes in Lemma 2.6.

(a) \( D_{l1} = \frac{2N_l}{4-(t_2/t_1)} \Rightarrow \frac{dD_{l1}}{d(t_2/t_1)} > 0; \)
\( D_{l2} = \frac{N_l}{4-(t_2/t_1)} \Rightarrow \frac{dD_{l2}}{d(t_2/t_1)} > 0 \)
\[(b) \frac{dp_{11}}{dt_2}, t_1 = \frac{6(N_1) t_1^2 (2t_1 + t_2)}{(4t_1 - t_2)^3} < 0\]
\[\frac{dp_{12}}{dt_2}, t_1 = \frac{3(N_1) t_2^2 (4t_1 - 7t_2)}{(4t_1 - t_2)^3}, \text{ which is non-monotonic in } t_2 / t_1.\]
\[\frac{d\pi_1}{dt_2}, t_1 = -\frac{2N_B N_1 t_1^2 (t_1 + 2t_2)}{(4t_1 - t_2)^4} < 0\]
\[\frac{d\pi_2}{dt_2}, t_1 = \frac{6N_B N_1 t_2^2 (4t_1^2 - 6t_1 t_2 - t_2^2)}{(4t_1 - t_2)^4}, \text{ which is non-monotonic in } t_2 / t_1.\]
\[\frac{d(CS)}{dt_2}, t_1 = \frac{16N_B N_1 t_1^2 (32t_1 + 5t_2)}{(8t_1 - t_2)^4} > 0\]
\[\frac{d(TS)}{dt_2}, t_1 = \frac{8N_B N_1 t_1^2 (64t_1^2 - 18t_1 t_2 - t_2^2)}{(8t_1 - t_2)^4} > 0\]

**Proof of Proposition 2.4:** The results all follow from a comparison of platform profits in the open competition (OC) case (Lemma 2.2) with those in the direct interconnection (DI) case (Lemma 2.6) with \( t_1 = 1 \). Three indifference points can be established. \( \pi^*_1 \geq \pi^*_1 \text{ for } r \in (0, 0.67); \pi^*_2 \geq \pi^*_2 \text{ for } r \in (0, 0.87); \text{ and } \pi^*_1 + \pi^*_2 \geq \pi^*_1 + \pi^*_2 \text{ for } r \in (0, 0.71). \) All of these profits on the LHS are lower than those on the RHS for all higher values of \( r \). Network sharing is Pareto optimal when \( \pi^*_j \geq \pi^*_j \text{ for } j = 1, 2 \) and feasible through a transfer from Platform 2 to Platform 1 when \( \pi^*_1 < \pi^*_1 \text{ but } \pi^*_1 + \pi^*_2 > \pi^*_1 + \pi^*_2 \text{. This gives us the necessary result. [Note that the bounds are rounded to the } 2^{nd} \text{ decimal place]}\)

**Proof of Proposition 2.5:** The proof here mirrors that of Proposition 2.4. In each case, we identify indifference points for \( r \) for each of the platforms’ profits as well as the total industry profits where the profits in the Indirect Interconnection (II) case are identical to those in the open competition (OC) case. These form the boundaries for the different regions.

**Case 1:** \( \gamma_j(t_1, t_2) = \text{Min}(t_1, t_2) \)

\( \pi^*_1 \geq \pi^*_1 \text{ for } r \in (0, 0.3); \pi^*_2 \geq \pi^*_2 \text{ for } r \in (0, 0.82); \text{ and } \pi^*_1 + \pi^*_2 \geq \pi^*_1 + \pi^*_2 \text{ for } r \in (0, 0.45). \)
Case 2: \( \gamma_j(t_1,t_2) = \text{Avg}(t_1,t_2) \)

\( \pi^*_1 \leq \pi^*_1 \text{ for } r \in (0,0.09) \); \( \pi^*_2 \leq \pi^*_2 \text{ for } r \in (0,0.77) \); and \( \pi^*_1 + \pi^*_2 \geq \pi^*_1 + \pi^*_2 \text{ for } r \in (0,0.30) \).

Case 3: \( \gamma_j(t_1,t_2) = \text{Max}(t_1,t_2) \)

\( \pi^*_1 < \pi^*_1 \text{ for all } r; \pi^*_2 \geq \pi^*_2 \text{ for } r \in (0,0.69) \); and \( \pi^*_1 + \pi^*_2 \geq \pi^*_1 + \pi^*_2 \text{ for } r \in (0,0.01) \).

In each case, the profits on the LHS are lower than those on the RHS for all values of \( r \) higher than those specified. Indirect network sharing is Pareto optimal when \( \pi^*_j \leq \pi^*_j \) for \( j = 1,2 \) and feasible through a transfer from Platform 2 to Platform 1 when \( \pi^*_1 < \pi^*_1 \) but \( \pi^*_1 + \pi^*_2 \geq \pi^*_1 + \pi^*_2 \). This gives us the necessary result. [Note that all bounds are rounded to 2 decimal places]

Proof of Lemma 2.7: Replace both \( t_j \) and \( t_j \) with \( t_1 \) in the equilibrium outcomes of Lemma 2.2

Proof of Proposition 2.6: The result once again relies on a comparison of the total industry profits in the technology licensing (TL) case with that of the open competition (OC) case.

Total profits in the open competition case are:
\[
\pi^*_1 + \pi^*_2 = \frac{8N_bN_1 t_1(2-t_2/t_1)(8+t_2/t_1)}{(8-t_2/t_1)^3},
\]

while those in the tech licensing case are:
\[
\pi^*_1 + \pi^*_2 = \frac{72N_bN_1 t_1}{343},
\]

Further, total profits are equal in both cases at \( \frac{t_2}{t_1} = 1 \). This implies that \( \pi^*_1 + \pi^*_2 = \pi^*_1 + \pi^*_2 \) for all \( \frac{t_2}{t_1} < 1 \) and, therefore, licensing is infeasible.
**Proof of Lemma 2.8:** Recall that $t_1 = 1$, $r = t_2/t_1$ and that the entrant is on top. Let, on side $i$, $\theta_{i1}^*$ be the customer type, for whom the IC binds, and $\theta_{i2}^*$ the customer type for whom the IR constraint binds.

IR: $r\theta_{i2}^* (n_{i2}^e + n) = p_{i2},$

IC: $\theta_{i1}^* n_{i1}^e - p_{i1} = \theta_{i1}^* r(n_{i2}^e + n) - p_{i2}.$

This yields $\theta_{i2}^* = p_{i2}/(r(n_{i2}^e + n))$ and $\theta_{i1}^* = (p_{i1} - p_{i2})/(n_{i1}^e - r(n_{i2}^e + n))$.

The corresponding platform profits of the entrant and the incumbent platforms are, respectively,

$$\pi_1 = p_{b1} (1 - \theta_{b1}^*) + p_{s1} (1 - \theta_{s1}^*),$$

$$\pi_2 = p_{b2} (\theta_{b2}^* - \theta_{b2}^*) + p_{s2} (\theta_{s1}^* - \theta_{s2}^*).$$

The profit functions are concave and, therefore, the FOCs are sufficient and yield a unique solution. Solving the four FOCs and imposing the FEE condition, we get:

$$\theta_{i1}^* = \frac{4 - r - 2nr}{8 - r}; \quad \theta_{i2}^* = \frac{2 - r - 3nr}{8 - r}.$$

Substituting back into the FOCs, and calculating the equilibrium prices, demands and profits we obtain the given outcomes. For this equilibrium to be feasible, we need $D_{i1} + D_{i2} = \frac{2(2+nr)}{8-r} + \frac{2+nr}{8-r} \leq 1$. Simplifying, this yields the condition: $n \leq \frac{2-r}{3r}$.

**Proof of Lemma 2.9:** We start with the assumption that the incumbent is on top. Let $\theta_{i1}^*$ be the customer type on side $i$, for whom the IC binds, and $\theta_{i2}^*$ the customer type for whom the IR constraint binds.

IR: $\theta_{i1}^* n_{i1}^e = p_{i1},$

IC: $\theta_{i1}^* n_{i1}^e - p_{i1} = \theta_{i1}^* r(n_{i2}^e + n) - p_{i2}.$

This yields $\theta_{i2}^* = p_{i2}/n_{i1}^e$ and $\theta_{i1}^* = (p_{i1} - p_{i2})/(n_{i1}^e - r(n_{i2}^e + n)).$

The corresponding platform profits of the entrant and the incumbent platforms are, respectively,

$$\pi_1 = p_{b1} (\theta_{b1}^* - \theta_{b2}^*) + p_{s1} (\theta_{s1}^* - \theta_{s2}^*),$$

$$\pi_2 = p_{b2} (1 - \theta_{b1}^*) + p_{s2} (1 - \theta_{s1}^*).$$
The profit functions are concave and, therefore, the FOCs are sufficient and yield a unique solution. Solving the four FOCs and imposing the FEE condition, we get:

\[
\theta_{i_1}^* = \frac{1 - 6r - 4nr + 2\sqrt{r(-n + r + 4nr + 4n^2r)}}{1 - 8r},
\]

\[
\theta_{i_2}^* = \frac{1 - 5r - 6nr + 3\sqrt{r(-n + r + 4nr + 4n^2r)}}{1 - 8r}.
\]

Substituting back into the FOCs, and calculating the equilibrium prices, demands and profits yields the stated results. For this equilibrium to be feasible, we need \(D_{i_1} + D_{i_2} \leq 1\). Substituting and simplifying yields \(0 < r \leq \frac{1}{2} AND n \geq \frac{1-2r}{3r} II \left(\frac{1}{2} < r < 1 AND n \geq 0\right)\).

**Proof of Lemma 2.10:** We start with the assumption of Incumbent-on-Top with the networks interconnected. Let \(\theta_{i_1}^*\) and \(\theta_{i_2}^*\) be the customer types for whom the IC and IR constraints bind.

**IR:** \(\theta_{i_2}^* n_{i_1}^e + \theta_{i_2}^* g_1(n_{i_2}^e + n) = p_{i_1}\),

**IC:** \(\theta_{i_1}^* n_{i_1}^e + \theta_{i_1}^* g_1(n_{i_2}^e + n) - p_{i_1} = \theta_{i_1}^* g_1(n_{i_2}^e + n) + \theta_{i_1}^* g_2 n_{i_1}^e - p_{i_2}\).

These yield:

\[
\theta_{i_2}^* = p_{i_1} / (n_{i_1}^e + g_1(n_{i_2}^e + n)),
\]

\[
\theta_{i_1}^* = (p_{i_1} - p_{i_2}) / \left( (n_{i_1}^e + g_1(n_{i_2}^e + n)) - (r(n_{i_2}^e + n) + g_2 n_{i_1}^e) \right).
\]

The corresponding platform profits of the entrant and the incumbent platforms are, respectively,

\[
\pi_1 = p_{b_1}(\theta_{b_1}^* - \theta_{b_2}^*) + p_{s_1}(\theta_{s_1}^* - \theta_{s_2}^*),
\]

\[
\pi_2 = p_{b_2}(1 - \theta_{b_1}^*) + p_{s_2}(1 - \theta_{s_1}^*).
\]

The profit functions are concave and, therefore, the FOCs are sufficient and yield a unique solution. Solving the four FOCs and imposing the FEE condition gives values for \(\theta_{i_1}^*\) and \(\theta_{i_2}^*\), and the corresponding demands. The expressions are very messy to reproduce here, but total demand given by the demand expressions does not satisfy the condition \(D_{i_1} + D_{i_2} \leq 1\) for \(1 \geq \gamma_1 \geq \gamma_2 \geq r\). Therefore, this outcome is not feasible.
Entrant-on-top equilibrium under network interconnection (Section 2.6.1)

Assuming that the entrant is on top, let $\theta^*_{i_1}$ and $\theta^*_{i_2}$ be the customer types for whom the IC and IR constraints bind.

\[
IR: \quad \theta^*_{i_2} r(n^e_{i_2} + n) + \theta^*_{i_2} \gamma_2 n^e_{i_1} = p_{i_2},
\]

\[
IC: \quad \theta^*_{i_1} n^e_{i_1} + \theta^*_{i_1} \gamma_1 (n^e_{i_2} + n) - p_{i_1} = \theta^*_{i_1} r(n^e_{i_2} + n) + \theta^*_{i_1} \gamma_2 n^e_{i_1} - p_{i_2}.
\]

These yield:

\[
\theta^*_{i_2} = p_{i_2} / (r(n^e_{i_2} + n) + \gamma_2 n^e_{i_1}),
\]

\[
\theta^*_{i_1} = (p_{i_1} - p_{i_2}) / \left( (n^e_{i_1} + \gamma_1 (n^e_{i_2} + n)) - (r(n^e_{i_2} + n) + \gamma_2 n^e_{i_1}) \right).
\]

The corresponding platform profits for the entrant and the incumbent platforms are, respectively,

\[
\pi_1 = p_{b_1} (1 - \theta^*_{b_1}) + p_{s_1} (1 - \theta^*_{s_1}),
\]

\[
\pi_2 = p_{b_2} (\theta^*_{b_1} - \theta^*_{b_2}) + p_{s_2} (\theta^*_{s_1} - \theta^*_{s_2}).
\]

The profit functions are concave and, therefore, the FOCs are sufficient and solutions are unique. Solving the four FOCs and imposing the FEE condition we get values for $\theta^*_{i_1}$ and $\theta^*_{i_2}$. Substituting back into the FOCs, and calculating the equilibrium prices, demands and profits we would obtain the results, which are not included here because they are extremely cumbersome algebraically.
### B. Appendix to Chapter 3

#### B.1 Notations

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B.2 Proofs of lemmas and propositions

Proof of Lemma 3.1: Differentiating $f(q)$ we have

$$f'(q) = (P_g - E[\bar{P}(q)|P_g]) - q \frac{dE[\bar{P}(q)|P_g]}{dq}$$

The quantity in the brackets is positive since $[\bar{P}(q)|P_g] \leq P_g$ (from Assumption 3.5). The last term is positive as well since $dE[\bar{P}(q)|P_g]/dq$ is negative (from Assumption 3.2).

(QED)

Proof of Lemma 3.2: The function $\hat{q}(P_g, C_H)$ satisfies the equations

$$\hat{q}(P_g - E[\bar{P}(q)|P_g]) = C_H$$

From the implicit function theorem we have:

$$\frac{\partial \hat{q}}{\partial P_g} = -\hat{q} \left( 1 - \frac{\partial E[\bar{P}(\hat{q})|P_g]}{\partial P_g} \right) \frac{1}{(P_g - E[\bar{P}(\hat{q})|P_g]) - \hat{q} \frac{\partial E[\bar{P}(\hat{q})|P_g]}{\partial \hat{q}}}$$

$$\frac{\partial \hat{q}}{\partial C_H} = \frac{1}{(P_g - E[\bar{P}(\hat{q})|P_g]) - \hat{q} \frac{\partial E[\bar{P}(\hat{q})|P_g]}{\partial \hat{q}}}$$

$$\frac{\partial \hat{q}}{\partial P_g} \leq 0 \text{ and } \frac{\partial \hat{q}}{\partial C_H} \geq 0 \text{ since } \frac{\partial E[\bar{P}(\hat{q})|P_g]}{\partial P_g} \leq 1/2 \text{ and } E[\bar{P}(\hat{q})|P_g] \leq P_g \text{ (from Assumption 3.5), and } dE[\bar{P}(\hat{q})|P_g]/dq \leq 0 \text{ (from Assumption 3.5 & Assumption 3.2).}$$

Proof of Proposition 3.1: Say, optimal prices are $P^*_g$ and $P^*_{g'}$ with cost of negotiation for the hospital $C_H$ and $C'_H$, respectively, and $C'_H > C_H$.

Profit without custom contracting when cost of negotiation is $C_H$

$$= \int_{\hat{q}} \hat{q}(P^*_g, C_H) \left( (1 - \lambda)P^*_g - m \right) g(x)dx$$
\[ \leq \int_{q}^{\bar{q} \left( p_g^* \cdot c_H^i \right)} x \left( (1 - \lambda) p_g^* - m \right) g(x) dx \quad \text{(as } \frac{\partial q}{\partial c_H} \geq 0 \text{ from Lemma 3.2)} \]

\[ \leq \int_{q}^{\bar{q} \left( p_g^{*'} \cdot c_H^i \right)} x \left( (1 - \lambda) p_g^{*'} - m \right) g(x) dx \quad \text{(since } p_g^{*'} \text{ is optimal price with cost of negotiation being } c_H^i \text{)} \]

\[ = \text{Profit without custom contracting when cost of negotiation is } c_H^i \quad \text{(QED)} \]

\[ \text{Profit with custom contracting when cost of negotiation is } c_H \]

\[ = \left( \int_{q}^{\bar{q} \left( p_g^* \cdot c_H \right)} x \left( (1 - \lambda) p_g^* - m \right) g(x) dx \right) \]
\[ + \int_{\bar{q} \left( p_g^* \cdot c_H \right)}^{\bar{q} \left( p_g^{*'} \cdot c_H \right)} \left( x \left( (1 - \lambda) E[p(x) | p_g^*] - m - c_V \right) g(x) dx \right) \]
\[ \left( \int_{q}^{\bar{q} \left( p_g^{*'} \cdot c_H \right)} x \left( (1 - \lambda) p_g^{*'} - m \right) g(x) dx \right) \]
\[ + \int_{\bar{q} \left( p_g^{*'} \cdot c_H \right)}^{\bar{q} \left( p_g^{*'} \cdot c_H \right)} \left( x \left( (1 - \lambda) E[p(x) | p_g^{*'}] - m - c_V \right) g(x) dx \right) \]
\[ \quad \text{(as } \frac{\partial q}{\partial c_H} \geq 0 \text{ from lemma 2)} \]

\[ \leq \left( \int_{q}^{\bar{q} \left( p_g^{*'} \cdot c_H \right)} x \left( (1 - \lambda) p_g^{*'} - m \right) g(x) dx \right) \]
\[ + \int_{\bar{q} \left( p_g^{*'} \cdot c_H \right)}^{\bar{q} \left( p_g^{*'} \cdot c_H \right)} \left( x \left( (1 - \lambda) E[p(x) | p_g^{*'}] - m - c_V \right) g(x) dx \right) \]
\[ \quad \text{(since } p_g^{*'} \text{ is optimal price with cost of negotiation being } c_H \text{)} \]

\[ = \text{Profit with custom contracting when cost of negotiation is } c_H^i \quad \text{(QED)} \]

**Proof of Proposition 3.2:** Say, without custom contracts, optimal GPO price is \( p_g^* \), and hospitals with demand up to \( q^* \) buy at the GPO price; with custom contracts, optimal GPO price is \( p_g^{*c} \), and hospitals with demand up to \( q^{*c} \) buy at the GPO price.

**Optimal profit without custom contracting with GPO price \( p_g^* \)**

\[ = \int_{q}^{q^*} x \left( (1 - \lambda) p_g^* - m \right) g(x) dx \]
\[
\leq \int_{\tilde{q}}^{\bar{q}} x((1 - \lambda)P_g^* - m)g(x)dx + \int_{\tilde{q}}^{\bar{q}} \left( x \left( (1 - \lambda)\mathbb{E}[\tilde{p}(x)|P_g^*] - m \right) - C_v \right) g(x)dx
\]

\] = Profit with custom contracting with GPO price \( P_g^* \)

\[
\leq \text{Optimal profit with custom contracting with GPO price } P_g^{e_c}
\]

\[\Rightarrow \text{Profit without custom contracting} \leq \text{Profit with custom contracting} \]

Now,
\[
\left( \int_{\tilde{q}}^{\bar{q}} x((1 - \lambda)P_g^* - m)g(x)dx \right)
\]

\[
\geq \left( \int_{\tilde{q}}^{\bar{q}} x((1 - \lambda)(P_g^* - \Delta) - m)g(x)dx \right), \forall \Delta \geq 0, \text{ since } P_g^* \text{ is optimal GPO price without custom contracting}
\]

\[\Rightarrow \]
\[
\left( \int_{\tilde{q}}^{\bar{q}} x((1 - \lambda)P_g^* - m)g(x)dx + \int_{\tilde{q}}^{\bar{q}} \left( x \left( (1 - \lambda)\mathbb{E}[\tilde{p}(x)|P_g^*] - m \right) - C_v \right) g(x)dx \right) \geq \left( \int_{\tilde{q}}^{\bar{q}} x((1 - \lambda)(P_g^* - \Delta) - m)g(x)dx \right), \forall \Delta \geq 0
\]

And,
\[
\left( \int_{\tilde{q}}^{\bar{q}} \left( x \left( (1 - \lambda)\mathbb{E}[\tilde{p}(x)|P_g^*] - m \right) - C_v \right) g(x)dx \right)
\]

\[
\geq \left( \int_{\tilde{q}}^{\bar{q}} \left( x \left( (1 - \lambda)\mathbb{E}[\tilde{p}(x)|P_g^* - \Delta] - m \right) - C_v \right) g(x)dx \right), \forall \Delta \geq 0
\]

( B.2 ) and ( B.3 ) together imply,
\[
\begin{align*}
&\left( \int_{q}^{q(P_{g}^*, cH)} x (1 - \lambda) P_{g}^* - m \right) g(x) dx \\
&+ \int_{q(P_{g}^* - \Delta, cH)}^{q(P_{g}^*, cH)} \left( x \left( (1 - \lambda)E[\bar{\theta}(x) | P_{g}^*] - m \right) - C_{V} \right) g(x) dx \\
&+ \int_{q(P_{g}^* - \Delta, cH)}^{q} \left( x \left( (1 - \lambda)E[\bar{\theta}(x) | P_{g}^* - \Delta] - m \right) - C_{V} \right) g(x) dx
\end{align*}
\]

\( \forall \Delta \geq 0 \) \hspace{1cm} (B.4)

\[
\begin{align*}
&\left( \int_{q}^{q(P_{g}^*, cH)} x (1 - \lambda) P_{g}^* - m \right) g(x) dx \\
&+ \int_{q(P_{g}^* - \Delta, cH)}^{q} \left( x \left( (1 - \lambda)E[\bar{\theta}(x) | P_{g}^* - \Delta] - m \right) - C_{V} \right) g(x) dx
\end{align*}
\]

\( \forall \Delta \geq 0 \) \hspace{1cm} (B.5)

\[ P_{g}^{c} \text{ cannot be less than } P_{g}^*. \text{ Also, } (P_{g}^{c} \geq P_{g}^*) \text{ implies } (q^{c} \leq q^*). \]

\[ \Rightarrow \text{ The GPO price is higher with custom contracting; Fewer hospitals buy at GPO price when custom contracting is permitted; } \]

Now, revenue without custom contracting = \( \int_{q}^{q^*} (x P_{g}^*) g(x) dx \)

Clearly,
\[
\int_{q}^{q^*} (xP^*_g)g(x)dx \leq \int_{q}^{q^*} (xP^*_g)g(x)dx + \int_{q}^{\bar{q}} (xE[\tilde{p}(x)|P^*_g])g(x)dx
\]

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

\[
\int_{q}^{q^*} (xP^*_g)g(x)dx + \int_{q}^{\bar{q}} (xE[\tilde{p}(x)|P^*_g])g(x)dx \\
\leq \text{revenue with custom contracting}
\]

\[
= \int_{q}^{q^{*c}} (xP^{*c}_g)g(x)dx + \int_{q}^{\bar{q}} (xE[\tilde{p}(x)|P^{*c}_g])g(x)dx
\]

Using (B.5) the fact that \(P^{*c}_g \geq P^*_g\) and \(q^{*c} \leq q^*\) it can be concluded that,

\[
\begin{align*}
\left( \int_{q}^{q^{*c}} x(1 - \lambda)P^{*c}_g - m \right)g(x)dx \\
+ \int_{q}^{\bar{q}} x(1 - \lambda)E[\tilde{p}(x)|P^{*c}_g] - m - C_V g(x)dx
\end{align*}
\]

\[
\geq 
\begin{align*}
\left( \int_{q}^{q^{*c}} x(1 - \lambda)P^{*c}_g g(x)dx \\
+ \int_{q}^{\bar{q}} x(1 - \lambda)E[\tilde{p}(x)|P^{*c}_g]g(x)dx
\end{align*}
\]

\[
- m \int_{q}^{\bar{q}} x g(x)dx - C_V \int_{q}^{\bar{q}} g(x)dx
\]

\[
\geq 
\begin{align*}
\left( \int_{q}^{q^{*c}} x(1 - \lambda)P^*_g g(x)dx \\
+ \int_{q}^{\bar{q}} x(1 - \lambda)E[\tilde{p}(x)|P^*_g]g(x)dx
\end{align*}
\]

\[
- m \int_{q}^{\bar{q}} x g(x)dx - C_V \int_{q}^{\bar{q}} g(x)dx
\]

\[
\geq 
\begin{align*}
\left( \int_{q}^{q^{*c}} xP^{*c}_g g(x)dx + \int_{q}^{\bar{q}} xE[\tilde{p}(x)|P^{*c}_g]g(x)dx - \frac{C_V}{1 - \lambda} \int_{q}^{\bar{q}} g(x)dx
\end{align*}
\]

\[
\left( \int_{q}^{q^{*c}} xP^*_g g(x)dx + \int_{q}^{\bar{q}} xE[\tilde{p}(x)|P^*_g]g(x)dx - \frac{C_V}{1 - \lambda} \int_{q}^{\bar{q}} g(x)dx
\]
\[
\Rightarrow \left( \int_{q}^{q^c} xP_{g}^{c}g(x)dx + \int_{q}^{q^c} xE[\tilde{p}(x)|P_{g}^{c}]g(x)dx \right) \geq \left( \int_{q}^{q^*} xP_{g}^{*}g(x)dx + \int_{q}^{q^*} xE[\tilde{p}(x)|P_{g}^{*}]g(x)dx \right), \text{ since } \frac{c_{V}}{1-\lambda} \int_{q}^{q^*} g(x)dx \geq \frac{c_{V}}{1-\lambda} \int_{q}^{q^c} g(x)dx
\]

QED

**Proof of Proposition 3.3:** Let’s say, without custom contracts, hospitals with demand up to \( q \) buy at the GPO price, \( P_{g} \), and the rest buy from vendor(s) outside the GPO, at price \( E[\tilde{p}(x)|P_{g}] \); 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 \( E[\tilde{p}(x)|P_{g}^{c}] \).

Following Proposition 3.2, \( P_{g}^{c} \geq P_{g} \) and \( q^c \leq q \).

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

**Category I:** Hospitals with demand \( x \), \( \underline{q} \leq x \leq q^c \) buy at the GPO price irrespective of whether custom contracting is allowed or not:

Cost of procurement

\[
\begin{align*}
\begin{cases}
\text{with no GPO membership:} & (xE[\tilde{p}(x)] + C_H) \\
\text{with GPO membership:} & \begin{cases}
\text{custom contracting is allowed:} & (xP_{g}^{c}) \\
\text{custom contracting is not allowed:} & (xP_{g})
\end{cases}
\end{cases}
\end{align*}
\]

\( (xE[\tilde{p}(x)|P_{g}^{c}] + C_H) \geq xP_{g}^{c} \geq xP_{g}, \text{ using } (3.1) \text{ and as } (P_{g}^{c} \geq P_{g}) \)

\( \Rightarrow (xE[\tilde{p}(x)] + C_H) \geq xP_{g}^{c} \geq xP_{g}, \text{ using Assumption 3.5 (QED)} \)

**Category II:** Hospitals with demand \( x \), \( q^c \leq x \leq q \) buy at the GPO price in the absence of custom contract, however, renegotiate when custom contracting is allowed:
Procurement cost

\[
= \begin{cases} 
\text{with no GPO membership:} & (\mathbb{E}[\bar{P}(x)] + C_H) \\
\text{with GPO membership:} & \begin{cases} 
\text{custom contracting is allowed:} & (\mathbb{E}[\bar{P}(x)|P_g^c] + C_H) \\
\text{custom contracting is not allowed:} & (xP_g) 
\end{cases}
\end{cases}
\]

\[E[\bar{P}(x)] \geq E[\bar{P}(x)|P_g^c] \geq E[\bar{P}(x)|P_g], \text{ using Assumption 3.5} \]
\[\Rightarrow (\mathbb{E}[\bar{P}(x)] + C_H) \geq (\mathbb{E}[\bar{P}(x)|P_g^c] + C_H) \geq (\mathbb{E}[\bar{P}(x)|P_g] + C_H) \geq xP_g, \text{ using (3.1)} \]
\[\Rightarrow (\mathbb{E}[\bar{P}(x)] + C_H) \geq (\mathbb{E}[\bar{P}(x)|P_g^c] + C_H) \geq xP_g \text{ (QED)} \]

**Category III:** Hospitals with demand \(x\), \((q \leq x \leq \bar{q})\) do not buy at the GPO price irrespective of whether custom contracting is allowed or not:

Procurement cost

\[
= \begin{cases} 
\text{with no GPO membership:} & (\mathbb{E}[\bar{P}(x)] + C_H) \\
\text{with GPO membership:} & \begin{cases} 
\text{custom contracting is allowed:} & (\mathbb{E}[\bar{P}(x)|P_g^c] + C_H) \\
\text{custom contracting is not allowed:} & (\mathbb{E}[\bar{P}(x)|P_g] + C_H) 
\end{cases}
\end{cases}
\]

\[E[\bar{P}(x)] \geq E[\bar{P}(x)|P_g^c] \geq E[\bar{P}(x)|P_g], \text{ using Assumption 3.5} \]
\[\Rightarrow (\mathbb{E}[\bar{P}(x)] + C_H) \geq (\mathbb{E}[\bar{P}(x)|P_g^c] + C_H) \geq (\mathbb{E}[\bar{P}(x)|P_g] + C_H) \text{ (QED)} \]
C. Appendix to Chapter 4

C.1 Notations

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**Equilibrium A** (only vendor 1 sells)

| Price offered by vendor 1         | $p_{1A}$          |
| Profit of vendor 1                | $\Pi_{1A}$        |
| Aggregate disutility for the hospital | $D_A$             |
| Total cost of procurement for the hospital | $C_A$             |

**Equilibrium B** (only vendor 2 sells)

| Price offered by vendor 2         | $p_{2B}$          |
| Profit of vendor 2                | $\Pi_{2B}$        |
| Aggregate disutility for the hospital | $D_B$             |
| Total cost of procurement for the hospital | $C_B$             |

**Equilibrium C** (both vendors sell)

| Price offered by vendor $i$       | $p_{iC}$          |
| Fraction of demand bought from vendor $i$ | $f_{iC}$         |
| Profit of vendor $i$              | $\Pi_{iC}$        |
| Aggregate disutility for the hospital | $D_C$             |
| Total cost of procurement for the hospital | $C_C$             |
C.2 Proofs of lemmas and propositions

Proof of Lemma 4.1: If it is optimal for the hospital to procure from both vendors, i.e., \((c - l/2 < k < c + l/2)\), the total cost for the hospital is minimized when \(p_1 + kt = p_2 + (1 - k)t\).

Solving for \(k\) gives: 
\[
k = \frac{p_2 - p_1}{2t} + \frac{1}{2}.
\]

This implies:
\[
f_1 = \frac{(p_2 - p_1 + \frac{1}{2}) - (c - l/2)}{l} \quad \text{and} \quad f_2 = \frac{(c + l/2) - (p_2 - p_1 + \frac{1}{2})}{l}.
\]

The profit of vendor \(i\) is then:
\[
\Pi_i(p_1, p_2) = \left( (p_i - m)Qf_i - F_V \ast 1_{(Qf_i > 0)} \right).
\]

Substituting the values of \(f_i\) in the above expression I get,
\[
\Pi_1(p_1, p_2) = \frac{Q}{2lt} \left( (p_1 - m)(t(l - 2c + 1) - p_1 + p_2) \right), \quad \text{and therefore},
\]
\[
\frac{\partial \Pi_1(p_1, p_2)}{\partial p_1} = \frac{Q}{2lt} \left( t(l - 2c + 1) - 2p_1 + p_2 + m \right) \quad \text{and} \quad \left( \frac{\partial^2 \Pi_1(p_1, p_2)}{\partial p_1^2} = -\frac{Q}{lt} < 0 \right).
\]

The profit functions are, therefore, concave and first order conditions are satisfied.

Solving \(\frac{\partial \Pi_1(p_1, p_2)}{\partial p_1} = 0\), we get \(p_1 = \frac{1}{2} \left( p_2 + m + t(l - 2c + 1) \right)\). So, vendor 1’s maximum possible profit given vendor 2’s price as \(p_2\) is (if a positive sale is made):
\[
\left( (p_1 - m)Qf_1 - F_V \ast 1_{(Qf_1 > 0)} \right), \quad \text{where} \quad p_1 = \frac{1}{2} \left( p_2 + m + t(l - 2c + 1) \right), \quad \text{or}
\]
\[
= \frac{Q}{8lt} \left( p_2 - m + t(l - 2c + 1) \right)^2 - F_V.
\]

If the above expression is negative, vendor 1 is better off not making a sale. For the above expression to be non-negative, the following has to be true:
\[
p_2 \geq \left( m - t(l - 2c + 1) + \sqrt{\frac{8F_Vl}{Q}} \right) = p_{2L} \text{(say)}.
\]

So, vendor 1’s price reaction curve as a function of vendor 2’s price is expressed as:
\[ p_{1R}(p_2) = \begin{cases} 
\text{Do not sell, if } p_2 \leq p_{2L} = \left( m - t(l - 2c + 1) + \sqrt{\frac{8F_vlt}{Q}} \right), & \\
\frac{1}{2}(p_2 + m + t(l - 2c + 1)) \text{ otherwise} \end{cases} \]

This implies,
\[ p_{1R}(p_2) = \begin{cases} 
 f_1 = 0, \text{ if } p_2 \leq p_{2L} = \left( m - t(l - 2c + 1) + \sqrt{\frac{8F_vlt}{Q}} \right), & \\
\frac{1}{2}(p_2 + m + t(l - 2c + 1)) \text{ otherwise} \end{cases} \]

This further implies,
\[ p_{1R}(p_2) = \begin{cases} 
 \geq (p_2 + t(l - 2c + 1)), \text{ if } p_2 \leq p_{2L} = \left( m - t(l - 2c + 1) + \sqrt{\frac{8F_vlt}{Q}} \right), & \\
\frac{1}{2}(p_2 + m + t(l - 2c + 1)) \text{ otherwise} \end{cases} \]

Vendor 2’s price reaction curve \((p_{2R})\) is formulated by replacing \(c\) with \((1 - c)\) and \(p_2\) with \(p_1\) in the expression for \(p_{1R}(p_2)\) above as follows:
\[ p_{2R}(p_1) = \begin{cases} 
 \geq (p_1 + t(l - 2(1 - c) + 1)), \text{ if } p_1 \leq \left( m - t(l - 2(1 - c) + 1) + \sqrt{\frac{8F_vlt}{Q}} \right) = p_{1L} \] 
\[ \frac{1}{2}(p_1 + m + t(l - 2(1 - c) + 1)) \text{ otherwise} \end{cases} \]

This simplifies to,
\[ p_{2R}(p_1) = \begin{cases} 
(p_1 + t(l + 2c - 1)), & \text{if } p_1 \leq p_{1L} = \left(m - t(l + 2c - 1) + \sqrt{\frac{8F_Vt}{Q}} \right) \\
\frac{1}{2} (p_1 + m + t(l + 2c - 1)), & \text{otherwise} 
\end{cases} \]

**Proof of Lemma 4.2:** The Proof here follows from the price reactions curves as specified in Lemma 4.1.

**Equilibrium at A:** Vendor 2 stays off the market, vendor 1’s optimal price offer is

\[ p_{1A} = p_{1L} = \left(m - t(l + 2c - 1) + \sqrt{\frac{8F_Vt}{Q}} \right) \],

and vendor 1 makes a profit of \( \Pi_{1A} = Q(p_{1A} - m) - F_V = \sqrt{8QF_Vlt} - Qt(l + 2c - 1) - F_V \), and vendor 2 makes a profit of \( \Pi_{2A} = 0 \). The aggregate disutility cost for the hospital is given by

\[ D_A = \int_{c-l/2}^{c+l/2} \left( \frac{Q}{1} \right) x \, dx = cQt, \]

and the total cost of procurement for the hospital is given by

\[ C_A = Qp_{1L} + D_A + F_H = \sqrt{8QF_Vlt} + mQ - Qt(l + c - 1) + F_H. \]

**Equilibrium at B:** Vendor 1 stays off the market, vendor 2’s optimal price offer is

\[ p_{2B} = p_{2L} = \left(m - t(l - 2c + 1) + \sqrt{\frac{8F_Vt}{Q}} \right) \],

and vendor 2 makes a profit of \( \Pi_{2B} = Q(p_{2B} - m) - F_V = \sqrt{8QF_Vlt} - Qt(l - 2c + 1) - F_V \), and vendor 1 makes a profit of \( \Pi_{1B} = 0 \). The aggregate disutility cost for the hospital is given by

\[ D_B = \int_{c-l/2}^{c+l/2} \left( \frac{Q}{1} \right) (1 - x) \, dx = (1 - c)Qt, \]

and the total cost of procurement for the hospital is given by

\[ C_B = Qp_{2L} + D_B + F_H = \sqrt{8QF_Vlt} + mQ - Qt(l - c) + F_H. \]

**Equilibrium at C:** In the equilibrium where the hospital allocates demand to both vendors, optimal prices \( \{p_{1C}, p_{2C}\} \) for the vendors are obtained by solving the following simultaneous equations —
\[ p_{1c} = \frac{1}{2} \left( p_{2c} + m + t(l - 2c + 1) \right), \quad p_{2c} = \frac{1}{2} \left( p_{1c} + m + t(l + 2c - 1) \right). \]

It gives,
\[ p_{1c} = m + \frac{t}{3}(3l - 2c + 1); \quad p_{2c} = m + \frac{t}{3}(3l + 2c - 1). \]

By replacing \( p_1 \) with \( p_{1c} \) and \( p_2 \) with \( p_{2c} \) in the expression for \( f_1 \) and \( f_2 \) in Lemma 4.1, it gives the fractions of demand bought from vendors 1 and 2, respectively, as,
\[ f_{1c} = \frac{1}{2} + \frac{1 - 2c}{6l}; \quad f_{2c} = \frac{1}{2} + \frac{2c - 1}{6l}. \]

Profits of vendors are given by,
\[ \Pi_{1c} = (p_{1c} - m)Qf_{1c} - F_V = \frac{Qt(3l - 2c + 1)^2}{18l} - F_V; \]
\[ \Pi_{2c} = (p_{2c} - m)Qf_{2c} - F_V = \frac{Qt(3l + 2c - 1)^2}{18l} - F_V. \]

The aggregate cost of disutility is given by,
\[ D_c = D_{1c} + D_{2c} = \int_{c - \frac{l}{2}}^{c + \frac{l}{2}} \left( \frac{Q}{T} \right) xtdx + \int_{c - \frac{l}{2}}^{c + \frac{l}{2}} \left( \frac{Q}{T} \right) (1 - x)tdx \]
\[ = \frac{(5 + 20c(1 - c) + 9(2l - 1))Qt}{36l}. \]

The corresponding total cost of procurement for the hospital is
\[ C_c = (Qf_1p_1 + D_{1c} + F_H) + (Qf_2p_2 + D_{2c} + F_H) \]
\[ = mQ + \frac{Qt(27l^2 + 18l - 4c^2 + 4c - 1)}{36l} + 2F_H. \]

**Proof of Proposition 4.1:** *Follows from simplifying* \(((\Pi_{1A} \geq \Pi_{1C}) AND (p_{1C} \leq p_{1A}))\) *and replacing* \( c \) *with* \( d \) *for vendor 1, and simplifying* \(((\Pi_{2B} \geq \Pi_{2C}) AND (p_{2B} \leq p_{2C}))\) *and replacing* \( c \) *with* \( (1 - d) \) *for vendor 2.*
Proof of Proposition 4.2: It suffices to show that there exists pair of hospitals \( H^S := \{Q^S, t^S, F_H^S, c^S, l^S\} \) and \( H^L := \{Q^L, t^L, F_H^L, c^L, l^L\} \), such that in equilibrium either 1) \( H^S \) buys all units from vendor 1 paying a unit price of \( p_{1A}^S \) 2) \( H^L \) buys \( f_{1C}^L \) fraction of its demand from vendor 1 paying a unit price of \( p_{1C}^L \) and 3) \( (Q^S \leq Q^L f_{1C}^L) \) AND \( (p_{1A}^S \leq p_{1C}^L) \), or 1) \( H^S \) buys all units from vendor 2 paying a unit price of \( p_{2B}^S \) 2) \( H^L \) buys \( f_{2C}^L \) fraction of its demand from vendor 2 paying a unit price of \( p_{2C}^L \) and 3) \( (Q^S \leq Q^L f_{2C}^L) \) AND \( (p_{2B}^S \leq p_{2C}^L) \)

For the \( H^S \) to buy all its units from one vendor, the following logical expression \( L_1 \) or \( L_2 \) has to be true:

\[
L_1 := \left( (\Pi_{1A}^S \geq 0) \land (\Pi_{1A}^S \geq \Pi_{1C}^S) \right) \land \left( (\Pi_{1C}^S \leq 0) \lor (C_A^S \leq C_C^S) \right) \land \left( (C_A^S \leq C_B^S) \right) \quad \text{(follows from condition of equilibrium A)}
\]

\[
L_2 := \left( (\Pi_{2B}^S \geq 0) \land (\Pi_{2B}^S \geq \Pi_{2C}^S) \right) \land \left( (\Pi_{2C}^S \leq 0) \lor (C_B^S \leq C_C^S) \right) \land \left( (C_B^S \leq C_A^S) \right) \quad \text{(follows from condition of equilibrium B)}
\]

For \( H^L \) to allocate its demand between vendors, the following logical expression \( L_3 \) has to be true:

\[
L_3 := \left( (\Pi_{1C}^L \geq 0) \land (\Pi_{2C}^L \geq 0) \right) \land \left( (\Pi_{1C}^L \geq \Pi_{1A}^L) \lor (C_C^L \leq C_A^L) \right) \land \left( (\Pi_{2C}^L \geq \Pi_{2B}^L) \lor (C_C^L \leq C_B^L) \right) \quad \text{(follows from condition of equilibrium C)}
\]

Set of all possible hospital is given by,

\[
H := \{ (Q, t, F_H, c, l) : Q > 0, t > 0, F_H > 0, 0 \leq c \leq 1, 0 \leq l/2 \leq \min\{c, 1 - c\}\}
\]

It suffices to prove that the following set \( S \) is non-empty.

\[
S := \left\{ \left\{ Q^S, t^S, F_H^S, c^S, l^S \right\}, \left\{ Q^L, t^L, F_H^L, c^L, l^L \right\} : \begin{array}{l}
\{ Q^S, t^S, F_H^S, c^S, l^S \} \in H, \{ Q^L, t^L, F_H^L, c^L, l^L \} \in H,
L_3 \land \left( L_1 \land (Q^S \leq Q^L f_{1C}^L) \land (p_{1A}^S \leq p_{1C}^L) \right) \lor \left( L_2 \land (Q^S \leq Q^L f_{2C}^L) \land (p_{2B}^S \leq p_{2C}^L) \right) \end{array} \right\}
\]
I prove that the above set is non-empty by presenting an example that belongs to the set.

Vendors 1 & 2

\[ F'_\nu = 100; m = 1; \]

<table>
<thead>
<tr>
<th>Small hospital</th>
<th>Large hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q^S = 700, t^S = 0.85, F_H = 100, c^S = 0.5, l^S = 0.5 ) ( \in H )</td>
<td>( Q^L = 2000, t^L = 0.85, F_H = 100, c^L = 0.5, l^L = 0.33 ) ( \in H )</td>
</tr>
<tr>
<td>( { p_{1A}^S = 1.27, \Pi_{1A}^S = 90.35, C_A^S = 1287.85 } )</td>
<td>( { p_{1A}^L = 1.05, \Pi_{1A}^L = 8.92, C_A^L = 3058.93 } )</td>
</tr>
<tr>
<td>( { p_{2B}^S = 1.27, \Pi_{2B}^S = 90.35, C_B^S = 1287.85 } )</td>
<td>( { p_{2B}^L = 1.05, \Pi_{2B}^L = 8.92, C_B^L = 3058.93 } )</td>
</tr>
<tr>
<td>[ p_{1C}^S = 1.42, p_{2C}^S = 1.42, f_{1C}^S = 0.5, f_{2C}^S = 0.5, \Pi_{1C}^S = 48.75, \Pi_{2C}^S = 48.75, C_C^S = 1420.6 ]</td>
<td>( { p_{1C}^L = 1.28, p_{2C}^L = 1.28, f_{1C}^L = 0.5, f_{2C}^L = 0.5, \Pi_{1C}^L = 180.5, \Pi_{2C}^L = 180.5, C_C^L = 3470.7 } )</td>
</tr>
</tbody>
</table>

It can be easily verified that, \( \{(700,0.85,100,0.5,0.5), (2000,0.85,100,0.5,0.33)\} \in S \)

Both vendor 1 and 2 will offer a regular price of 1.42 and a discounted price 1.27 conditional on full compliance as \( (\Pi_{1A}^S \geq \Pi_{1C}^S) \) and \( (\Pi_{2B}^S \geq \Pi_{2C}^S) \).

Vendor 1 and 2 both will offer only a regular price of 1.28 as profit of both vendors are higher in equilibrium C as compared to in equilibrium A or B. \( (\Pi_{1C}^L \geq \Pi_{1A}^L) \) as well as \( (\Pi_{2C}^L \geq \Pi_{2B}^L) \)

The small hospital buys all of its 700 units from either vendor 1 or vendor 2 as \( (C_A^S \leq C_C^S) \) as well as \( (C_B^S \leq C_C^S) \); pays 1.27 per unit; note that vendor is indifferent between buying from vendor 1.

The large hospital buys 1000 units from vendor 1 and 1000 units from vendor 2; pays 1.28 per unit to each vendor.
and vendor 2 as $C_A^S$ equals $C_B^S$.

The smaller hospital is paying a lower price (1.27 < 1.28) to vendor 1 despite buying fewer units (700 < 2000 * 0.5) than what the large hospital is buying.

**Proof of Proposition 4.3:** It suffices to show that there exists a hospital $H := \{Q, t, F_H, c, l\}$, such that, in equilibrium, 1) either $H$ buys all units from vendor 1, incurs a total cost of $C_A$, the vendor makes a profit of $\Pi_{1A}$; or $H$ buys all units from vendor 2, incurs a total cost of $C_B$, the vendor makes a profit of $\Pi_{2B}$ 2) regular prices without requiring full compliance are offered by both vendors, and if the hospital bought from both vendors it would have incurred a total cost of $C_C$, and the two vendors would have made profits of $\Pi_{1C}$ and $\Pi_{2C}$, respectively 3) ($\Pi_{1A} \geq \Pi_{1C}$) AND ($C_A \leq C_C$) AND ($\Pi_{1A} - C_A \geq \Pi_{1C} + \Pi_{2C} - C_C$) if $H$ bought all units from vendor 1; ($\Pi_{2B} \geq \Pi_{2C}$) AND ($C_B \leq C_C$) AND ($\Pi_{2B} - C_B \geq \Pi_{1C} + \Pi_{2C} - C_C$) if $H$ bought all units from vendor 2, 4) ($\Pi_{1A} \geq \Pi_{1C}$) AND ($C_A \leq C_C$) AND ($D_A + F_H + F_V \leq D_c + 2F_H + 2F_V$) if $H$ bought all units from vendor 1; ($\Pi_{2B} \geq \Pi_{2C}$) AND ($C_B \leq C_C$) AND ($D_B + F_H + F_V \leq D_c + 2F_H + 2F_V$) if $H$ bought all units from vendor 2.

For the hospital $H$ to buy all its units from one vendor, the following logical expression $L_1$ or $L_2$ has to be true:

$L_1 :=

\left( (\Pi_{1A} \geq 0) AND (\Pi_{1A} \geq \Pi_{1C}) \right) AND \left( (\Pi_{1C} \leq 0) OR (C_A \leq C_C) \right) AND \left( (\Pi_{2B} \leq 0) OR (C_A \leq C_B) \right) \text{ (follows from condition of equilibrium A)}$

$L_2 :=

\left( (\Pi_{2B} \geq 0) AND (\Pi_{2B} \geq \Pi_{2C}) \right) AND \left( (\Pi_{2C} \leq 0) OR (C_B \leq C_C) \right) AND \left( (\Pi_{1A} \leq 0) OR (C_B \leq C_A) \right) \text{ (follows from condition of equilibrium B)}$

For vendors to offer regular price, i.e., not conditional on full participation, the following logical expression $L_3$ has to be true:

$L_3 := (\Pi_{1C} \geq 0) AND (\Pi_{2C} \geq 0)$
Set of all possible hospital is given by,
\[ \mathbf{H} := \{ (Q, t, F_H, c, l) : Q > 0, t > 0, F_H > 0, 0 \leq c \leq 1, 0 \leq l/2 \leq \min(c, 1 - c) \} \]

It suffices to prove that the following set \( S \) is non-empty.
\[
\{ (Q, t, F_H, c, l) : (Q, t, F_H, c, l) \in \mathbf{H}, \\
L_3 \land \left( \begin{array}{l}
\{ L_1 \land (\Pi_{1A} - C_A \geq \Pi_{1C} + \Pi_{2C} - C_C) \\
\land (D_A + F_H + F_V \leq D_c + 2F_H + 2F_V) \}
\end{array} \right) \\
\lor \left( \begin{array}{l}
L_2 \land (\Pi_{2B} - C_B \geq \Pi_{1C} + \Pi_{2C} - C_C) \\
\land (D_A + F_H + F_V \leq D_c + 2F_H + 2F_V) \end{array} \right) \}
\]

I prove that the above set is non-empty by presenting an example that belongs to the set.

\[
F_V = 50; \ m = 1; \ (Q = 500, t = 1, F_H = 50, c = 0.53, l = 0.25) \in H;
\]

\[
\{ p_{1A} = 1.14, \Pi_{1A} = 18.61, C_A = 883.61, D_A = 265 \}
\]

\[
\{ p_{2B} = 1.26, \Pi_{2B} = 78.61, C_B = 913.61, D_B = 235 \}
\]

\[
\begin{array}{l}
p_{1C} = 1.23, p_{2C} = 1.27, \\
f_{1C} = 0.46, f_{2C} = 0.54, \\
\Pi_{1C} = 2.9, \Pi_{2C} = 22.9, C_C = 943.55, D_C = 217.75
\end{array}
\]

It can be easily verified that, \( \{500,150,0.53,0.25\} \in S \)

In the above scenario, equilibrium A will be realized as \((\Pi_{1A} \geq \Pi_{1C}), (C_A \leq C_C)\), and \((C_A \leq C_B)\).

The total surplus at equilibrium A: \( \Pi_{1A} - C_A = 18.61 - 883.61 = -865 \)

The total surplus at equilibrium C (if exclusivity contract was not allowed): \( \Pi_{1C} + \Pi_{2C} - C_C = 2.9 + 22.9 - 843.55 = -917.75 \)

Clearly, in this case, at equilibrium A, not only the profit of the vendor is higher so is the total surplus. The cost of procurement is also lower at equilibrium A.

The social cost at equilibrium A: \( D_A + F_H + F_V = 365 \)

The total surplus at equilibrium C (if exclusivity contract was not allowed): \( D_C + 2F_H + 2F_V = 417.75 \)

Clearly, the social cost it lower at A.
Proof of Proposition 4.4:

1. a)\[
\frac{dC_A}{dt} \text{ or } \frac{dC_B}{dt} \text{ or } \frac{d\Pi_{1A}}{dt} \text{ or } \frac{d\Pi_{2B}}{dt} = \sqrt{\sqrt{F} / V / \sqrt{Q / T}} - Qt.
\]
\[
\frac{d^2C_A}{dt^2} \text{ or } \frac{d^2C_B}{dt^2} \text{ or } \frac{d^2\Pi_{1A}}{dt^2} \text{ or } \frac{d^2\Pi_{2B}}{dt^2} = -\frac{\sqrt{F} / \sqrt{Q / T}}{\sqrt{V / T} / 2} < 0 \Rightarrow \text{ total cost and profit are concave in } l
\]
\[
\frac{dC_A}{dt} \text{ or } \frac{dC_B}{dt} \text{ or } \frac{d\Pi_{1A}}{dt} \text{ or } \frac{d\Pi_{2B}}{dt} = 0 \text{ gives } l = \frac{2FV}{Qt} \Rightarrow \text{ total cost and profit reach maximum at } l = \frac{2FV}{Qt}
\]

1.b)\[
\frac{dC_A}{dc} \text{ or } \frac{dC_B}{d(1-c)} = -Qt < 0 \Rightarrow \text{ the total cost is decreasing in } d
\]
\[
\frac{d\Pi_{1A}}{dc} \text{ or } \frac{d\Pi_{2B}}{d(1-c)} = -2Qt < 0 \Rightarrow \text{ the profit is decreasing in } d
\]

2.a)\[
\frac{dC_c}{dt} = \frac{(1-2c)^2 + 27l^2}{36l^2} > 0 \Rightarrow \text{ the total cost is increasing in } l
\]

2.b)\[
\frac{dC_c}{dc} = \frac{1-2c}{9l}.
\]
\[
\frac{d^2C_c}{dc^2} = -\frac{2}{9l} < 0 \Rightarrow \text{ the total cost is concave in } c
\]
\[
\frac{dC_c}{dc} = 0 \text{ gives } c = 1/2 \Rightarrow \text{ the total cost is maximum at } c = 1/2
\]

2.c)\[
p_{1c} = m + \frac{t}{3}(3l - 2c + 1) \text{ and } p_{2c} = m + \frac{t}{3}(3l + 2c - 1) \text{ both increase with increase in } l. \ f_{1c} = \frac{1}{2} + \frac{1-2c}{6l} \text{ increases when } c \geq 1/2, \text{ decreases otherwise; } f_{2c} = \frac{1}{2} + \frac{2c-1}{6l} \text{ increase when } c \leq 1/2 \text{ or } (1-c) \geq 1/2, \text{ decreases otherwise.}
So, $\Pi_{1c} = (p_{1c} - m)Qf_{1c} - F_V$ is increasing in $l$ when $c \geq 1/2$; $\Pi_{2c} = (p_{2c} - m)Qf_{2c} - F_V$ is increasing in $l$ when $(1 - c) \geq 1/2$.

Otherwise,

$$\frac{d\Pi_{1c}}{dl} \text{ or } \frac{d\Pi_{2c}}{dl} = \frac{(1-2c+3l)(-1+2c+3l)Qt}{18l^2}$$

$$\frac{d^2\Pi_{1c}}{dl^2} \text{ or } \frac{d^2\Pi_{2c}}{dl^2} = \frac{(1-2c)^2Qt}{9l^3} > 0 \Rightarrow \text{the profits are convex in } l.$$

$$\frac{d\Pi_{1c}}{dl} = 0 \text{ gives } l = \frac{1}{3}(1 - 2c) \text{ with } c \leq 1/2 \Rightarrow \text{the profit is minimum at } l = \frac{1}{3}(1 - 2d); (d \text{ is the distance of the center of the hospital with respect to vendor 1' location})$$

$$\frac{d\Pi_{2c}}{dl} = 0 \text{ gives } l = \frac{1}{3}(2c - 1) \text{ with } c \geq 1/2 \Rightarrow \text{the profit is minimum at } l = \frac{1}{3}(1 - 2d); (d \text{ is the distance of the center of the hospital with respect to vendor 2' location})$$

(QED)

2.d)

$p_{1c} = m + \frac{t}{3}(3l - 2c + 1)$ decreases in $c$. $p_{2c} = m + \frac{t}{3}(3l + 2c - 1)$ decreases in $(1 - c)$;

$f_{1c} = \frac{1}{2} + \frac{1-2c}{6l}$ decreases in $c$; $f_{2c} = \frac{1}{2} + \frac{2c-1}{6l}$ decreases in $(1 - c)$;

So, $\Pi_{1c} = (p_{1c} - m)Qf_{1c} - F_V$ decreases in $c$; $\Pi_{2c} = (p_{2c} - m)Qf_{2c} - F_V$ decreases in $(1 - c)$;

(QED)