ECONOMICS OF WEB SERVICE PROVISIONING:
OPTIMAL MARKET STRUCTURE AND INTERMEDIARY STRATEGIES

By

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To Yanzan and my parents

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The Web services technology empowers a service-oriented architecture featured by "Just-in-Time" software integration and "on-demand" software provisioning. My objective is to study the impact of this new technology on firm strategies. To the best of my knowledge, mine is among the first studies of optimal strategies for offering Web services from an economic perspective.

First I address the optimal market structure to provide complementary Web services. In particular, three market structures are compared: independent service vendors; strategic alliance; and marketplace. The optimal market structure with different integration cost and market settings is derived. The model incorporates the integration cost that was not considered in previous literature on physical product bundling. Results indicate that in the context of Web service integration, a Web service marketplace (which corresponds to a structure of mixed bundling of physical goods) is not necessarily always the best market structure.

Next, I consider the optimal location and pricing problem of a Web services intermediary (WSI) that sells an integrated time-sensitive Web service. My study differs from previous research on facility locations in that I solve for the optimal location and price of the integrated Web service simultaneously. Two spatial models are analyzed, first a linear city model and then a unit circle model. I show that the integrated Web service is optimally located between the Web service vendors and the WSI should charge a penetration price if the delay cost is low. In addition, there could be multiple optimal locations for the WSI if the service vendors are located far away.

Finally, I analyze the optimal subscription and listing fee for a WSI that provides value-added service, such as aggregation services and technical services. My study extends current research on information intermediaries by considering multiple groups of Web service vendors and consumers. Analyses suggest that the intermediary is best off by setting the listing fee such that all service vendors list on it. Further, the optimal subscription fee is determined by network intensity, value of technical services, and properties of Web services.

CHAPTER 1
INTRODUCTION

The Web services architecture represents a new computing paradigm that allows for the distribution, discovery, production and consumption of loosely coupled software components over the Internet. The objective of the dissertation is to study the optimal strategies for providing Web services from an economic perspective. In particular, I aim to address three research problems: optimal market structure for providing complementary Web services; optimal location and pricing of an integrated Web service provided by a Web service intermediary; optimal subscription and listing fee charged by a Web services intermediary in a Web service supply chain.

The organization of the dissertation is as follows. Chapter 1 first gives a general introduction of the Web services technology, which includes the evolution of Web services and its technical characteristics. Then I discuss the business implications of Web services and introduce the research issues. Major findings are summarized at the end of Chapter 1. In Chapter 2, I examine the problem of optimal Web service market structure. Chapter 3 solves the joint decision problem of optimal location and pricing for an integrated Web service with the analysis of two spatial models. Chapter 4 analyzes the optimal subscription and listing fee charged by a Web service intermediary. In each chapter, I provide literature review and discuss the relevance to and distinctions from this research. Managerial insights are interpreted after presenting results from the analytical and numerical studies. Chapter 5 concludes this dissertation with discussion on future research plans.

1.1 Web Services: History and Overview

The business world is undergoing a globalization trend. Firms are expanding their territories into new markets abroad to create growth. Supply chains are being established among partners in different geographical regions to increase sourcing efficiency. To reap the full benefit of globalization, a firm oftentimes needs to standardize or reengineer its business processes, which requires the integration of various information systems built on different platforms at different times. Further, the globalization of business requires a distributed computing environment that allows companies to take advantage of the computing power at various operational units, regardless of geographical location and platform. Web services, a recent paradigm of computing, represents the most promising solution to date to addressing the challenge of distributed enterprise computing required by the globalization of business.

Hailed as revolutionary, Web Services technology came along an evolutionary path of growth. There has been continuous effort to improve the reusability, flexibility and interoperability of information systems. The advent of object-oriented languages makes it possible to encapsulate functionality in software components called "objects." Sun Microsystems introduced the platform-independent, bytecode-based Java language so that programs can be downloaded and run anywhere in the world. Microsoft catered to this componentization trend by providing the Object Linking and Embedding (OLE) technology. As Internet popularity grows and network technology matures, firms began to seek solutions for distributed computing. Yet the problem of incompatibility soon gets in the way when it comes to the collaboration and interaction among heterogeneous systems. Sun's Java Remote Method Invocation (RMI) over Internet Inter-Orb Protocol (IIOP) aims to deliver distributed computing capabilities, but it is overwhelmingly

complex and requires of Java end nodes. Likewise, Distributed Common Object Model (DCOM) proposed by Microsoft works only on Windows platforms (Schmelzer 2002).

For the first time, Web services technology poses a promising solution to the "plug-and-play" Holy Grail based on open standards and the decomposition of software application. According to the Stencil Group (Sleeper 2001), Web services are "loosely coupled, reusable software components that semantically encapsulate discrete functionality and are distributed and programmatically accessible over standard Internet protocols." From a technical perspective, Web services represent a collection of standard protocols for the creation, distribution, discovery and integration of semantic software components that encapsulate business functionalities. The key to Web services is dynamic software discovery and just-in-time software service creation (ingtegration) through the integration of loosely coupled software components. Central to the Web services architecture are the concepts of software as service and platform independence.

1.1.1 Software as service

As opposed to packaged monolithic applications that must be written or licensed, Web services encapsulate specific business functionalities that can be "rented" over the Internet. The idea of software as services dates back to the provision of application as services by Application Service Providers (ASP). But the Web services are not merely a newer version of ASP. Traditional ASP usually provides complex application systems, like Enterprise Resource Planning (ERP), through proprietary connection. Web services decompose business processes into granular components and thus allow customers to select services on an as-needed basis (Sharma and Gupta 2002). Further, Web services are distributed over the Internet, while traditional ASPs host their applications on a centrally located server. Figure 1-1 shows an example of Web service application for a

travel agency, which invokes several software modules (Web services) through the Internet to complete a vacation-planning process. The Web services involved might be written in different programming languages and distributed on different systems.

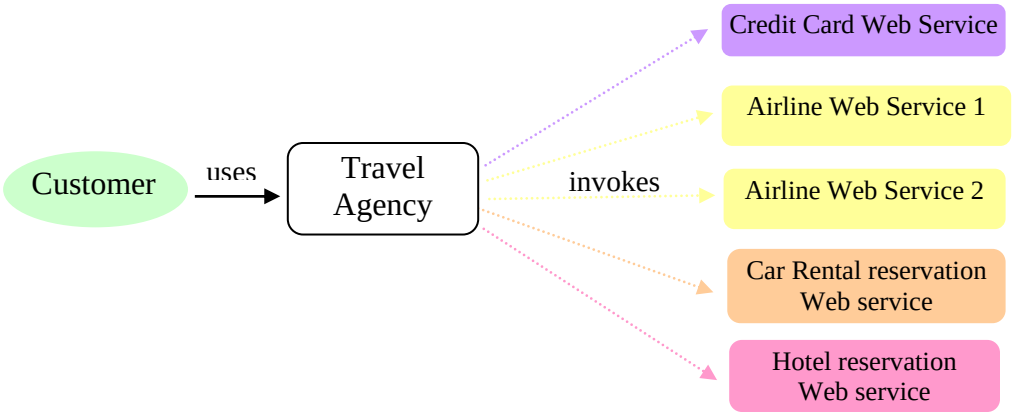

Figure 1-1. Example of Web service application

The service-oriented architecture also opens new business opportunities for firms because it allows firms to sell their software components as Web services over the Internet. For example, CitiBank developed CitiConnect, a payment-processing Web service that can be plugged into other company's transaction process (Hagel and Brown 2001). The spectrum of Web services spans from personal services, such as stock quote, messaging services; to enterprise-centric services, such as call center control, payroll management, and shipping and logistics.

1.1.2 Platform independence

The economic globalization and the continuously changing business environment necessitate an interoperable and flexible computing infrastructure. Web services technology can be used to create a platform-independent distributed computing environment, since it is built on a set of universally agreed upon standards such as XML, WSDL, SOAP, UDDI, and other specifications developed by various industrial consortiums. The Extensible Markup Language (XML) protocol allows self-describing

data to be exchanged independent of platform and language. The Web Services Description Language (WSDL) builds on XML and specifies how Web services can communicate with each other. The XML-based messaging protocol Simple Object Access Protocol (SOAP), recently renamed Services-Oriented Architecture Protocol, supports the invocation of software components over existing networks like HTTP and FTP in a fashion similar to Remote Procedure Call (RPC). The Universal Description, Discovery and Integration (UDDI) specification specifies the mechanism for the description, registration, dynamic lookup and integration of software components.

1.1.3 Integration of Web services

In essence, the Web services architecture represents a platform-, language-, and vendor-neutral framework for the interaction and integration of software components via standard networking technologies. Figure 1-2 shows how the Web service protocols work together to compose two complementary Web services: the customer relationship management (CRM) Web service and the enterprise resource planning (ERP) Web service (Samtani and Sadhwani 2001). In the example, users request information about a particular person. The request is first handled by a UDDI server, which looks up its registry for relevant services that handle user information. Both CRM and ERP services are found. The UDDI server then forwards the location and WSDL information of the two services to an application server, which invokes the services to retrieve requested information. All communications between the application server and the two services are based on the SOAP protocol. In the end, the retrieved information is sent back to the user. The location of the services is transparent to the user who may not even be aware that two services are involved in the process.

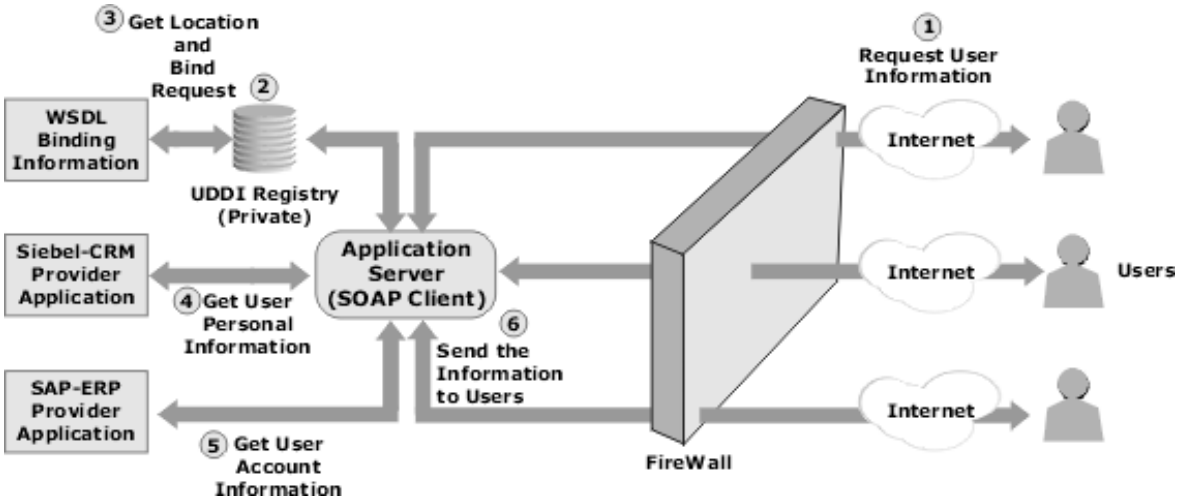

Figure1-2. Web service integration

1.2 Business Implications of Web Services

Despite the debate over Web services' advantages and disadvantage, Web services are definitely in production in the software industry. Many software vendors are rushing to reengineer their product offerings and provide Web-service-savvy products (Kreger 2003). For example, Amazon.com is providing tools to let its sales associates, booksellers and developers develop Web services to take advantage of the services offered by Amazon (such as inventory management, book reviews). GM used a Web-service-based platform to act as a translator between its old and new systems and realized a reduction of $1 billion on software support (Welch 2003). ZapThink, a Waltham (MA) consultancy that tracks the growth of Web services market , estimates that spending on Web services technology was $1.8 billion in 2002; and projects an over $5 billion investment in year 2003 (Salkever, 2003). The application of Web services varies from cost-cutting projects to establishing service-oriented architecture within an enterprise or between business partners (Ferris and Farrell 2003). To study the impact of Web services

on firm strategies, let's first examine the benefits of Web service from a business perspective.

1.2.1 Reduction of integration cost

The standardizing of protocols has profound business implications. One of the key benefits of Web services lies in reduced integration cost because of the openness of technology. Firms are relieved of the complexity of integrating applications built on different platforms or located on different networks. The application of Web services often involves the integration of disparate software components, either within an enterprise or among trading partners.

Internally, the Web Service architecture changes the fundamental cost structure of Enterprise Application Integration (EAI). A firm can decrease development cost and duration dramatically by leveraging existing systems and outsourcing standard modules. Externally, Business-to-Business (B2B) integration or collaboration is made more cost efficient because the firms no longer have to set up a separate integration project with each business partner. Thus, business alliances can be created and decoupled on the fly.

1.2.2 Service-oriented architecture

The service-oriented architecture (sometimes called e-service) is defined as offering software components as services that can be purchased or rented over a network, such as the Internet. As standardized, self-describing application modules that can be described, published, located and invoked over the Internet, Web services form the foundation of a service-oriented architecture to support universal application integration (Rust and Kannan 2003). For example, Huang and Chung (2003) proposed a framework of application integration based on Web services technology, addressing issues such as security, transaction control, and reliability.

The essence of a service-oriented architecture lies in "service on demand" and "just-in-time" service integration. Firms benefit from the service-oriented architecture powered by Web services in many ways. For example, firms have the ability to choose components that best match the company's business processes, to tailor components to the individual needs of business units, and to incrementally pay for the overall system (Fingar 2000; Sundarraj and Talluri 2003).

1.2.3 Web service intermediary

Although Web services are designed to be platform-independent, they leave unspecified the context necessary for service integration on the process level. For example, the Web service consumers have to define the order of sequence, control information flow, exceptions handlings, and transactional integrity enforcement, just to name a few (Cubera et al. 2003, Little 2003). Furthermore, a directory service is required if run-time discovery and integration are to be materialized.

To help realize the "plug-and-play" service-oriented architecture, a new business model, referred to as the Web service intermediaries (WSI), has seen rapid growth in practice in industry recently. A WSI provides value-added services including directory and search engine, auditing, quality of service (QoS) assurance and integration and orchestration of Web services. For example, Salcentral.com (which originally called itself "the Napster of Web services") provides a Web service search engine and tools for developing and integrating Web services. Maintenance of Web services is made more simplified since the WSI hosts the latest version of Web services and offers tools so that the Web service producers can manage and control their Web services. By offering aggregation services and technical support for Web service development, management

and integration, a Web service intermediary benefits both ends of the Web service supply chain: the Web service vendors and consumers.

1.3 Research Issues

With growing adoption of Web services technology, the research landscape in many fields, such as software engineering and management, is about to experience a major shift. For instance, the Web service technology emphasizes on reducing the size of software components while at the same time introduces new issues on Web service integration. The execution of Web services over the Internet causes a network delay not associated with traditional standalone systems. Thus, Web services technology could change software development and marketing strategies, such as software quality, development costs, and pricing. Therefore, it is imperative that information systems researchers delve into this new computing paradigm and provide useful insights to guide business practice.

At the same time, it should be noted that the ultimate value of Web services technology is not in itself. Rather, it lies in the productivity gain and the creation of new business opportunities due to its reusability, flexibility and interoperability. My objective is to study the impact of Web services technology on firm strategies and software development with the use of economic models. In particular, I aim to analyze the Web services technology from the following three perspectives.

1.3.1 Optimal market structure

By building on standard technologies, Web services technology enables dynamic software integration that is essential to enterprise application integration and business-to-business integration. Therefore, a natural start for Web services research is to examine

the impact of integration cost when composing Web services of complementary functionalities.

Several research questions arise when Web services are exploited for application integration. First, does a software producer always benefit from the interoperability of Web services? Second, how should software producers take advantage of Web service technologies and optimally provide complementary Web services to maximize total profit? Finally, should firms offer their software components separately, form a strategic alliance to provide a composite Web service or establish a marketplace that sells both individual and composite Web services? The first part of my study answers these questions by analyzing the optimal market structure for providing two complementary Web services.

1.3.2 Optimal location and pricing of an integrated Web service

Besides traditional functions such as matchmaking, aggregation of demand and supply, providing trust, and offering market characteristics to suppliers and consumers as in the electronic intermediaries (Bailey and Bakos 1997, Bakos 1998), a Web service intermediary (WSI) has several unique features worthy of special interest. For instance, unlike traditional electronic intermediaries that generally offer static information, a WSI can participate actively in the Web service supply chain by offering dynamic information goods such as Web services.

In the second part of the dissertation, I study the optimal strategy of a Web service intermediary that sells an integrated Web service to compete with Web service vendors. As discussed previously, the composition of Web services incurs an integration cost. Therefore, a Web service consumer interested in the composite Web service must take into account the integration cost when deciding whether to buy the integrated service

from the WSI or integrate by oneself the Web services bought separately from the Web service vendors. On the other hand, the execution of Web services on remote servers causes a response delay that consists of program running time and network delay. As a result, a Web service consumer must factor in the delay cost when deciding whether to "buy" (or execute) the integrated Web service from the intermediary. Since the network delay is related to the physical distance between the Web service intermediary and the client, the optimal strategy of the WSI requires solving the joint decision problem of location and pricing of the integrated Web service.

Specifically, I seek to address the following research questions. What is the optimal pricing strategy for the composite Web service: a penetration price or a high price? Where should the WSI in competition with two individual service providers host its integrated Web service? Should the WSI be located close to the service providers or stay away from the service providers to avoid competition?

1.3.3 Optimal subscription and listing fee charged by a WSI

Depending on technical strengths and business scope, Web service intermediaries can play various roles in linking the service vendors and service requestors. For example, Salcentral.com, maintains a comprehensive directory of Web services so that service consumers can browse, search for, and audit particular Web services. Another Web service intermediary, GrandCentral.com, provides a centralized Web service network and acts as a trust broker that handles all the issues around message delivery and routing, security, etc. In summary, a WSI provides value-added services to both Web service vendors and Web service requestors, allowing it to charge fees to both sides of the Web service supply chain.

Finally, I focus on studying the optimal strategy for a Web service intermediary that provides aggregation and technical services to Web service vendors and consumers. The Web service intermediary charges fees to both sides of the Web service supply chain. I address the optimal pricing strategies for a Web services intermediary in a supply chain of complementary Web services. That is, the WSI serves multiple groups of Web service vendors and consumers. The following research questions are explored. First, what are the optimal subscription fee and listing fee? Second, should the intermediary subsidize one side of the market to maximize its profit? If so, which side of the market should the intermediary subsidize? Next, what is the impact of technical strength and intensity of network effect on the intermediary's pricing strategy? Finally, how do the characteristics of Web services affect the optimal strategies of the intermediary?

1.4 Summary of Major Findings

To analyze optimal market structures, I compare three market structures–independent service vendors (ISV), strategic alliance (SA) and Web service marketplace. Analytical results and computational explorations suggest that Web service vendors benefit from the integration of Web services because the Web service marketplace always dominates the ISV market structure, regardless of the integration cost. The optimal market structure is determined by the integration cost, and the valuations and market potentials of the individual and composite Web services. As the valuation of the integrated Web service is small, the service providers prefer marketplace to strategic alliance. For larger valuation of the integrated software service, service providers prefer marketplace if the integration cost is high; while strategic alliance dominates if the integration cost is low. If the valuation of the integrated software service is sufficiently high, strategic alliance becomes the optimal market structure.

The joint decision problem of optimal location and pricing for an integrated Web service provided by a Web services intermediary (WSI) is analyzed with two spatial models. In general, optimal location and price depend on integration cost, delay cost and prices of the individual Web services. In a linear city model, I show that the midpoint position between the service providers is always the optimal location for the integrated Web service. Furthermore, when the delay cost is quite small, the best pricing strategy is to charge a penetration price to capture entire market demand. On the other hand, the WSI should charge a high price to share the market with the service providers when the delay cost is high. Analysis of a unit circle model shows that the WSI is optimally located midway between the service providers and charges a market-covering price when the delay cost is small. In addition, if the distance between the service providers is large, there are multiple optimal locations for the integrated Web service.

Finally, I find that in the presence of cross network externalities between two ends of a Web service supply chain, a WSI always has incentive to subsidize the service vendors by setting a low listing fee that induces all service vendors to list their Web services on it. On the other hand, the intermediary may choose to attract only portion of the Web service consumers, depending on the relationship between the intensity of cross network externalities and consumer's valuation of the WSI's value-added technical services. If the consumers value the technical services more than the network effect, the optimal subscription fee and profit are increasing in network effect. Furthermore, the WSI should allow more consumers to subscribe to its service as network effect intensifies. The optimal subscription fee is also affected by the nature of Web services provided by the service vendors, such as the prices of Web services and market potentials

of the composite Web service. For example, if the market potential of the composite Web service is large and the consumers have high valuation for the technical services, the intermediary should never set a low subscription fee to attract all consumers to subscribe when the consumers value the network effect more than the technical services. On the other hand, the WSI should set the subscription to allow all Web service consumers to subscribe if the market potential of the composite service is smaller than the market potentials of the two individual Web services and the network intensity is high.

CHAPTER 2
OPTIMAL WEB SERVICE MARKET STRUCTURE

In this chapter, I study the optimal market structure for providing complementary Web services when consumers incur an integration cost to compose multiple Web services. In particular, I compare three market structures for two software vendors offering two complementary Web services: (1) the independent service vendors (ISV) structure in which the two firms sell Web services separately; (2) the strategic alliance (SA) structure in which the two firms establish partnership to offer an integrated Web service; and (3) the Web services marketplace structure in which the two firms sell both the individual and the composite Web services.

One example of complementary Web services is a school calendar scheduling Web service and a weather forecast Web service. The calendar-scheduling Web service can be integrated with the weather forecast Web service so that the school can schedule certain events (such as such as football games and skiing competitions) in accord with the weather conditions. Another example of Web services that can be integrated is an inventory management system and a purchasing system. The two systems can work together so that purchasing orders can be automatically generated when the inventory is below a certain level and the inventory can be updated in real time when purchases are made.

This chapter is organized as follows. First, I review literature on physical good bundling and integration, followed by discussion about the uniqueness of Web service integration. Then I present the models of three market structures and derive profit

functions in each market structure. After that, the optimal market structure is found by comparing the profits of three market structures with varying integration cost and market conditions. The analysis includes analytical study of a simplified model and numerical explorations of the general model.

2.1 Related Literature

The bundling strategy for complementary products and services has been an active research topic in marketing and economics. Economides and Salop (1992) study the optimal market structure in light of the tradeoff between vertical integration of complementary products and horizontal competition among substitutable composite products. They model a market of two complementary products, each provided by two firms. A number of market structures, which differ in the degree of competition and integration, exist under different combinations of the four firms. Their research focuses on comparing the equilibrium price of the composite product under different market structures.

Matutues and Regibeau (1992) study the optimal strategy on product compatibility and bundling with a spatial model in which consumers have heterogeneous fit cost (or taste) of different product components. They set up a model of two firms each selling two complementary products. Farrell and Katz (2000) study a market composed of a monopoly offering one product component and several companies (possibly including the monopoly) offering another complementary product component. Their study concentrates on the monopoly's incentive to "squeeze" the producers of the other product component by means of pricing, product innovation, or exclusive trading rules. Implications on social welfare are explored.

Venkatesh and Mahajan (1993) examine the optimal pricing strategy under three bundling strategies: pure component, pure bundling and mixed bundling with a probabilistic model. Similar bundling strategies are analyzed by Chuang and Sirbu (1999) with application to N goods (journal articles). Both papers (Venkatesh and Mahajan 1993, Chuang and Sirbu 1999) conclude that the mixed bundling strategy yields maximum profit for firms.

Several unique features of Web services technology necessitate a different approach to the study of Web service integration. First, Web services are essentially programmable software components. Unlike physical goods that can be bundled (or put together) at ease, the integration of two arbitrary software components requires both human expertise and financial resources because of the complexity of addressing the platform- and language-disparities, such as recoding of data and/or application interfaces. In essence, the integration of software components introduces an *integration cost* not considered in all previous research on product or service bundling strategies to the best of my knowledge.

Second, Web services technology provides the flexibility of selecting software components on an as-needed basis. In other words, there are demands for both the individual and the composite Web services. Many previous studies focus on the market structure for the composite product while ignoring the demand for the individual components (Economides and Salop 1992, Matutues and Regibeau 1992, Farrell and Katz 2000).

Third, an integrated software application is usually a new software product that is indivisible and has different value and function than simply adding the values and

functions individual software components. Product bundles, on the other hand, are put together without change to each component. An analogy of integrated Web service is alloy wheal, which is made from tin and aluminum. Many previous works on product bundling treat the value of the bundled product as the sum of values of the components, which is referred to as the assumption of strict addition. Typically mixed bundling emerges as the profit-maximizing strategy (Venkatesh and Mahajan 1993, Chuang and Sirbu 1999). As I will show later, mixed bundling is not necessarily always optimal for Web services.

Although Venkatesh and Kamakura (2003) relax the strict addition assumption and consider contingent valuation for bundling complementary and substitute products, their result can't be applied to Web services directly because of two reasons. First, unlike physical goods, the marginal cost of providing one copy of Web service is negligible. Second, since the integrated Web service is indivisible, it is impossible to buy the integrated software and if the consumer is only interested in one component. Likewise, the papers by Bakos and Bryjolfsson (1999, 2000) have to be modified to fit in the context of Web service integration. I address the impact of integration cost on Web service market structure by taking into account different the demand of both the individual and the integrated Web services.

2.2 A General Model

Consider two service vendors selling two distinct but functionally complementary software components (S1 and S2). Components S1 and S2 can be integrated into a composite service (S3). Correspondingly, the potential buyers of Web services are classified into three groups: the potential buyers of S1, the potential buyers of S2, and

potential buyers of S3. Let the size of the three groups of potential buyers be Q_1, Q_2 and Q_3. The buyers in each group have a homogeneous reservation price (valuation) of V_1, V_2 and V_3 for S1, S2, and S3, respectively.

I consider three market structures that can be adopted by two profit-maximizing Web service vendors. In the first market structure, independent service vendors (ISV), the two firms sell the Web services independently. Consumers interest in the composite service must integrate S1 and S2 by themselves and thus incur an integration cost of c. In the second market structure, strategic alliance (SA), the two firms form an alliance to sell only S3, the integrated Web service. In the third market structure, Web service marketplace (Marketplace), the two firms sell S1, S2, and S3. There is no integration cost for customers in the SA or Marketplace structures.

The two service vendors seek the optimal market structure to maximize their profits. Intuitively, the valuations of the three services, the sizes of the three groups of customers, and the integration cost will affect the service vendors' decisions. Of special interest is the impact of the integration cost, since one key benefit from Web services technology is reduced integration cost. I develop an economic model to examine the optimal market structure for the Web service vendors with respect to various integration costs. To reflect industry reality, two assumptions are made regarding the integration cost and service valuations. First, I assume that the composite Web service is valued more than any of the individual services alone. Second, I assume the integration cost can not exceed the values of each Web service. In summary,

$$0 < c < V_i < V_3,\ i = 1, 2. \tag{2.1}$$

2.2.1 Independent service vendors

Under the independent service vendors (ISV) market structure, each service vendor sells its software component at price P_{s1} and P_{s2} (Figure 2-1). The demand for each of the Web services S1 (or S2) is composed of two groups of buyers – the buyers interested in S1 (or S2) and the buyers who are interested in the composite Web service (S3).

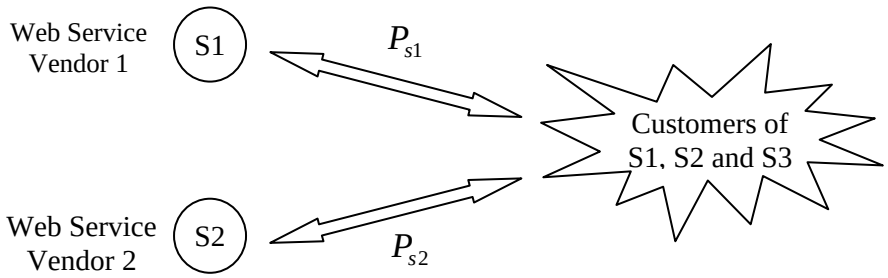

Figure 2-1. Independent service vendors

I adopt a linear demand function as in Parker and Alstyne (2001) to calculate the number of buyers of S1, S2 and S3, denoted by q_{s1}, q_{s2} and q_{s3}, as follows.

$$q_{si} = Q_i - \frac{P_{si}}{V_i} Q_i, \; i = 1, 2 \tag{2.2}$$

$$q_{s3} = Q_3 - \frac{P_{s1} + P_{s2} + c}{V_3} Q_3 \tag{2.3}$$

Note that in the ISV market structure, buyers of the composite Web service have to spend an integration cost of c, see Eq. (2.3). Accordingly, the demands of each service vendor D_{s1} and D_{s2} are

$$D_{si} = q_{si} + q_{s3}, \; i = 1, 2. \tag{2.4}$$

Both Web service vendors seek to set the price of their products to maximize profit, which is formulated in the following problems.

$$\max_{P_{si}} \ \pi_{si} = P_{si} \cdot D_{si} = P_{si}(Q_i - \frac{P_{si}}{V_i} Q_i) + P_{si}(Q_3 - \frac{P_{s1} + P_{s2} + c}{V_3} Q_3), \ i = 1, 2 \tag{2.5}$$

By solving the first order conditions of both service vendors simultaneously, one derives the equilibrium optimal prices of Web services S1 and S2 in Eq. (2.6). Subsequently, the optimal profits of the two service vendors π_{si}^* can be calculated by plugging the prices in Eq. (2.6) into the profit function. Unfortunately, the complexity of π_{si}^* prohibits an explicit display of its functional from.

$$\begin{aligned} P_{s1}^* &= \left(\frac{2Q_1Q_2V_3^2 + 2Q_2Q_3V_3^2 + 2Q_1Q_3V_2V_3 - 2cQ_2Q_3V_3 + Q_3^2V_2V_3 - cQ_3^2V_2 - Q_2Q_3V_2V_3}{4Q_1Q_2V_3^2 + 4Q_1Q_3V_2V_3 + 4Q_2Q_3V_1V_3 + 3Q_3^2V_1V_2} \right) V_1 \\ P_{s2}^* &= \left(\frac{2Q_1Q_2V_3^2 + 2Q_1Q_3V_3^2 + 2Q_2Q_3V_1V_3 - 2cQ_1Q_3V_3 + Q_3^2V_1V_3 - cQ_3^2V_1 - Q_1Q_3V_1V_3}{4Q_1Q_2V_3^2 + 4Q_1Q_3V_2V_3 + 4Q_2Q_3V_1V_3 + 3Q_3^2V_1V_2} \right) V_2 \end{aligned} \tag{2.6}$$

It should be pointed out, however, that if the integration cost is prohibitively high, there could be no demand of the integrated product, i.e., $q_{s3} = 0$. In that case, the service vendors' profit-maximizing problem reduces to

$$\max_{\hat{P}_{si}} \ \hat{\pi}_{si} = \hat{P}_{si}(Q_i - \frac{\hat{P}_{si}}{V_i} Q_i), i = 1, 2. \tag{2.7}$$

By inspection, the optimal prices and profits in case of no demand for the composite Web service are

$$\hat{P}_{si}^* = \frac{V_i}{2}, \ \hat{\pi}_{si}^* = \frac{V_i Q_i}{4}, \ i = 1, 2. \tag{2.8}$$

Summarizing the results of Eqs. (2.6) and (2.8), one gets the optimal profits for the each of the independent service vendors in the ISV market structure as follows.

$$\Pi_{si}^* = \max\{\hat{\pi}_{si}^*, \pi_{si}^*\}, \ i = 1, 2. \tag{2.9}$$

In order to make the three market strategies comparable, I take a "macro" market view of the independent service vendors. That is, I use the sum of the independent service vendor's optimal profits as a measurement of the goodness of ISV market structure. The optimal profit of the ISV market strategy is defined as $\Pi_s^* = \Pi_{s1}^* + \Pi_{s2}^*$, where Π_{si}^* ($i = 1, 2$) are described in Eq. (2.9).

2.2.2 Strategic alliance

Under the strategic alliance (SA) market structure, the two Web service vendors form a strategic alliance by integrating the Web services into one composite service S3, see Figure 2-2. To distinguish from the Web services marketplace strategy, I assume that the composite service is not divisible. That is, the potential customers of the strategic alliance are those who are interested in the *composite* Web service S3.

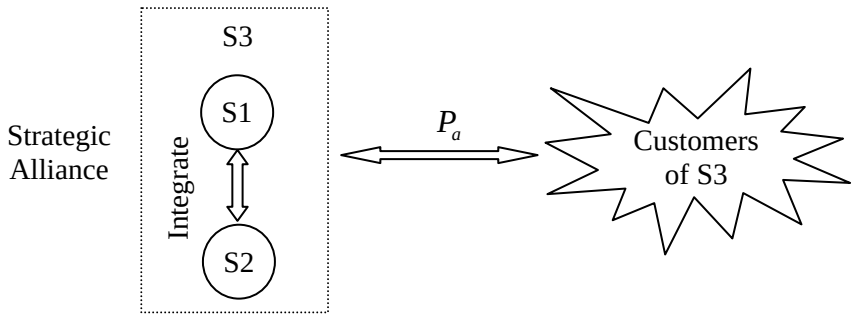

Figure 2-2. Strategic alliance

As described in the introduction, one key advantage of the Web services technology lies in the easy integration of software components. Therefore, I assume that the SA incurs a minor one-time integration cost to produce the composite service. In addition, the cost of providing the integrated Web service is negligible due to the technological simplicity of Web services, i.e., the marginal cost of providing one more copy of the composite Web service is assumed to be zero. The strategic alliance sells the

composite service at price P_a. The consumers don't incur additional integration cost when they buy S3 from the SA. Since the integrated Web service is indivisible, the potential buyers of the SA are the buyers of S3. The strategic alliance seeks to optimally set the price of the composite service (P_a) to maximize profit, which is formulated as

$$\max_{P_a} \ \pi_a = P_a(Q_3 - \frac{P_a}{V_3} Q_3) \tag{2.10}$$

Solving the first order condition of Eq. (2.10) yields the optimal price and profit of the strategic alliance, summarized as follows.

$$P_a^* = \frac{V_3}{2}, \ \Pi_a^* = \frac{V_3 Q_3}{4}. \tag{2.11}$$

2.2.3 Web service marketplace

The third market structure, Web service marketplace (Marketplace), can be viewed as a combination of the ISV and SA market structures, where three types of services–S1, S2 and S3 are offered, see Figure 2-3. Similar to the strategic alliance, the "sunk" cost of composing Web services by the marketplace is negligible and the marginal costs are assumed to be zero.

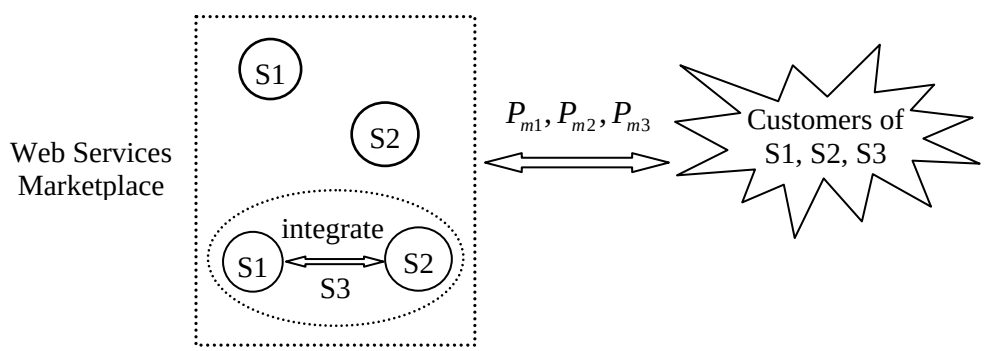

Figure 2-3. Web service marketplace

Under the Web services marketplace market structure, the Web service vendors seek to optimally set the prices of the Web services, P_{m1}, P_{m2} and P_{m3} to maximize total

profit. To ensure that the demand for the composite Web service S3 is non-negative, the price of the composite Web service sold by the marketplace cannot exceed the total cost of creating S3 by the consumers themselves, i.e., $P_{m3} \le P_{m1} + P_{m2} + c$. Put in math, the optimization problem in the Marketplace structure can be formulated in Eq. (2.12).

$$\begin{aligned} \max_{P_{m1}, P_{m2}, P_{m3}} \quad & \pi_m = P_{m1}(Q_1 - \frac{P_{m1}}{V_1} Q_1) + P_{m2}(Q_2 - \frac{P_{m2}}{V_2} Q_2) + P_{m3}(Q_3 - \frac{P_{m3}}{V_3} Q_3) \\ \text{s.t} \quad & P_{m3} \le P_{m1} + P_{m2} + c \end{aligned} \tag{2.12}$$

The constrained profit maximization problem defined in Eq. (2.12) can be solved using KKT conditions. The similar approach is used in proving Lemma 2-3 in the next section. The optimal total profit under the Web service marketplace market structure is described as follows.

$$\Pi_m^* = \begin{cases} \pi_m^* & \text{if} \quad c < \dfrac{V_3 - (V_1 + V_2)}{2} \\ \dfrac{1}{4}(V_1 Q_1 + V_2 Q_2 + V_3 Q_3) & \text{if} \quad c \ge \dfrac{V_3 - (V_1 + V_2)}{2} \end{cases}, \tag{2.13}$$

where

$$\begin{aligned} \pi_m^* = & \frac{Q_1^2 Q_2 V_1 V_3 + Q_1^2 Q_3 V_1 V_2 + Q_2^2 Q_1 V_2 V_3 + Q_2^2 Q_3 V_2 V_1 + Q_3^2 Q_1 V_3 V_2 + Q_3^2 Q_2 V_3 V_1}{4(Q_1 Q_3 V_2 + Q_1 Q_2 V_3 + Q_2 Q_3 V_1)} \\ & + \frac{Q_1 Q_2 Q_3 (4cV_3 - 4cV_1 - 4cV_2 - 4c^2 + 2V_2 V_3 + 2V_1 V_3 - 2V_1 V_2)}{4(Q_1 Q_3 V_2 + Q_1 Q_2 V_3 + Q_2 Q_3 V_1)} \end{aligned}.$$

2.3 Analytical Insights from a Simplified Model

The best profit-maximizing market structure for the Web service vendors is found by comparing the service vendors' total profit in the three market structures. The analysis of the general model in the previous section suggests that the service vendors' optimal strategy is determined by several factors – the size of potential buyers in each group, the valuations of the services and the integration cost. However, the mathematical

complexity of the general model, especially the optimal total profit of the independent service vendors (see the optimal prices in Eq. (2.6)), makes the analysis of optimal market structure technically intractable. Therefore, the following two simplifying assumptions are made to modify the general model in order to gain insights from analytical study. First, I assume that there are (approximately) equal number of potential customers of S1 and S2. Secondly, it is assumed that the potential customers of S1 and S2 have (approximately) equal valuations of the two services. By imposing the assumptions, we can focus on studying the impact of integration cost on optimal market structure first. The assumptions are specified mathematically as follows.

$$Q_1 = Q_2 = Q \text{ and } V_1 = V_2 = V \tag{2.14}$$

In the simplified model, I study a symmetric market where the two complementary services are valued equally and both Web service vendors enjoy the same market potential. At the same time, the relationship between the integration cost and the valuations of the services, described in Eq. (2.1), still holds in the simplified model. Plugging Eq. (2.14) into the general model, I derive the optimal total profits under the three market structures in the context of a symmetric market, which are summarized in the following lemmas.

Lemma 2-1. *In a symmetric market, the optimal total profit under the independent service vendors (ISV) market structure is specified in Eq. (2.15). In addition,* π_s^* *is decreasing and convex in the integration cost* c.

$$\Pi_s^* = \max\left\{\frac{1}{2}VQ, \pi_s^*\right\}, \tag{2.15}$$

where $\pi_s^* = \dfrac{2V(V_3Q + V_3Q_3 - cQ_3)(V_3^2Q^2 + VV_3QQ_3 + V_3^2QQ_3 + VV_3Q_3^2 - cV_3QQ_3 - cVQ_3^2)}{V_3(2QV_3 + 3VQ_3)^2}$.

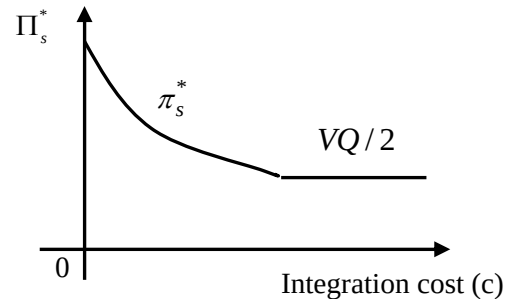

Figure 2-4. Optimal profit of ISV

Lemma 2-2. *In a symmetric market, the optimal total profit of the strategic alliance is specified in Eq. (2.11).*

Proof. Because the strategic alliance sells the composite Web service only, the valuation and market size of the individual Web services won't affect the strategic alliance's profit. Q.E.D.

Lemma 2-3. *In a symmetric market, the optimal total profit of the Web services marketplace is*

$$\Pi_m^* = \begin{cases} \pi_m^* & \text{if } c < \dfrac{V_3 - 2V}{2} \\ \dfrac{1}{2}VQ + \dfrac{1}{4}V_3Q_3 & \text{if } c \geq \dfrac{V_3 - 2V}{2} \end{cases}, \tag{2.16}$$

where $\pi_m^* = \dfrac{1}{2}VQ + \dfrac{1}{4}V_3Q_3 - \dfrac{QQ_3(V_3 - 2V - 2c)^2}{4(QV_3 + 2Q_3V)}$.

Lemma 2-4. π_m^* *is increasing and concave in the integration cost* c. Π_m^* *is increasing in the valuation* (V_3) *and market potential* (Q_3) *of the composite service. In addition, the total profit of the marketplace is at minimum when* $c = 0$, *which is described in Eq. (2.17).*

$$\pi_m^*(c = 0) = \frac{VV_3(Q + Q_3)^2}{2(QV_3 + 2VQ_3)} \tag{2.17}$$

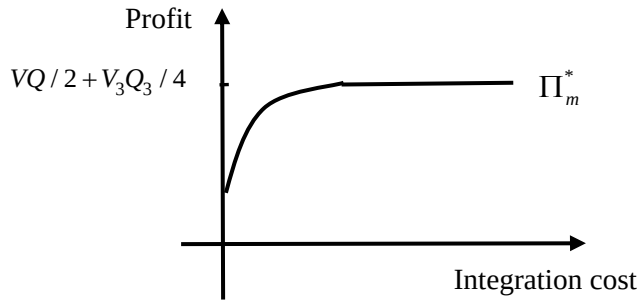

Figure 2-5. Optimal profit of marketplace w.r.t. c

Lemma 2-5. *In a symmetric market, the optimal profit of the Web services marketplace takes the form of* π_m^* *when* $V_3 > 4V$ *; the optimal profit switches from* π_m^* *to* $\frac{1}{2}VQ+\frac{1}{4}V_3Q_3$ *when* $2V < V_3 < 4V$ *; the optimal profit takes the form of* $\frac{1}{2}VQ+\frac{1}{4}V_3Q_3$ *if* $V < V_3 < 2V$ *.*

Proof. Lemma 2-3 suggests that the optimal profit of the Web services marketplace is bimodal, which depends on the relationship between V, V_3 and c. According to Eq. (2.16), the optimal profit is π_m^* if $c < \frac{V_3-2V}{2}$ while the optimal profit is $\frac{1}{2}VQ+\frac{1}{4}V_3Q_3$ if $c \geq \frac{V_3-2V}{2}$. Recall our assumption in Eq. (2.1) that the integration cost can't exceed the values of Web services being integrated, i.e., $0 < c < V$, accordingly, there are three possible functional forms of the profit with respect to V_3. In particular, if $V_3 > 4V$, $c < \frac{V_3-2V}{2}$ is always satisfied; if $V < V_3 < 2V$, $c \geq \frac{V_3-2V}{2}$ is always satisfied; if $2V < V_3 < 4V$, either $c < \frac{V_3-2V}{2}$ or $c \geq \frac{V_3-2V}{2}$ applies. Q.E.D.

Lemma 2-1 to 2-4 describes the optimal profits under three market structures. Figures 2-4 and 2-5 plot the behavior of the profit under the ISV and marketplace market

structure with respect to integration cost respectively. Furthermore, Lemma 2-5 specifies three functional forms of profit of the marketplace under the assumption that $0 < c < V$. Correspondingly, Figures 2-6 (a), (b), and (c) illustrate these three cases.

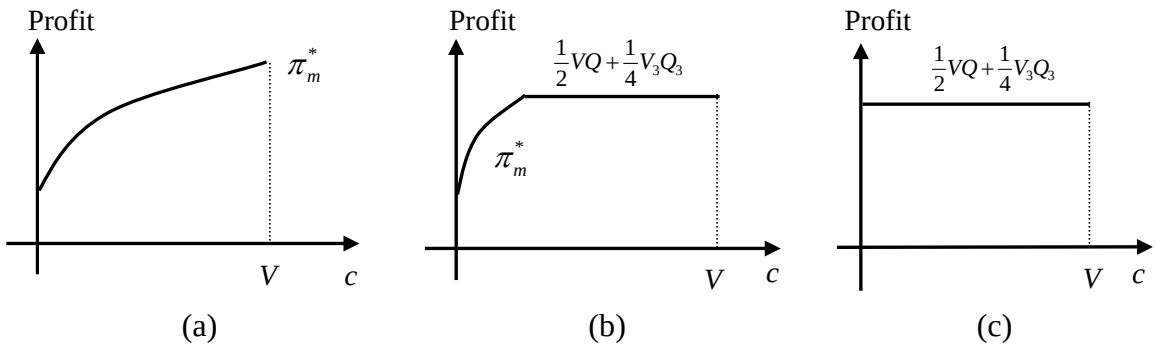

Figure 2-6. Optimal profit of marketplace w.r.t. V_3 (a) $V_3 > 4V$ (b) $2V < V_3 < 4V$ (c) $V < V_3 < 2V$

Given the optimal profits under three market structures, one can derive the optimal market structure for the Web service vendors with respect to different integration cost (c) and market characteristics (market sizes and valuations of Web services). Propositions 2-6 to 2-9 summarize our key findings.

Proposition 2-6. *The service vendors are always better off under the Web services marketplaces than staying as independent service providers regardless of the integration cost.*

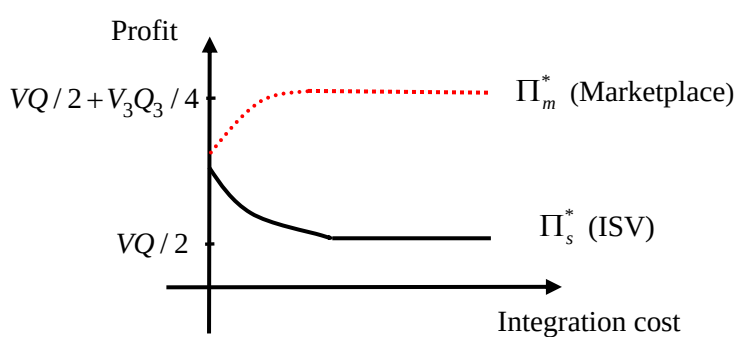

Figure 2-7. ISV vs. marketplace

Proposition 2-7. *When* $V < V_3 < V^*$, *Web services marketplace is the dominant market structure, regardless of the integration cost. Specifically,*

$$V^* = (2Q + 4Q_3)/(Q_3 V) \tag{2.18}$$

Proposition 2-8. *When* $V^* < V_3 < V^{**}$, *strategic alliance is the optimal market structure if the integration cost is below* $\bar{c}$; *marketplace is the optimal market structure if the integration cost is above* $\bar{c}$. *In particular,* V^* *is defined in Eq. (2.18) and*

$$c = \frac{1}{2}V_3 - V - \frac{\sqrt{4Q_3^2 V^2 + 2VV_3 QQ_3}}{2Q_3}, \tag{2.19}$$

$$V^{**} = \frac{4Q_3 + Q + \sqrt{Q^2 + 8QQ_3 + 4Q_3^2}}{Q_3} V \tag{2.20}$$

Proposition 2-9. *When* $V_3 > V^{**}$, *strategic alliance is the optimal market structure, regardless of the integration cost, where* V^{**} *is defined in Eq. (2.20).*

Proofs of Propositions 2-6 to 2-9 are relegated to Appendix A. Figure 2-7 depicts the total profit for the service vendors in the ISV vs. marketplace structure. We observe that the marketplace yields more profit, regardless of the integration cost. Figures 2-8 and 2-9 give graphical illustration of Propositions 2-8 and 2-9 respectively.

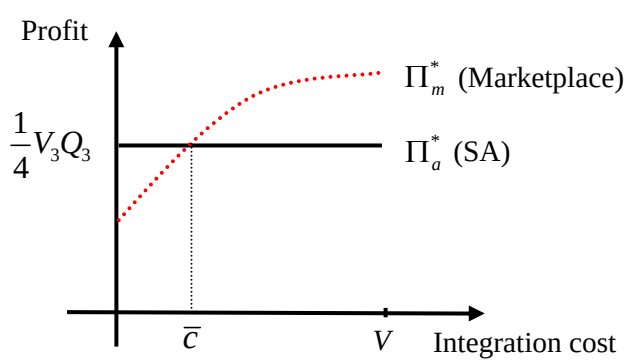

Figure 2-8. SA vs. marketplace ($V^* < V_3 < V^{**}$)

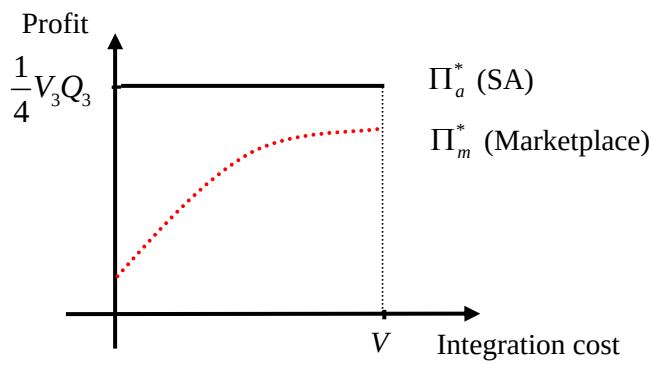

Figure 2-9. SA vs. marketplace ($V_3 > V^{**}$)

2.4 Computational Explorations

From the simplified model, we observe that the integration cost plays a critical role in determining the optimal market structure for the Web service vendors. In addition, the optimal market structure also depends on the valuations and the sizes of market potential of the individual and composite Web services in a symmetric market. To complete our analysis on optimal market structure, one should consider the general cases where $V_1 \neq V_2$ and $Q_1 \neq Q_2$. Due to the technical intractability, we resort to numerical experiments to draw insights from the generalized model in this section.

In the numerical experiments, I focus on the situations where the valuations and the market potentials of the individual services are different. Without loss of generality, experiments are conducted assuming $V_1 > V_2$ since one can always exchange Web service 1 and service 2 without changing the results. In addition, we run the experiments under the constraints specified in Eq. 2-1 (i.e., $V_3 > \max\{V_1, V_2\}$, $c < \min\{V_1, V_2\}$).

Insights from the numerical experiments are summarized in Observations 2-1 and 2-2. Table 2-1 describes the design of the experiments, which classifies six combination scenarios of V_i and Q_i ($i = 1, 2, 3$).

Table 2-1. Design of numerical experiments

Case	V_1 vs. V_2	Q_1 vs. Q_2	Q_3 vs. Q_1 and Q_2
1	$V_1 > V_2$	$Q_1 > Q_2$	$Q_3 > \max\{Q_1, Q_2\}$
2	$V_1 > V_2$	$Q_1 > Q_2$	$Q_3 < \min\{Q_1, Q_2\}$
3	$V_1 > V_2$	$Q_1 > Q_2$	$Q_1 > Q_3 > Q_2$
4	$V_1 > V_2$	$Q_1 < Q_2$	$Q_3 > \max\{Q_1, Q_2\}$
5	$V_1 > V_2$	$Q_1 < Q_2$	$Q_3 < \min\{Q_1, Q_2\}$
6	$V_1 > V_2$	$Q_1 < Q_2$	$Q_1 < Q_3 < Q_2$

Observation 2-1. *Ceteris paribus, the optimal market structure switches from Web service marketplace to strategic alliance as the valuation of the composite service (V_3) increases. Further, the Marketplace always dominates the ISV market structure.*

Observation 2-1 suggests that the results from the numerical experiments are consistent with the analytical study of the simplified model. When V_3 is small, the service vendors are best off by implementing a marketplace, regardless of the integration cost. As the valuation of the composite Web service increases, the optimal market structure turns to a mixture of marketplace and strategic alliance, with the SA market structure as optimal for small integration cost and the Web services marketplace as dominant for large integration cost. When V_3 is sufficiently high, the Web service vendors always form a strategic alliance, regardless of the integration cost.

Figures 2-10, 2-11, and 2-12 plot three examples of the optimal market structure with varying integration cost and market conditions. Notice that in all experiments, the marketplace always dominates the ISV, implying that the service vendors always benefit from the interoperability of the Web services.

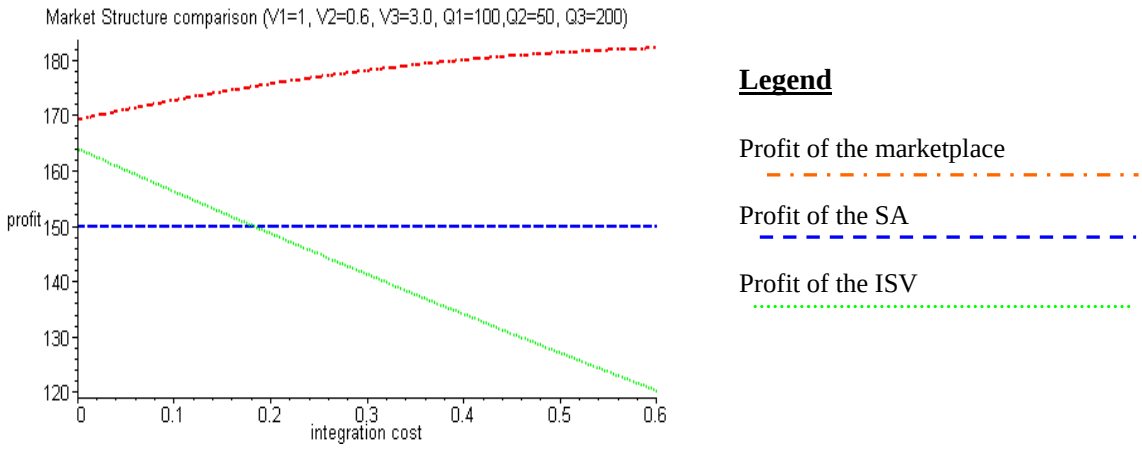

Figure 2-10. Marketplace is optimal

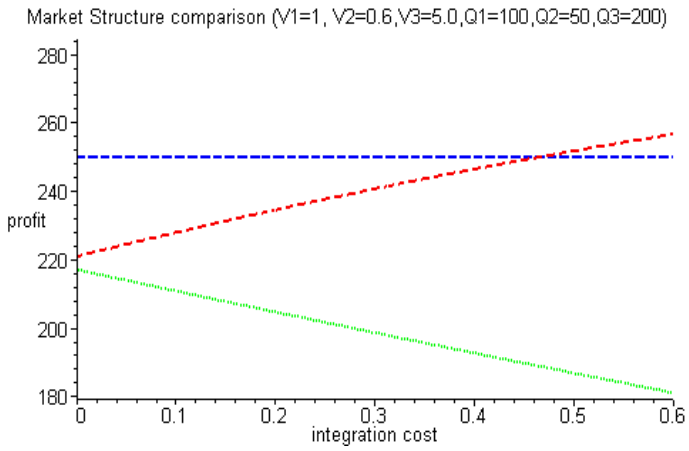

Figure 2-11. SA dominates for small integration cost while marketplace dominates for large integration cost

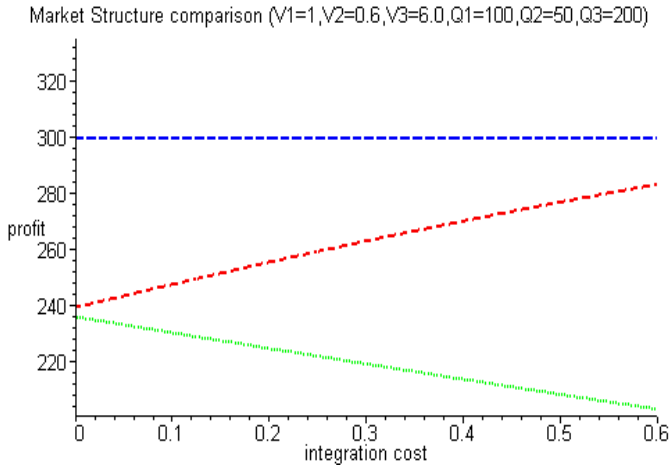

Figure 2-12. Strategic alliance is optimal

Observation 2-2. The threshold of V_3 for SA to surpass Marketplace is decreasing in potential market size of the composite service (Q_3). In addition, the threshold value is smaller in a market where $V_1 > V_2$ and $Q_1 < Q_2$ than in market where $V_1 > V_2$ and $Q_1 > Q_2$.

Table 2-2. Optimal market structure w.r.t V_3

Scenario		Parameter Values	Optimal Market Structure		
			M	SA if c for smaller c; M for bigger c	SA
1	$V_1 > V_2$ $Q_3 > Q_1 > Q_2$	$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 100, Q_2 = 50, Q_3 = 200$	$(0.6, 3.9)$	$[3.9, 5.35]$	> 5.35
2	$V_1 > V_2$ $Q_1 > Q_2 > Q_3$	$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 100, Q_2 = 60, Q_3 = 40$	$(0.6, 6.6)$	$[6.6, 8.4]$	> 8.4
		$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 100, Q_2 = 60, Q_3 = 50$	$(0.6, 5.9)$	$[5.9, 7.7]$	> 7.7
3	$V_1 > V_2$ $Q_1 > Q_3 > Q_2$	$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 100, Q_2 = 40, Q_3 = 60$	$(0.6, 5.35)$	$[5.35, 7.0]$	> 7.0
4	$V_1 > V_2$ $Q_1 < Q_2 < Q_3$	$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 50, Q_2 = 100, Q_3 = 200$	$(0.6, 3.8)$	$[3.8, 5.25]$	> 5.25
5	$V_1 > V_2$ $Q_3 < Q_1 < Q_2$	$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 60, Q_2 = 100, Q_3 = 40$	$(0.6, 6.2)$	$[6.2, 8.0]$	> 8.0
6	$V_1 > V_2$ $Q_1 < Q_3 < Q_2$	$V_1 = 1.0,\ V_2 = 0.6$ $Q_1 = 40, Q_2 = 100, Q_3 = 60$	$(0.6, 4.95)$	$[4.95, 6.55]$	> 6.55

Table 2-2 shows an example of optimal market structure with respect to V_3 in six scenarios. For example, in the first scenario, we set $V_1 = 1$, $V_2 = 0.6$ ($V_1 > V_2$) and $Q_1 = 100$, $Q_2 = 50$, $Q_3 = 200$ ($Q_3 > Q_1 > Q_2$). The integration cost is restricted in the range of $0 < c < 0.6$. The marketplace is the optimal market structure regardless of the integration cost if the valuation of the composite service $V_3 \in (0.6, 3.9]$; if the valuation of

the composite service $V_3 \in (3.9, 5.35]$, the optimal market structure is dependent on the integration cost, with the strategic alliance as optimal for small integration cost and the marketplace as optimal for large integration cost; the strategic alliances becomes the dominant strategy for the service vendors if the valuation of the composite service satisfies $V_3 > 5.35$, regardless of the integration cost. The threshold values of the composite service valuations (V_3) in this experiment are 3.9 and 5.35, where the marketplace turns from less dominant to being dominated. Another interesting observation from the numerical experiment is that a more "balanced" market tends to favor the strategic alliance. This can be shown by comparing case 3, a polarized market where service vendor 1 has apparent advantages over service vendor 2 ($V_1 > V_2$, $Q_1 > Q_2$), against case 6, a balanced market where both service provider 1 and service provider 2 has certain market advantage ($V_1 > V_2$, $Q_1 < Q_2$). With the same market potential of the integrated service (Q_3), the Strategic Alliance beats the marketplace if $V_3 > 7.0$ in case 3 while the marketplace is dominated by the strategic alliance if $V_3 > 6.55$ in case 6.

Observation 2-1 suggests that a higher valuation for the composite component (V_3) tends to favor the strategic alliance. Observation 2-2 further describes how the threshold value is affected by the market potential of the composite service. At first sight, this observation is somewhat obvious since the optimal profit of the strategic alliance is $V_3 Q_3 / 4$, which is increasing in V_3 and Q_3. However, the marketplace also sells the composite product and its optimal profit is also increasing in the valuation and market potential of the composite service (see Lemma 2-4). Observation 2-2 might result from the fact that the profit of the marketplace is restricted in its price setting policy

$P_{m3} \leq P_{m1} + P_{m2} + c$. In fact, it can be proved that the optimal price of the composite software component in the marketplace is less than the optimal price in the strategic alliance, see Appendix A. This suggests that the service vendors don't necessarily always benefit from diversifying their products. If the composite service is highly valuable and has a large market potential, the service vendors are better off by establishing a strategic alliance selling simply the composite service.

Another interesting observation from the numerical experiments suggests that a more "balanced" market seem to favor the strategic alliance more than the marketplace. The market is balanced if one service vendor sells a valuable service with small market potential while the other service vendor sells a less valuable service with larger market potential. In other words, if the service vendor each has some advantage in service valuation or market power, they are more likely to form a cooperative strategic alliance. On the other hand, if the market is extremely asymmetric with one service vendor selling a highly valuable service and enjoying a large potential market, the service vendors are more likely to prefer the Web services marketplace, which gives them a certain degree of autonomy.

CHAPTER 3
OPTIMAL LOCATION AND PRICING OF AN INTEGRATED WEB SERVICE

While the Web services technology is a promising solution to bridging the platform discrepancy and geographical distance between software components, some constraints may impede the widespread adoption of Web services and the service-oriented architecture. In particular, the performance of Web services is refrained by the computing power of local servers and the robustness and capabilities of the underlying network through which the Web services are distributed.

From technical perspectives, the execution of Web services follows the traditional Client/Sever paradigm. Figure 3-1 illustrates an example of Web service consumption. First, the Web service client sends a processing request to a remote Web service application server. The Web service application server locates the appropriate Web service and transforms (or "serializes") the request into Web-services-compliant format (SOAP) and then forward to a particular Web service to handle the request. The result is transmitted over the network and finally transformed (or "deserializes") in a format understood by the end user. Overall, the response delay in Web service execution consists of the computation time at the server and the network delay. Sometimes, response time is especially important for *time-sensitive* applications such as stock quote and instant messaging. As the computing power keeps increasing at decreasing cost, in accord with the well-known Moore's Law of computing, it's not hard to predict that the network latency will become a prominent part of the response delay for applications distributed over the Internet. This chapter studies the impact of network delay on the

pricing and location of an integrated Web service provided by a Web service intermediary (WSI).

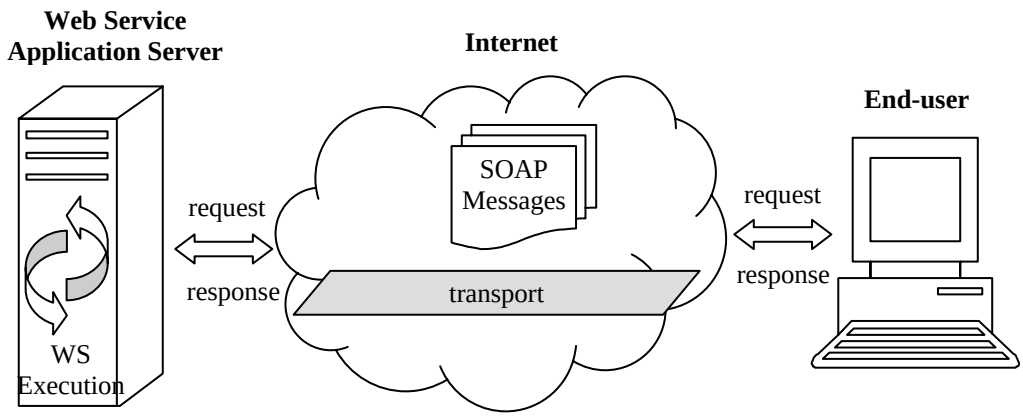

Figure 3-1. Web service execution model

3.1 Problem Description and Related Literature

Consider two independent software vendors offering two complementary Web services denoted by S1 and S2. Let P_1 and P_2 be the price of S1 and S2 respectively. At the same time, a Web service intermediary (WSI) offers a time-sensitive composite Web service denoted by S3, which is developed by integrating S1 and S2. Examples of time-sensitive Web services include stock quote, credit check required for payment, and so on. The WSI charges a price of P_3 for its integrated Web service S3. Customers who are interested in the integrated Web service can either buy the composite service from the WSI or buy the two Web services S1 and S2 from the service providers and integrate by themselves, in which case the customer incurs an integration cost c.

In the context of Web services paradigm, the customers "buy" a Web service by executing the Web service hosted at the service provider's server. The customers do not own and house the software component. Consequently, customers experience a response delay resulting from the turnaround time of executing the Web service.

In this chapter, we focus on the demand for the integrated Web service. Suppose the reservation prices of the customers for the integrated service are sufficiently high so that all customers have one unit demand for the composite Web service and they either buy from the WSI or from the service vendors. A customer evaluates the total cost to decide whether to buy the integrated Web service from the WSI or buy the individual Web services from the service vendors and then create the integrated Web service by herself. To be more specific, the total cost to "purchase" the integrated Web service includes the price charged by the WSI (or the Web service vendors), delay cost and integration cost (if the customer buys from the service vendors). In case a customer incurs the same cost to, the customer will buy the composite Web service from the WSI due to some valued-added services by the WSI.

As the response time is a major concern for consumers of time-sensitive integrated Web service, it is important to analyze the composition of response time of applications over the Internet. According to Johansson, et al. (2000), the response time of applications over the Internet is composed of two parts – local processing time and network response time. Local processing time is determined by the capacity of the local server and the request load. Network response time can be further divided into transmit time, queuing delay and network latency. Transmit time is related to network bandwidth while the queuing delay is determined by capacity of network devices and amount of data transmission jobs. Network latency is the time taken to transport data between two locations on the network and is generally a function of physical distance between the two nodes on the network. Johansson (2000) points out that while much research has been done on network design in consideration of network bandwidth and device capacity, the

network latency is usually ignored in previous research. Since the cost of computing is halved roughly every eighteen months and the network infrastructure has seen an accelerating growth recently, the network latency will become one dominant term of response time of applications over the Internet.

In an abstract sense, the Internet is composed of two parts, the cores and the edges. Local servers and client machines are located at the edges, connected by the switches and routers at the core. The network latency for exchanging data between the server and the client is a function of number of routers and switches between them, which is correlated with the physical distance between the server and the client. To model the impact of network latency on the response time of Web services, let t be the delay cost per unit of distance between the customer and the Web service provider where the distance corresponds to the number of routers and switches between them.

The choice of optimal location for the WSI bears some resemblance to the facility location problem in previous literature. Information systems research on network design has traditionally taken an operations research (OR) approach, borrowing methods from classic OR problems such as the facility location problem (Erlenkotter 1977). The facility location problem, usually modeled as a mixed integer programming problem, is defined as choosing the number of facilities and locations to minimize total cost (or maximize profit) subject to capacity constraints, demand constraints and others. Solution methodologies include developing heuristics based on dynamic programming (Li et al. 1999), Lagrangean relaxation (Liu et al. 2001), and so on. Sun (2003) and Sun and Koehler (2003) were among the first to study the location model for Web service intermediaries. Mixed integer programming models are proposed in Sun (2003) and Sun

and Koehler (2003) to decide the best location of a WSI by considering the usage requirement, server's capacity, and assignment constraints. Efficient heuristics were developed to tackle the location problem as the proposed model became computationally intractable.

Several special characteristics of Web services suggest solving the location and pricing problem of the integrated Web service in a different way from traditional facility location problems. First, while the facility setup cost is an important factor in the facility location problem, I treat it as sunk cost and focus on the WSI's revenue from selling the composite Web service. Second, usually the facility location problem deals with cost minimization and solves the decision problem for one single company without consideration of competitions. The WSI, however, has to compete with the Web service providers by choosing the right location and the right price for its integrated Web service. Our problem is unique in that we consider the joint decision of location and pricing problem in a market of complementary Web services. Last, as will be illustrated below, the delay cost of accessing Web services for a customer in the network has several complex functional forms, which is dependent on the location of the customer. Although in facility location problems one can model the delay cost as a function of distance between computing nodes, it does not provide the flexibility to choose different delay cost functions for customers at different locations.

In this chapter, I propose a spatial model to study the joint location and pricing decision problem for the WSI. The optimal location and price is first derived in a linear city model. Then a unit circle model is applied to study the joint decision problem in a more general context.

3.2 The Linear City Model

We assume the two Web service providers offering S1 and S2 are located at the end points of a unit length linear city (LC) and let x be the WSI's location on the linear city (Figure 3-2). Due to the symmetry of this linear city model, we consider without loss of generality the case where $0 \le x \le 1/2$. The potential customers of the integrated service are uniformly distributed in this linear city between 0 and 1. Recall that the customers incur a delay cost t per unit of distance from consuming (or accessing) the Web services.

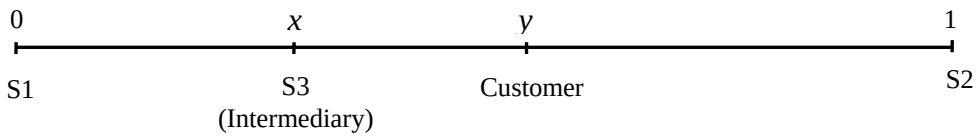

Figure 3-2. Linear city model

3.2.1 Cost to buy from WSI in linear city

The customer at location y $(0 \le y \le 1)$ incurs a network delay cost of $t \cdot y$ for consuming the Web service S1 and $t \cdot (1-y)$ for S2. The network delay cost for the same customer to access the integrated Web service offered by the WSI is $t\,|\,y-x\,|$. Then, the total cost for the consumer located at y to buy the integrated service from the WSI is composed of the price of the integrated service (P_3) and the delay cost, i.e.,

$$P_3 + t\,|\,y-x\,| \tag{3.1}$$

3.2.2 Cost to buy from service vendors in linear city

The total cost for customers between 0 and 1 to purchase the Web services S1 and *S2* separately and integrate by themselves includes the prices of the individual Web services (P_1 and P_2), the integration cost (c), and the total delay cost which equals to the sum of network delay of accessing each Web service, i.e., $ty + t(1-y) = t$. In math, the

total cost for customers who choose to create the integrated Web service by themselves is as follows.

$$P_1 + P_2 + c + t \tag{3.2}$$

3.2.3 Optimal location and pricing in linear city

By evaluating the total costs described in Equations (3.1) and (3.2), each customer decides whether to buy the integrated service from the WSI or to create the integrated service by purchasing the individual Web services from the service vendors separately. The marginal customers who are indifferent between buying from the WSI and creating the integrated Web service by themselves are described as below, where y_1^m and y_2^m denote the distance between the marginal customer and the WSI (Figure 3-3).

$$P_1 + P_2 + c + t = P_3 + ty_1^m,\ P_1 + P_2 + c + t = P_3 + ty_2^m \tag{3.3}$$

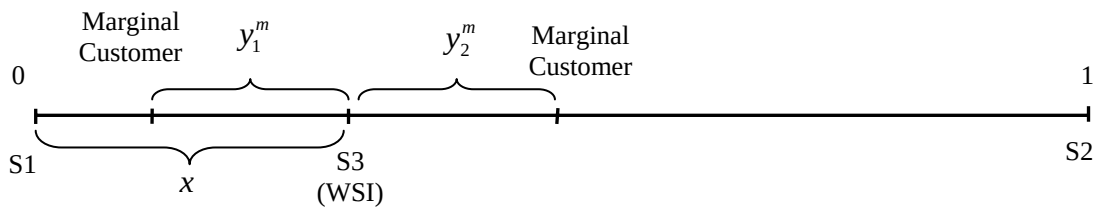

Figure 3-3. Marginal customer in LC model

For customers between the two marginal customers at y_1^m and y_2^m, the total cost to buy the composite Web service from the WSI is lower than that to buy S1 and S2 separately and then create the composite service by themselves. Therefore, they will buy from the WSI. However, if the WSI sets price P_3 too high, all customers between 0 and 1 would create the integrated service by themselves, leaving no demand for the WSI. On the other hand, if the WSI set the price P_3 low enough, all customers between 0 and 1 would buy from the WSI. In summary, the demand of the WSI is $D = y_1 + y_2$, where

$$y_i = \begin{cases} 0, & \text{if} \quad y_i^m \le 0 \\ y_i^m, & \text{if} \quad 0 < y_i^m < x, \ i = 1,2 \\ x, & \text{if} \quad y_i^m \ge x \end{cases} \tag{3.4}$$

Accordingly, the joint decision of optimal location and pricing for the integrated Web service by the WSI is formulated as follows

$$\begin{aligned} &\max_{P_3, x} \ \pi = P_3 \cdot D = P_3(y_1 + y_2) \\ &\text{s.t} \qquad \text{Eq. (3.4)} \end{aligned} \tag{3.5}$$

Proposition 3-1. *In the unit-length linear city model, the optimal price and profit of the integrated Web service are* $P_3^* = P_1 + P_2 + c + \frac{1}{2}t$ *and* $\pi^* = P_1 + P_2 + c + \frac{1}{2}t$. *The mid-point position between the service providers is the optimal location for the integrated Web service, i.e.,* $x^* = \frac{1}{2}$. *Furthermore, the WSI captures the entire market demand by charging* P_3^* *and* P_3^* *increases faster with* c *than* t.

Proof. The derivation of the optimal profit and location is quite tedious and the details are delegated to the Appendix B. I just provide a sketch of proof here. This joint decision problem is solved in two steps. First, I derive the optimal price and profit for the WSI given any particular position x. Then, the optimal location is selected as the one that yields the highest profit obtained in the previous step. Q.E.D.

Proposition 3-1 suggests that if all customers are located between the service providers, in which case all customers incur the same cost if they integrate the composite Web services by purchasing S1 and S2 from the service providers, the optimal location of the WSI would be the midpoint position between the service providers. In addition, the WSI is best off by charging a penetration price to capture entire market demand. In

addition, as the delay cost or the integration cost increases, the WSI should increase the price of the composite Web service and obtain more profit. However, integration cost has bigger impact on profit (and price) than the delay cost. It is quite intuitive that the WSI gains more profit when the integration cost is higher since more customers will switch to the WSI due to the higher cost of integrating the individual Web services. However, when the delay cost increases, the costs of buying from the WSI and the service providers will both increase. The increased profit of the WSI in the presence of larger delay cost suggests that the negative impact of delay cost is higher for the service providers than the WSI.

In the linear city model, it is assumed that the service vendors are located at "extreme points" such that all customers are located between the service providers. As a result, all customers experience equal delay cost if they buy the two Web services from service vendors. In the next section, I shall relax this assumption by considering a unit circle model.

3.3 The Unit Circle Model

In this section, I study the more general case with a unit circle (UC) model in which not all customers are located between two Web service vendors. Let 0 be the location of the first service provider on the unit circle, and the second service provider is located at distance d clockwise from the first provider. Without loss of generality, we restrict our attention to consider the case where $0 \le d \le \frac{1}{2}$. Suppose the integrated Web service is located at x clockwise ($0 \le x < 1$) on the unit circle. There are N potential customers of the integrated service uniformly distributed along the unit circle.

The unit circle model is depicted in Figure 3-4, where points A and B correspond to the locations of the two Web service providers and the integrated Web service is located at point E. For the purpose of analysis, we mark points C, D and F, which are diagonal to points A, B and E on the unit circle respectively.

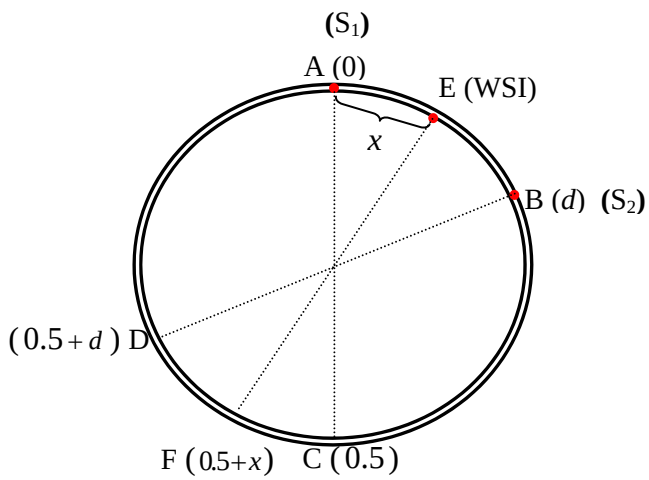

Figure 3-4. Unit circle model

3.3.1 Cost to buy from WSI in unit circle

One distinctive feature of the unit circle model is that the delay cost for a customer along the unit circle is conditional on his location, since the shortest route to reach a node could be traveled either clockwise or counter-clockwise. For example, for a particular customer located at y clockwise from point A, the total cost to purchase the integrated service from the WSI (tc_I) is

$$tc_I = \begin{cases} P_3 + t\,|\,y - x\,|, & \text{if } |\,y - x\,| \le 1/2 \\ P_3 + t(1 - |\,y - x\,|), & \text{if } |\,y - x\,| > 1/2 \end{cases} \tag{3.6}$$

3.3.2 Cost to buy from service vendors in unit circle

If a customer integrates the services by herself, the delay cost is the sum of delay costs of accessing the Web services S1 and S2. Unlike the linear city model where all

customers are located between the two service providers and incur the same delay cost when accessing the Web services S1 and S2, customers at different locations experience different response delay due to different shortest route of access. For example, a customer located between A and B incur a delay cost of td, while a customer located between C and D incur a delay cost of $t(1-d)$. Customers located within the BC and DA segments incur a delay cost between td and $t(1-d)$. Equation (3.7) formulates the total cost (tc_{NI}) for a customer at y ($0 \le y < 1$) if he (or she) integrate the Web service by oneself, which includes the prices of the Web services S1 and S2, the integration cost, and delay cost.

$$tc_{NI} = \begin{cases} P_1 + P_2 + c + td, & \text{if } 0 \le y \le d \\ P_1 + P_2 + c + t(2y - d), & \text{if } d < y \le 1/2 \\ P_1 + P_2 + c + t(1-d), & \text{if } 1/2 < y \le 1/2 + d \\ P_1 + P_2 + c + t(2 - 2y + d), & \text{if } 1/2 + d < y < 1 \end{cases} \tag{3.7}$$

3.3.3 Optimal location and pricing in unit circle

Given the total costs tc_I and tc_{NI}, one can find the location of the marginal customer who is indifferent between buying the integrated Web service from the WSI and from the Web service vendors. Consequently, the demand for the integrated Web service at a particular location on the unit circle can be calculated as a function of the delay cost, integration cost, distance between the individual service providers and their prices. Using the same approach as in the previous section, one can solve the joint decision problem of optimal location and pricing for the integrated Web service. However, it is rather tedious since the cost functions of tc_I and tc_{NI} have conditional format, which in turn leads to complex profit function for the WSI. Therefore, I use a different approach to solve the location and pricing problem in the unit circle model. The

following lemmas explain our logic of derivation. Further, results from analytical study are presented in Propositions 3-5 and 3-6, followed by interpretations of managerial insights.

Lemma 3-2. *The highest market-covering price for the integrated Web service at* x *is*

$$\bar{P}_3 = \begin{cases} \min\{P_1 + P_2 + c + tx,\ P_1 + P_2 + c + t(0.5 - d),\ P_1 + P_2 + c + t(d - x)\}, & 0 \le x \le d \\ P_1 + P_2 + c + t(d - x), & d < x \le 0.5 \\ P_1 + P_2 + c + t(d - 0.5), & 0.5 < x \le 0.5 + d \\ P_1 + P_2 + c + t(x - 1), & 0.5 + d \le x < 1 \end{cases} \tag{3.8}$$

Proof. The highest market-covering price is the highest price the WSI can charge while still attracting all customers in market. This price is calculated in two steps. First, for each customer I calculate the total cost to buy Web services from the service vendors and then create the integrated Web service by himself (or herself). Then, the highest market-covering price is selected as the lowest total costs for all customers in market. Detailed derivation is left to Appendix B.

Lemma 3-3. *When the WSI charges the highest market-covering price, the WSI achieves maximum profit if the integrated Web service is located between the two Web service providers.*

Proof. When the WSI captures the entire market demand, its profit is constrained by the highest price it can charge, which is conditional on the location of the integrated Web service, as specified by the four cases in Eq. (3.8). By inspection, one gets $\bar{P}_3 \ge P_1 + P_2 + c$ in the first case while $\bar{P}_3 \le P_1 + P_2 + c$ in the rest three cases. In other words, if the integrated Web service is placed between the two service vendors, the intermediary can charge a higher price while still captures entire market demand.

Therefore, the WSI will choose to locate the integrated Web service between the service providers to maximize profit. Q.E.D.

Lemma 3-4. *If the WSI raises its market-covering price* $\overline{P}_3$ *by* $\Delta P_3 = \frac{kt}{N}$, *where* k *is a positive integer, it will lose no less than* $\min\{k, N\}$ *customers. Furthermore, if* $\frac{kt}{N} < \Delta P_3 < \frac{(k+1)t}{N}$, *the WSI loses demand of no less than* $\min\{k+1, N\}$.

Proof. See Appendix B.

Proposition 3-5. *When* $t \le 2(P_1 + P_2 + c)$, *it is optimal to host the integrated Web service between the service providers of S1 and S2 and the optimal price is the highest market-covering price specified in (3.8), i.e.,*

$$\overline{P}_3^* = \min\{P_1 + P_2 + c + tx,\ P_1 + P_2 + c + t(0.5 - d),\ P_1 + P_2 + c + t(d - x)\} \qquad (3.9)$$

Proof. Proposition 3-5 is derived from Lemma 3-2, 3-3 and 3-4. See Appendix B for a detailed proof.

Proposition 3-6. *When* $t \le 2(P_1 + P_2 + c)$ *and* $d > \frac{1}{3}$, *there are multiple optimal locations for the WSI. The optimal location and pricing of the integrated Web service are described in (3.10).*

$$\text{If } \frac{1}{3} < d \le \frac{1}{2},\ P_3^* = P_1 + P_2 + c + t(\frac{1}{2} - d) \text{ and } \frac{1}{2} - d \le x^* \le 2d - \frac{1}{2} \qquad (3.10)$$

On the other hand, when $t \le 2(P_1 + P_2 + c)$ *and* $0 \le d \le \frac{1}{3}$, *the optimal location and pricing of the integrated Web service are described in Eq. (3.11).*

$$\text{If } 0 \le d \le \frac{1}{3}, P_3^* = P_1 + P_2 + c + t/2 \text{ and } x^* = \frac{d}{2} \qquad (3.11)$$

Propositions 3-5 and 3-6 are consistent with the analysis in the linear city model. However, in the linear city model, the two Web service vendors are located at the end points such that the integrated Web service can only be stored between them. In the unit circle model, the WSI can choose the intensity of competition by locating at different regions on the unit circle. For example, the competition between the WSI and the service providers is maximal if the integrated Web service is located between A and B; In contrast, the competition is minimal in section between C and D; Further, the sections between BC and DA represent regions of moderate competition.

Proposition 3-5 suggests that if the delay cost is small, the WSI prefers maximum competition and will set a low penetration price to capture the entire market demand. At first sight, this result is quite "unconventional" in that classic economic theories, such as the theory of Bertrand competition, suggest that firms prefer lesser competition in order to avoid price war. This unusual result can be explained by two characteristics of the Web service market. First, as an executable program distributed over the Internet, the performance of a Web services based platform is greatly constrained by the underlying networking infrastructure. In particular, a customer accessing the Web service incurs a delay cost due to network latency, which is associated with the physical distance between the customer and Web service application server. Second, due to the platform independence and software modularity, a Web services based platform boasts the flexibility of integrating multiple Web services on the fly, across the street or across the ocean. Consequently, in case when multiple Web services at different locations are accessed to compose an integrated Web service, the network delay of accessing the integrated Web service is the sum of network latency of accessing each constituent Web

services. On the other hand, there's only one single network delay when a customer accesses an integrated Web service from the WSI directly. Therefore, although the WSI faces a stronger competition when the integrated Web service is located between the two Web service vendors, it will be compensated since it can charge a higher market-covering price. In fact, this is not a deviant from the results in a Bertrand competition, since the WSI sets a low penetration price to cover the entire market.

While the linear city model yields one single optimal location for the WSI, Proposition 3-6 suggests that there could be multiple optimal locations for the integrated Web service in the unit circle model. In fact, the result in the linear city model can be viewed as a special case of the unit circle model since the mid-point position is always the optimal location according to Proposition 3-6.

CHAPTER 4
OPTIMAL SUBSCRIPTION AND LISING FEE OF A WEB SERVICE INTERMEDIARY

Depending on technical strengths and business scope, the Web service intermediary (WSI) can play various roles in the Web service supply chain. In the previous chapter, I focused on studying the optimal strategy for a WSI that provides integration service and sells an integrated Web service. In this chapter, I study another model of WSI that does not sell Web services of its own. Instead, the WSI offers aggregation service to match the Web service vendors with the Web service consumers. In addition, the WSI provides value-added services to take the advantage of its technical expertise.

One example of such WSI is Salcentral.com, which maintains a comprehensive directory of Web services so that service consumers can browse, search for and audit particular Web services. Another WSI, GrandCentral.com, provides a centralized Web services network and acts as a trust broker that handles issues of message delivery and routing, security, …, etc. In summary, the WSIs provide certain value-added services to both Web service vendors and service requestors, allowing them to charge a fee to both sides of the Web services supply chain.

In this chapter, I study the optimal strategies for the WSI in a supply chain of complementary Web services. In particular, the WSI serves two groups of web service vendors that provide Web services of complementary functionalities. The two complementary Web services can be integrated by consumers to create a new composite Web service. Correspondingly, the consumers are divided into three groups – those who

desire the two individual Web services and those for the composite Web service. The WSI charges the Web service vendors a listing fee and the Web service consumers a subscription fee in order to access the added value provided by the WSI. The added value of the WSI consists of the "intrinsic" value and the "cross network externality" value. The intrinsic value of the WSI refers to the standalone services offered by the WSI such as Web service development tools, maintenance, and security. The cross network externality value is proportional to the number of service vendors listed in and the customers subscribing to the WSI. That is, the more service vendors listed on the WSI, the more valuable it is for service consumers to subscribe to the intermediary, and vice versa.

The Web services supply chain has several unique characteristics. First, unlike traditional supply chain, the object supplied and consumed in the Web services supply chain is not tangible physical goods, but rather software components residing at the service provider's computer server. Hence, most issues considered in traditional supply chain literature such as inventory and ordering decisions of the distributor are no longer relevant to the WSI. The major decision facing the WSI is how to optimally set the listing fee for the Web service providers and the subscription fee for the Web service consumers. Second, most supply chain literature involves one supplier and one customer, or one group of suppliers and one group of customers. One of the most appealing features of the Web service technology is the ease of creating a new composite web service (i.e., new business functionality) from integrating two Web services of complementary functionalities. To account for this reality, this model includes two groups of Web service vendors providing complementary Web services. The consumers

of the Web service supply chain are thus comprised of three groups – those demanding the individual Web services and those in need of the composite Web service. Third, in addition to the intrinsic value offered by the WSI, we study the impact of "cross network externality" effect on the WSI's optimal strategies. The intensity of the cross-network externality effect is found to be a key factor affecting the WSI's pricing strategies.

The objective of this chapter is to study what are the best strategies for the profit-maximizing WSI. Specifically, I address the following research questions. First, what are the optimal subscription fee and listing fee? Second, is it optimal for the WSI to attract all the Web service providers and/or all the Web service customers? Next, what is the impact of the WSI's intrinsic value and intensity of network externality effect on its pricing strategies? Finally, how does the nature of the Web services market affect the optimal strategy of the WSI?

This chapter is organized as follows. First, I provide critical background of the Web service supply chain. Next, I review related literature and outline the uniqueness of this research. After that, I introduce the analytical model and derive the optimal listing fee and subscription fee, followed by discussion on managerial insights.

4.1 The Web Service Supply Chain

A Web service supply chain is composed of three parties, the Web service vendors, the Web service consumers and the Web service intermediary. A Web service vendor develops some Web service with certain business function and makes it accessible through its Web site. To make the Web service interoperable and discoverable, a Web service description file (WSDL), which describes the function of the Web service and specifies the technical signatures such as entry point, transport protocol and encoding

style, etc., is uploaded to a registry service, which can be either the public business registry (PBR) or a private registry provided by the WSI.

Currently, the PBR is cooperatively operated by four companies, IBM, Microsoft, SAP and NTT. A Web services registry can be understood as a database of Web service descriptions (WSDL files).which accepts queries on base of multiple criteria, such as functionality, industry, geographical region. Listing and searching via the public business registry is free while a Web service intermediary may charge subscription fee to the service consumers and listing fee to the service vendors.

When a Web service requester (consumer) considers using a software component offered by other companies (service vendors) instead of developing it in house, she searches for the desired Web services via the WSI or PBR. After obtaining information from the registry, i.e., retrieving the WSDL file, the service requestor can choose to purchase the Web service. In the context of Web services, the "purchase" of a Web service involves binding the service requestor's client application with the remote Web service and then invoking the Web service hosted on the service vendor's Web site. Figure 4-1 illustrates the interactions among the parties of the Web services supply chain.

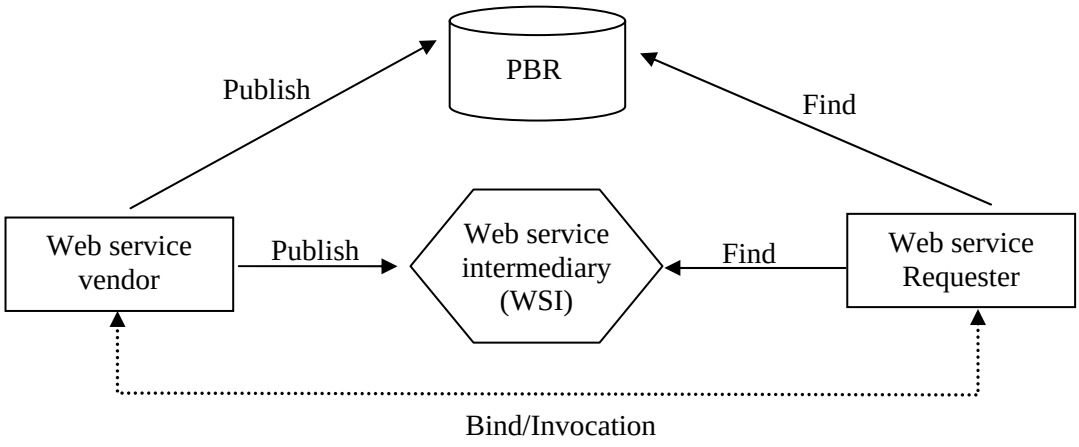

Figure 4-1. Web service supply chain

In addition to providing registry services, a WSI also provides value-added services to consumers of Web services. For example, the intermediary can help reduce transaction costs among trading partners by providing account management so that consumers only need one account to access multiple Web services (e.g., SalCentral.com). The WSI may improve Web services management by enforcing contract to guarantee quality of service and security (e.g., FlamencoNetworks.com). The WSI can also exploit its technical expertise and provide integration services to realize "service on demand" (e.g., GrandCentral.com). The WSI can set up a networking infrastructure to provide reliable service provisioning (e.g., BlueTitan.com). At the same time, Web service vendors benefit from publishing their Web services on the WSI since the added values by the WSI help increase the chance of a successful transaction with subscribers of the intermediary.

4.2 Literature Review

Vast amount of research has been conducted on traditional intermediaries, with applications mostly in financial market, labor market and supply chain markets. Research on Web services in general and Web services intermediaries (WSI) in particular has primarily centered around technical issues in the computer science field, while there is a lack of research on Web services and WSI from the perspective of business management. Prior literature on traditional intermediaries can be generally classified into two categories.

The first stream of research on traditional intermediaries studies the role of intermediaries. According to Spulber (1996), intermediaries can play several roles in a vertical market – matching and searching, price setting and market clearing, providing

liquidity and immediacy as well as guaranteeing of quality. There is ample research on each aspect of the roles played by the intermediaries. Rubinstein and Wolinsky (1987) model the interaction between buyers and sellers as a time-consuming bilateral search process and studies how a matchmaking intermediary can affect profit division between the two parties of transaction. Yavas (1994) studies the impact of an intermediary on consumer search behavior, while Naert (1971) takes the perspective of producers and analyzes the producer's optimal decisions on advertising and markup in an intermediated market. Biglaiser (1993) takes another avenue of research and shows that an expert intermediary can contribute to quality guarantee. The advent of the Internet technologies and the ensuing e-commerce heralds recent research on the functions of electronic intermediaries (Bailey and Bakos 1997, Bakos 1998, Kaplan and Sawhney 2000). By observing the that the Internet helps reduce search cost (Bakos 1997), Bailey (1998) sets out to study whether the intermediation via the Internet reduces friction and finds empirically that there is greater price dispersion in online intermediaries.

The second stream of abundant research on traditional intermediaries examines the optimal strategies of intermediaries. Gehrig (1993) studies the tradeoff between ask-bid spread and cost of delay in private search and finds that a monopoly intermediary will charge a positive spread. In another paper by Wooders (1997), it is shown that a profit-maximizing intermediary may act as a Walrasian auctioneer by setting bid and ask prices to nearly Walrasian equilibrium prices. Prior research on intermediaries of traditional physical goods market unfortunately cannot be directly applied to online intermediaries, since most online intermediaries take the role of "matchmakers" instead of "market makers". That is, they provide value-added services and don't sell products on their own.

There are no issues of inventory costs, shipping costs, order quantities and transfer prices that underline the framework of numerous previous research.

Recent work on optimal strategies of information intermediaries is more related to our research on WSI. Baye and Morgan (2001) study how an information gatekeeper, which provides product and price information to consumers, should optimally set subscription fee to consumers and advertising fee to producers. Baye and Morgan (2001) find that the gatekeeper will set a low subscription fee to attract all customers. There are two key differences between Baye and Morgan (2001) and this research. First, they assume that customers are geographically segmented so that consumers only buy from local firms if they do not subscribe to the gatekeeper. In contrast, Web services requestors can always search via a public business registry and obtain an entire list of available service vendors. Second, the advertised price is lower than unadvertised price in requestors, while in the context of Web services market, the service vendors and requestors trade directly even if they find the match via the WSI, see Fig. 1. This feature combined with the Web service requestors' ability to search the entire list of service providers leads to no difference between listed and unlisted prices. These two key differences between the information gatekeeper and the WSI result in opposite conclusions to those in Baye and Morgan (2001). Bhargava and Choudhary (2004) study the product line design (vertical differentiation) of an information intermediary in the presence of aggregation benefits. In their model, consumers have heterogeneous search costs and producers have heterogeneous expectations of gains from joining the intermediary. In this paper, we model the interaction among the service vendors, the

WSI, and consumers in response to the subscription fee and listing fee charged by the WSI.

Recent work on optimal strategies of information intermediaries is more related to this research on Web service intermediaries. Baye and Morgan (2001) study how should an information gatekeeper, which provides product and price information to consumers, optimally set subscription fee to consumers and advertising fee to producers. It is shown that the gatekeeper should set a low subscription fee to attract all customers. There are several key differences from this research. First, they assume that customers are geographically segmented so that consumers only buy from local firms if they do not subscribe to the gatekeeper. In contrast, as explained in the previous section, the requestors of Web services can always search via a public business registry and obtain an entire list of available service vendors. Second, they explicitly allow price dispersion, making advertised price lower than unadvertised price while in the context of a Web service supply chain, the service vendors and requestors trade directly even if they find the match via an intermediary. This implies that there's no price difference between listed and unlisted prices. It is worth noting that due to the major discrepancies of problem setup, this research leads to opposite conclusions from those by Baye and Morgan (2001).

Of most relevance to this research is the work by Corbett and Karmarkar (1999), which analyzes optimal subscription fee and listing fee by an intermediary when there exhibit cross network externalities. Their study, however, focuses on one group of sellers and consumers of one product. Since a major benefit of Web services technology is the ease of software integration, the WSI we study faces two groups of service vendors

providing complementary functionalities, resulting in three groups of customers – namely two groups of consumers of the individual Web services and a third group of consumers of the integrated Web service. Consequently, the problem facing the WSI is much more complicated.

4.3 The Model

Following the modeling approach of Corbett and Karmarkar (1999), I consider two groups of Web service vendors which provide two complementary Web services, denoted by S1 and S2. The two complementary Web services can be integrated into one composite Web service S3. There are N_1 service vendors of S1 and N_2 service vendors of S2. The numbers of service providers N_1 and N_2 are sufficiently large, and the Web service market of S1 and S2 is highly competitive. The prices of S1 and S2, denoted by P_1 and P_2 respectively, are thus treated as exogenously given.

The Web service consumers consist of three distinct groups – Q_1 consumers interested in S1, Q_2 consumers interested in S2, and Q_3 consumers interested in the composite Web service S3. In case a consumer is interested in the individual Web service (S1 or S2) and the composite Web service S3, he is counted as a consumer of S3 since the composite Web service always performs the functions of S1 and S2.

A monopolist WSI that provides value-added services charges a fixed listing fee L to Web service providers and charges a fixed subscription fee F to service consumers. Let x_i ($i = 1, 2$) be the proportion of service vendors listed on the WSI and y_j ($j = 1, 2, 3$) be the proportion of consumers subscribing to the intermediary. Figure 4-2 delineates the basic setup of the model discussed above.

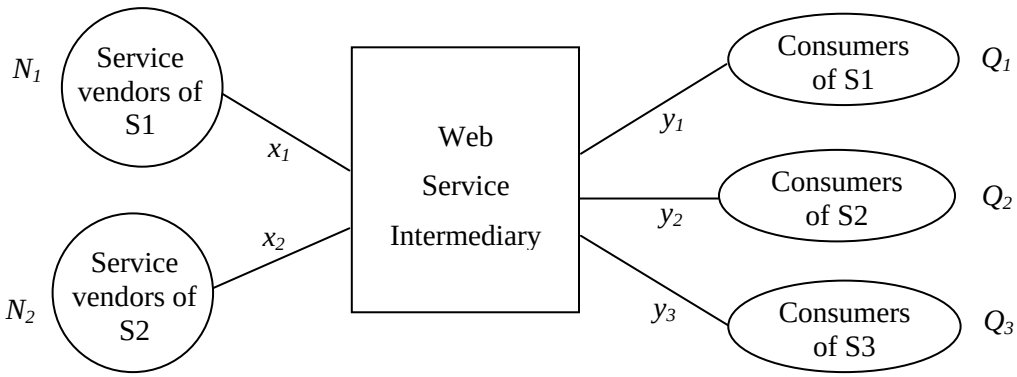

Figure 4-2. Model of subscription and listing fee

The sequence of events is described as follows. First, the WSI sets the subscription fee F and listing fee L. Observing the listing fee and subscription fee, consumers decide whether to subscribe to the WSI based on their judgment of expected value from the subscription. At the same time, the service vendors decide whether to list on the WSI, in consideration of the expected number of subscribers and vendors joining the intermediary. In equilibrium, service consumers have rational expectation of proportion of listed service vendors, and vice versa.

I use backward induction to solve the WSI's decision of optimal subscription fee and listing fee. First we derive the proportions of Web service consumers ($y_j, j = 1,2,3$) and vendors ($x_i, i = 1,2$) who decide to join the WSI given the subscription fee F and listing fee L. In the next section, I analyze how the WSI optimally sets the subscription fee and listing fee

4.3.1 Consumer's subscription decision

From the service consumer's point of view, the added value offered by the WSI consists of *intrinsic value* and *cross network externality effect*. The intrinsic value of the WSI results from the reduction of transaction cost, enhanced security and management,

and improved reliability, etc. In general, the intrinsic value is related to the technical strength of the WSI and is independent of the number of service vendors listed on it. The consumers are heterogeneous in their judgment of the intrinsic value, denoted by the random variable v uniformly distributed in the interval $[0,\bar{v}]$. The ceiling of the distribution, $\bar{v}$, is used as a representative measure of consumers' valuation of the WSI's intrinsic value. The second part of the WSI's added value is *network effect*, which is increasing in the number of Web service vendors listed on the intermediary. Let γ indicate the intensity of the cross network externality, or consumer's valuation for the network effect. Then, the network value to a consumer equals γ multiplied by the number of service vendors listed on the WSI.

Web service consumers decide whether to subscribe to the WSI by evaluating the cost (subscription fee) and value from subscribing to it. For a customer who is interested in S1, the total benefit from subscribing to the intermediary is $v+\gamma x_1$ where v is the consumer's valuation of the WSI's intrinsic value, and x_1 is the proportion of listed Web service vendors providing S1. Let v_{01} be the valuation of the marginal consumer of S1 indifferent between subscribing and not subscribing to the WSI. Then equation $v_{01}+\gamma x_1 = F$ holds. Similarly, the marginal consumer of S2 with intrinsic value of v_{02} is described by $v_{02}+\gamma x_2 = F$. The proportion of consumers of S1 (or S2) who subscribe to the WSI corresponds to those consumers who have higher valuation than that of the marginal consumer, specified as follows. Note that if the subscription fee is prohibitively high, all consumers will stay away from the WSI ($y=0$), while a sufficiently low subscription fee attracts all consumers to subscribe ($y=1$).

$$y_{\substack{i \\ i=1,2}}(x_i) = \begin{cases} (\overline{v} - F + \gamma x_i)/\overline{v} & \text{if} \quad \gamma x_i \le F \le \overline{v} + \gamma x_i \\ 1, & \text{if} \quad F < \gamma x_i \quad \text{(all subscribe)} \\ 0, & \text{if} \quad F > \overline{v} + \gamma x_i \quad \text{(nobody subscribe)} \end{cases} \tag{4.1}$$

The consumer who is interested in the composite Web service derives $v + \gamma x_1 + \gamma x_2$ benefit from subscribing to the WSI. That is, the network value for the consumers of composite service S3 is increasing in the proportion of listed service vendors of S1 and the proportion of listed service vendors of S2. In accordance, the proportion of consumers of S3 who subscribe to the intermediary is as follows.

$$y_3(x_1, x_2) = \begin{cases} (\overline{v} - F + \gamma x_1 + \gamma x_2)/\overline{v} & \text{if} \quad \gamma x_1 + \gamma x_2 \le F \le \overline{v} + \gamma x_1 + \gamma x_2 \\ 0 & \text{if} \quad F > \overline{v} + \gamma x_1 + \gamma x_2 \\ 1 & \text{if} \quad F < \gamma x_1 + \gamma x_2 \end{cases} \tag{4.2}$$

4.3.2 Service vendor's listing decision

Subscribers to the WSI search the Web services listed on the intermediary and choose to transact with those vendors listed on the WSI, while non-subscribers search through the public business registry (PBR) which contains the entire list of service vendors. Since the price of the same Web service in this competitive market is the same, consumers pick the service vendor with equal likelihood. In other words, listing to the WSI helps the service vendors increase the chance of accomplishing transactions with more consumers (unless none of the consumers subscribe to the WSI) and reduce the competition from peer service vendors (if not all service vendors publish on the intermediary).

Given the proportion of consumers subscribing to the intermediary (y_1, y_2 and y_3), the profits for a service vendor to list (π_i^I) or not list (π_i^{NI}) are formulated in Equations (4.3) and (4.4), respectively. The subscript i is an index of Web services (S1

or S2). Notice that the demand of Web service S1 (likewise, S2) comes from both the consumers of S1 (S2) and those of the composite Web service S3.

$$\pi_i^I = P_i Q_i (\frac{1-y_i}{N_i} + \frac{y_i}{x_i N_i}) + P_i Q_3 (\frac{1-y_3}{N_i} + \frac{y_3}{x_i N_i}) - L \text{ , } i = 1,2 \tag{4.3}$$

$$\pi_i^{NI} = \frac{1-y_i}{N_i} P_i Q_i + \frac{1-y_3}{N_i} P_i Q_3 \text{ , } i = 1,2 \tag{4.4}$$

A Web service vendor of S1 will choose to list on the WSI if it gains more profit from listing ($\pi^I \geq \pi^{NI}$) while otherwise it will not list. Hence, one derives the proportion of service vendors listing on the WSI from the equation $\pi_i^{NI} = \pi_i^I$ ($i = 1,2$), which is described below. Similar to the consumer side, the intermediary will attract all service vendors if the listing fee is low enough ($x = 1$). It is interesting that that although a high subscription fee will drive all consumers away from the intermediary, a high listing fee won't deter all service vendors. This is because those consumers who subscribe to the intermediary won't search beyond the WSI, creating a niche market of subscribers for the service vendors listed on the WSI.

$$x_i(y_i, y_3) = \begin{cases} \dfrac{P_i(y_i Q_i + y_3 Q_3)}{L N_i} & \text{if } \; L \geq \dfrac{P_i(y_i Q_i + y_3 Q_3)}{N_i} \\ 1 & \text{otherwise} \end{cases} \text{ , } i = 1,2 \tag{4.5}$$

4.4 Optimal Subscription and Listing Fee

After deriving the response functions of the service consumers and service vendors, the WSI solves the decision problem described as follows. The initial cost to set up for the WSI is sunk and the marginal operational cost incurred by the intermediary is assumed to be negligible.

$$\max_{L,F} \ \Pi = (y_1Q_1 + y_2Q_2 + y_3Q_3)F + (x_1N_1 + x_2N_2)L$$
$$\text{s.t.} \quad \text{Eqs. (4.1), (4.2),and (4.5)} \tag{4.6}$$

Lemma 4-1. *The optimal strategy of the WSI is to induce all service vendors to list on the intermediary, i.e.,* $x_1 = x_2 = 1$. *Specifically, the WSI will set the listing fee at* $L^* = \min\{L_1, L_2\}$, *where* $L_i = \dfrac{P_i(y_iQ_i + y_3Q_3)}{N_i}$ $(i = 1, 2)$.

Lemma 4-1 specifies that the listing fee should be low enough such that all service vendors list on the WSI ($x_1 = x_2 = 1$). The exact value of the listing fee cannot be determined until we derive the proportion of the subscribers (y_j's), which in turn is determined by the subscription fee F. In addition, the minimum of L_1 and L_2 is dependent on the values of P_i, N_i and Q_i.

Knowing that its optimal strategy is to attract all service vendors to list on it, the WSI is naturally confronted with the following question: whether it should attract all customers to subscribe? Lemma 4-2 suggests that this is not the case.

Lemma 4-2. *The intermediary's profit is not always maximized when all customers subscribe to its service, i.e.,* $y_1 = y_2 = y_3 = 1$.

Proof. I prove Lemma 4-2 by showing an example where the intermediary obtains more profit without full subscription from the service consumers. First note that $F = \gamma$ is the maximum subscription the intermediary can charge to induce total subscription. From Lemma 4-1 we know that the intermediary has incentive to allow all service vendors to list on it. Consequently, the maximum profit the intermediary can achieve when all consumers subscribe to it is $\pi_1 = \gamma(Q_1 + Q_2 + Q_3) + P_1(Q_1 + Q_3) + P_2(Q_2 + Q_3)$. Next consider the case when the intermediary charge a subscription fee of $F' = 2\gamma$,

which induces all customers of S3 to subscribe but not all customers of S1 and S2 will subscribe, i.e., $0 \le y_1, y_2 < 1$ and $y_3 = 1$. Then the intermediary's profit is $\pi' \ge \pi_2$, where $\pi_2 = 2\gamma Q_3 + P_1 Q_3 + P_2 Q_3$ is calculated when we plug in $F = 2\gamma$, $y_3 = 1$ and $y_1 = y_2 = 0$ into the profit function. With simple algebra, it's easy to show that the intermediary obtains more profit if $\gamma Q_3 > \gamma(Q_1 + Q_2) + P_1 Q_1 + P_2 Q_2$, i.e., $\pi' \ge \pi_2 > \pi_1$. Q.E.D.

Next we reformulate the optimal decision problem faced by the WSI by applying Lemma 4-1 and Lemma 4-2 in Eq. (4.7).

$$\begin{aligned} \max_F \ \Pi_N &= (y_1 Q_1 + y_2 Q_2 + y_3 Q_3)F + P_1(y_1 Q_1 + y_3 Q_3) + P_2(y_2 Q_2 + y_3 Q_3) \\ \text{s.t.} \quad & (4.1),\ (4.2),\ (4.5) \end{aligned} \tag{4.7}$$

Note that the functional form of proportions of subscribers ($y_j's$) is conditional on the value of subscription fee (F). Accordingly, the WSI's profit function takes different format under various subscription fee. In order to solve for the optimal subscription fee, we need to compare the profit under each possible combination of $y_j's$ ($j = 1, 2, 3$). That is, we need to consider internal solutions ($0 < y_j < 1$) as well as the boundary solutions ($y_j = 0$ or 1). Furthermore, the proportion of consumers who subscribe to the WSI varies under different relationship of γ and $\bar{v}$. For example, if the intermediary charge a subscription fee of $\bar{v} + \gamma$, all consumers of S3 will subscribe to it if $\gamma > \bar{v}$. On the other hand, only partial consumers of S3 will subscribe to it if $\gamma < \bar{v}$ with subscription fee charged at $\bar{v} + \gamma$. In the following two subsections, I solve for the optimal subscription fee F^* under different relationships between consumer's valuation of the network effect (γ) and the WSI's intrinsic value ($\bar{v}$).

4.4.1 Network value is less than intrinsic value

When consumers value intrinsic value more than network value ($\gamma < \bar{v}$), the proportion of subscribers with respect to subscription fee is illustrated in Figure 4-3, which breaks down into the following three sub-cases. If the subscription fee is between γ and 2γ (case I-1), partial consumers of S1 and S2 subscribe to the intermediary while all consumers of S3 subscribe to the intermediary; If the subscription fee is between 2γ and $\bar{v}+\gamma$ (case I-2), partial consumers of S1, S2 and S3 subscribe to the intermediary; If the subscription fee is between $\bar{v}+\gamma$ and $\bar{v}+2\gamma$ (case I-3), only partial consumers of S3 subscribe to the intermediary. Obviously, the intermediary has no incentive to set the subscription fee lower than γ or higher than $\bar{v}+2\gamma$, since the market is saturated under subscription fee at γ and in the latter case no consumer will subscribe.

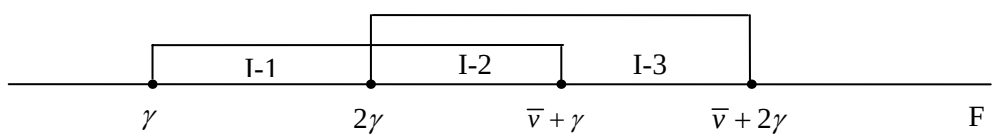

Figure 4-3. Proportion of Subscribers when $\gamma < \bar{v}$

I first derive the locally optimal subscription fee and then compare the WSI's profit in each sub-case. The optimal subscription fee is found as the one that generates the highest profit for the WSI.

Case I-1: $\gamma \le F \le 2\gamma$

If the subscription fee charged by the intermediary is between γ and 2γ, all consumers of S3 will subscribe to the intermediary while only partial customers S1 and S2 will subscribe to the intermediary, i.e., $0 < y_1, y_2 \le 1$ and $y_3 = 1$. Correspondingly, the intermediary's profit maximization problem is defined in Eq. (4.8). Lemma 4-3 describes

the optimal subscription fee when the intermediary desires to attract all consumers of S3 and partial consumers of S1 and S2.

$$\max_{F} \ \Pi_{11} = \left[\frac{\overline{v}+\gamma-F}{\overline{v}}(Q_1+Q_2)+Q_3 \right] F + \sum_{i=1,2} P_i \left(\frac{\overline{v}+\gamma-F}{\overline{v}} Q_i + Q_3 \right) \qquad (4.8)$$
$$\text{s.t} \qquad \gamma \le F \le 2\gamma$$

Lemma 4-3. *If* $\gamma < \overline{v}$ *and* $\gamma \le F \le 2\gamma$*, the subscription fee that maximizes the profit of the intermediary (*F_{11}^**) is specified as follows.*

a. If $\dfrac{(\overline{v}-P_1)Q_1+(\overline{v}-P_2)Q_2+\overline{v}Q_3}{(Q_1+Q_2)} \le \gamma < \overline{v}$, $F_{11}^* = \gamma$*;*

b. If $\dfrac{(\overline{v}-P_1)Q_1+(\overline{v}-P_2)Q_2+\overline{v}Q_3}{3(Q_1+Q_2)} < \gamma < \dfrac{(\overline{v}-P_1)Q_1+(\overline{v}-P_2)Q_2+\overline{v}Q_3}{Q_1+Q_2}$, $F_{11}^* = F_{11}$,
where F_{11} *is defined as* $F_{11} = \dfrac{(\overline{v}+\gamma-P_1)Q_1+(\overline{v}+\gamma-P_2)Q_2+\overline{v}Q_3}{2(Q_1+Q_2)}$*;*

c. If $0 < \gamma \le \dfrac{(\overline{v}-P_1)Q_1+(\overline{v}-P_2)Q_2+\overline{v}Q_3}{3(Q_1+Q_2)}$, $F_{11}^* = 2\gamma$.

Proof. Lemma 4-3 is derived from solving the constrained optimization problem defined in (4.8). See Appendix C for a detailed derivation.

Case I-2: $2\gamma \le F \le \overline{v}+\gamma$

If the subscription fee charged by the intermediary is between 2γ and $\overline{v}+\gamma$, part of customers interested in each of the Web services S1, S2 and S3 will subscribe to the intermediary, i.e., $0 < y_j < 1$ ($j = 1,2,3$). Correspondingly, the intermediary's profit maximization problem is defined as follows. Lemma 4-4 describes the optimal subscription fee when the intermediary desires to allow all groups of consumers to subscribe.

$$\max_{F} \ \Pi_{12} = \left[\frac{\bar{v}+\gamma-F}{\bar{v}}(Q_1+Q_2) + \frac{\bar{v}+2\gamma-F}{\bar{v}}Q_3 \right] F + \sum_{i=1,2} P_i \left(\frac{\bar{v}+\gamma-F}{\bar{v}}Q_i + \frac{\bar{v}+2\gamma-F}{\bar{v}}Q_3 \right) \quad (4.9)$$
$$\text{s.t} \ \ 2\gamma \le F \le \bar{v}+\gamma$$

Lemma 4-4. *If* $\gamma < \bar{v}$ *and* $2\gamma \le F \le \bar{v}+\gamma$, *the subscription fee that maximizes the profit of the intermediary (* F_{12}^* *) is specified as follows.*

a. If $0 \le \gamma < \dfrac{(\bar{v}-P_1)Q_1 + (\bar{v}-P_2)Q_2 + (\bar{v}-P_1-P_2)Q_3}{3Q_1+3Q_2+2Q_3}$, $F_{12}^* = F_{12}$, *where* F_{12} *is defined as* $F_{12} = \dfrac{(\bar{v}+\gamma-P_1)Q_1 + (\bar{v}+\gamma-P_2)Q_2 + (\bar{v}+2\gamma-P_1-P_2)Q_3}{2(Q_1+Q_2+Q_3)}$;

b. If $\dfrac{(\bar{v}-P_1)Q_1 + (\bar{v}-P_2)Q_2 + (\bar{v}-P_1-P_2)Q_3}{3Q_1+3Q_2+2Q_3} \le \gamma < \bar{v}$, $F_{12}^* = 2\gamma$.

Proof. Lemma 4-4 is drawn from solving the constrained optimization problem defined in (4.9). It is quite similar to proving Lemma 3. So we won't repeat here.

Case I-3: $\bar{v}+\gamma \le F \le \bar{v}+2\gamma$

If the subscription fee charged by the intermediary is between $\bar{v}+\gamma$ and $\bar{v}+2\gamma$, no consumers of S1 and S2 will subscribe to the intermediary while partial consumers of S3 will subscribe to the intermediary, i.e., $y_1 = y_2 = 0$ and $0 \le y_3 < 1$. Correspondingly, the intermediary's profit maximization problem is defined as follows. Lemma 4-5 describes the optimal subscription fee when the intermediary desires to get subscription from proportional consumers of S3 only.

$$\max_{F} \ \Pi_{13} = \frac{\bar{v}+2\gamma-F}{\bar{v}}Q_3F + (P_1+P_2)\frac{\bar{v}+2\gamma-F}{\bar{v}}Q_3 \quad (4.10)$$
$$\text{s.t.} \quad \bar{v}+\gamma \le F \le \bar{v}+2\gamma$$

Lemma 4-5. *If* $\gamma < \bar{v}$ *and* $\bar{v}+\gamma \le F \le \bar{v}+2\gamma$, *the subscription fee that maximizes the profit of the intermediary is* $F_{13}^* = \bar{v}+\gamma$.

Proof. We derive Lemma 4-5 by solving the constrained optimization problem and it's quite similar to proving Lemma 4-3. Detailed proof will be omitted.

Proposition 4-6. *If the intrinsic value of the intermediary is larger than the network value ($\gamma < \bar{v}$), the optimal subscription fee charged by the intermediary is specified as follows.*

a. *If $0 \le \gamma < \gamma_{11}$, the optimal subscription fee is F_{12} defined in Lemma 4-4. Proportional consumers of S1, S2 and S3 will subscribe to the intermediary, i.e., $0 < y_j < 1$ ($j = 1, 2, 3$);*

b. *If $\gamma_{11} \le \gamma < \gamma_{12}$, optimal subscription fee is 2γ. All consumers of S3 will subscribe to the intermediary while only partial consumers of S1 and S2 will subscribe to the intermediary, i.e., $y_3 = 1$ and $0 < y_1, y_2 < 1$;*

c. *If $\gamma_{12} \le \gamma < \gamma_{13}$, optimal subscription fee is F_{11} defined in Lemma 4-3. All customers of S3 subscribe to the intermediary while only partial customers of S1 and S2 subscribe to the intermediary, i.e., $y_3 = 1$ and $0 < y_1, y_2 < 1$;*

d. *If $\gamma_{13} \le \gamma < \bar{v}$, optimal subscription fee is γ. All customers of S1, S2 and S3 will subscribe to the intermediary, i.e., $y_j = 1$ ($j = 1, 2, 3$),*

where $\gamma_{11} = \dfrac{(\bar{v} - P_1)Q_1 + (\bar{v} - P_2)Q_2 + (\bar{v} - P_1 - P_2)Q_3}{3Q_1 + 3Q_2 + 2Q_3}$, $\gamma_{12} = \dfrac{(\bar{v} - P_1)Q_1 + (\bar{v} - P_2)Q_2 + \bar{v}Q_3}{3(Q_1 + Q_2)}$,
and γ_{13} *is defined as* $\gamma_{13} = \dfrac{(\bar{v} - P_1)Q_1 + (\bar{v} - P_2)Q_2 + \bar{v}Q_3}{Q_1 + Q_2}$.

One interesting observation from Proposition 4-6 is that the intermediary has more incentive to serve consumers of the integrated Web service than to serve consumers of individual Web services. Unless the network effect is very large, see (d) of Proposition 4-6, the intermediary only desires to allow partial consumers of S1 and S2 to subscribe to. In contrast, the intermediary will set the subscription fee to attract all consumers of S3 except for very small network effect, e.g., see (a) of Proposition 4-6.

Furthermore, Proposition 4-6 suggests that the optimal subscription fee is conditional on intensity of the network effect (γ). Note that $\gamma_{11} < \gamma_{12} < \gamma_{13}$, this implies that as the intensity of network effect increases, or consumer's valuation of the network effect increases, the intermediary has incentive to allow more and more consumers to subscribe to it, since the proportion of subscribers increases from (a) to (d). The behavior of optimal subscription fee and profit is summarized in Proposition 4-7.

Proposition 4-7. *If the intrinsic value of the intermediary is larger than the network value ($\gamma < \bar{v}$), the optimal subscription fee and optimal profit are increasing in network intensity (γ).*

Proof. By inspection, the subscription fee is increasing in network intensity under each conditions specified in (a)-(d). In addition, note that the subscription fee coincides at each point that delimits successive cases from (a) to (d). For example, when $\gamma = \gamma_{11}$, the optimal subscription fee F_{12} under the condition (a) equals 2γ, which is the optimal subscription fee under the condition (b). Therefore, the optimal subscription increases with network intensity. The network effect has similar effect on the optimal profit for the intermediary. Q.E.D.

Figures 4-4 and 4-5 illustrate the behavior of optimal subscription fee and profit when the network effect is lower than the intrinsic value of the WSI ($\gamma < \bar{v}$). The parameters in the shown example are: $Q_1 = 100$, $Q_2 = 150$, $Q_3 = 90$, $P_1 = 5$, $P_2 = 2$, $\bar{v} = 5$, $\gamma_{11} = 0.29$, $\gamma_{12} = 1.2$, $\gamma_{13} = 3.6$. Note that the optimal subscription fee (or profit) is a kinked one (different functional forms with varying network intensity). But the optimal subscription fee (or profit) is generally increasing in network intensity.

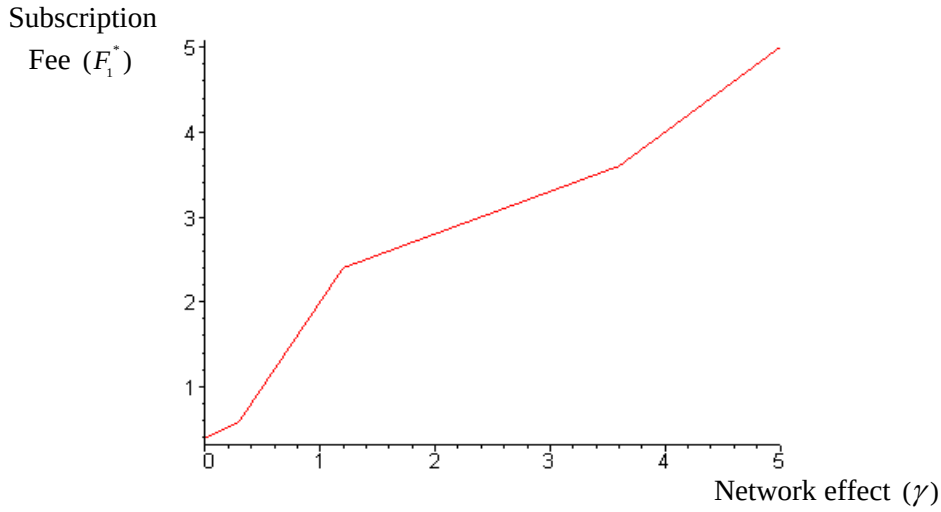

Figure 4-4. Optimal subscription fee when $\gamma < \overline{v}$

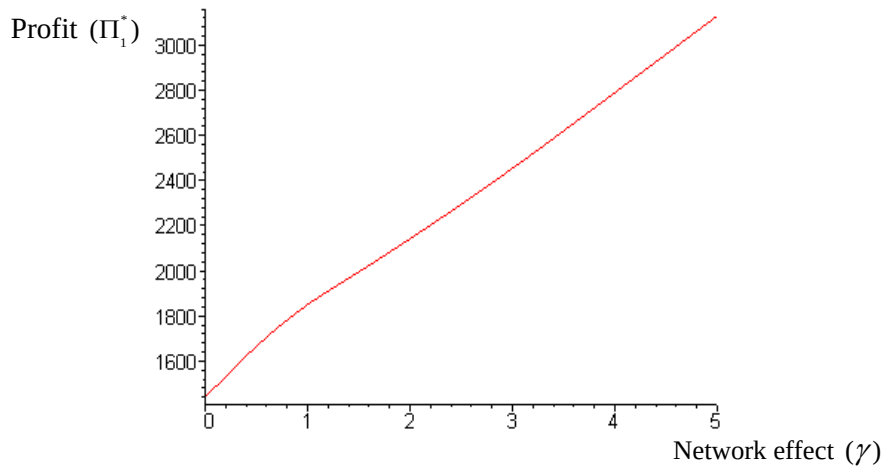

Figure 4-5. Optimal profit when $\gamma < \overline{v}$

It's worthy noting that although Proposition 4-6 describes the optimal subscription fee with respect to different values of the network intensity (γ), not all conditions prescribed in Proposition 4-6 can be met in reality. For example, in case when $\gamma_{13} > \overline{v}$, the condition specified in (d) will never be satisfied. In other works, the intermediary will never set the subscription fee at γ, which attracts all consumers to subscribe to the intermediary, when the condition in (d) is met. Corollaries 4-8 and 4-9 present more insights from Proposition 4-6 by studying the impact of intrinsic value on the optimal subscription fee.

Corollary 4-8. *The intermediary will set the subscription fee to attract all customers of S3 to subscribe if* $\bar{v} < \bar{V}$ *, where* $\bar{V} = \dfrac{P_1Q_1 + P_2Q_2 + (P_1 + P_2)Q_3}{Q_1 + Q_2 + Q_3}$.

Proof. If $\gamma_{11} < 0$, the condition specified in (a) of Proposition 4-6 will never be satisfied. Therefore, the optimal subscription fee charged by the intermediary must be realized in one of the remaining cases of (b)-(d), which all suggest a total subscription from consumers of S3, i.e., $y_3 = 1$. Q.E.D.

Corollary 4-9. *The intermediary won't serve all Web service consumers if* $\bar{v} > \underline{V}$ *, where* $\underline{V} = \dfrac{P_1Q_1 + P_2Q_2}{Q_3}$.

Proof. To achieve total subscription from all customers, the intermediary has to set up its subscription fee at γ. According to Proposition 4-6, the subscription fee γ is optimal only when $\gamma_{13} \le \gamma < \bar{v}$. But if $\gamma_{13} > \bar{v}$, which translates to $\bar{v} > \underline{V}$, the condition in d of Proposition 6 can never be satisfied. Q.E.D.

Corollary 4-8 specifies the condition under which the WSI will set the subscription to allow all subscribers of S3 to subscribe to it. This relates the intermediary's optimal strategy with the nature of Web services provided by the service vendors since the threshold value $\bar{V}$ is increasing in prices of Web services (P_1 and P_2). Specifically, the WSI will strategically attract more consumers with higher value (or price) of the Web services.

Corollary 4-9 can be viewed to some extent as the opposite case of Corollary 8. Instead of answering when the intermediary should allow more consumers to subscribe to it, Corollary 9 specifies the condition under which the intermediary desires to serve *less*

consumers. Corollary 4-9 also relates the intermediary's optimal strategy with the nature of Web services provided by the service vendors. Note that the threshold value $\underline{V}$ is determined by the prices of the Web services (P_1 and P_2). According to Corollary 9, if the consumers have a relatively higher valuation of the value-added services from the WSI compared to prices of Web services, the intermediary need not set a low subscription fee to attract all consumers to subscribe to it.

4.4.2 Network value is greater than intrinsic value

Similar analysis can be applied to the second scenario where consumers place a higher value of the network effect than the intrinsic value ($\gamma > \overline{v}$). The proportion of subscribers with respect to subscription fee is illustrated in Figure 4-6, which breaks down into the following three sub-cases. If the subscription fee is between γ and $\overline{v}+\gamma$ (case II-1), partial consumers of S1 and S2 subscribe to the intermediary while all consumers of S3 subscribe to the intermediary, If the subscription fee is between $\overline{v}+\gamma$ and 2γ (case II-2), no consumer of S1 and S2 will subscribe while all consumers of S3 will subscribe to the intermediary; If the subscription fee is between 2γ and $\overline{v}+2\gamma$ (case II-3), partial consumers of S3 subscribe to the intermediary and no consumer of S1 and S2 will subscribe. Similar to the previous scenario, we don't consider the cases when the subscription fee is lower than γ or higher than $\overline{v}+2\gamma$.

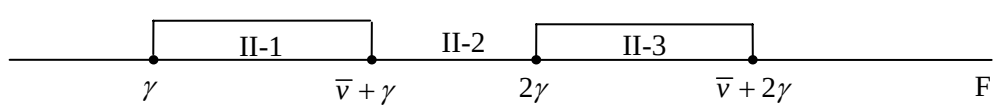

Figure 4-6. Proportion of subscribers when $\gamma > \overline{v}$

Case II-1: $\gamma \le F \le \bar{v} + \gamma$

In Case II-1 the intermediary's profit function is the same as the one defined in Case I-1. All consumers of S3 will subscribe to the intermediary while only partial customers S1 and S2 will subscribe to the intermediary, i.e., $0 < y_1, y_2 \le 1$ and $y_3 = 1$. However, the range of subscription fee is different from that of case I-1. We define the intermediary's decision problem in Eq. (4.11). Lemma 4-10 specifies the optimal subscription fee when the intermediary desires to attract all consumers of S3 and partial consumers of S1 and S2.

$$\max_F \ \Pi_{21} = \left[\frac{\bar{v} + \gamma - F}{\bar{v}} (Q_1 + Q_2) + Q_3 \right] F + \sum_{i=1,2} P_i \left(\frac{\bar{v} + \gamma - F}{\bar{v}} Q_i + Q_3 \right) \qquad (4.11)$$
$$\text{s.t} \qquad \gamma \le F \le \bar{v} + \gamma$$

Lemma 4-10. *If* $\gamma < \bar{v}$ *and* $\gamma \le F \le \bar{v} + \gamma$, *the subscription fee that maximizes the profit of the intermediary (* F_{21}^* *) is specified as follows.*

a. *If* $\bar{v} \le \gamma \le \dfrac{\bar{v}Q_3 - (\bar{v} + \gamma + P_1)Q_1 - (\bar{v} + \gamma + P_2)Q_2}{Q_1 + Q_2}$, $F_{21}^* = \bar{v} + \gamma$;

b. *If* $\dfrac{\bar{v}Q_3 - (\bar{v} + \gamma + P_1)Q_1 - (\bar{v} + \gamma + P_2)Q_2}{Q_1 + Q_2} < \gamma < \dfrac{(\bar{v} - P_1)Q_1 + (\bar{v} - P_2)Q_2 + \bar{v}Q_3}{Q_1 + Q_2}$,
$F_{21}^* = F_{21}$, *where* F_{21} *is defined as* $F_{21} = \dfrac{(\bar{v} + \gamma - P_1)Q_1 + (\bar{v} + \gamma - P_2)Q_2 + \bar{v}Q_3}{2(Q_1 + Q_2)}$;

c. *If* $\gamma \ge \dfrac{(\bar{v} - P_1)Q_1 + (\bar{v} - P_2)Q_2 + \bar{v}Q_3}{Q_1 + Q_2}$, $F_{21}^* = \gamma$.

Proof. Lemma 4-10 is proved using the same approach in proving Lemma 4-3.

Case II-2: $\bar{v} + \gamma \le F \le 2\gamma$

If the subscription fee is between $\bar{v} + \gamma$ and 2γ, all consumers of S3 will subscribe while no consumers of S1 or S2 will subscribe to the WSI, i.e., $y_1 = y_2 = 0$ and $y_3 = 1$.

Furthermore, the WSI must set the subscription fee at 2γ, which is the highest subscription fee the WSI can charge in order to have all consumers of S3 subscribe to it. This is because any subscription fee less than 2γ won't attract more consumers and thus will render less profit for the WSI. Therefore, Case II-2 can be viewed as a special case of Case II-3 to be discussed below.

Case II-3: $2\gamma \le F \le \overline{v} + 2\gamma$

If the intermediary set the subscription fee between 2γ and $\overline{v} + 2\gamma$, no consumer of S1 or S2 will subscribe while some consumers of S3 might subscribe to it, i.e., $y_1 = y_2 = 0$ and $0 \le y_3 \le 1$. The profit maximization problem is described in Eq. (4.12). It is same with the one defined in case I-3, except for different constraint the subscription fee. Lemma 4-11 specifies the optimal subscription fee when the intermediary desires to get subscription from proportional consumers of S3 only.

$$\max_F \ \Pi_{23} = \frac{\overline{v} + 2\gamma - F}{\overline{v}} Q_3 F + (P_1 + P_2)\frac{\overline{v} + 2\gamma - F}{\overline{v}} Q_3 \qquad (4.12)$$
$$\text{s.t.} \quad 2\gamma \le F \le \overline{v} + 2\gamma$$

Lemma 4-11. *If* $\gamma > \overline{v}$ *and* $2\gamma \le F \le \overline{v} + 2\gamma$, *the subscription fee that maximizes the profit of the intermediary is* $F_{23}^* = \overline{v} + \gamma$.

Proof. The proof is similar to that of Lemma 4-5.

Proposition 4-12. *If consumer evaluate the value from network effect more than that of the technical services ($\gamma > \overline{v}$), the optimal subscription fee is described as follows, where* $\gamma_{21} = \dfrac{\overline{v}Q_3 - (\overline{v} + P_1)Q_1 - (\overline{v} + P_2)Q_2}{Q_1 + Q_2}$ *and* $\gamma_{22} = \dfrac{(\overline{v} - P_1)Q_1 + (\overline{v} - P_2)Q_2 + \overline{v}Q_3}{Q_1 + Q_2}$.

a. *If* $\bar{v} \le \gamma \le \gamma_{21}$*, the optimal subscription fee is* 2γ*. All customers of S3 subscribe to the intermediary while no customers of S1 and S2 subscribe, i.e.,* $y_1 = y_2 = 0$ *and* $y_3 = 1$*;*

b. *If* $\gamma_{21} < \gamma < \gamma_{22}$*, the optimal strategy for the intermediary is to set the subscription so that all consumers of S3 subscribe while some consumers of S1 or S2 subscribe, i.e.,* $y_3 = 1$ *and* $0 < y_1, y_2 \le 1$*. In particular, the subscription fee is*

d. $$F^* = \begin{cases} F_{21,} & \text{if } \Phi \ge 0 \\ 2\gamma, & \text{if } \Phi < 0 \end{cases}$$ *, where* F_{21} *is defined in Lemma 4-10 and*

$$\Phi = \left[Q_1(\bar{v} + \gamma + P_1) + Q_2(\bar{v} + \gamma + P_2) - \bar{v}Q_3\right]^2 + 4\bar{v}(\bar{v} - \gamma)Q_3(Q_1 + Q_2)$$

c. *If* $\gamma \ge \gamma_{22}$*, the optimal subscription fee and proportions of subscribers are*

$$F^* = \begin{cases} \gamma, & \text{if } \Psi > 0 \\ 2\gamma, & \text{if } \Psi \le 0 \end{cases}, \text{ where } \Psi = \gamma(Q_1 + Q_2 - Q_3) + P_1Q_1 + P_2Q_2,$$

leading to all consumers of S1, S2, and S3 to subscribe if $F^* = \gamma$*, or all consumers of S3 to subscribe but none of customers of S1 and S2 when* $F^* = 2\gamma$*.*

Proof. See Appendix C.

Similar to the previous scenario for $\gamma < \bar{v}$, I derive the optimal subscription fee for the WSI by comparing the WSI's profit in Case II-1 and Case II-3, which is summarized in Proposition 4-12. But this scenario ($\gamma > \bar{v}$) is a bit more complex than the case when $\gamma < \bar{v}$, since we don't have conclusive solutions for the optimal subscription fee under conditions (b) and (c), which are determined by functions Φ and Ψ respectively. That is, the optimal subscription fee is determined not only by the network intensity but also the nature of the Web services, e.g., prices of individual Web services (P's), market size (Q's), and the intrinsic value of the intermediary's service $\bar{v}$.

Figures 4-7 and 4-8 draw an example of the behavior of optimal subscription fee with respect to network effect under conditions (b) and (c), which are determined by

functions Φ and Ψ respectively. The parameters in Figure 4-7 are: $Q_1 = 80$, $Q_2 = 80$, $Q_3 = 200$, $P_1 = 1$, $P_2 = 1$, $\bar{v} = 10$. The parameters in Figure 4-8 are: $Q_1 = 80$, $Q_2 = 80$, $Q_3 = 200$, $P_1 = 1$, $P_2 = 0.5$, $\bar{v} = 1$.

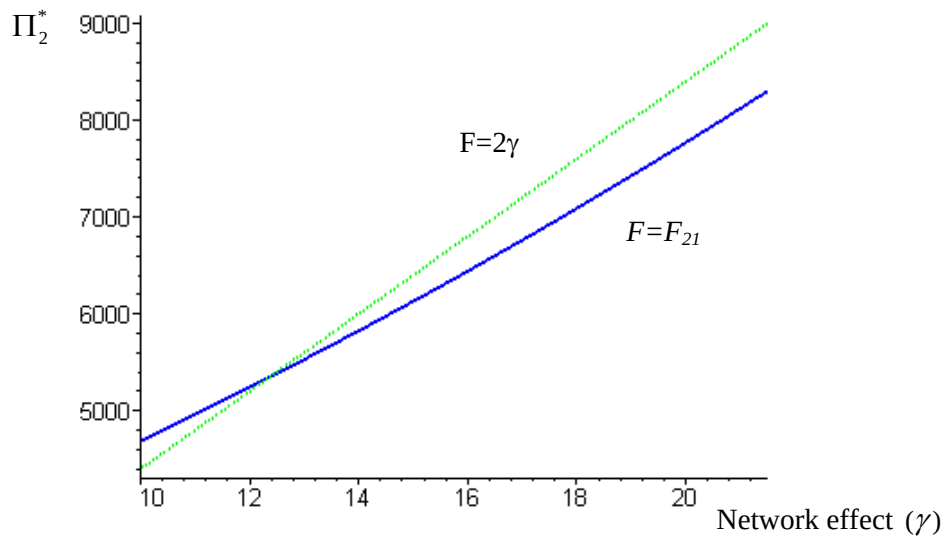

Figure 4-7. Optimal subscription fee depends on Φ when $\gamma_{21} < \gamma < \gamma_{22}$

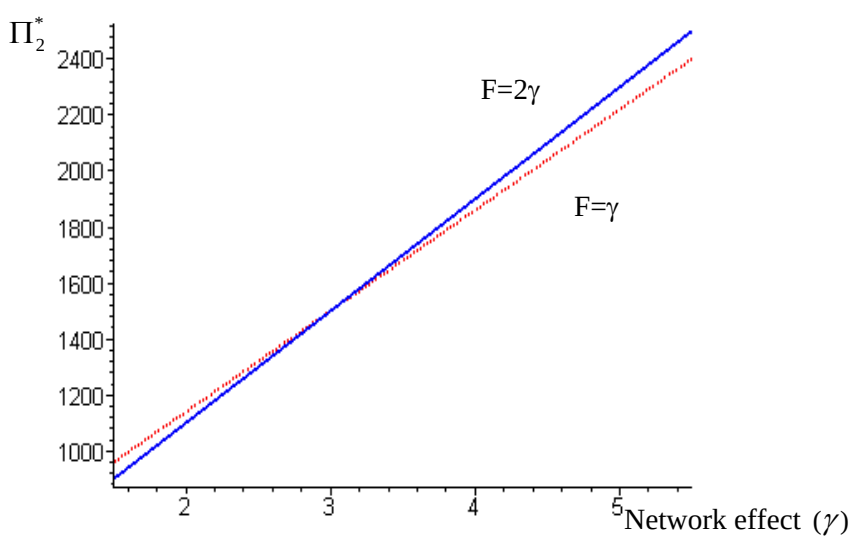

Figure 4-8. Optimal subscription fee depends on Ψ when $\gamma > \gamma_{22}$

Furthermore, we summarize the characteristics of the optimal subscription fee with respect to the specific relationship of $\bar{v}$, P and Q in Corollaries 4-13, 4-14, 4-15 and 4-16.

Corollary 4-13. *When the network value is greater than the intrinsic value ($\gamma > \bar{v}$), the intermediary will never set the subscription fee at γ if $Q_1 + Q_2 < Q_3$ and* $\bar{v} > \dfrac{P_1Q_1 + P_2Q_2}{Q_3 - Q_1 - Q_2}$.

Proof. According to condition (c) in Proposition 4-12, the WSI has incentive to set the subscription fee at γ, which will allow all consumers subscribe to it, if $\Psi > 0$ and $\gamma > \gamma_{22}$. However, if $Q_1 + Q_2 < Q_3$, we must have $\gamma < \dfrac{P_1Q_1 + P_2Q_2}{Q_3 - Q_1 - Q_2}$ so that Ψ is positive. Since $\gamma > \bar{v}$, it follows that if $\bar{v} > \dfrac{P_1Q_1 + P_2Q_2}{Q_3 - Q_1 - Q_2}$, Ψ must be negative. Q.E.D.

Corollary 4-14. *When the network value is greater than the intrinsic value, the optimal subscription fee is 2γ if $2(Q_1 + Q_2) < Q_3$ and* $\bar{v} \geq \dfrac{P_1Q_1 + P_2Q_2}{Q_3 - 2Q_1 - 2Q_2}$

Proof. I show that under the conditions in Corollary 4-14, the following inequalities hold: $\gamma_{21} > \bar{v}$, $\Phi < 0$, and $\Psi < 0$. Detailed proof is relegated to Appendix C.

Corollary 4-15. *When the network value is greater than the intrinsic value, the optimal subscription fee is increasing in network intensity if $2(Q_1 + Q_2) < Q_3$ and* $\bar{v} < \dfrac{P_1Q_1 + P_2Q_2}{Q_3 - 2Q_1 - 2Q_2}$.

Proof. See Appendix C for detailed proof. We show that there are only three possible cases of the optimal subscription fee: (1) 2γ for the entire region $\gamma > \bar{v}$; (2) F_{21}

for $\gamma_{21} < \gamma < \gamma_{22}$, γ and then 2γ for $\gamma > \gamma_{22}$; (3) F_{21} and then 2γ for $\gamma_{21} < \gamma < \gamma_{22}$, 2γ for $\gamma > \gamma_{22}$.

Corollary 4-16. *If $\gamma > \gamma_{22}$ and $Q_1 + Q_2 > Q_3$, the optimal subscription fee is γ.*

Proof. By inspection, Ψ is positive when $Q_1 + Q_2 > Q_3$ under condition c in Proposition 4-12. Q.E.D.

Proposition 4-12 specifies three strategies for the intermediary when the network effect is more significant ($\gamma > \bar{v}$): charge a low subscription fee to attract all consumers (γ); allow only consumers of S3 to subscribe (2γ); or allow partial consumers of S1 (or S2) and all consumers of S3 to subscribe (F_{21}). Although the optimal strategy should be determined by the network intensity and functions of Φ and Ψ, there are cases where the WSI is certain about the optimal subscription without having to evaluate the values of Φ or Ψ.

Corollary 4-13 states the condition when the intermediary will never charge a low subscription fee to attract all consumers to subscribe to its service. It suggests that if the market for the composite service is large and consumers have high valuation of the technical expertise (intrinsic value) of the WSI, it will never offer a low subscription fee to attract all consumers. Corollary 4-14 further states the condition under which the intermediary only needs to attract consumers of S3 to subscribe to its service. Corollary 4-15 characterizes the behavior of the optimal subscription fee if the market for the composite service is large but the consumer's valuation of the WSI's intrinsic value is not as high. It should be noted that if at some point, the optimal subscription fee is 2γ, the WSI will never set the subscription fee of γ. In other words, if the WSI's strategy is to

attract consumers of S3 only, it won't lower the subscription fee to attract all consumers as network effect intensifies. On the other hand, if the market size of the composite Web service S3 is small, Corollary 4-16 suggests that the WSI should set the subscription fee to attract all consumers if the network effect is large.

CHAPTER 5
CONCLUSIONS AND FUTURE RESEARCH

The intense competition and the constant changing nature of the global economy call for an agile information technology infrastructure for businesses to stay competitive and adapt to new threats and opportunities. Astute managers face an enormous pressure to cut costs and leverage existing information technology resources, a task complicated by legacy systems built on technologies of different ages. Web services technology, touted as the foundation to an interoperable, location transparent service-oriented architecture has been developed as a promising solution to the challenge of heterogeneity and change.

Despite the enormous hype and doubt in industry, there has been a lack of academic awareness on this new computing paradigm, especially from business angle. The objective of my dissertation is to study the business implications of Web services on firm strategies. Specifically, I focus on the optimal strategies to provide Web services for Web service vendors and Web service intermediaries. The dissertation is divided into three research topics.

The first part of the dissertation deals with the optimal market structure to provide complementary Web services. In particular, I compare three market structures– independent service vendors (ISV), strategic alliance (SA), and Web service marketplace. Under the ISV market structure, two Web service vendors offer two complementary Web services separately and it is left to consumers to integrate the two Web services. Under the SA market structure, two Web service vendors form an alliance to sell an integrated

Web service. Under the market structure of Web service marketplace, both individual and composite Web services are provided.

Interesting managerial insights have been derived from theoretical analysis of a simplified model and numerical explorations on a generalized model. First, it is found that the marketplace dominates the ISV market structure, implying that Web service vendors can benefit from the integration of Web services. Second, the integration cost and the market characteristics of Web services play important roles in determining the optimal market structure. If the valuation of the integrated software service is small, the service vendors prefer marketplace to SA. For larger valuation of the integrated Web service, the marketplace is preferred if the integration cost is high while SA dominates if the integration cost is low. As the valuation of the integrated software service becomes sufficiently high, SA turns to be the optimal market structure. In addition, if the integrated service enjoys a larger market potential, SA will beat marketplace for a smaller valuation of the integrated service. Finally, in a more balanced market, where one service vendor has advantage over software valuation while the other service vendor has advantage over market potential, SA is preferred to marketplace for a smaller valuation of the integrated service.

The second part of the dissertation is intrigued by observing Web service consumption model. In a Web-service-based computing environment, the Web service consumers no longer need to license or house the software modules (Web services). Instead, the consumption of Web services involves accessing the software component on the remote server of Web service vendors. This causes network latency because of the

turnaround time between Web service vendors and consumers. As a result, the performance of Web services is affected by where the Web services are located.

In the second part of the dissertation, I solve the joint decision of location and pricing for a time-sensitive composite Web service provided by a Web service intermediary. I propose two spatial models to solve the joint optimization problem by taking into account both delay cost and integration cost. A linear city model is first presented to study a special case where the individual Web service providers are located at the ends of the linear city model. Optimal location and price are derived in the linear city model. Analytical results indicate that the optimal location for the integrated Web service is midpoint between the service providers. When the delay cost is small, the WSI should set a low penetration price to capture entire market demand. When the delay cost is high, the best strategy for the WSI is to share the market with the service providers. Furthermore, the optimal price and profit are increasing in delay cost and integration cost. To study the general cases where not all customers reside between the service providers, a unit circle model is applied. Analysis in the unit circle model shows that when the delay cost is low, the highest market-covering price is the optimal price and the optimal location is midpoint between the service providers. Interestingly, analysis of the unit circle model suggests that there exist multiple optimal locations for the integrated Web service if the distance between the two Web service vendors is large.

Finally, I study the optimal strategies of a Web services intermediary (WSI) that provides aggregation service and value-added technical services in a supply chain of complementary Web services. The value of the aggregation service is dependent on the number of participants in the Web service supply chain. Specifically, the Web service

consumers appreciate the aggregation service more if there are more vendors listed on the WSI. Likewise, the Web service vendors think it is more worthwhile to list the Web services on the WSI if more consumers are aware of it. The value-added technical services are network-dependent, such as enforcing quality of service, enhancing security, improving Web service management.

The aggregation and value-added services give the WSI the privilege to charge subscription fee to Web service consumers and listing fee to Web service vendors. The last part of the dissertation aims to solve for the optimal subscription and listing fees. In particular, I consider a WSI that faces service vendors providing two complementary Web services and there are demand for both the individual Web services and the composite Web service. Analytical results suggest that in the presence of inter-network externalities, the optimal strategy for the intermediary is to set a listing fee such that all Web service vendors list their Web services on it. On the other hand, the optimal subscription fee is determined by the relationship between the network value and the value of technical services. When the consumers appreciate the technical services more than the network effect, the optimal subscription fee is increasing in network effect and the intermediary will attract more consumers as network effect intensifies. In addition, the intermediary's strategy is affected by the natures of Web services being traded, such as the prices of Web services, the market size, and the relationship between consumer's valuation of technical services by the WSI and the prices of Web services.

This dissertation should serve as a ground for extended research in the future. There are many interesting issues worthy of future work. In the study on optimal market structure, I shall consider more market structures. For example, instead of having the

Web service vendors form a marketplace, a third-party company could serve the same task of providing both individual and composite Web services. In some cases, the two complementary Web services are not of equal importance. In other words, there could be no demand for a supplementary Web service by its own. Another interesting issue of Web service market structure is the tradeoff between customization and integration. While a strategic alliance or marketplace helps reduce integration cost, the Web service consumer suffers from loss of customization. Therefore, I shall incorporate the effect of customization for the analysis on optimal market structure in the future. Furthermore, the current research on market structure takes a "macro" view of the problem, ignoring the profit distribution among service vendors. It is interesting to analyze the market structures under different profit division mechanisms.

In the analysis of optimal location and pricing of an integrated Web service, I only derive analytical results for the case when the delay cost is low in the unit circle model. While analytical derivations of general scenarios for large delay cost become mathematically impracticable to solve, I can adopt other numerical approaches, such as simulations, to draw more insights.

The second and third part of the dissertation address different types of Web service intermediary–a "matchmaker" that provides value-added services and a "market maker" that sells an integrated Web service. A WSI that has the technical capabilities can provide both integration and aggregation services. This means the relationship between the WSI and the Web service vendors could be both cooperative and competitive. It's worth studying the optimal strategies of such Web service intermediaries. Another

avenue of future research is to extend the monopolistic WSI to consider competition in the duopoly setting.

APPENDIX A
PROOFS OF CHAPTER 2

A.1 Proof of Lemma 2-1

In a symmetric market, where the valuations and market sizes of the two Web services are equal, the profit maximization problem for the service vendors is

$$\max_{P_{si}} \ \pi_{si} = P_{si} \cdot D_{si} = P_{si}(Q - \frac{P_{si}}{V}Q) + P_{si}(Q_3 - \frac{P_{s1} + P_{s2} + c}{V_3}Q_3), \ i = 1, 2 \tag{A.1}$$

By solving the above problems for each Web service vendor simultaneously, one gets the optimal solutions described as follows.

$$P_{si}^* = \frac{VV_3Q + VV_3Q_3 - cVQ_3}{2QV_3 + 3VQ_3} \tag{A.2}$$

$$\pi_{si}^* = \frac{V(V_3Q + V_3Q_3 - cQ_3)(V_3^2Q^2 + VV_3QQ_3 + V_3^2QQ_3 + VV_3Q_3^2 - cV_3QQ_3 - cVQ_3^2)}{V_3(2QV_3 + 3VQ_3)^2} \tag{A.3}$$

Take the first and second derivatives of π_{si}^* with respect to c.

$$\frac{\partial \pi_{si}^*}{\partial c} = -\frac{2VQ_3[V_3^2(Q^2 + QQ_3) + V_3QQ_3(V - c) + VQ_3^2(V_3 - c)]}{V_3(2V_3Q + 3VQ_3)^2} \tag{A.4}$$

$$\frac{\partial^2 \pi_{si}^*}{\partial c^2} = \frac{2Q_3^2V(Q_3V + QV_3)}{V_3(2QV_3 + 3Q_3V)^2} \tag{A.5}$$

By inspection, the first derivative is negative under the assumption that $0 < c < V < V_3$ while the second derivative is positive. Therefore, π_s^* is decreasing and convex in c, where $\pi_s^* = \pi_{s1}^* + \pi_{s2}^*$. In addition, π_s^* is maximized when $c = 0$. Recall that

the optimal total profit under the ISV market structure is $\Pi_s^* = \max\left\{\frac{1}{2}VQ, \pi_s^*\right\}$. It follows that the optimal total profit is π_s^* when $c = 0$, since

$$\pi_s^*(c=0) - \frac{1}{2}VQ = \frac{QQ_3(V_3 - V)(V_3 + 9V) + 8Q^2V_3(V_3 - V) + 4VV_3Q_3^2}{2(2QV_3 + 3VQ_3)^2}. \qquad \text{(A.6)}$$

Obviously, when $V_3 > V$, we always have $\pi_s^*(c=0) > \frac{1}{2}VQ$. Therefore, the shape of the function Π_s^* switches from π_s^* to $\frac{1}{2}VQ$ as the integration cost increases.

A.2 Proof of Lemma 2-3

We solve the constrained profit maximization problem by establishing Lagrangean function, see (A.7) and then solving for the KKT conditions in Equations (A.8) to (A.11).

$$L(\lambda) = P_{m1}(Q - \frac{P_{m1}}{V}Q) + P_{m2}(Q - \frac{P_{m2}}{V}Q) + P_{m3}(Q_3 - \frac{P_3}{V_3}Q_3) + \lambda(P_{m1} + P_{m2} + c - P_{m3}) \qquad \text{(A.7)}$$

$$L_{P_{m1}} = Q - \frac{2P_{m1}}{V}Q + \lambda \le 0, \quad P_{m1}L_{P_{m1}} = 0 \qquad \text{(A.8)}$$

$$L_{Pm_2} = Q - \frac{2P_{m2}}{V}Q + \lambda \le 0, \quad P_{m2}L_{P_{m2}} = 0 \qquad \text{(A.9)}$$

$$L_{P_{m2}} = Q_3 - \frac{2P_{m3}}{V_3}Q_3 - \lambda \le 0, \quad P_{m3}L_{P_{m3}} = 0 \qquad \text{(A.10)}$$

$$L_\lambda = P_{m1} + P_{m2} + c - P_{m3} \ge 0, \quad \lambda L_\lambda = 0 \qquad \text{(A.11)}$$

Obviously, the zero price solution can't be optimal. So we must have equalities in Equations (A.8) to (A.10). If $\lambda > 0$, then according to (A.11) we have $L_\lambda = 0$, which implies $P_{m3} = P_{m1} + P_{m2} + c$. Substitute into Equations (A.8) to (A.10) and one gets the optimal solutions as follows.

$$P_{m1}^{*} = P_{m2}^{*} = \frac{V}{2} + \frac{Q_3 V(V_3 - 2V - 2c)}{2(QV_3 + 2Q_3 V)} > \frac{V}{2} \tag{A.12}$$

$$P_{m3}^{*} = \frac{V_3}{2} - \frac{QV_3(V_3 - 2V - 2c)}{2(QV_3 + 2Q_3 V)} < \frac{V_3}{2} \tag{A.13}$$

$$\pi_m^{*} = \frac{1}{2}VQ + \frac{1}{4}V_3 Q_3 - \frac{QQ_3(V_3 - 2V - 2c)^2}{4(QV_3 + 2Q_3 V)} \tag{A.14}$$

Note that $\lambda > 0$ requires $V_3 > 2V + 2c$. On the other hand, if $V_3 \le 2V + 2c$, we must have we have $\lambda = 0$. The corresponding optimal solutions are

$$\hat{P}_{m1}^{*} = \frac{V}{2},\ \hat{P}_{m2}^{*} = \frac{V}{2},\ \hat{P}_{m3}^{*} = \frac{V_3}{2} \tag{A.15}$$

$$\hat{\pi}_m^{*} = \frac{1}{2}VQ + \frac{1}{4}V_3 Q_3 \tag{A.16}$$

In summary, the optimal profit of the marketplace is specified in Eq. (A.14) if $V_3 > 2V + 2c$ and specified in Eq. (A.16) otherwise. Q.E.D.

A.3 Proof of Lemma 2-4

Take the first and second order derivative of π_m^{*} with respect to c

$$\frac{\partial \pi_m^{*}}{\partial c} = \frac{QQ_3(V_3 - 2V - 2c)}{V_3 Q + 2VQ_3},\ \frac{\partial^2 \pi_m^{*}}{\partial c^2} = \frac{-2QQ_3}{V_3 Q + 2VQ_3} \tag{A.17}$$

According to Lemma 2-3, π_m^{*} is valid in the interval $V_3 > 2V + 2c$. Therefore, π_m^{*} is increasing and concave in c.

It is obvious that the optimal profit when $V_3 \le 2V + 2c$ ($\hat{\pi}_m^{*}$) is increasing in V_3 and Q_3. Next we take the derivative of π_m^{*} with respect to V_3 and Q_3 as follows.

$$\frac{\partial \pi_m^{*}}{\partial V_3} = \frac{Q_3(Q_3^2 V^2 + Q^2 V^2 + Q^2 c^2 + 2QQ_3 V^2 + 2cVQQ_3 + 2cVQ^2)}{(QV_3 + 2Q_3 V)^2} \tag{A.18}$$

$$\frac{\partial \pi_m^*}{\partial Q_3} = \frac{V_3(VV_3QQ_3 + V^2Q_3^2 + cV_3Q^2 + VV_3Q^2 - Q^2V^2 - c^2Q^2 - 2cVQ^2)}{(QV_3 + 2Q_3V)^2} \tag{A.19}$$

Obviously, π_m^* is increasing in V_3 since $\frac{\partial \pi_m^*}{\partial V_3} > 0$. In addition, under the constraints $V_3 > 2V + 2c$ and $c < V$, we have $\frac{\partial \pi_m^*}{\partial Q_3} > 0$. In summary, Π_m^* (π_m^* and $\hat{\pi}_m^*$) is increasing in both V_3 and Q_3. Q.E.D.

A.4 Proof of Proposition 2-6

First we compare the profit under ISV market structure (π_s^*) vs. that of a marketplace (π_m^*) with respect to zero integration cost as follows.

$$\pi_m^*(c=0) - \pi_s^*(c=0) = \frac{V^3V_3Q_3^2(Q+Q_3)^2}{(2Q_3V + V_3Q)(2V_3Q + 3Q_3V)^2} \tag{A.20}$$

Obviously, π_m^* is always greater than π_s^* at $c = 0$. From lemma 2-1, we know that the optimal total profit of the independent service vendors is maximized when the integration cost is zero. Further, Lemma 2-3 suggests that the marketplace's optimal profit minimizes when the integration cost is zero. Therefore, the marketplace is always a better market structure than the ISV market structure. Q.E.D.

A.5 Proof of Proposition 2-7

Proposition 2-6 suggests that the marketplaces always dominates the ISV market structure. So we focus on comparing the profits under the market structure of SA against marketplace. First note that when $V < V_3 < 2V$, we have $V_3 < 2V + 2c$ for all $c > 0$. According to Lemma 2-5, the optimal profit of the marketplace is $\frac{1}{2}VQ + \frac{1}{4}V_3Q_3$ in the interval $c \in [0, V]$. This suggests that the strategic alliance is always dominated in this

situation since its optimal profit is $\frac{1}{4}V_3Q_3$. Therefore, when $V < V_3 < 2V$, the marketplace is the optimal strategy for the service vendors.

Next we compare the optimal profit of the marketplace against that of the strategic alliance by analyzing the difference of optimal profits under the two market structures when $2V < V_3 < (4+\frac{2Q}{Q_3})V$. Note that when the integration cost is zero, the profit difference is

$$\varphi(V_3) = \pi_m^*(c=0) - \Pi_a^* = \frac{V_3Q(4Q_3V + 2QV - Q_3V_3)}{4(V_3Q + 2Q_3V)} \tag{A.21}$$

When $2V < V_3 < (4+\frac{2Q}{Q_3})V$, we have $2Q_3V < Q_3V_3 < 4Q_3V + 2QV$, suggesting that φ is always positive. Therefore, strategic alliance is dominated by the Web services marketplace if $2V < V_3 < (4+\frac{2Q}{Q_3})V$. Summarizing the results above, we conclude that the marketplace is the optimal market strategy for the service vendors regardless of the integration cost when $V < V_3 < (4+\frac{2Q}{Q_3})V$. Q.E.D.

A.6 Proof of Proposition 2-8

From the proof of Proposition 2-7, we know that $\pi_m^*(c=0) < \Pi_a^*$ if $V_3 > (4+\frac{2Q}{Q_3})V$. Note that under the assumption $0 < c < V$, we have $V_3 > 2V + 2c$ since $V_3 > (4+\frac{2Q}{Q_3})V$. This implies that the functional form of the marketplace is π_m^*, according to Lemma 2-3.

By equating π_m^* with Π_a^*, one gets two roots of the integration cost c, where the marketplace generates the same profit as the strategic alliance, described as follows

$$\frac{1}{2}V_3 - V \pm \frac{\sqrt{4Q_3^2V^2 + 2VV_3QQ_3}}{2Q_3} \tag{A.22}$$

Since $0 < c < V$ and $\frac{1}{2}V_3 - V > V$, we have the smaller root as the threshold value $\bar{c}$. From lemma 2-3, we know that π_m^* is increasing in the integration cost. Therefore, the strategic alliance is superior to the marketplace when $c < \bar{c}$ while the marketplace is superior to the strategic alliance when $c > \bar{c}$.□

A.7 Proof of Proposition 2-9

According to lemma 2-5, the optimal profit of the Web services marketplace takes the form of π_m^* when $V_3 > 4V$. From lemma 2-4, we note that π_m^* is increasing in integration cost. Therefore, in the interval $0 \le c \le V$, the optimal profit of the marketplace reaches maximum at $c = V$. The difference of the optimal profit of the marketplace and the strategic alliance is

$$\phi(V_3) \equiv \Pi_m^*(c = V) - \Pi_a^* = \frac{Q(2VV_3Q + 8VV_3Q_3 - 12V^2Q_3 - Q_3V_3^2)}{4(V_3Q + 2Q_3V)} \tag{A.23}$$

If $\phi(V_3) < 0$, we conclude that the profit of the strategic alliance is greater than that of the marketplace in the interval $0 \le c \le V$. The condition $\phi(V_3) < 0$ is equivalent to

$$Q_3V_3^2 - (2VQ + 8VQ_3)V_3 + 12V^2Q_3 > 0, \tag{A.24}$$

which is satisfied under the following to conditions

$$V_3 > \underline{V} \text{ or } V_3 < \bar{V}, \tag{A.25}$$

where $\underline{V} = (4 + \frac{Q + \sqrt{Q^2 + 8QQ_3 + 4Q_3^2}}{Q_3})V$, $\bar{V} = (4 + \frac{Q - \sqrt{Q^2 + 8QQ_3 + 4Q_3^2}}{Q_3})V$.

From proposition 2-8, we know that the strategic alliance dominates the marketplace if $V_3 > (4 + \frac{2Q}{Q_3})V$. Obviously, the second condition is not feasible since $\bar{V} < (4 + \frac{2Q}{Q_3})V$. Therefore, the strategic alliance dominates the marketplace under the first condition, i.e., $V_3 > \underline{V}$. Q.E.D.

APPENDIX B
PROOFS OF CHAPTER 3

B.1 Proof of Proposition 3-1

First, we derive the WSI's optimal price and profit at given location x. Note that the WSI's demand is conditional on the price of the integrated service P_3, therefore, we need to calculate the WSI's optimal price and profit under different classifications of the demand function.

Case 1: If $P_3 \geq P_1 + P_2 + c + t$, we have $y_1 = y_2 = 0$. This makes zero profit for the WSI since the price is too high. We will disregard this situation in the future analysis.

Case 2: If $P_1 + P_2 + c + t(1-x) \leq P_3 \leq P_1 + P_2 + c + t$, we have $0 \leq y_1^m, y_2^m \leq x$. The total demand of the WSI is $D = y_1^m + y_2^m$. The decision problem of the WSI is to optimally set the price P_3 to maximize profit, described in (B.1).

$$\begin{aligned} &\max_{P_3} \ \pi = 2P_3 \cdot \frac{(P_1 + P_2 + c + t - P_3)}{t} \\ &\text{s.t.} \quad P_1 + P_2 + c + t(1-x) \leq P_3 \leq P_1 + P_2 + c + t \end{aligned} \tag{B.1}$$

By solving the profit maximization problem in (A1), one gets the optimal price and profit as follows.

$$P_3^* = P_1 + P_2 + c + t(1-x), \ \pi^* = 2x[P_1 + P_2 + c + t(1-x)] \tag{B.2}$$

Case 3: If $P_1 + P_2 + c + tx \leq P_3 \leq P_1 + P_2 + c + t(1-x)$, we must have $y_1^m \geq x$ and $y_2^m \leq 1-x$, so the total demand of the WSI is $D = x + y_2^m$. Similar to the case 1-2, we

solve the profit maximization problem for the WSI. The optimal price and profit in this case are summarized as below.

a. If $t \geq 2(P_1 + P_2 + c)$ and $\frac{P_1 + P_2 + c + t}{3t} \leq x \leq \frac{1}{2}$, the optimal price and profit are the same as in (B.2).

b. If $t \geq 2(P_1 + P_2 + c)$ and $0 \leq x \leq \frac{P_1 + P_2 + c + t}{3t}$ or if $0 \leq t \leq 2(P_1 + P_2 + c)$ and $0 \leq x \leq \frac{t - (P_1 + P_2 + c)}{t}$, the optimal price and profits are

$$P_3^* = \frac{P_1 + P_2 + c + t(1+x)}{2}, \ \pi^* = \frac{[P_1 + P_2 + c + t(1+x)]^2}{4t} \tag{B.3}$$

c. If $0 \leq t \leq 2(P_1 + P_2 + c)$ and $\frac{t - (P_1 + P_2 + c)}{t} \leq x \leq \frac{1}{2}$, the price and profits are

$$P_3^* = P_1 + P_2 + c + tx, \ \pi^* = P_1 + P_2 + c + tx \tag{B.4}$$

Case 4: If $P_3 \leq P_1 + P_2 + c + tx$, we have $y_1^m \geq x$ and $y_2^m \geq 1 - x$. This suggests that the WSI captures the whole market demand. In addition, if the WSI attracts all demand in market, it doesn't gain more profit if it lowers the price. Therefore, the bounding solution gives the optimal price and profit in this case, which is the same as in Eq. (B.4).

By comparing the maximal profits in Cases B-2 to B-4, we can determine the optimal profit π^* for the WSI given any location x. Next, given the WSI's optimal profit at any location x, the optimal location of the WSI is selected as the one that yields maximum profit.

Since the profit in case 1-3 is conditional on the delay cost t, we determine the optimal location and profit for the WSI under different setting of t. First, we look at the scenario when $t \geq 2(P_1 + P_2 + c)$. If $0 \leq x \leq \frac{P_1 + P_2 + c + t}{3t}$, we need to compare the profits

specified in Equations (B.2), (B.3), and (B.4) to derive the optimal price and profit. It can be shown that the optimal profit is described in Eq. (B.3). Note that the profit in Eq. (B.3) is increasing in x. Therefore, the intermediary will set its location at the upper-bound. In summary, the optimal location, price and profit for the range $0 \le x \le \frac{P_1 + P_2 + c + t}{3t}$ are

$$\tilde{x} = \frac{P_1 + P_2 + c + t}{3t},\ \tilde{P}_3 = \frac{2(P_1 + P_2 + c + t)}{3},\ \tilde{\pi} = \frac{4(P_1 + P_2 + c + t)^2}{9t} \tag{B.5}$$

In a similar manner, we compare the profits in Equations (B.2) and (B.4) for the scenario when $\frac{P_1 + P_2 + c + t}{3t} \le x \le \frac{1}{2}$. Our analysis shows that the maximum profit is found in (B.2). Consequently, the optimal location, price and profit for the range $\frac{P_1 + P_2 + c + t}{3t} \le x \le \frac{1}{2}$ are

$$\hat{x} = \frac{1}{2},\ \hat{P}_3 = P_1 + P_2 + c + 0.5t\ ,\ \hat{\pi} = P_1 + P_2 + c + 0.5t \tag{B.6}$$

By comparing the profits in Equations (B.5) and (B.6), we conclude that $x^* = \frac{1}{2}$ is the optimal location for the WSI. This is because when $t \ge 2(P_1 + P_2 + c)$

$$\hat{\pi} - \tilde{\pi} = \frac{0.5t^2 + t(P_1 + P_2 + c) - 4(P_1 + P_2 + c)^2}{9t} \ge 0 \tag{B.7}$$

The corresponding optimal price and profit are

$$P_3^* = P_1 + P_2 + c + 0.5t\ ,\ \pi^* = P_1 + P_2 + c + 0.5t \tag{B.8}$$

Next, we consider the scenario when $0 \le t \le 2(P_1 + P_2 + c)$. Following a similar solution procedure, we find that the optimal location is $x^* = \frac{1}{2}$ and the corresponding price and profit are the same as in Eq. (B.8).

To summarize the above two scenarios, the optimal location of the WSI is $x^* = \frac{1}{2}$, independent of the delay cost. In addition, the optimal price and profit is shown in Eq. (B.8). By inspection, the optimal profits and prices are increasing in delay cost t and integration cost c. In addition, the comparative statics is straightforward since $\frac{\partial \pi^*}{\partial c} > \frac{\partial \pi^*}{\partial t}$. Q.E.D.

B.2 Proof of Lemma 3-2

Note that the total cost to buy from the Web service intermediary (WSI) or to create the integrated Web service by buying *S1* and *S2* from individual service providers (SP) is determined by the customer's and the WSI's locations, see Equations. (3.6) and (3.8). Therefore, we need to calculate the highest market penetration price $\overline{P}_3$ under four scenarios, i.e., the WSI is located in the AB, BC, CD or DA segment. In each scenario, we consider demand of customers in AB, BC, CD and DA.

Scenario 1. The WSI is between A and B ($0 \le x \le d$)

For customers between AB, the total cost to buy from the SP is $P_1 + P_2 + c + td$ while the highest cost to buy from the WSI is $P_3 + tx$ if $0 \le x \le \frac{d}{2}$, or $P_3 + t(d - x)$ if $\frac{d}{2} < x \le d$. Thus, the WSI attracts all customers between AB if

$P_3 \le \min\{P_1 + P_2 + c + tx, P_1 + P_2 + c + t(d - x)\}$. Similarly, all customers between CD will buy from the WSI if $P_3 \le P_1 + P_2 + c + t(\frac{1}{2} - d)$.

For customers between BC, the cost to buy from SP and WSI are greater than the cost incurred by the customer at location B, but the increased cost is greater if buying from SP. This implies that if customer at point B will buy from WSI, all customers between BC will buy from the WSI too. Likewise, all customers between DA will buy from the WSI if the customer at location A prefers the WSI.

Scenario 2. The WSI is between B and C ($d < x \le \frac{1}{2}$)

Due to similar argument as in scenario 1, the WSI captures the entire market demand in section AB if $P_3 \le P_1 + P_2 + c + t(d - x)$ while all customers between CD prefer the WSI if $P_3 \le P_1 + P_2 + c + t(\frac{1}{2} - 2d + x)$. In addition, all customers between BC will buy from WSI if the customer at location B buys from WSI and all customers between DA will buy from the WSI as long as customer at A prefers to buy from the WSI. Adding the fact that $d < x \le \frac{1}{2}$ and $d - x < 0$, the highest price that could still capture the whole market is $P_1 + P_2 + c + t(d - x)$.

Scenario 3. The WSI is between C and D ($\frac{1}{2} < x \le \frac{1}{2} + d$)

Consider the marginal customer who is located between AB and diagonal to the WSI. The cost to buy from SP is $P_1 + P_2 + c + td$ while the cost to buy from WSI is $P_3 + t/2$. Therefore, the customer will buy from WSI if $P_3 \le P_1 + P_2 + c + t(d - 1/2)$. For all other customers, they have a higher or equal cost to buy from SP while a lower cost to

buy from WSI. Thus, they will all buy from WSI if the marginal customer buys from WSI.

Scenario 4. The WSI is between D and A ($\frac{1}{2}+d \le x < 1$)

Similar to the argument in previous scenarios, all customers will buy from WSI if the customer at point B buys from the WSI. The highest price the WSI can charge is $P_1 + P_2 + c + t(x-1)$. Q.E.D.

B.3 Proof of Lemma 3-4

We prove this lemma by induction. Let ΔN denote the reduced demand when the WSI raises its price above the market-covering price. First consider raising price to $\bar{P}_3 + \frac{t}{N}(k=1)$. Since $\bar{P}_3$ is the highest market penetration price, there is one marginal customer who is indifferent between the WSI and the service providers. This marginal consumer will switch to the service providers if the WSI raises the price, i.e., $\Delta N = 1$. At the same time, the customer next to the marginal customer but closer to the WSI becomes indifferent between the service providers and the WSI. Suppose we have $\Delta N \ge k-1$ when $\Delta P_3 = (k-1)\frac{t}{N}$ and there is one marginal customer (denoted by θ_0). If we further raise the price by $\frac{t}{N}$, the marginal customer at θ_0 will switch to the service providers. At the same time, the customer next to θ_0 and closer to or further from the WSI becomes the next marginal customer. The WSI continues to loose customers in this way until all customers in market switch to the service providers. In summary, we have $\Delta N \ge \min\{k, N\}$ when $\Delta P_3 = \frac{kt}{N}$. If $\frac{kt}{N} < \Delta P_3 < \frac{(k+1)t}{N}$, it's similar to the case of

$\Delta P_3 = \frac{kt}{N}$ except that one more customer switches to the WSI instead of becoming the kth marginal customer. Q.E.D.

B.4 Proof of Proposition 3-5

We first prove that the market-covering price is optimal for the WSI if $t \le 2(P_1 + P_2 + c)$. When the price of the integrated service is $\bar{P}_3$, the WSI obtains total profit $\pi = \bar{P}_3 N$. If the WSI sets a price below $\bar{P}_3$, it will lose profit since reducing price won't increase the WSI's demand. On the other hand, if the WSI raises its price by ΔP_3, the WSI's profit becomes

$$\tilde{\pi} = (\bar{P}_3 + \Delta P_3)(N - \Delta N) = \bar{P}_3 N + \Delta P_3 (N - \Delta N) - \Delta N \bar{P}_3 \tag{B.9}$$

Obviously, if ΔP_3 is very large, all customers will switch to the service providers ($\Delta N = N$) and the WSI has zero profit. We now restrict our attention when $\Delta N < N$. Lemma 3-3 suggests that when $\frac{(k-1)t}{N} < \Delta P_3 < \frac{kt}{N}$, $\Delta N \ge k$ thus $\Delta N \bar{P}_3 \ge k\bar{P}_3$. Further, we have $\Delta P_3 (N - \Delta N) \le \Delta P_3 N = kt$. According to the functional form of $\bar{P}_3$ in Lemma 1, we have $\bar{P}_3 > t$ if $t \le 2(P_1 + P_2 + c)$. Therefore, the WSI's profit decreases when it charges a price higher than $\bar{P}_3$ regardless of its location x. Moreover, Lemma 3-2 suggests that if the WSI charges the highest market-covering price $\bar{P}_3$, it gains maximum profit if it is located between the service providers. In summary, the WSI's total profit is maximized if it is located between the service providers and sets the price at $\bar{P}_3$. Q.E.D.

B.5 Proof of Proposition 3-6

The highest penetration price charged by the WSI when it is located between the Web service vendors can be rewritten as follows.

$$\bar{P}_3 = \begin{cases} (1)\ P_1 + P_2 + c + tx, & \text{if } 0 \le x \le \frac{d}{2} \text{ and } x \le \frac{1}{2} - d \\ (2)\ P_1 + P_2 + c + t(d - x), & \text{if } \frac{d}{2} \le x \le d \text{ and } x \ge 2d - \frac{1}{2} \\ (3)\ P_1 + P_2 + c + t(\frac{1}{2} - d), & \text{if } d \ge \frac{1}{3} \text{ and } \frac{1}{2} - d \le x \le 2d - \frac{1}{2} \end{cases} \tag{B.10}$$

Look at the highest market-covering price described in (1) to (3) of Eq. (B.10). Note that if $d \ge \frac{1}{3}$, there could be multiple optimal locations ($\frac{1}{2} - d \le x \le 2d - \frac{1}{2}$) for the WSI since the price in (3) is lower than in (1) and (2). In addition, note that price in (1) is increasing in x while the price in (2) is decreasing in x. Therefore, the optimal location for the WSI is $\frac{d}{2}$ for (1) or (2). In cases where there are multiple optimal locations, $\frac{d}{2}$ is in the range between $\frac{1}{2} - d$ and $2d - \frac{1}{2}$. In summary, $\frac{d}{2}$ is the optimal location, regardless of the functional form of the optimal price $\bar{P}_3$. Q.E.D.

APPENDIX C
PROOFS OF CHAPTER 4

C.1 Proof of Lemma 4-1

We consider the intermediary's revenue from subscription and listing separately. First observe from the definition of $y_j^{'}s$ in Equations (4.1) to (4.3) that the intermediary's revenue from collecting subscription fee is non-decreasing in the proportion of listed service vendors ($x_i^{'}s$). Next we analyze the intermediary's revenue from charging listing fee to the service vendors. According the definition of x in Eq. (4.5), we can rewrite the intermediary's revenue from listing (Π_L) is defined as follows.

$$\Pi_L = \begin{cases} (1)\ P_1(y_1Q_1 + y_3Q_3) + P_2(y_2Q_2 + y_3Q_3) & \text{if } L \geq \max\{L_1, L_2\} \\ (2)\ P_1(y_1Q_1 + y_3Q_3) + LN_2 & \text{if } \mathrm{L}_1 < L_2 \text{ and } L_1 < L < L_2 \\ (3)\ P_2(y_2Q_2 + y_3Q_3) + LN_1 & \text{if } \mathrm{L}_2 < L_1 \text{ and } L_2 < L < L_1 \\ (4)\ LN_1 + LN_2 & \text{if } \mathrm{L} \leq \min\{\mathrm{L}_1, \mathrm{L}_2\} \end{cases} \quad \text{(C.1)}$$

where $L_1 = \dfrac{P_1(y_1Q_1 + y_3Q_3)}{N_1}$ and $L_2 = \dfrac{P_2(y_2Q_2 + y_3Q_3)}{N_2}$ are defined as the highest listing fee the intermediary can charge in order to induce all service vendors to list on it. The revenue from listing is described in (1) to (4) of Eq. (C.1), which is a kinked one, depending on the value of the listing fee. Note that case (1) corresponds to $0 \leq x_1, x_2 \leq 1$; case (2) corresponds to $x_2 = 1$ and $0 < x_1 < 1$; case (3) corresponds to $x_1 = 1$ and $0 < x_2 < 1$; case (4) corresponds to $x_1 = x_2 = 1$.

If the intermediary charge a listing fee of L_1, all service vendors of S1 will list on the intermediary ($x_1 = 1$) and correspondingly, the revenue from charging listing fee to

service vendor of S1 is $x_1 LN_1 = P_1(y_1 Q_1 + y_3 Q_3)$. If the listing fee is higher than L_1 ($L' > L_1$), then there will be less service vendors listing on the intermediary, i.e., $x_1' < 1$. This in turn leads to a lower subscription rate, i.e., $y_1' < y_1$ and $y_3' < y_3$. It follows that $P_1(y_1' Q_1 + y_3' Q_3) < P_1(y_1 Q_1 + y_3 Q_3)$. This means that the intermediary obtains less profit from service vendors of S1. At the same time, the profit from the subscription side is decreasing due to lesser proportion of subscribers. The similar argument applies to the case when the listing fee is higher than L_2 ($L'' > L_2$). Finally, the intermediary's profit will not improve if it charges a listing fee lower than $\min\{L_1, L_2\}$ since the proportion of listing service vendors and subscribers remains unchanged and thus a lower listing will cause lower revenue from collecting listing fee. In summary, the intermediary should set the listing fee to allow all service vendors list on it. □

C.2 Proof of Lemma 4-3

Lemma 4-3 is drawn from solving the profit maximization problem defined in Eq. (4.8), which is a constrained optimization problem with quadratic objective function. The approach presented here is equivalent to applying KKT conditions. Since the optimal solution is either an interior solution or boundary solution, we first solve the unconstrained version problem. Optimal subscription fee and profit for the unconstrained optimization problem are described as follows.

$$F_{11} = \frac{(\bar{v} + \gamma - P_1)Q_1 + (\bar{v} + \gamma - P_2)Q_2 + \bar{v}Q_3}{2(Q_1 + Q_2)} \tag{C.2}$$

$$\begin{aligned} \Pi_{11}(F_{11}) = & \frac{\left[Q_1(\bar{v} + \gamma + P_1) + Q_2(\bar{v} + \gamma + P_2)\right]^2 + \bar{v}^2 Q_3^2}{4\bar{v}(Q_1 + Q_2)} \\ & + \frac{2Q_1Q_3(\bar{v}^2 + \gamma\bar{v} + \bar{v}P_1 + 2\bar{v}P_2) + 2Q_2Q_3(\bar{v}^2 + \gamma\bar{v} + \bar{v}P_2 + 2\bar{v}P_1)}{4\bar{v}(Q_1 + Q_2)} \end{aligned} \tag{C.3}$$

Next we analyze whether F_{11} is a feasible solution as follows.

$$F_{11} - \gamma = \frac{(\bar{v} - \gamma - P_1)Q_1 + (\bar{v} - \gamma - P_2)Q_2 + \bar{v}Q_3}{2(Q_1 + Q_2)} \tag{C.4}$$

$$F_{11} - 2\gamma = \frac{(\bar{v} - 3\gamma - P_1)Q_1 + (\bar{v} - 3\gamma - P_2)Q_2 + \bar{v}Q_3}{2(Q_1 + Q_2)} \tag{C.5}$$

Finally we calculate and compare the profits at lower- and upper bound as follows.

$$\Pi_{11}(\gamma) = (\gamma + P_1)Q_1 + (\gamma + P_2)Q_2 + (\gamma + P_1 + P_2)Q_3 \tag{C.6}$$

$$\Pi_{11}(2\gamma) = \frac{(\bar{v} - \gamma)(2\gamma + P_1)Q_1 + (\bar{v} - \gamma)(2\gamma + P_2)Q_2 + \bar{v}(2\gamma + P_1 + P_2)Q_3}{\bar{v}} \tag{C.7}$$

$$\Pi_{11}(2\gamma) - \Pi_{11}(\gamma) = \frac{\gamma(\bar{v} - 2\gamma - P_1)Q_1 + \gamma(\bar{v} - 2\gamma - P_2)Q_2 + \gamma\bar{v}Q_3}{\bar{v}} \tag{C.8}$$

Now we conclude:

a. If $(\bar{v} - \gamma - P_1)Q_1 + (\bar{v} - \gamma - P_2)Q_2 + \bar{v}Q_3 \le 0$, from Eq. (C.4) we know that $F_{11} \le \gamma$ and further $\Pi_{11}(2\gamma) < \Pi_{11}(\gamma)$ according to Eq. (C.8). Therefore, the optimal subscription fee is γ, as specified in condition (a) in Lemma 4-3;

b. According to Eqs. (C.4) and. (C.5), if $(\bar{v} - \gamma - P_1)Q_1 + (\bar{v} - \gamma - P_2)Q_2 + \bar{v}Q_3 > 0$ and $(\bar{v} - 3\gamma - P_1)Q_1 + (\bar{v} - 3\gamma - P_2)Q_2 + \bar{v}Q_3 < 0$, we must have $\gamma < F_{11} < 2\gamma$. Therefore, the optimal subscription fee is F_{11}, which corresponds to condition (b) in Lemma 4-3;

c. If $(\bar{v} - 3\gamma - P_1)Q_1 + (\bar{v} - 3\gamma - P_2)Q_2 + \bar{v}Q_3 \ge 0$, then according to Eq. (C.5) we know that $F \ge 2\gamma$ and $\Pi_{11}(2\gamma) > \Pi_{11}(\gamma)$. Therefore, the optimal subscription fee is 2γ, as presented under the third condition of Lemma 4-3. Q.E.D.

C.3 Proof of Proposition 4-6

Lemma 4-3, 4-4 and 4-5 specify the optimal strategy if the intermediary desires to achieve different combinations of $y_j^{'}s$ ($j = 1, 2, 3$), which is summarized in Table C-1. Since the optimal strategy is dependent on the network intensity (γ), we solve for the optimal subscription fee under each of the four situations in Table C-1.

Table C-1. Optimal Subscription Fee when $\gamma < \overline{v}$

F_{1i}^*	$0 \le \gamma \le \gamma_{11}$	$\gamma_{11} < \gamma < \gamma_{12}$	$\gamma_{12} \le \gamma < \gamma_{13}$	$\gamma_{13} \le \gamma < \overline{v}$
F_{11}^*	2γ	2γ	F_{11}	γ
F_{12}^*	F_{12}	2γ	2γ	2γ
F_{13}^*	$\overline{v}+\gamma$	$\overline{v}+\gamma$	$\overline{v}+\gamma$	$\overline{v}+\gamma$

The optimal subscription fee can be found as the one of F_{11}^*, F_{12}^*, and F_{13}^* that maximizes the profit of the WSI. We observe:

a. If $0 \le \gamma \le \gamma_{11}$, the optimal subscription fee is F_{12} as specified in (a) of Proposition 4-6 since

$$\Pi_{12}(F_{12}) - \Pi_{11}(2\gamma) = \frac{\left[Q_1(\overline{v}-3\gamma-P_1)+Q_2(\overline{v}-3\gamma-P_2)+Q_3(\overline{v}-2\gamma-P_1-P_2)\right]^2}{4\overline{v}(Q_1+Q_2+Q_3)} > 0 \quad \text{(C.9)}$$

$$\Pi_{12}(F_{12}) - \Pi_{13}(\overline{v}+\gamma) = \frac{[Q_1(\overline{v}+\gamma+P_1)+Q_2(\overline{v}+\gamma+P_2)+Q_3(\overline{v}+P_1+P_2)]^2}{4\overline{v}(Q_1+Q_2+Q_3)} > 0 \quad \text{(C.10)}$$

b. If $\gamma_{11} \le \gamma < \gamma_{12}$, the optimal subscription fee is 2γ as specified in (b) of Proposition 4-6 since

$$\Pi_{11}(2\gamma) - \Pi_{13}(\overline{v}+\gamma) = \frac{(\overline{v}-\gamma)\left[Q_1(2\gamma+P_1)+Q_2(2\gamma+P_2)\right]+Q_3(\overline{v}-\gamma)(\gamma+P_1+P_2)}{\overline{v}} > 0 \quad \text{(C.11)}$$

c. If $\gamma_{12} \le \gamma < \gamma_{13}$, the optimal subscription fee is F_{11} as specified in (c) of Proposition 4-6 since

$$\Pi_{11}(F_{11}) - \Pi_{12}(2\gamma) = \frac{[Q_1(\overline{v}-3\gamma-P_1)+Q_2(v-3\gamma-P_2)+\overline{v}Q_3]^2}{4\overline{v}(Q_1+Q_2)} > 0 \quad \text{(C.12)}$$

d. If $\gamma_{13} \le \gamma < \overline{v}$, we conclude that the optimal subscription fee is γ as specified in (d) of Proposition 4-6 by observing the fact that $\Pi_{11}(\gamma) > \Pi_{11}(2\gamma)$ in the proof of (1) in Lemma 4-3 and $\Pi_{11}(2\gamma) > \Pi_{13}(\overline{v}+\gamma)$ from Eq. (C.11). Q.E.D.

C.4 Proof of Proposition 4-12

Proposition 4-12 can be proved by using the similar approach when we prove Proposition 4-6. First we summarize the optimal strategy of the intermediary under

different settings of the network intensity (γ) and propositions of subscribers ($y_j^{'}s$, $j = 1, 2, 3$) obtained in discussing Cases II-1 to II-3, see Table C-2.

Table C-2. Optimal Subscription Fee when $\gamma \geq \overline{v}$

F_{2i}^*	$\overline{v} \leq \gamma \leq \gamma_{21}$	$\gamma_{21} < \gamma < \gamma_{22}$	$\gamma > \gamma_{22}$
F_{21}^*	$\overline{v} + \gamma$	F_{21}	γ
F_{22}^*	2γ	2γ	2γ
F_{23}^*	2γ	2γ	2γ

The optimal subscription fee can be found as the one of F_{11}^*, F_{12}^*, and F_{13}^* that maximizes the profit of the WSI. We observe:

a. If $\overline{v} \leq \gamma \leq \gamma_{21}$, the optimal subscription fee is 2γ as specified in (a) of Proposition 4-12 since $\Pi_{21}(\overline{v} + \gamma) - \Pi_{23}(2\gamma) = Q_3(\overline{v} - \gamma) < 0$;

b. If $\gamma_{21} < \gamma < \gamma_{22}$, the optimal subscription fee is dependent on the sign of function Φ because

$$\Pi_{21}(F_{21}) - \Pi_{23}(2\gamma) = \frac{\left[Q_1(\overline{v} + \gamma + P_1) + Q_2(\overline{v} + \gamma + P_2) - \overline{v}Q_3\right]^2 + 4\overline{v}(\overline{v} - \gamma)Q_3(Q_1 + Q_2)}{4\overline{v}(Q_1 + Q_2)}$$

c. If $\gamma > \gamma_{22}$, the optimal subscription fee is dependent on the sign of function Ψ because $\Pi_{21}(\gamma) - \Pi_{23}(2\gamma) \equiv \Psi = (\gamma + P_1)Q_1 + (\gamma + P_2)Q_2 - \gamma Q_3$. Q.E.D.

C.5 Proof of Corollary 4-14

It can be easily checked after simple algebra that under the conditions specified in Corollary 4-14, we must have $\gamma_{21} > \overline{v}$ and $\overline{v}Q_3 > (2\overline{v} + P_1)Q_1 + (2\overline{v} + P_2)Q_3$. It follows from (a) in Proposition 4-12 that the optimal subscription fee is 2γ when $\overline{v} \leq \gamma \leq \gamma_{21}$. As for the optimal subscription fee in the range of $\gamma_{21} < \gamma < \gamma_{22}$, first note that Φ is negative if $\gamma = \gamma_{21}$, since

$$\Phi(\gamma_{21}) = 4\overline{v}Q_3[(2\overline{v} + P_1)Q_1 + (2\overline{v} + P_2)Q_2 - \overline{v}Q_3] < 0 \qquad \text{(C.13)}$$

Next, we calculate the first derivative of Φ with respect to γ and evaluate the sign for $\gamma = \gamma_{22}$, described in Eqs. (C.14) and (C.15).

$$\Phi_\gamma \equiv \frac{\partial \Phi}{\partial \gamma} = (Q_1 + Q_2)[(\overline{v} + \gamma + P_1)Q_1 + (\overline{v} + \gamma + P_2)Q_2 - 3\overline{v}Q_3] \tag{C.14}$$

$$\Phi_\gamma(\gamma_{22}) = 2\overline{v}(Q_1 + Q_2 - Q_3) < 0 \tag{C.15}$$

Since Φ_γ is increasing in γ and it is evaluated negative at γ_{22}, it follows that Φ_γ is negative for the interval $\gamma_{21} < \gamma < \gamma_{22}$. Adding the fact that Φ is negative at γ_{21}, we conclude that $\Phi < 0$ is negative in the interval $\gamma_{21} < \gamma < \gamma_{22}$. According to (b) in Proposition 4-12, we know that the optimal subscription fee is 2γ under the condition that $\gamma_{21} < \gamma < \gamma_{22}$. In addition, the optimal subscription fee will never switch from 2γ to F_{21} with the increase of γ when $Q_1 + Q_2 < Q_3$.

Finally, we show that if $\Phi(\gamma_{22}) < 0$, the function Ψ is negative in the interval $\gamma \geq \gamma_{22}$ due to two facts: (1) functions Φ and Ψ have same sign when $\gamma = \gamma_{22}$, see Eqs. (C.16) and (C.17); (2) Ψ is decreasing in γ when $2(Q_1 + Q_2) < Q_3$.

$$\Phi(\gamma_{22}) = 4\overline{v}(\overline{v}Q_1^2 + 2\overline{v}Q_1Q_2 + P_1Q_1Q_3 + \overline{v}Q_2^2 + P_2Q_2Q_3 - \overline{v}Q_3^2) \tag{C.16}$$

$$\Psi(\gamma_{22}) = \frac{\overline{v}Q_1^2 + 2\overline{v}Q_1Q_2 + P_1Q_1Q_3 + \overline{v}Q_2^2 + P_2Q_2Q_3 - \overline{v}Q_3^2}{Q_1 + Q_2} \tag{C.17}$$

In summary, under the conditions specified in Corollary 4-14, the optimal subscription charged by the intermediary is 2γ if $\gamma \geq \overline{v}$. Q.E.D.

C.6 Proof of Corollary 4-15

First note from the definition of γ_{21}, that under the conditions specified in Corollary 4-15, we have $\gamma_{21} < \overline{v}$. This implies that first condition specified in

Proposition 4-12 will never be satisfied. Therefore, we only need to consider the optimal subscription fee under conditions (b) and (c), i.e, the optimal subscription fee is either F_{21} or 2γ when $\gamma_{21} < \gamma < \gamma_{22}$ while the optimal subscription fee is either γ or 2γ when $\gamma > \gamma_{22}$. Since F_{21} is found between γ and $\overline{v} + \gamma < 2\gamma$ and $F_{21} = \gamma$ when $\gamma = \gamma_{21}$, we can prove that the optimal subscription fee is increasing in γ if there are only three possible cases for the optimal subscription fee: (a) 2γ for the entire region $\gamma > \overline{v}$; (b) F_{21} for $\gamma_{21} < \gamma < \gamma_{22}$; γ then 2γ for $\gamma > \gamma_{22}$; (c) F_{21} and then 2γ for $\gamma_{21} < \gamma < \gamma_{22}$; 2γ for $\gamma > \gamma_{22}$.

We note that:

a. From the proof of Corollary 4-14, we know that when $2(Q_1 + Q_2) < Q_3$, the optimal subscription will never switch from 2γ to F_{21} in the interval $\gamma_{21} < \gamma < \gamma_{22}$. Furthermore, we have shown in the previous Corollary that if the optimal subscription fee is 2γ when $\gamma_{21} < \gamma < \gamma_{22}$, i.e., $\Phi(\gamma_{22}) < 0$ we must have $\Psi < 0$ for the region $\gamma > \gamma_{22}$;

b. If the optimal subscription fee is F_{21} in the interval $\gamma_{21} < \gamma < \gamma_{22}$, we must have $\Phi(\gamma_{22}) > 0$. Since functions Φ and Ψ have same sign, we must have $\Psi(\gamma_{22}) > 0$, which implies that the optimal subscription take the form of γ at $\gamma = \gamma_{22}$;

c. It is already shown in the previous Corollary that if $\Phi(\gamma_{22}) < 0$, the optimal subscription fee takes the form of 2γ in the interval $\gamma > \gamma_{22}$. Q.E.D.

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