Abstract—As a new network computing technology, Web services help reduce application integration cost and have become the foundation for the next generation of service-oriented architecture. While there is ample research on the technological issues of Web services, little has been done thus far on the business implications of this groundbreaking technology. In this paper, we attempt to close this research gap by comparing three application service strategies for providing Web services of complementary functionalities, i.e., independent service vendors (ISVs), joint venture (JV), and strategic alliance (SA). Although Web service integration is analogous to product bundling, the unique features of software integration, such as low integration cost and the possibility of creating an integrated Web service with new functionalities, have led to interesting analytical results not seen in the product bundling literature. We find that the optimal application service strategy is determined by several factors, including the integration cost, the valuations, and market potentials of the individual and integrated Web services. Our study shows that the application service strategy of ISVs is always dominated by the SA, implying that Web service providers benefit from the increased interoperability of Web services. In cases where the integrated Web service is highly valued and the integration cost is small, JV becomes the optimal application service strategy. In other cases, the Web service providers are better off to form SAs.

Index Terms—Application service strategy, complementarity, integration cost, software integration, web services.

I. NOMENCLATURE

$c$ Integration cost.

$Q_1$ Number of customers interested in Web service $S_1$.

$Q_2$ Number of customers interested in Web service $S_2$.

$Q_3$ Number of customers interested in the integrated Web service.

$V_1$ (or $V_2$) Maximum reservation price of $S_1$ ($S_2$).

$V_3$ Maximum reservation price of $S_3$.

$P_{a_1}$ (or $P_{a_2}$) Price of Web service $S_1$ ($S_2$).

$q_{a_1}$ (or $q_{a_2}$) Demand of Web service $S_1$ ($S_2$).

$p_v$ Price of the integrated Web service.

$P_{a_1}$, $P_{a_2}$, $P_{a_3}$ Prices of Web services $S_1$, $S_2$, and $S_3$.

$\Pi^*_v$ Optimal industry profit in the ISV strategy.

$\Pi^*_v$ Optimal industry profit in the JV strategy.

$\Pi^*_v$ Optimal industry profit in the SA strategy.

II. INTRODUCTION

The core challenge for information technology has been and will continue to be the integration of interenterprise and intraenterprise applications. Recently, the Web service technology has captured the attention of practitioners and academia as a promising solution to cost-efficient and manageable application integration. According to the Stencil Group, Web services are “loosely coupled, reusable software components that semantically encapsulate discrete functionality and are distributed and programatically accessible over standard Internet protocols” (www.stencilgroup.com). Many software vendors are rushing to reengineer their products to support Web services [19]. The International Data Corporation (IDC) estimated that US$2.3 billion was spent worldwide on Web services software in 2004 and projected an increasing growth of expenditure to reach to US$14.9 billion by 2009 (http://www.idc.com).

A Web service is characterized by its flexibility to encapsulate discrete business functionalities and its interoperability to support universal application integration. These two characteristics make Web services the most promising technology for a service-oriented architecture, defined as the provision of software applications as services, sometimes called e-services, over the
Internet [26]. The service-oriented architecture offers organizations a number of advantages, including the ability to choose software components that best match the company’s business processes, to tailor software components to the individual needs of business units, and to incrementally pay for the overall system [10], [29].

With the growing popularity of Web services, the research landscape of many traditional issues in software engineering and management may experience a major shift. Many research areas are affected by the adoption of the Web service technology and the e-service business paradigm, such as software maintenance [4], software development risk [21], software development productivity and quality [20], and software development infrastructure [17]. Although many projects have been carried out to improve the technical aspects of Web services in the computing industry, there is little research thus far on the business issues of Web services. For example, does a software producer really benefit from the Web services technology? What’s the optimal strategy for a software producer to exploit the Web services technology? How can software vendors that provide complementary Web services collaborate with one another to maximize profit? We believe that researchers in both engineering management and information systems should strive to provide answers to these questions.

The flexibility and interoperability of Web services are ideal for enterprise-level and interbusiness application integration. Therefore, a natural start on Web services research is to examine the integration of Web services that implement complementary business functions. Although the integration of Web services affects both Web service providers and service providers that utilize integrated Web services, our study focuses on the software vendors that benefit from the Web service technology directly.1 Currently, there are two types of software vendors involved in Web service integration: 1) those providing integration services for Web services (e.g., Grandcentral.com); 2) those providing integrated Web service (e.g., Salesforce.com). While abundant research has been carried out to address the technical issues for the first type of vendors in the computer science field, little attention is paid to the second-type software vendors from the management perspective. Therefore, our goal is to bridge this research gap by analyzing the optimal application service strategies for Web service providers. In this paper, we compare three potential application service strategies for two software vendors selling complementary Web services: 1) the ISVs in which the software vendors sell individual Web services separately; 2) the JV in which the software vendors merge into a new company which offers the integrated Web service only; 3) the SA in which the software service vendors sell both the individual and the integrated Web services.

By analyzing the optimal service strategy for Web services, we address the following critical questions regarding the business impact of Web services on software producers. First, we investigate whether software vendors are better off in the Web service-based architecture. We find that the service strategy of ISV is always dominated by the SA strategy regardless of the integration cost, implying that software vendors can benefit from the interoperability of Web services by providing an integrated Web service. Second, we explore what factors determine the optimal service strategy for complementary Web services and examine how these factors affect the optimality of application service strategies. Our analyses show that the optimal service strategy is dependent on integration cost, and valuations and market potentials of (individual and integrated) Web services. If the consumers’ valuation of the integrated Web service is small, the service providers prefer the SA than the JV. On the other hand, if the valuation of the integrated Web service is high, the service providers will prefer the SA when the integration cost is high, while the JV is preferred when the integration cost is low. If the valuation of the integrated Web service is sufficiently high, the JV becomes the optimal service strategy.

The remainder of the paper is organized as follows. Section II explains two fundamental features of Web services: software as service and platform independence; their implications on intercompany and intracompany application integration. Section III introduces literature on product bundling strategies and optimal application service strategies, and discusses the relevance and differences between this paper and previous work. We present a general analytical model in Section IV, followed by insights from a simplified model in Section V. Section VI provides results from computational experiments based on the general model, along with managerial insights on optimal Web service strategies. Section VII concludes the paper with discussion about limitations and future extensions of the current work.

III. BACKGROUND: SOFTWARE AS SERVICE AND PLATFORM INDEPENDENCE

From a technical perspective, the Web service technologies consist of a collection of standard protocols that enable the creation, distribution, discovery and integration of software components over the Internet. Central to the Web service technologies are the concepts of “software as service” and “platform independence.”

As opposed to packaged monolithic applications that have to 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 Application Service Providers (ASP). Yet Web services are not merely the newer version of ASP. Traditional ASP usually provides complex application systems like Enterprise Resource Planning (ERP) software through proprietary connection. Web services decompose business processes into granular components and, thus, allow customers to select the services on an as-needed basis [28]. Further, the Web services are distributed over the Internet while traditional ASPs host their applications on a centrally located server over proprietary network.

The economic globalization and the continuously changing business environment call for an interoperable and flexible computing infrastructure. Web services cater to this need by building on universally agreed-upon (open) specifications. As a result,
Web services are platform-, language- and vendor-independent. Although a detailed description of the technical specifications is beyond the scope of this paper, one can easily understand the benefit from standardization of Web service technologies in today’s distributed computing environment: it allows for the interaction and integration of heterogeneous software components at a low cost.

The flexibility and interoperability of Web services have profound business implications. The primary advantage of Web service technologies is just-in-time service (software application) creation through the integration of loosely coupled software components (Web services). Therefore, Web services can be adopted to realize enterprise application integration and business-to-business application integration in a cost-efficient manner [9], [18]. By leveraging existing systems and outsourcing standard modules, a firm can decrease application development cost and duration dramatically. Firms are endowed with the flexibility to choose the best of breed software in market instead of being tied to a particular software vendor. Business-to-Business integration (B2Bi) or collaboration is made easier because the firms no longer have to set up a separate integration project with each business partner. As a result, business alliances can be created and decoupled on the fly.

B2B integration is carried out on two levels: process level and application level. Process level integration handles the business process coordination between two firms, such as defining rules (or sequence) of interaction and the responsibilities of each partner. Application level integration, on the other hand, is responsible for implementing business process integration and solving system heterogeneity, which can be potentially supported by Web services. Since the success of B2B integration depends on both levels of integration, the wider acceptance of Web services still relies on the development of technologies that facilitates process integration, for instance, developing industry-specific semantics for the composition of Web services. There have already been on-going projects that are dedicated to such ends, such as Electronic Business using eXtensible Markup Language (ebXML), Business Process Execution Language for Web Services (BPEL4WS). Currently, the business industry is still concerned with the immaturity of the Web services technology, notably its performance, security and reliability issues. With sufficient support and development from the IT industry, Web services and the service-oriented architecture is expected to become the mainstream computing infrastructure in the near future.

In summary, web services can be rendered over the Internet as building bricks for a service-oriented computing environment with relatively low integration costs. As indicated in [23], the three orders of effects of any technologies have been described as: 1) The availability of more efficient services based on the new technology; 2) the emergence of new products and services because of the new technology; 3) the restructuring of organizations and markets resulting from the adoption of the new technology. That is, new business models are possible when the cost of technology changes dramatically. This begs the question whether or not new business alliances and new service strategies can be developed profitably, which we strive to provide insights in this paper.

IV. LITERATURE REVIEW

A. Product Bundling

The three Web service strategies analyzed in this paper to some extent are analogous to different bundling strategies described in [1]. For example, the ISV strategy, in which two Web service providers sell individual Web services independently, is related to the pure component strategy where the firm sells individual components only. Likewise, the JV is related to the pure bundling strategy; and the SA is related to the mixed bundling strategy. Therefore, previous work on product bundling strategies may shed some light on the optimal application service strategy for Web services.

Conventional wisdom indicates that bundling “averages out” the heterogeneity of consumer preferences and, thus, reduces the unpredictability of consumer’s valuation for the bundled goods. Adams and Yellen [1] were probably among the first to study the profitability of different bundling strategies. They argued that besides cost saving, bundling can be used as an effective device for price discrimination. Using the law of large numbers, Bakos and Brynjolfsson [2], [3] showed that the bundling strategies for information goods are different from those of physical goods due mainly to the zero marginal production cost.

B. Optimal Application Service Strategy

Another stream of research relevant to our paper is the study of application service strategy in a multi-firm setting. Economides and Salop [7] studied the optimal market structure in light of the tradeoff between vertical integration and horizontal competition. They modeled a market with two complementary products, each of which provided by two firms. A number of service strategies with different degrees of competition and integration were analyzed. Their research focused on comparing the equilibrium price of the integrated product under different service strategies. The paper by Matuttes and Regibeau [24] studied the optimal strategy of product compatibility and bundling using a spatial model where consumers have heterogeneous fit cost of different product components. They set up a model of two firms each selling two complementary products. In a more recent paper by Farrell and Katz [8], which modeled a situation where the market is composed of a monopoly offering one component and several companies (possibly including the monopoly) offering another complementary component, they concentrated on the monopoly’s incentive to “squeeze” the independent producers by means of pricing, innovation or exclusive trading rules and consequently the implications on social welfare.

C. Unique Features of Web Services

Several unique features of Web services technology necessitate a different approach to the study of Web service application service strategy. First and foremost, an integrated Web service represents a new and different product. The consumers of the integrated Web services are different from those of the constituent Web services. Take for instance, a purchasing Web service and an inventory management Web service are integrated to form a new Web service. The new integrated Web service provides
additional functions such as automatic inventory update upon procurement and automatic purchasing order generation under condition of low inventory. In comparison, the composition of a CD album from multiple songs does not change the format and value of each song. Hence, we explicitly consider three different groups of consumers to model the demand for the two complimentary components and the resulting integrated Web service.

In contrast, the consumers facing the individual and the bundled goods are the same group in the bundling literature. As a result, the demand (or valuation) of bundled goods is correlated to that of the individual goods. Most literature on product bundling strategies makes the strict additivity assumption [15]. That is, the value of the bundled good is the sum of values of each component [1, 5, 22, 27, 30]. Interestingly, many previous studies on market structure focused on the demand for the composite product while ignoring the demand for the individual components [7, 8, 24].

Second, Web services are essentially programmable software components. Unlike physical goods that can be put together at ease, the integration of two software components is more complex and requires both human expertise and financial resources. For example, data or application interface has to be transformed to conform to Web service standards. In essence, the integration of Web services introduces an integration cost not considered in all previous research on product or service bundling strategies.

Finally, while [31] relaxed the strict additivity assumption and considered contingent valuation for bundling complementary and substitute components, their result cannot be applied to Web service integration directly for two reasons. First, their model includes marginal production cost for physical goods. However, the marginal production cost of Web services (i.e., software components) once developed is negligible. Second, [31] assumed that the bundled product is divisible. That is, consumers who buy the bundled product can separate individual components from the bundle in the case of a CD of songs. The integrated Web service, however, is not divisible due to the intertwined coding structure of software. For similar reasons, the work by Dansby and Conrad [6] cannot fit into the Web service context either. As we will show in this paper, the SA, which corresponds to the mixed bundling strategy, is not always the optimal markets structure for Web services. In contrast, mixed bundling usually emerges as the optimal bundling strategy in traditional literature on product bundling [22, 27].

V. THE GENERAL MODEL

Consider two monopoly software vendors that provide two distinct but functionally complimentary Web services, denoted by $S_1$ and $S_2$. The two complementary Web services can be integrated into an integrated Web service, denoted by $S_3$. The Web service for inventory management and the web service for procurement management constitute an example of complementary Web services in supply chain management. Integrating the inventory management and procure management Web services can be used for automatic purchasing and inventory up-

date. Correspondingly, the potential buyers are classified into three groups – those interested in $S_1$, $S_2$, and $S_3$. Let the sizes of the three groups of potential buyers be $Q_1$, $Q_2$ and $Q_3$. The potential customers of $S_1$, $S_2$, and $S_3$ have reservation prices uniformly distributed between the interval $[0, V_1]$, $[0, V_2]$ and $[0, V_3]$, respectively. We use separate distributions to provide generality of the model, which does not require any specific relationship among individual and integrated Web services.

As similar to other software components, the integration of Web services might involve data format transformation (if different data structures or databases are used), definition of synchronization rules and workflow processes, including processing orders, locking and unlocking of data sources, and commit and rollback of transactions. In essence, the integration of two complementary Web services requires certain integration cost. In our model, we use $c$ to denote the integration cost incurred by each customer.

We consider three service strategies that can be adopted by the two Web service providers. In the first application service strategy, ISVs, the two firms sell $S_1$ and $S_2$ independently. Consumers who are interested in the integrated Web service have to buy $S_1$ and $S_2$ and then integrate into $S_3$ by themselves at an integration cost of $c$. In the second application service strategy, JV, the two firms merge into a new firm to sell only $S_3$, the integrated Web service. In the third application service strategy, SA, the two firms sell $S_1$, $S_2$, and $S_3$. Under JV and SA, consumers who are interested in $S_2$ do not have to integrate by themselves since the integrated Web service is readily available. In order to focus on studying the impact of application strategy on firm’s profitability, we assume integration cost is independent of application provisioning strategy. That is, consumers incur the same integration cost in SA or ISV strategies.

The objective of this research is to find the optimal application service strategy for the two profit-maximizing software vendors. Intuitively, the optimality of service strategies depends on various market characteristics, such as the values of the Web services, the sizes of potential markets and the integration cost. Of special interest is the impact of integration cost, which has not been considered in the literature on physical product bundling.

To reflect industry reality, two assumptions are made in our model. First, we assume that the integrated Web service is valued more than each of the individual Web service components. Second, we assume that the integration cost cannot exceed the values of each Web service components. That is, we assume

$$0 < c < V_i, i = 1, 2.$$  \quad (1)$$

To solve for the optimal application service strategy, we build an economic model to compare the vendors’ profits in each application service strategy in the following sections.

---

2The model assumes that the integration cost is fixed once a particular set of complementary web services is determined since all Web service providers use the same Web service standards. This cost, however, may change due to the advancement of technology over time and other reasons. Section V provides insights into the impact of this integration cost on the optimal application service strategy for the Web service providers.
A. Independent Service Vendors (ISV)

The ISVs application service strategy is illustrated in Fig. 1. The two Web service providers sell S1 and S2 at P_{s1} and P_{s2} separately. Consumers who need the integrated Web service have to buy S1 and S2 and integrate by themselves. Therefore, the demand for each of the Web service S1 (or S2) consists of those who in need of S1 (or S2) only and those in need of S3.

Since the reservation prices of consumers who are only interested in S1 (or S2) are uniformly distributed between 0 and V_1 (or V_2), one can easily calculate the number of consumers who only buy S1 (or S2), denoted as q_{s1} (or q_{s2}), in (2). For consumers who are interested in S3, the total cost to get the integrated Web service includes the prices of S1 and S2 and the integration cost C. Therefore, the number of buyers of the integrated Web service (q_{s3}) is described in (3). Finally, the total demand for S1 (or S2), denoted by D_{si}, consists of those who buy S1 (or S2) only and those who buy the integrated Web service, as specified in (4).

\begin{align*}
q_{s1} &= Q_i - \frac{P_{s1}}{V_1}Q_i, \ i = 1, 2 \\
q_{s2} &= Q_3 - \frac{P_{s1} + P_{s2} + C}{V_3}Q_3 \\
D_{si} &= q_{si} + q_{s3}, \ i = 1, 2
\end{align*}

Each Web service provider seeks to set the price of its product to maximize its profit, as described in (5). As standard in literature on information goods, the marginal production cost of Web services is set to zero.

\begin{align*}
\max_{P_{si}} \pi_{si} = P_{si} \cdot D_{si} &= P_{si} \left( Q_i - \frac{P_{s1}}{V_1}Q_i \right) \\
&+ P_{si} \left( Q_3 - \frac{P_{s1} + P_{s2} + C}{V_3}Q_3 \right), \ i = 1, 2
\end{align*}

By solving the profit maximization problem for each of the Web service providers simultaneously, one derives the optimal prices of the Web service S1 and S2 in the ISV application service strategy in (6), shown at the bottom of the page. The optimal profits of the Web service providers (\pi_{s1}^* and \pi_{s2}^*) can be calculated by substituting the optimal prices in (6) into the profit functions in (5).

\begin{align*}
\max_{P_{si}} \pi_{si}^* &= P_{si} \left( Q_i - \frac{P_{s1}Q_i}{V_1} \right), \ i = 1, 2 \\
\text{By inspection, the optimal prices and profits when there is no demand for the integrated Web service are}
\end{align*}

\begin{align*}
P_{s1}^* &= V_1, \ \pi_{s1}^* = V_1Q_i, \ i = 1, 2
\end{align*}

Summarizing the results from (6) and (8), one gets the optimal profits for the Web service providers in the ISV application service strategy as follows:

\begin{align*}
\Pi_{si}^* &= \max\{\pi_{s1}^*, \pi_{s2}^*\}, \ i = 1, 2
\end{align*}

Accordingly, the optimal industry profit in the ISV application service strategy is \Pi^* = \Pi_{s1}^* + \Pi_{s2}^* and each provider contributes \rho_i^* portion of the industry profit, where

\begin{align*}
\rho_i^* &= \frac{\Pi_{si}^*}{\Pi_{s1}^* + \Pi_{s2}^*}, \ i = 1, 2
\end{align*}

B. Joint Venture (JV)

In the JV application service strategy, the software vendors merge into one company that sells the integrated Web service S1 at price P_{c1}, see Fig. 2. Since the integration of Web services often involves the transformation of Web service components, the integrated Web service is generally undividable. That is, consumers cannot get the individual Web services S1 or S2.
by purchasing $S_3$. As a result, the potential customers for the JV are only those customers interested in the integrated Web service $S_3$.

The JV invests in a one-time integration cost to provide the integrated Web service. Once integrated, the marginal cost to provide additional copies of the integrated Web service over the Internet is negligible. Therefore, we treat the integration cost incurred by the JV as sunk cost and assume zero marginal production cost for $S_3$. Customers who are interested in $S_3$ can purchase the integrated Web service from the JV directly and, thus, do not incur any integration cost. The objective of the JV is to optimally set the price of the integrated Web service ($P_v$) to maximize profit, described in (11)

$$
\max P_v \pi_v = P_v \left( Q_3 - \frac{P_v}{V_3} Q_3 \right).
$$

By inspection, the optimal industry profit for the JV is

$$
\Pi^*_v = \frac{V_3 Q_3}{4}.
$$

C. Strategic Alliance (SA)

The SA strategy can be viewed as a combination of ISV and JV service strategies, where all three types of Web services – $S_1$, $S_2$, and $S_3$ are offered, see Fig. 3. Similar to the JV strategy, the cost of composing the integrated Web service from $S_1$ and $S_2$ is considered sunk cost and the marginal production cost is assumed to be zero.

The objective of the SA is to optimally set the prices of the three Web services, denoted by $P_{a1}$, $P_{a2}$, and $P_{a3}$, to maximize its total profit. To ensure that the demand for the integrated Web service $S_3$ sold by the SA is non-negative, the price of $S_3$ cannot exceed the consumers’ total cost of creating $S_3$ from $S_1$ and $S_2$, i.e., $P_{a3} \leq P_{a1} + P_{a2} + c$. Otherwise, the customers will integrate $S_3$ by themselves and this makes the SA reduce to the ISV strategy. Further, we do not consider the special case where the prices of individual Web services are so high that there is no demand of $S_1$ or $S_2$, since we have covered this situation in the JV strategy. Mathematically, the optimization problem of the SA can be formulated as follows:

$$
\max P_{a1}, P_{a2}, P_{a3} \pi_a = P_{a1} \left( Q_1 - \frac{P_{a1}}{V_1} Q_1 \right) + P_{a2} \left( Q_2 - \frac{P_{a2}}{V_2} Q_2 \right)
$$

$$
+ P_{a3} \left( Q_3 - \frac{P_{a3}}{V_3} Q_3 \right) \quad \text{s.t. } P_{a3} \leq P_{a1} + P_{a2} + c.
$$

By establishing the Lagrangean function and using Kuhn-Tucker conditions, we derive the optimal industry profit of the SA as follows:

$$
\Pi^*_a = \begin{cases} 
\pi^*_a, & \text{if } c < \frac{V_3}{4} \left( \frac{V_1}{V_1 + V_2} + \frac{V_2}{V_1 + V_2} \right) \\
\frac{1}{4} (V_1 Q_1 + V_2 Q_2 + V_3 Q_3), & \text{if } c \geq \frac{V_3}{4} \left( \frac{V_1}{V_1 + V_2} + \frac{V_2}{V_1 + V_2} \right)
\end{cases}
$$

where the equation shown at the bottom of the page holds.

Under the service strategies of JV and SA, we assume that the two software vendors under consideration adopt the following profit sharing scheme. Each firm obtains a proportion of $\rho^*_i$ ($i = 1, 2$) out of the total profit in each application service strategy, where $\rho^*_i$ is defined in (10). Although other profit-sharing schemes are possible, this mechanism is simple, straightforward, and incentive-compatible. Note that given the parameters in the model ($V$’s, $Q$’s, and $c$’s), this profit sharing scheme ($\rho^*_i$’s) remains constant, regardless of the application service strategy. Therefore, it suffices to examine the total industry profit because a higher industry profit of a particular strategy ensures a higher profit for the participating software vendors.

VI. ANALYTICAL INSIGHTS FROM A SIMPLIFIED MODEL

The mathematical complexity of the profit in the ISV strategy, see (5) and (6), makes the analytical comparison of three service strategies of the general model analytically intractable, if not impossible. Hence, we adopt a simplified model in order to gain analytical insights. In particular, we make two simplifying assumptions. First, we assume that there are (approximately)
equal number of potential customers who are interested in \( S_1 \) or \( S_2 \), i.e.,
\[
Q_1 = Q_2 = Q \tag{15}
\]
Second, we assume that \( S_1 \) and \( S_2 \) are about equally valued by consumers, i.e.,
\[
V_1 = V_2 = V. \tag{16}
\]
In short, we are analyzing a symmetric market where two Web service components have equivalent valuations and market potentials in the simplified model. Note that the assumption in the general model regarding the integration cost and the valuations of Web services in (1) still holds in the simplified model. By substituting (15) and (16) into the general model, we obtain the optimal industry profits of three service strategies in the context of a symmetric market summarized in Lemmas 1–5.

**Lemma 1**: In a symmetric market, the optimal industry profit in the ISV strategy is as shown in (17) at the bottom of the page.

Further, \( \pi^*_s \) is decreasing and convex in the integration cost \( c \). Fig. 4 plots the maximal total profit in the ISV strategy with respect to integration cost \( c \).

**Proof**: See the Appendix.

**Lemma 2**: In a symmetric market, the optimal total profit of the JV remains the same as in (12).

**Proof**: Because the JV only sells the integrated Web service, the valuations and market potentials of the individual Web services will not affect the JV’s profit. Thus, it remains unchanged in the simplified model. \( \square \)

**Lemma 3**: In a symmetric market, the maximal total profit of the Web service SA strategy (\( \Pi^*_{sa} \)) is

\[
\begin{align*}
(\text{i}) \quad \pi^*_{sa} & = \frac{1}{2} V Q + \frac{1}{4} V_3 Q_3 - \frac{Q Q_3 (V_3 - 2 V - 2 c)^2}{4 (Q V_3 + 2 Q_3 V)} ,
\quad \text{if } c < \frac{V_3 - 2 V}{2} \tag{18-a} \\
(\text{ii}) \quad \frac{1}{2} V Q + \frac{1}{4} V_3 Q_3 , & \quad \text{if } c \geq \frac{V_3 - 2 V}{2} \tag{18-b}
\end{align*}
\]

**Proof**: See the Appendix.

**Lemma 4**: \( \pi^*_{sa} \) in Lemma 3 is increasing and concave in the integration cost \( c \). Further, the optimal industry profit of the SA (\( \Pi^*_{sa} \)) is increasing in valuation \( (V_3) \) and market size \( (Q_3) \) of the integrated service.

**Proof**: See the Appendix.

**Lemma 5**: In a symmetric market, the optimal industry profit of the SA switches from \( \pi^*_{sa} \) to \( \frac{V Q}{2} + \frac{V_3 Q_3}{4} \) as the integration cost increases. In other words, when the integration cost is low, the SA has to lower the price of the integrated Web service to avoid consumer self-integration and, thus, suffer from a lower profit \( (\pi^*_a) \) while the SA can exploit its expertise and gain a higher profit \( (\frac{V Q}{2} + \frac{V_3 Q_3}{4}) \) when the integration cost is high. Further, Lemma 4 suggests that \( \pi^*_{sa} \) is increasing and concave in integration cost \( c \). Fig. 5 plots the optimal industry profit as a function of the integration cost. Note that the optimal industry profit of the SA is minimized when the integration cost is at minimum \( (c = 0) \), as described in (19).

\[
\pi^*_{sa}(c=0) = \frac{V^2 (Q + Q_3)^2}{2 (Q V_3 + 2 Q_3 V)}. \tag{19}
\]

**Proposition 1**: The Web service providers are always better off in the SA strategy than in the ISVs strategy, regardless of the
integration cost. Fig. 7 plots the optimal industry profits in the ISV and SA service strategies.

**Proposition 2:** If \( V \leq V_3 \leq (4+2Q/Q_3)V \), the SA is always the dominant strategy, regardless of the integration cost.

**Proof:** See the Appendix.

**Proposition 3:** If \( (4+2Q/Q_3)V < V_3 \leq (4 + (Q + \sqrt{Q^2 + 8QQ_3 + 4Q_3^2})/Q_3)V \), the JV is the optimal strategy if the integration cost is below \( \bar{c} \), while the SA is the optimal strategy if the integration cost is above \( \bar{c} \), where the threshold value of the integration cost is defined as

\[
\bar{c} = \frac{1}{2}V_3 - V - \frac{\sqrt{4V^2 + 2V_3Q_3Q}}{2Q_3}. \tag{20}
\]

**Proof:** See the Appendix. The optimal industry profits of JV and SA are drawn in Fig. 8.

**Proposition 4:** If \( V_3 > (4 + (Q + \sqrt{Q^2 + 8QQ_3 + 4Q_3^2})/Q_3)V \), the JV is the optimal strategy, regardless of the integration cost. Fig. 9 depicts the optimal industry profit of the JV against that of the SA.

**Proof:** See the Appendix.

### VII. COMPUTATIONAL EXPLORATIONS

From the analysis of the simplified model, we find that the optimal application service strategy for the Web service providers depends on the value of integration cost. Further, we find that the optimal strategy is conditional on the valuations and the market potentials of Web services (see Propositions 2–4). However, our results have limitations as we only consider the special case of a symmetric market in the simplified model, i.e., \( V_1 = V_2 \) and \( Q_1 = Q_2 \). In this section, we relax the simplifying assumptions to draw more managerial insights by using numerical experiments.

We focus on situations where the values and market potentials of Web services \( S_1 \) and \( S_2 \) are different. Without loss of generality, we assume \( S_1 \) has greater value \((V_1 > V_2)\) since one can always rename \( S_1 \) and \( S_2 \) without changing the results. Further, the general assumptions in (1), i.e., \( V_3 > \max\{V_1, V_2\} \) and \( c < \min\{V_1, V_2\} \) still apply to our numerical experiments. There are six possible scenarios with different combinations of values and market sizes of Web services \( S_1, S_2, \) and \( S_3 \), see Table I.

1. **Observation 1:** Ceteris paribus, the optimal strategy switches from SA to JV as the value of the integrated Web service \((V_3)\) increases. Further, the SA always dominates the ISV.

<table>
<thead>
<tr>
<th>Case</th>
<th>( V_1 ) vs. ( V_2 )</th>
<th>( Q_1 ) vs. ( Q_2 )</th>
<th>( Q_1 ) vs. ( Q_2 ) and ( Q_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( V_1 &gt; V_2 )</td>
<td>( Q_1 &gt; Q_2 )</td>
<td>( Q_1 &gt; \max{Q_1, Q_2} )</td>
</tr>
<tr>
<td>2</td>
<td>( V_1 &gt; V_2 )</td>
<td>( Q_1 &gt; Q_2 )</td>
<td>( Q_1 &lt; \min{Q_1, Q_2} )</td>
</tr>
<tr>
<td>3</td>
<td>( V_1 &gt; V_2 )</td>
<td>( Q_1 &gt; Q_2 )</td>
<td>( Q_1 &gt; Q_2 )</td>
</tr>
<tr>
<td>4</td>
<td>( V_1 &gt; V_2 )</td>
<td>( Q_1 &lt; Q_2 )</td>
<td>( Q_1 &gt; \max{Q_1, Q_2} )</td>
</tr>
<tr>
<td>5</td>
<td>( V_1 &gt; V_2 )</td>
<td>( Q_1 &lt; Q_2 )</td>
<td>( Q_1 &lt; \min{Q_1, Q_2} )</td>
</tr>
<tr>
<td>6</td>
<td>( V_1 &gt; V_2 )</td>
<td>( Q_1 &lt; Q_2 )</td>
<td>( Q_1 &lt; Q_1 &lt; Q_2 )</td>
</tr>
</tbody>
</table>
Observation 1 suggests that the results from the numerical experiments are consistent with the analysis of the simplified model. When consumer’s valuation of the integrated Web service ($V_3$) is small, the software vendors are better off providing both individual and integrated Web services (in the SA strategy). As the valuation of the integrated Web increases, the optimal strategy turns to a mixture of SA and JV, with the JV as optimal for small integration cost and the SA as optimal for large integration cost. When the valuation for $S_3$ is sufficiently high, the best strategy for the Web service providers is to form a JV and sell the integrated Web service only. Figs. 10–12 give graphical examples of the optimal strategy in the above mentioned three cases. In all experiments, we observe that the SA always dominates the ISV strategy.

As we have shown in analytical analyses and numerical experiments, the SA, which is related to the mixed bundling strategy, is not always the optimal strategy. The result is largely determined by the nature of Web service integration – consumers incur an integration cost when they integrate two Web services by themselves. Since the consumers have the option to choose between doing the integration by themselves and buying $S_3$ under the strategy of SA, the price of the integrated Web service is constrained by the integration cost. That is, if the integration cost is relatively low, the price of $S_3$ cannot be boundlessly high. Otherwise, the consumers would prefer doing the integration by themselves and will not buy the integrated Web service.

If the consumers value the integrated Web service highly, the firms can charge a high price for $S_3$ in the JV while the SA has to sell it at a (relatively low) price bounded by the integration cost. In fact, it can be shown that the optimal price of $S_3$ is less in the SA than in the JV [see (A9) in the Appendix]. Therefore, if the value of the integrated Web service is small, SA is better than JV since the firms can sell to all types of customers. If the value of the integrated Web service is moderate, the SA is only preferable when the integration cost is high. Last, since it’s not realistic to integrate Web services at a cost higher than the values of Web services ($V_i \leq V$), the JV becomes the dominant strategy when the value for the integrated Web service is sufficiently high.

2) Observation 2: The threshold value of $V_3$ for JV to SA is decreasing in potential market size of the Web integrated 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 a market where $V_1 > V_2$ and $Q_1 > Q_2$.

Observation 1 suggests that the Web service providers do not necessarily always benefit from diversifying their products. If the integrated Web service is highly valuable, the service vendors are better off by establishing a JV simply selling the integrated Web service. In other words, a higher valuation for the integrated Web service ($V_3$) tends to make the JV strategy more attractive. Observation 2 further describes how the threshold value of $V_3$ is affected by the market potential of the integrated Web service given the fact that the optimal total profits in JV and SA are all increasing in valuation and market size of the integrated Web service (see Lemma 4).

An interesting observation from the behavior of the threshold value suggests that a more “balanced” market seems to make the JV more favorable. The market is considered balanced if one Web service provider sells a more valuable Web service with a smaller market size while the other provider sells a less valuable Web service with larger market potential. In other words, if each of the Web service providers enjoys some advantage in valuation or market power, they are more likely to form a cooperative JV. On the other hand, if the market is dominated by one Web service provider selling a highly valuable Web service and enjoying a large potential market, the service providers are more likely to prefer the SA strategy, which gives them a certain degree of autonomy.

Table II shows examples of optimal service strategies with respect to different values of the integrated Web service ($V_3$) 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 to the range of $[0, 0.6]$. The SA is the optimal strategy if the value of the integrated Web service is low ($V_3 \in [0.6, 3.93]$); if the valuation

![Fig. 10. SA is the optimal market structure.](image1)

![Fig. 11. JV dominates for small integration cost. SA dominates for large integration cost.](image2)

![Fig. 12. JV is the optimal market structure.](image3)
of the integrated Web service is moderate ($V_3 \in [3.93, 5.31]$), the optimal strategy depends on the integration cost (the JV is optimal for small integration cost while the SA is optimal for large integration cost); the JVs becomes the dominant strategy if the valuation of the integrated Web service is high ($V_3 > 5.35$). The threshold values of the integrated Web service valuation ($V_3$) in this experiment are 3.93 and 5.31, where the SA turns from less dominant to being dominated.

From the numerical experiments, we observe that a higher market potential of $Q_3$ is beneficial for the JV strategy. For example, the threshold values in (2b) are lower than that of (2a) since the integrated Web service has a greater market potential in (2b). Another interesting observation is that a more “balanced” market tends to favor the JV. This can be illustrated by comparing case (3) against case (6). The former exemplifies a polarized market where one service provider has apparent advantages over the other ($V_1 > V_2$ and $Q_1 > Q_2$), while the latter exemplifies a balanced market ($V_1 > V_2$ and $Q_1 < Q_2$) where each Web service provider has certain market advantage in one area but not the other. With other parameters remain the same ($Q_3$, $V_1$, and $V_2$), the JV beats the SA if $V_3 > 6.00$ in case (3), while the SA is dominated by the JV if $V_3 > 6.54$ in case (6).

### VIII. Conclusion and Future Research

Web services are software components that perform discrete business functionalities and can be discovered and integrated over the Internet. Based on open standards, Web services have brought new business opportunities. The openness of technology and the interoperability of Web services make them the most promising solution to date to cutting the cost of enterprise application integration and interoperation collaboration. Many strategic issues have become important including how software vendors should market their e-service products.

In this paper, we present an economic model to study the various factors that determine the optimal strategy for Web services with complementary functionalities. In particular, we compare three service strategies: ISV; JV; SA. In the ISV strategy, two Web service providers offer two complementary Web services components separately; in the JV strategy, only the integrated Web service is offered, and in the strategy of SA, both individual and integrated Web services are offered. We suggest the application service strategy that maximizes the profit of the two Web service providers.

Our findings are based on theoretical analysis of a simplified model and numerical experiments of a generalized model. First, we find that the Web service providers benefit from the interoperability of the Web Service-based architecture because it is always more profitable to sell an integrated Web service in the SA than to remain independent in the ISV strategy. Second, the optimal strategy depends on the integration cost as well as the characteristics of the Web services, including the valuations and the sizes of the potential market. When the valuation of the integrated Web service is small, the service providers prefer the SA than the JV. For a larger valuation of the integrated Web service, the service providers prefer the SA if the integration cost is high, while the JV is preferred if the integration cost is low. When the valuation of the integrated Web service is sufficiently high, the JV becomes the optimal strategy. In addition, if the demand for the integrated Web service is high, the JV can beat the SA even if the valuation of the integrated Web service is small. Finally, in a more balanced market, where one Web service provider has advantage over the other, the JV can become the optimal strategy with a smaller threshold valuation of the integrated Web service. In sum, our model and analytical results can be used as a decision support component to aid top management in deciding which application service provisioning strategy is optimal.

Our research does have its limitations. Like any analytical study, the availability of analytical insights is bounded by the possibility of deriving closed form solutions. While there could be more than two Web service providers in a service-oriented

### TABLE II

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Parameter Values</th>
<th>Optimal strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_3 &gt; Q_1 &gt; Q_2$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 50$, $Q_3 = 200$</td>
</tr>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_1 &gt; Q_2 &gt; Q_3$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 60$, $Q_3 = 40$</td>
</tr>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_1 &gt; Q_2 &gt; Q_3$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 60$, $Q_3 = 50$</td>
</tr>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_1 &gt; Q_2 &gt; Q_3$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 60$, $Q_3 = 50$</td>
</tr>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_1 &gt; Q_2 &gt; Q_3$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 60$, $Q_3 = 60$</td>
</tr>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_1 &gt; Q_2 &gt; Q_3$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 60$, $Q_3 = 60$</td>
</tr>
<tr>
<td>$V_1 &gt; V_2$</td>
<td>$Q_1 &gt; Q_2 &gt; Q_3$</td>
<td>$V_1 = 1.0$, $V_2 = 0.6$ $Q_1 = 100$, $Q_2 = 60$, $Q_3 = 60$</td>
</tr>
</tbody>
</table>
environment, the mathematical model becomes analytically intractable even when only two Web service providers are considered because of the intervendor terms. Consequently, a simplified model has to be used to derive analytical results. Adding more Web service providers providing different Web services to the model will greatly complicate the model and analyses. Consider for example, if the number of different Web services is increased to \( N \), then there will be \( C_N^2 \) integration points involved in providing the integrated Web service. The total integration cost, however, can be linear to the number of different Web services, if there exists a significantly high level of standardization. For example, the Travel Industry uses OTA specification for Web Services XML payloads, significantly reducing the cost of integration as standard messages are used between various partners including travel agents, airlines, etc. In this case, adding more different Web services to the model does not affect the trend of the analytical insights derived from the two-provider model.

There are several possible extensions to our current research. In this paper, we assume that the SA is established by the two Web service providers. It is interesting to study what the optimal application service strategy will be if the SA is operated by a third-party company. Another extension is to study service strategies for supplementary Web services. That is, one Web service has primary functionality while the other Web service is valuable only if it is integrated with the primary Web service.

APPENDIX
Proofs

Proof of Lemma 1: In the simplified model, where the valuations and the sizes of potential market for the two Web services are approximately equal, the Web service providers’ decision problems defined in (5) can be written as

\[
\max \pi_{si} = P_{si} \cdot D_{si} = P_{si} \left( Q - \frac{P_{si}}{V} Q \right) + P_{si} \left( Q - \frac{P_{s1} + P_{s2} + c}{V_3} Q_3 \right). \tag{A1}
\]

We derive the optimal prices and profits by solving the maximization problems for both service providers simultaneously, as shown in (A2) and (A3) at the bottom of the page.

Then, we analyze the properties of the profits (\( \pi_{si}^{*} \)) in (A3). Take the first derivatives of \( \pi_{si}^{*} \) with respect to \( c \), one has

\[
\frac{\partial \pi_{si}^{*}}{\partial c} = V_3 Q_3 V_3^2 (Q_2 + Q_3) + V_3 Q_3 Q_3 (V - c) + V_3^2 Q_3 (V_3 - c),
\]

\( \partial^2 \pi_{si}^{*} / \partial c^2 = 2 V_3^3 (Q_3 + Q) > 0 \),

\( \frac{\partial^2 \pi_{si}^{*}}{\partial c^2} = 2 V_3^2 (Q_3 + Q_3) / 3 V_3 Q_3^2 > 0 \).

By inspection, the first derivative is negative when \( 0 < c < V < V_3 \). Further, the second derivative is calculated positive, since

\[
\frac{\partial^2 \pi_{si}^{*}}{\partial c^2} = 2 V_3^2 (Q_3 + Q_3) / 3 V_3 Q_3^2 > 0.
\]

In summary, the total profit (\( \pi_{si}^{*} \)) is decreasing and convex in integration cost (c). Consequently, \( \pi_{si}^{*} \) is maximized when the integration cost is at minimum, i.e., \( c = 0 \). The maximal value of \( \pi_{si}^{*} \) is described in (A4)

\[
\pi_{si}^{*} \bigg|_{c=0} = \frac{2 V_3 V_3 Q_3 V_3 Q_3 + V_3 Q_3 Q_3}{(2 V_3 + 3 V_3 Q_3)^2} \tag{A4}
\]

According to (8), the optimal industry profit in the ISV strategy is defined as \( \Pi_0^{\pi} = \max \left\{ (1/2) V Q \pi_{si}^{*} \right\} \). When the integration cost is zero (\( c = 0 \)), the total profit must be evaluated in (A4) since

\[
\pi_{si}^{*} \bigg|_{c=0} = \frac{1}{2} V Q
\]

\[
\frac{QQ_3(Q_3 V_3 + 9 V_3) + 8 Q_3(Q_3 V_3 - V_3) + 4 V_3 Q_3^2}{(2 Q_3 + 3 V_3 Q_3)^2} > 0.
\]

Proof of Lemma 3: First we define the Lagrangean function as

\[
L(\lambda) = \pi_{a1} \left( Q - \frac{P_{a1} V_3}{V} Q \right) + \pi_{a2} \left( Q - \frac{P_{a2} V_3}{V} Q \right) + \pi_{a3} \left( Q_3 - \frac{P_{a3} V_3}{V_3} Q_3 \right) + \lambda \left( P_{a1} + P_{a2} + c - P_{a3} \right)
\]

\[
\text{s.t.} \quad P_{a1} + P_{a2} + c - P_{a3} \geq 0, \lambda \geq 0.
\]

The Kuhn-Tucker conditions for the maximization problem are

\[
L_{Pi} = \pi_{a1} \left( Q - \frac{P_{a1} V_3}{V} Q \right) + \lambda \left( P_{a1} + P_{a2} + c - P_{a3} \right)
\]

\[
L_{P_{a1}} = \pi_{a1} \left( Q - \frac{P_{a1} V_3}{V} Q \right) + \lambda \left( P_{a1} + P_{a2} + c - P_{a3} \right), \quad i = 1, 2, 3 \tag{A6}
\]

\[
L_{\lambda} = \pi_{a1} + P_{a2} + c - P_{a3} \geq 0, \lambda \geq 0. \tag{A7}
\]

Obviously, the Lagrangean function is not maximized if \( P_{a1} = 0 \). So we must have \( L_{Pi} = 0 \) required by constraints in (A6). Next we consider the constraint defined in (A7). If \( \lambda > 0 \), it follows that \( L_{\lambda} = 0 \). Accordingly, the prices and profits in the Lagrangean function are evaluated as

\[
\pi_{a1}^{*} \pi_{a2}^{*} \pi_{a3}^{*} = \pi_{a1} \left( Q - \frac{P_{a1} V_3}{V} Q \right) + \lambda \left( P_{a1} + P_{a2} + c - P_{a3} \right)
\]

\[
P_{a1}^{*} P_{a2}^{*} p_{a3}^{*} = \frac{V_3 Q_3 V_3 Q_3 - c V_3 Q_3}{2 V_3^2 + 3 V_3 Q_3} > 0 \tag{A8}
\]

\[
P_{a1}^{*} P_{a2}^{*} P_{a3}^{*} = \frac{V_3 Q_3 V_3 Q_3 - c V_3 Q_3}{2 V_3^2 + 3 V_3 Q_3} < 0 \tag{A9}
\]

\[
\pi_{a1}^{*} = \frac{1}{2} V Q + \frac{1}{4} V_3 Q_3 - \frac{QQ_3 V_3 (V_3 - 2V - 2c)^2}{(2 Q_3 + V_3 Q_3)^2}, \tag{A10}
\]

\[
\pi_{a2}^{*} = \frac{V_3 Q_3 V_3 Q_3 - c V_3 Q_3}{2 V_3^2 + 3 V_3 Q_3} \tag{A2}
\]

\[
\pi_{a3}^{*} = \frac{V_3 Q_3 V_3 Q_3 - c V_3 Q_3}{2 V_3^2 + 3 V_3 Q_3} \tag{A3}
\]
To satisfy the constraint \( \lambda > 0 \), it is required that \( V_3 > 2V + 2c \). On the other hand, if \( V_3 \leq 2V + 2c \), we can plug \( \lambda = 0 \) into (A6) to derive the prices and profits as follows:

\[
\hat{p}_{a1} = \hat{p}_{a2} = \frac{V}{2}, \quad \hat{p}_{a3} = \frac{V_3}{2} \tag{A11}
\]

\[
\hat{\pi}_a = \frac{1}{2} V Q + \frac{1}{4} V_3 Q_3. \tag{A12}
\]

In summary, the optimal profit of the SA is described by (A10) if \( V_3 > 2V + 2c \) and by (A2) if \( V_3 \leq 2V + 2c \).

**Proof of Lemma 4**: If \( V_3 > 2V + 2c \), the optimal profit of the SA is defined in \( \hat{\pi}_a \). Take the first derivative of \( \pi_a^* \) with respect to integration cost \( c \), one finds that \( \pi_a^* \) is increasing in \( c \) since \( \partial \pi_a^*/\partial c = Q Q_3 (V_3 - 2V - 2c)/(V_3 Q + 2V Q_3) \) is positive when \( V_3 > 2V + 2c \). Further, the second derivative with respect to \( c \) is negative. Therefore, \( \pi_a^* \) is increasing and concave in integration cost \( c \), as shown in Fig. 5.

Next we compute the comparative statics of \( \pi_a^* \) with respect to \( V_3 \) and \( Q_3 \) in (A13) and (A14) shown at the bottom of the page.

Since \( \pi_a^* \) is decreasing and convex in \( c \), the optimal industry profit in the ISV strategy must switch from \( \pi_a^* \) to \( (1/2) V Q \) as the integration cost increases. Accordingly, the optimal industry profit with respect to integration cost \( c \) is depicted in Fig. 4.

Obviously, \( \pi_a^* \) is increasing in \( V_3 \) since the first derivative in (A13) is positive. Note that \( \pi_a^* \) is defined under the condition \( V_3 > 2V + 2c \). Together with the assumption that \( c < V \), one can easily prove that \( \pi_a^* \) is increasing in \( Q_3 \). By inspection, we observe that the optimal profit described in (A12) is increasing in \( V_3 \) and \( Q_3 \). In summary, the optimal industry profit of the SA (\( \Pi_a^* \)) is increasing in both \( V_3 \) and \( Q_3 \).

**Proof of Proposition 1**: Evaluated at zero integration cost \( (c = 0) \), the total profit is greater in SA strategy than in ISV strategy, as shown in

\[
\pi_a^*|_{c=0} - \pi_a^*|_{c=0} = \frac{V^3 V_3 Q_3^4 (Q + Q_3^2)}{2 Q_3 (V_3 Q + 2V Q_3 + 3Q_3 V)^2} > 0. \tag{A15}
\]

According to Lemma 1, the optimal industry profit in the ISV strategy is maximized when the integration cost is zero while Lemma 3 suggests that the total profit of the SA minimizes when the integration cost is zero. Therefore, (A15) suggests that the minimum total profit in the SA is greater than the maximum total profit in the ISV. In summary, the SA always dominates the ISV strategy, regardless of the integration cost.

**Proof of Proposition 2**: First, note that when \( V < V_3 < 2V + 2c \), the total profit of the SA is \( V Q/2 + V_3 Q_3 /4 \) according to Lemma 3. Since the total profit of the JV is only \( V_3 Q_3 /4 \), it’s obvious that the JV is dominated by the SA. Therefore, SA is the optimal strategy when \( V < V_3 < 2V + 2c \).

Second, the total profit of the SA is defined as \( \pi_a^* \) in (A10) when \( 2V + 2c < V_3 < (4 + 2Q/Q_3) V \) according to Lemma 3. Then the difference between the total profits in SA and JV at zero integration cost is

\[
\varphi(V_3) = \pi_a^*|_{c=0} - \Pi_v^* = \frac{V_3 Q (4V_3 Q + 2V_3 Q_3 - 2Q_3 V_3)}{4(V_3 Q + 2Q_3 V)^2}. \tag{A16}
\]

If \( 2V < V_3 < (4 + 2Q/Q_3) V \), we must have \( 2Q_3 V < Q_3 V_3 < 4Q_3 V + 2V Q \). Thus \( \varphi \) in (A16) is always positive. Therefore, the JV is dominated by the SA when \( 2V < V_3 < (4 + 2Q/Q_3) V \).

In summary, the SA is the optimal strategy when \( V < V_3 < (4 + 2Q/Q_3) V \), regardless of integration cost.

**Proof of Proposition 3**: According to (A16), the total profit of the SA is less than that of the JV at zero integration cost when \( V_3 > (4 + 2Q/Q_3) V \). Equating \( \pi_a^* \) with \( \Pi_v^* \), one gets two roots of the integration cost, \( \bar{c} \), for which the SA generates the same total profit as the JV, described as follows:

\[
c_1 = \frac{1}{2} V_3 - V - \sqrt{4V_3^2 V + 2V_3 Q_3 Q_3} \tag{A17}
\]

\[
c_2 = \frac{1}{2} V_3 - V + \sqrt{4V_3^2 V + 2V_3 Q_3 Q_3}. \tag{A18}
\]

Since \( (1/2) V_3 - V > V \), the larger root \( c_2 \) is infeasible under the assumption that \( 0 \leq c \leq V \). Therefore, the total profit of the SA equates that of the JV when the integration cost is \( c_1 \) [defined as \( \bar{c} \) in (20)]. According to lemma 3, \( \pi_a^* \) is increasing in the integration cost. Therefore, the total profit of the JV is greater than that of the SA when \( c < \bar{c} \) while the total profit of the SA is greater than that of the JV when \( c > \bar{c} \), as depicted in Fig. 8.

On the other hand, the profit of the SA reaches maximum when \( c = V \). The difference of the maximal total profit of the SA and the JV is

\[
\phi(V_3) \equiv \Pi_v^*|_{c=V} - \Pi_v^* = \frac{Q (2V_3 Q + 8V V_3 Q_3 - 12V^2 Q_3 - 2Q_3 V_3^2)}{4(V_3 Q + 2Q_3 V)^2}, \tag{A18}
\]

From simple algebra, we know that the \( \phi(V_3) \) is non-negative if \( V_3 \leq V_3 \leq V_3 \), where

\[
V_3 = \begin{cases} 4 + \sqrt{Q^2 + 8Q Q_3 + 4Q_3^2} \to V, & \text{if } V_3 \leq V_3 \leq V_3 \end{cases}
\]

\[
V_3 = \begin{cases} 4 + \sqrt{Q^2 + 8Q Q_3 + 4Q_3^2} \to V, & \text{if } V_3 \leq V_3 \leq V_3 \end{cases}
\]

Note that one necessary condition under which the SA dominates the JV is that \( \phi(V_3) \) must be non-negative. Since \( V_3 \) is less
than $V_3 > (4 + 2Q/q_0)V$, the optimal strategy switches from the JV to SA when $(4 + 2Q/q_0)V < V_3 \leq V_5$.

Proof of Proposition 4: According to (A18), the maximum total profit of the SA (when $c = V$) is less than that of the JV if $V_3 > V_7$. Since $\pi_0^2$ is increasing in $c$, the JV always yields greater profit for the interval $0 \leq c \leq V$ if $V_3 > V_7$. ☐

ACKNOWLEDGMENT

The authors are indebted to the very thorough comments of the department editor and two anonymous reviewers, which led to great improvement of this paper. Any remaining error belongs to the authors.

REFERENCES


Hsing Kenneth Cheng received the Ph.D. degree in computers and information systems from William E. Simon Graduate School of Business Administration, the University of Rochester, Rochester, NY, in 1992.

He is Associate Professor of Information Technology and the AEI Faculty Fellow with the Department of Decision and Information Sciences of Warrington College of Business Administration, the University of Florida (UF), Gainesville. Prior to joining UF, he served on the faculty at The College of William and Mary from 1992 to 1998. His research interests focus on modeling the impact of Internet technology on software development and marketing, and issues surrounding the application services supply chain and web services. His work has appeared in Computers and Operations Research, Decision Support Systems, the European Journal of Operational Research, the IEICE Transactions, IEEE Transactions on Engineering Management, Information Technology and Management, the International Journal of Electronic Commerce, the International Journal of Web Services Research, Journal of Business Ethics, the Journal of Information Systems and e-Business Management, the Journal of Management Information Systems, and Socio-Economic Planning Sciences. Dr. Cheng has co-edited several special issues in various information systems journals. He has served on the program committee of many information systems conferences and workshops, and is a program co-chair for the Workshop on E-Business (2003).

Qian “Candy” Tang received the Ph.D. degree from the Department of Decision and Information Sciences, Warrington College of Business Administration, the University of Florida, Gainesville, in 2004.

She is an Assistant Professor with the Department of Information Systems, National University of Singapore. Her research interest includes economics of IS, software pricing and piracy, economics of Web services and intermediary strategies, open source software adoption and competition, and software security. Her research has appeared in Decision Support Systems, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, and the Journal of Management Information Systems.

Dr. Tang is a member of AIS, DSI, and INFORMS. She has served as the committee member of Workshop on e-Business (Web).
J. Leon Zhao received the Ph.D. degree in business administration from the Haas School of Business, the University of California, Berkeley, in 1992. He is a Professor and Honeywell Fellow in MIS at the University of Arizona, Tucson. He was an Assistant Professor in HKUST and College of William and Mary, respectively. He has published over 30 journal articles including *Management Science, ISR, JMIS, CACM, Information Systems Frontier*, the *IEEE Transactions on Knowledge and Data Engineering*, and *Decision Support Systems*. His work also appeared in over 60 refereed conference papers. He is an Associate Editor of *Information Systems Research, Decision Support Systems, Electronic Commerce Research and Applications, the International Journal of Business Process Integration and Management, the International Journal of Web and Grid Services, and the International Journal of Web Services Research* and serves on the editorial board of the *Journal of Database Management*. He has co-edited seven special issues in various IS journals. He is a program co-chair for the Workshop on E-Business (2003) and the 15th Workshop on Information Technology and Systems (2005) and the IEEE Conference on Services Computing (2006).