Design Science

Designing profitable joint product–service channels: case study on tablet and eBook markets

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Abstract

Consumers' choice of services and the product platforms that deliver them, such as apps and mobile devices, or eBooks and eReaders, are becoming inextricably interrelated. Market viability demands that product–service combinations be compatible across multiple producers and service channels, and that the producers' profitability must include both service and product design. Some services may be delivered contractually or physically, through a wider range of products than others. Thus, optimization of producers' contingent products, services, and channel decisions becomes a combined decision problem. This article examines three common product–service design scenarios: *exclusive*, *non-exclusive asymmetric*, and *non-exclusive symmetric*. An enterprise-wide decision framework has been proposed to optimize integrated services and products for each scenario. Optimization results provide guidelines for strategies that are mutually profitable for partner–competitor firms. The article examines an example of an eBook service and tablet, with market-level information from four firms (Amazon, Apple, Barnes & Noble, and Google) and conjoint-based product–service choice data to illustrate the proposed framework using a scalable sequential optimization algorithm. The results suggest that firms in market equilibrium can markedly differ in the services they seek to provide via other firms' products and demonstrate the interrelationship among marketing, services, and product design.

Key words: products, services, channel design, conjoint analysis, product–service systems

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1. Introduction

The integration of services and products enhances both the profitability and sustainability of innovating firms. An oft-cited example concerns the interrelation of digital services delivered via tablets, e.g., from the App Store in an iPad, or through Amazon in a Kindle. The importance of product–service (PS) integration extends well beyond handheld devices (Brady, Davies & Hobday 2006; Hudson, Fudge & Rae 2011), with early definitions establishing 'a marketable set of products and services capable of jointly fulfilling a user's need' (Mont 2002) to achieve greater economic value than conventional product-oriented businesses (Baines *et al.* 2009; Roy & Baxter 2009). Research on these so-called

Product–Service Systems (PSS) has been conducted on the full spectrum of the product/service life cycle, from planning to delivery (Sakao & Lindahl 2009). While jointly designing services, products, and their channels, the role of services may be undervalued: 'Some of the companies that have made tablets and put them on the market have not been successful, because they made *tablets*. They did not make *services*.' (Jeff Bezos quoted in Hudson *et al.* (2011)).

The present article reports research focused on the tablet and eBook markets. The definitions of key terms used are as follows: (1) *producers* are firms developing and providing both tablets and eBooks, such as Amazon, Barnes & Noble (B&N), Apple, and Google; (2) *competitors* indicate other producers in the market other than the focal firm; (3) *products* are tablets such as Kindle, Nook, iPad, and Nexus, which are devices for using services; (4) *services* indicate online content such as eBooks; (5) *service platforms* are online markets to buy eBooks, such as Amazon, B&N, iBooks, and Google Play; note that Amazon and B&N use the same name in the producer and service platforms; and (6) *product–service channels* or simply *channels* indicate the connections between tablets and eBooks; e.g., if a channel connects Kindle with iBooks, Kindle users can buy eBooks from iBooks.

Product–Service (PS) channels are generally used to transfer, amplify, and control service contests, and they can be explained in various ways and perspectives depending on the context (Sakao & Shimomura 2007). While PS channels can represent compatibility between services and products from the *customer's* perspective, they can also represent the cooperation between a competitor's service and product from the *producer's* perspective. Moreover, competitors' services can complement the firm's products but are substitutes for the firm's own services. Furthermore, while competitors' products are substitutes for the firm's product, they can complement the firm's own services. PS channels can also interact with the supply chains, where the product is part of a supply chain and services are provided by the firm but also by its competitors.

In our research, PS channels differ substantially from conventional distribution channels across at least four dimensions. First, rather than being delivered via an intermediary retailer, PS channel services are delivered through products. Second, in a PS channel, producers can be both product and service suppliers; service platforms (e.g., app stores) can include a wide array of external service suppliers (e.g., app developers). Third, rather than focusing on a single customer choice, PS channels are designed around customers making multiple choices sequentially: a typical customer first chooses a product, and then chooses services through that product for the period of product ownership; this differs from a complementary goods market, where a retailer sells a bundle of services and products to a customer just once. Fourth, while the PS channel structure is itself a design decision (hence amenable to optimization), the analyses of traditional channels typically assume a predetermined fixed structure.

To operate and compete successfully in an integrated PS market, producers must examine profitability jointly, that is, with both services and product design(s) serving as their delivery vehicles. Research in profit-maximizing product design methodology has long been a staple of academic marketing, especially via the conjoint approach (Green & Krieger 1991; Moore, Louviere & Verma 1999), with ancillary applications to optimal service design (Pullman & Moore 1999; Easton & Pullman 2001). Research in the operations management and engineering design fields have extended this approach to multidisciplinary design comprising engineering, manufacturing, and policy (Michalek, Feinberg & Papalambros 2005; Lewis, Chen & Schmidt 2006; Frischknecht, Whitefoot & Papalambros 2010; Kang 2014). Much of the previous research in profit-maximizing design has focused on either the service or the product aspect in isolation. However, some studies have addressed service and product design jointly, mainly in after sales and related services such as scheduled maintenance and repair (Cohen & Whang 1997), or wait time and reliability in delivery (Verma *et al.* 2001). Channels analyzed in prior literature where consumers consider only whether add-on services may be useful after product purchase differ from current market integration conditions, where the choice of services is an integral part of product choice. In Barczak, Griffin & Kahn's (2009) review of drivers of success in new product development, only about one tenth of the firms were primarily service-oriented, while one third were a mixture of services and products. The latter have a complex array of decisions to make regarding the attributes of their products, what services to offer, whether to license those services to other firms or not, and whether to allow other firms' services on their own devices. The present paper offers a way to organize, formalize, and optimize these interlinked decisions.

Producers must have foresight about service offerings, since they drive primary consumer product choice and affect a firm's overall profitability. Two issues need to be focused on: (i) compatibility between services and products from the customer's perspective, and (ii) strategic cooperation among competitors' services and products. Hence, a broad class of PS markets, characterized by several core assumptions are modeled and analyzed:

(1) Producers supply both services and associated products;
(2) Customers can purchase other producers' services, if available;
(3) Customers desire multiple services, and purchase a particular product that enables such multiple access (i.e., purchases through a service platform); and
(4) Channel decisions among competitors require contractual agreements.

Despite the variety of decisions across this market set-up, all the assumptions can be addressed via formal optimization with respect to three interrelated quantities: product prices and attributes, service prices and attributes, and the nature of the PS channel itself. The difficulty in directly optimizing the entire system using common tools arises from the PS channel structure being a shared decision variable *across* competitors.

The aim here is to present an enterprise-driven decision-making framework to design products, services, and especially PS channels at the same time, with application to the tablet–eBook market. The study shows how to leverage game theory techniques to establish and determine market equilibria for various common market structures, and then illustrates the (equilibrium) solution method using real data from tablets and eBook services to calibrate quantities of managerial importance.

The remainder of the paper is organized as follows. Section 2 describes related work in PSS, while Section 3 introduces the associated design profit maximization framework. Section 4 illustrates the proposed method using an application of the tablet and eBook services design example, and the results are discussed. Section 5 offers conclusions, limitations, and directions for future research.

2. Theoretical framework: related prior research

Systems comprising services and products have appeared in prior literature in various disciplines. PSSs were introduced by Goedkoop *et al.* (1999), who defined them as 'a marketable set of services and products capable of jointly fulfilling a user's need.' This has since been regarded as an emerging research area for integrated PS ecosystems (Mont 2002; Baines *et al.* 2009; Roy & Baxter 2009); full reviews of recent literature appear in Beuren, Ferreira & Miguel (2013), and Reim, Parida & Örtqvist (2015). Besides the tablet and digital service market example discussed earlier, a frequently used example in this line of research is the case of Rolls-Royce PLC, which supplies total-care package services to airlines, as opposed to merely selling gas turbine engines alone. This business model, often referred to as 'power by the hour' (e.g., Smith 2013), works by supplying services to maintain and repair engines, collecting data on product performance, and using them to upgrade engine efficiency, while reducing the costs and environmental impact. Sundin & Bras (2005) also claim that product remanufacturing in PSS makes the business model more environmentally and economically attractive compared to conventional ones. Baines *et al.* (2007) explained this as a special case of 'servitization,' a business model transformation of 'sale of product' to 'sale of use.' Although the range of extant service integration research is vast, relatively little research is aimed at market-driven profit maximization design approaches for producers to implement this paradigm in a practical manner (Vasantha *et al.* 2012), with notable exceptions being financial service 'products' (e.g., Thornton & White 2001; Lee 2002).

In marketing, product design research focusing on profit optimization has a rich history (e.g., Moore *et al.* 1999; Green, Krieger & Wind 2001). One major input for such methods is the quantification of consumer preferences and choice shares, typically achieved via conjoint-based methods. Since demand can be written as a function of product attributes and price, conjoint methods allow optimization for various metrics such as sales, shares, and profit (given a product cost model, which manufacturers can supply internally).

A similar profit maximization approach (based on the conjoint/choice model) has been applied to service design (Pullman & Moore 1999; Easton & Pullman 2001). Service design research generally addresses both operations and marketing for the following reason: although product design methods are applicable to service design, services possess unique characteristics – such as simultaneity of production, consumption, perishability, inability to stockpile, etc. – so that operations management techniques can handle service capacity and demand management (Pullman & Moore 1999). Service design research considers not only tangible services (i.e., technical features), but also how the service is delivered, such as waiting lines, service delays, scheduling, and congestion in the service facility (Pullman & Moore 1999; Easton & Pullman 2001). Several articles have addressed service and product characteristics together, though not in PS channels specifically. For example, Cohen & Whang (1997) designed the joint product/service bundle, addressing trade-offs between product profit and after-sales service profit, and Verma *et al.* (2001) addressed product and process attributes as key inputs regarding the 'operating difficulty' of meeting customer demand patterns. Kang, Feinberg & Papalambros (2013) proposed an integrated optimization framework to codesign products (e.g., tablets) and services (e.g., eBooks and cloud services) to maximize overall profits.

Real product design decisions cannot be made based only on marketing considerations. The marketer and engineer need to consider the trade-offs between marketable design and feasible design (Michalek *et al.* 2005, 2011). Although marketing research does not typically consider design feasibility, engineering design research has begun to adopt profit optimization as an enterprise-driven design objective subject to engineering constraints. This design for market systems (DMS) approach integrates marketing, engineering, manufacturing, operations, and policy considerations into a profit optimization framework (Michalek *et al.* 2005; Lewis *et al.* 2006; Frischknecht *et al.* 2010; Kang 2014).

Profit optimization of multiplayer channels typically follows game theory, with the Nash equilibrium condition that no player can gain by altering his/her decisions (Nash 1950, 1951). While there are different game theory concepts such as Cournot, Bertrand, and Stackelberg solutions, the appropriate solution concept in our context is the Stackelberg solution because the focal firm producing the product/service moves first and the competitors then decide their products/services. This Stackelberg solution has been widely used for product design optimization under competition in DMS research (Michalek, Papalambros & Skerlos 2004; Shiau & Michalek 2009*b*; Kang *et al.* 2016).

Since each channel player's decision can affect the other channel player's profits and subsequent actions, it is important to understand the relationships between channel decisions, an observation that goes back to the findings of Jeuland & Shugan (1983). Sudhir (2001) further categorized these relationships according to manufacturer–manufacturer interaction, manufacturer–retailer interaction, the retailer pricing rule, demand functional form, and wholesale price information availability. Sadeghi & Zandieh (2011) developed a two-player non-cooperative game framework for product portfolios while considering customer–engineering interactions, while Cai, Dai & Zhou (2012) addressed the combination of exclusive channel and revenue sharing strategies for complementary goods markets. Some engineering design research (Williams, Azarm & Kannan 2008; Shiau & Michalek 2009*a*) have begun addressing the distribution channel to optimize product design for suppliers' profit, subject to enhanced profitability of retailers. Shiau & Michalek (2009*a*) focused on product design and the 'conventional' distribution channel via a game theory approach. Aribarg & Foutz (2009) addressed category-based choice modeling for complementary products in a study on cell phones and service plans, but in the context of a single choice of PS bundle, as opposed to sequential choices of products, and multiple services where market-based asymmetries exist.

Overall, as disciplines, marketing, design, and operations have each begun to address the complex task of optimizing subsets of product attribute, service attribute, and channel structure variables. To date, however, channel structure has been either predetermined or closely linked to the nature of the products themselves, for example, through unique service providers. In contrast, the channel structure is here considered as a *variable* that is interrelated with all other variables and allows asymmetries in service provision and sequential consumer choices. Game theory considerations guide solutions through this high-dimensional space of possible joint product, service, and channel configurations, where multiple services can be offered via each product's platform.

3. Methodology: proposed model

3.1. PS channel design decisions

For modeling a PS channel, the key trade-offs in PS channel design decisions need discussion. A simple example helps illustrate the interconnectedness of the service and product design optimization problems. When a product is launched, the producer must determine its price, which can be approached with standard techniques (e.g., conjoint and a time-discounted or finite-horizon profit model). For PS channels, the product price setting must consider the demand for associated services, in addition to what might happen if a lower initial product price spurs demand not only for the producer's own services, but also for the competitors' services that can be accessed through its device. If the channel is exclusive (the producer's customers can only access its services on its devices), the lower product price may translate into greater demand for costly services down the road – the inspiration behind the saying 'give away the razors and get them on the blades' (Anderson 2009). In a non-exclusive channel, one might give away the razors and see a competitors' sales surge for the blades, in effect, leading to a double loss. Yet the seemingly simple solution of ensuring no competitor's services are available makes the core product less versatile, and therefore placed at a disadvantage to more open platforms, a situation reminiscent of the early debates between the Apple (closed) and Microsoft (open) Operating System development platforms. This additional source of consumer freedom in the PS channel renders PS choice and demand far more complex to model. Since the particular PS channel availability is a shared decision variable, firms need to understand how the PS channel decisions affect not only their own service and product demand levels, but also those of competitors' shared channels.

The PS channel design problem is well exemplified by eBook service and tablet designs, the specific application examined later in this article. For example, Kindle/Amazon Books (Amazon), Nook/B&N (Barnes & Noble), iPad/iBook (Apple), and Nexus/Google Play (Google), supply both eBook services, and associated core tablet products. Assuming that all PS channels were exclusive, Kindle users could avail only Amazon eBooks, and Amazon can supply eBooks only to Kindle users; iPad users are limited to iBook; and iBook can supply iPad users alone. Yet in reality, PS channels are non-exclusive and, importantly, asymmetric: at the time of data collection (see Section 4.1), a Kindle user is limited exclusively to the Amazon eBook market, as Amazon's App Store lacks an iBook app; yet Amazon supplies eBook services not only to Kindle, but also the iPad (via the Kindle app in Apple's App store). That is, iPad users can use not only iBooks but also Amazon eBooks, but iBooks supplies eBook services to only the iPad users (Bläsi & Rothlauf 2013; Ritala, Golnam & Wegmann 2014).

3.1.1. Channels and customer choice

The effect of the PS channel structure on customer choices is clear from the fact that customers choose services from multiple providers, i.e., other than the ones explicitly provided by the manufacturers of their equipment. This effect cuts both ways: the choice of product is influenced by which services will be available while using any particular one. In a non-exclusive channel structure, when choosing a product, customers can consider service quality and price, as well as how many services (i.e., service variety) are available through any particular product. The PS channel thereby affects the product choice and service demand. For example, an Amazon customer who has many Amazon eBooks does not need to buy a Kindle specifically: she or he has other options, such as the iPad Kindle app. Analogously, an iPad user does not need to buy all, or indeed any, eBooks through iBooks, because other iPad-compatible options, like Amazon, are available.

3.1.2. Channels and product design

While PS channels have a clear impact on product choice, their structure also affects producers' *design* decisions. When a producer supplies its services to other competitors' products, it allows users of those products to access its own content. When that content is proprietary, those who chose the producer's product(s) merely to be able to access their content no longer have to use this choice criterion. For example, many current Apple programs are specific to their own operating system; those wishing to use these programs must purchase them from Apple, and importing the software to other operating systems might therefore lower the product demand for Apple, overall. On the other hand, when a producer allows its product to use other competitors' services, its product becomes more attractive due to increased service variety; however, it may also cede service demand to competitors. Thus, the decision to 'open up' a device to services from others presents a dilemma, involving trade-offs between demand or the share for a product, and for its formerly exclusive services.

3.1.3. Adding and deleting channels

This sharing of the PS channel decision is affected by competitors' decisions in at least two major ways. The first and most obvious is that the PS channel decision requires acceptance from competitors. Although deleting the channel – i.e., an equipment manufacturer deciding to no longer support content from a specific provider, or a provider electing to no longer serve a particular device – may be decided by each producer individually, adding a channel requires an agreement between two partners, a decision that can hinge on the predicted profit change for both. If adding a channel brings more of a valued quantity (usually, profit, but potentially also sales or share) to both producers, it should be accepted *ceteris paribus*.

Second and less obvious, the PS channel can entail different levels of ease of use. A producer may offer more advantages to its own PS channel than to a channel with other competitors. For example, in its early days, Apple allowed iPad users to shop for eBooks (from Amazon) through the Kindle app; however, Apple began to require a 30% portion of the revenue from each Amazon book purchase on iOS, perhaps in a bid to protect its own iBook service. Amazon decided not to include a store function in the Kindle app on iOS. Therefore, Kindle app users could no longer shop for Amazon eBooks directly; instead, iPad users needed to follow the more laborious route of shopping for Amazon eBooks from a web-based store outside the app, sync them with the app on the iPad, and then access them. In short, the ease of use of services can vary according to competitors' PS decisions. Notably, PS channels differ critically from 'mixed source' applications (e.g., Casadesus-Masanell & Llanes 2011), where the question is one of 'opening up' a platform to development by others, while not contractually licensing it for mutual profitability.

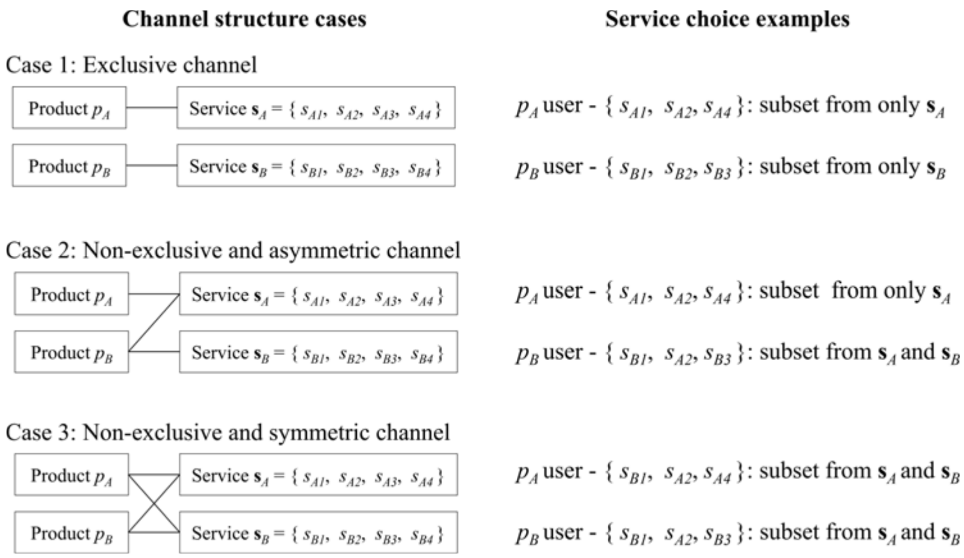

Figure 1. Examples of market settings.

To sum up, in order to coordinate PS profitability, producers need to strike a balance between exclusive and non-exclusive PS channels. In particular, they need to anticipate competitors' potential profit changes to negotiate a mutually beneficial channel decision. For example, a tablet producer can only reasonably propose the support of eBooks from another firm if the arrangement is profitable to that firm. In the modeling approach presented in this article, this insight will be used – for the first time to the best of our knowledge – to impose constraints on possible contractual solutions. One must note that optimal prices and attributes for both services and products depend on the PS channel structures themselves and cannot be optimized in an 'exogenous' manner, and then fed into the PS design problem as fixed quantities. That is, producers need to understand the relationships among all these variables, and then optimize them *concurrently*. Prior work in marketing and management (Jeuland & Shugan 1983; McGuire & Staelin 1983; Lee & Staelin 1997; Sudhir 2001; Luo, Kannan & Ratchford 2007; Cai *et al.* 2012), design (Williams *et al.* 2008; Shiau & Michalek 2009*a*), and systems (see, e.g., Jun, Ward & Clarkson 2010; Zhang *et al.* 2016) has addressed distribution channels for maximizing profit, but these are 'conventional' channels between suppliers and retailers with a given fixed structure, and not channels selected for joint optimization. Here, a purview of prior works is provided to consider the types of channel structures coming to dominate online commerce and their joint implications for product design and marketing.

3.2. Market setting

This section details the market setting for the integrated PS business model addressed in this study. Figure 1 depicts several representative PS channel structures involving two producers. Service choice examples are also shown according to their PS channel structures.

The key properties of the types of systems depicted in Figure 1:

(1) A *producer* supplies a service and product together. Producer A supplies product p_A and associated service $\mathbf{s}_A$; producer B supplies product p_B and associated service $\mathbf{s}_B$.

(2) A *service* consists of multiple subservices, e.g., $\mathbf{s}_A$ includes $\{s_{Ai}\} = \{s_{A1}, s_{A2}, s_{A3}, s_{A4}\}$, while $\mathbf{s}_B$ includes $\{s_{Bi}\} = \{s_{B1}, s_{B2}, s_{B3}, s_{B4}\}$. [For example, these could be items in a web store, such as a particular book or app, as long as they are potentially purchasable from different providers.]

(3) Subservices can be unique to a particular provider or similar across providers. In the case of similar services, pairs such as, (s_{A1}, s_{B1}), (s_{A2}, s_{B2}), (s_{A3}, s_{B3}), (s_{A4}, s_{B4}) may have different prices and qualities while providing functionally equivalent benefits to the user. [Given any set of subservices from A and B – partly overlapping or not – one can always conjoin them to create a key list with matched indices, and this will be done later.]

(4) Because the products are presumed to provide similar core benefits, each customer who buys a product, chooses exactly one, either p_A or p_B; customers may elect to choose the 'outside good' (i.e., no product at all, that is, waiting), but not more than one. [This will be explicitly incorporated in the forthcoming conjoint simulation.] S/he then chooses a service – either s_{Ai} or s_{Bi}. Elected services correspond to a subset of all available services.

(5) There are three cases, in general, for two producers:

    (i) Case 1, *exclusive* channels: p_A users can use subservices from only $\mathbf{s}_A$; p_B users can use subservices from only $\mathbf{s}_B$.

    (ii) Case 2, *non-exclusive* and *asymmetric* channels: p_A users can use subservices from only $\mathbf{s}_A$; but p_B users can use subservices from both $\mathbf{s}_A$ and $\mathbf{s}_B$, so that p_B users can choose some subservices from pairs such as (s_{A1}, s_{B1}), (s_{A2}, s_{B2}), (s_{A3}, s_{B3}), (s_{A4}, s_{B4}). For example, p_B users can choose $\{s_{B1}, s_{A2}, s_{B3}\}$, that is, two items from their own product manufacturer, B, and one from A.

    (iii) Case 3, *non-exclusive* and *symmetric* channels: regardless of product choice, customers can choose any subservices.

(6) Adding a channel requires acceptance from competitors, whereas removing a channel can be decided by only one partner (unless contractually disallowed). For example, when producer A wants to add a channel between p_A and $\mathbf{s}_B$, or a channel between $\mathbf{s}_A$ and p_B, acceptance by producer B is required.

The assumption is that a customer chooses a *product* based on product price, product attributes, and the PS channel; and chooses a *service* based on service price and attributes. Taking the example of the tablet and eBook service market, p_A and $\mathbf{s}_A$ can be the Kindle and Amazon market, respectively; p_B and $\mathbf{s}_B$ can be the iPad and iBooks markets, respectively. That is, $\{s_{A1}, s_{A2}, s_{A3}, \ldots, s_{AM}\}$ are eBooks in the Amazon market and $\{s_{B1}, s_{B2}, s_{B3}, \ldots, s_{BM}\}$ are eBooks in the iBooks market. In practice, M, the number of total potential books, can number in millions. Note that s_{At} and s_{Bt} are the same book, where $t = 1, 2, 3, \ldots, M$, and can either take on a value of 1, if the book is available, or 0 if it is not. In the service and product market, the book price and shopping methods can be different. Each customer can purchase a different number of eBooks for a different period of product ownership.

3.3. Demand and profit modeling under the PS channel

Services and products are modeled based on the market set-up described above, with a demand model that can be modified for different market settings. This study adopts the latent (to the researcher) consumer utility concept underlying random-utility-based discrete choice models (Green & Krieger 1996), which have come to dominate both theoretical and applied work in the marketing field, as has the Hierarchical Bayes (HB) choice-based conjoint (Rossi & Allenby 2003; Gustafsson, Herrmann & Huber 2013) for estimating heterogeneous customer preferences (often referred to as 'part-worths' for discrete or discretized attributes).

Product demand modeling follows recent design research using the HB approach (e.g., Michalek *et al.* 2011), which itself builds upon decades of research in preference elicitation and measurement (see, for additional detail, Green *et al.* (2001) or Gustafsson *et al.* (2013)). The basic process can be summarized as follows: (i) Data are gathered using a choice-based conjoint task; (ii) HB choice model parameters (i.e., individual-level part-worths) for the preference function are estimated; (iii) splines interpolate across (discrete) part-worths, enabling efficient optimization over a continuous design space; (iv) market demand is predicted, based on choice probabilities and potential market size.

The individual-level discrete utility, v_{ip_j}, of individual i and product p_j takes the usual form with respect to discrete attributes levels, as

$$v_{ip_j} = \sum_{k=1}^{K} \sum_{l=1}^{L_k} \beta_{ikl} z_{jkl}, \tag{1}$$

where z_{jkl} are binary dummy variables indicating if alternative product j possesses attribute k at level l; z_{jkl} represent product price, product attributes, and service compatibility; β_{ikl} are the part-worth coefficients of attribute k at level l for individual i.

Service compatibility is determined by the structure of the PS channel decisions made by producers. For example, in Figure 1, there are four PS channel decision variables: potential linkages between p_A & $\mathbf{s}_A$, p_A & $\mathbf{s}_B$, p_B & $\mathbf{s}_A$, and/or p_B & $\mathbf{s}_B$. Channel decision variables are binary: 1 indicates that a channel is connected (as depicted by lines in Figure 1), while 0 indicates that it is not. Note that p_A & $\mathbf{s}_A$, and p_B & $\mathbf{s}_B$ should *always* be connected, since producers will by necessity make their services available using their own product platforms. In this case, customers can avail three levels of service compatibility: $\mathbf{s}_A$, $\mathbf{s}_B$, and $(\mathbf{s}_A, \mathbf{s}_B)$, according to their product choice. In our forthcoming empirical example, there will be four producers, and therefore $2^4 - 1 = 15$ levels of service compatibility, as shown later in Table 2.

The HB choice model estimates the conjoint part-worths via a two-level process. At the 'upper level,' we assume individuals' part-worths, $\boldsymbol{\beta}_i$, follow a multivariate normal distribution, $\boldsymbol{\beta}_i \sim N(\boldsymbol{\theta}, \boldsymbol{\Lambda})$, where $\boldsymbol{\theta}$ indicates a vector of mean individual preference and $\boldsymbol{\Lambda}$ is their covariance matrix; that is, the former ($\boldsymbol{\theta}$) suggests what a 'typical' consumer would like, whereas the latter suggests how much variability there is in consumer preference (diagonal elements of $\boldsymbol{\Lambda}$), as well as how preferences for one attribute help predict those for a different attribute (off-diagonal elements of $\boldsymbol{\Lambda}$). At the 'lower level,' choice probabilities have a logit form, which is particularly amenable to gradient and elasticity computation:

$$Pr_i(p_j) = \exp(v_{ip_j}) \Bigg/ \sum_{j' \in \mathbf{J}} \exp(v_{ip_{j'}}), \tag{2}$$

where $Pr_i(p_j)$ is the probability that individual i chooses product option p_j from a set of product alternatives $\mathbf{J}$.

Product demand can be calculated, for various market scenarios, based on heterogeneous customer preference models. Either the total or average demand across participants can be used for optimization (as these contain identical information); the latter is given by:

$$q_{p_j} = \frac{1}{I} \sum_{i=1}^{I} \mu Pr_i(p_j), \tag{3}$$

where q_{p_j} is the product demand of product option p_j, μ indicates the potential product market size (i.e., number of users), and I indicates the total number of participants.

Next, *service* demand is calculated via conditional probability, given *product* choice and demand. A choice-based conjoint survey can be conducted (as described previously) to gather service preference data; the estimation of service attributes part-worths proceeds analogously to that of products. Note, however, that the setting is somewhat more complex, due to the following reasons: (1) service alternative options depend on product choice; (2) services consist of subservices; and (3) service choices occur on multiple occasions.

The individual-level discrete utility, $v_{is_{h_t}}$, of individual i and service s_{h_t}, can be expressed in linear form with respect to discrete attribute levels as

$$v_{is_{h_t}} = \sum_{m=1}^{M} \sum_{n=1}^{N_m} \beta_{imn} z_{h_t mn}, \tag{4}$$

where h is a service platform, t indicates subservice, $z_{h_t mn}$ are binary dummy variables representing service price, and attributes m at level n, and β_{imn} are the part-worth coefficients of service attribute m at level n for individual i. Using the HB choice model, β_{imn} are estimated, and then service choice probabilities can be calculated using the logit-based expression

$$Pr_i(s_{h_t}|p_j) = \frac{\exp(v_{is_{h_t}})}{\sum_{h' \in \mathbf{H}_{p_j}} \exp(v_{is_{h'_t}})}, \tag{5}$$

where $Pr_i(s_{h_t}|p_j)$ is the conditional probability that individual i, after choosing product p_j, will then choose service option s_{h_t} from the set of service alternatives $\mathbf{H}_{p_j}$ of product p_j. The service alternatives available to a consumer who has selected a particular product are dictated by the PS channel decision made by its producer. Equations (4) and (5) represent, for simplicity of exposition, single choices of subservices (e.g., one eBook choice). Service demand can be calculated by summing all subservice choices over all products during the product's life cycle.

As before, the averaged (across consumers) demand value is used for profit optimization:

$$q_{\mathbf{s}_h} = \frac{1}{I} \sum_{i=1}^{I} \sum_{t \in \mathbf{T}_i} \sum_{j' \in \mathbf{J}} \mu Pr_i(p_{j'}) Pr_i(s_{h_t}|p_{j'}), \tag{6}$$

where $q_{\mathbf{s}_h}$ is service demand of service option $\mathbf{s}_h$, μ indicates the potential product market size, $Pr_i(p_{j'})$ is choice probability of product $p_{j'}$, $Pr_i(s_{h_t}|p_{j'})$ is conditional probability of service s_{h_t} given $p_{j'}$, $\mathbf{J}$ is a set of product alternatives, $\mathbf{T}_i$ is a set of service choices of individual i, and I indicates total number of individuals. The set $\mathbf{T}_i$ is can be determined by foreknowledge, an additional survey, or inferred from market statistics (e.g., eBook purchase history).

To illustrate, Equations (1) to (6) are applied to Case 2, that is, a non-exclusive and asymmetric channel (as in Figure 1), for two products, A and B:

$$q_{p_A} = \frac{1}{I}\sum_{i=1}^{I}\mu\left[\frac{\exp(v_{ip_A})}{\exp(v_{ip_A})+\exp(v_{ip_B})+\exp(v_{ip_0})}\right] \tag{7}$$

$$q_{p_B} = \frac{1}{I}\sum_{i=1}^{I}\mu\left[\frac{\exp(v_{ip_B})}{\exp(v_{ip_A})+\exp(v_{ip_B})+\exp(v_{ip_0})}\right] \tag{8}$$

$$\begin{aligned} q_{\mathbf{s}_A} = \frac{1}{I}\sum_{i=1}^{I}\sum_{t\in\mathbf{T}_i}&\left[\mu\left[\frac{\exp(v_{ip_A})}{\exp(v_{ip_A})+\exp(v_{ip_B})+\exp(v_{ip_0})}\right]\right.\\ &\times\left[\frac{\exp(v_{is_{A_t}})}{\exp(v_{is_{A_t}})+\exp(v_{is_0})}\right]\\ &+\mu\left[\frac{\exp(v_{ip_B})}{\exp(v_{ip_A})+\exp(v_{ip_B})+\exp(v_{ip_0})}\right]\\ &\left.\times\left[\frac{\exp(v_{is_{A_t}})}{\exp(v_{is_{A_t}})+\exp(v_{is_{B_t}})+\exp(v_{is_0})}\right]\right] \end{aligned} \tag{9}$$

$$\begin{aligned} q_{\mathbf{s}_B} = \frac{1}{I}\sum_{i=1}^{I}\sum_{t\in\mathbf{T}_i}&\left[\mu\left[\frac{\exp(v_{ip_B})}{\exp(v_{ip_A})+\exp(v_{ip_B})+\exp(v_{ip_0})}\right]\right.\\ &\left.\times\left[\frac{\exp(v_{is_{B_t}})}{\exp(v_{is_{B_t}})+\exp(v_{is_0})}\right]\right]. \end{aligned} \tag{10}$$

Here, q_{p_A} and q_{p_B} are product demands of producers A and B, respectively, $q_{\mathbf{s}_A}$ and $q_{\mathbf{s}_B}$ are analogous service demands, and '0' indicates that the customer 'chooses the no-choice option,' that is, refrains from choosing entirely. Note that Eq. (9) has one term more than Eq. (10) because service $\mathbf{s}_A$ can be used by both p_A and p_B.

Based on this demand model, the product profit and service profit are calculated as

$$\Pi_{p_j} = q_{p_j}(P_{p_j} - C_{p_j}), \tag{11}$$

$$\Pi_{\mathbf{s}_h} = \frac{1}{I}\sum_{i=1}^{I}\sum_{t\in\mathbf{T}_i}\sum_{j'\in\mathbf{J}}\mu Pr_i(p_{j'})Pr_i(s_{h_t}|p_{j'})(P_{s_{h_t}} - C_{s_{h_t}}), \tag{12}$$

where Π_{p_j} is the profit of product p_j, q_{p_j} is product demand, P_{p_j} is product price, C_{p_j} is product cost, $\Pi_{\mathbf{s}_h}$ is the profit of service $\mathbf{s}_h$, $P_{s_{h_t}}$ is price of service s_{h_t}, $C_{s_{h_t}}$ is cost of service s_{h_t}, and other symbols retain their definitions from Eq. (6). Our goal is to optimize the sum of the service and product profits.

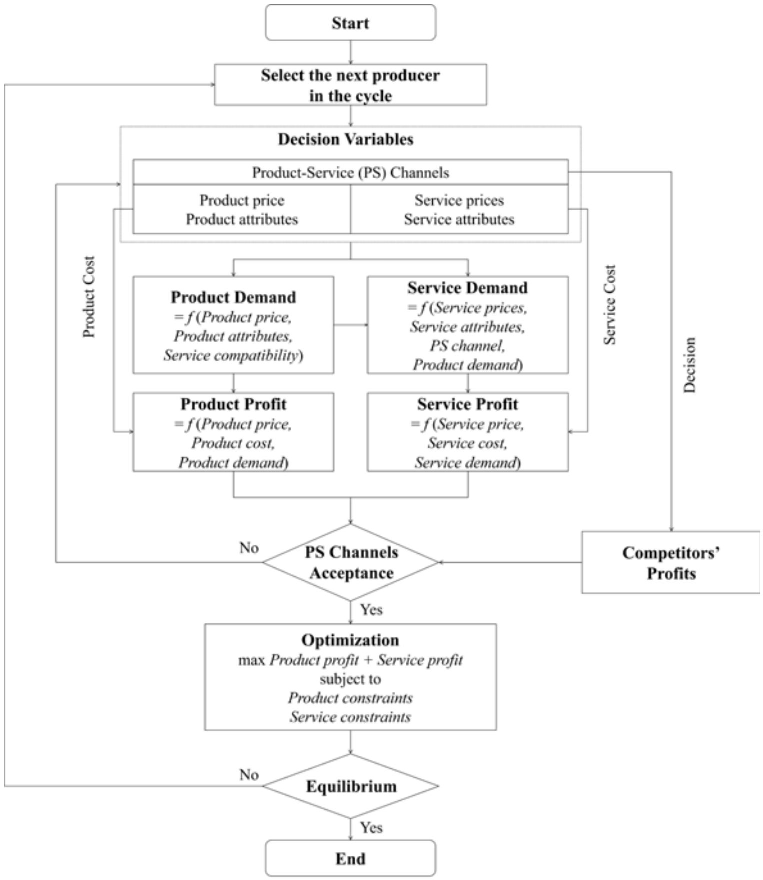

Figure 2. Profit maximization framework for PS design.

3.4. Product–service design framework

Based on the demand system above, a framework to optimize profits for PS design is proposed and depicted schematically in Figure 2. Following a predetermined order, one firm is selected as the focal firm among producers who optimizes its profit. Then, the next producer is selected as the focal firm who maximizes profit, while the previous focal firm becomes one of its competitors. This sequential optimization proceeds until the optimization result converges to the equilibrium.

Before optimization, the current PS channel structure and competitors' service and product prices/attributes are set. Decision variables are the PS channel structure, product price, product attributes, service prices, and service attributes. Note that the product attributes and service attributes for optimization are selected by the designer. This selection is beyond the scope of the research reported here and it is challenging in its own right.

These variables are set for the competitor, then optimized for the focal firm. Note that all decision variables are optimized at the same time and a producer can access all other previous decisions during its turn. This framework is used for the design of a *single product* and *multiple services* for each producer. (Extension to product family or line design would require a straightforward modification of the present optimization framework with a concomitantly higher-order dimensional optimization; see Michalek *et al.* (2011) for additional details.)

The optimization problem for the focal firm, in each iteration, is stated as follows:

$$\max_{\mathbf{x}_{p_j},\mathbf{x}_{\mathbf{s}_h},\mathbf{ch}_{jh}} \Pi_{p_j} + \Pi_{\mathbf{s}_h} \tag{13}$$

with respect to

$$\mathbf{x}_{p_j} = [p_{p_j}, \mathbf{a}_{p_j}] \tag{14}$$

$$\mathbf{x}_{\mathbf{s}_h} = [\mathbf{p}_{\mathbf{s}_h}, \mathbf{a}_{\mathbf{s}_h}] \tag{15}$$

$$\mathbf{ch}_{jh} = [ch_{jh_1}, ch_{jh_2}, \ldots, ch_{jh_{2n-2}}], ch_{jh} \in \{0, 1\}. \tag{16}$$

subject to

$$lb \leqslant [\mathbf{x}_{p_j}, \mathbf{x}_{\mathbf{s}_h}] \leqslant ub \tag{17}$$

$$\mathbf{g}_{ch}(\mathbf{x}_{p_j}, \mathbf{x}_{\mathbf{s}_h}, \mathbf{ch}_{jh}, \boldsymbol{\Pi}_{p_{j'\in\mathbf{J}}}, \boldsymbol{\Pi}_{\mathbf{s}_{h'\in\mathbf{H}}}) \leqslant 0. \tag{18}$$

The objective of Eq. (13) is to maximize the overall profit which is the sum of the product profit Π_{p_j}, of product p_j, and the service profit $\Pi_{\mathbf{s}_j}$ of service $\mathbf{s}_h$. As introduced in Section 3.3, the product demand is calculated based on product price, product attributes, and service compatibility as per Eqs. (1) to (3). Using individuals' potential services sets, service demand is calculated based on service prices, service attributes, the PS channel, and product demand, using Eqs. (4) to (6). Product and service profits are calculated using price, cost, and demand for services and products, using Eqs. (11) and (12).

In Eq. (14), $\mathbf{x}_{p_j}$ is the vector of product design variables, where p_{p_j} is the product price and $\mathbf{a}_{p_j}$ is the vector of product attributes. In Eq. (15), $\mathbf{x}_{\mathbf{s}_h}$ is the vector of service design variables, where $\mathbf{p}_{\mathbf{s}_h}$ is the vector of service prices and $\mathbf{a}_{\mathbf{s}_h}$ is the vector of service attributes. In Eq. (16), $\mathbf{ch}_{jh}$ is the vector of channel design variables.

As discussed earlier, the PS channel is a binary design variable. So, if a channel links a product and a service platform, its value is 1, otherwise, 0. When there are n producers in the market, the PS channel can be described as an $n \times n$ matrix, as shown in Table 1. Optimization amounts to a producer's choosing values from within this matrix for its service and product options; note that diagonal values are 1 because services and products from the same manufacturer are always connected. Therefore, the number of channel design variables for the focal firm is $2 \times (n - 1)$, where the firm decides whether to supply its product to $(n - 1)$ competitors' service platforms and whether to supply its service platform to $(n-1)$ competitors' products. Eq. (17) shows bound constraints on the product and service design variables, and Eq. (18) shows inequality constraints for PS channels acceptance. $\Pi_{p_{j'\in\mathbf{J}}}$ and $\Pi_{\mathbf{s}_{h'\in\mathbf{H}}}$ indicate product profits and service profits of competitors, respectively.

A notable feature of the proposed framework is that it uses a competitor's profit change as a constraint: when a given producer wants to add channels with a competitor's product or service, if its design decision affects the competitor's profit positively, it is taken to be a feasible design decision; otherwise, it is not. In other words, a producer can only reasonably propose channels to a competitor that will enhance that competitor's profit. However, when more than

Table 1. Market setting for eBook / tablet applications

	Service (eBook market)			
	Amazon	B&N	iBook	Google Play
Product (Tablet)	\$9.78 (2.14)[a]	\$9.98 (1.81)	\$10.41 (1.64)	\$10.14 (2.32)
Kindle, \$169, 7″, 16 GB	1	0	0	0
Nook, \$149, 7″, 16 GB	0	1	0	0
iPad, \$399, 9.7″, 16 GB	1	1	1	1
Nexus, \$229, 7″, 16 GB	1	1	0	1

a Prices and figures in parentheses refer to the average prices and standard deviations, respectively, across 20 bestseller books.

three producers make decisions sequentially, some channels can oscillate between two producers by repeatedly adding and deleting. In our research, it is assumed that adding oscillated channels is not permitted after all other channels have converged. Deleting an oscillated channel has priority over adding one. For feasibility constraints (e.g., whether a product's components can fit in its case), engineering and operations simulation models (Kang, Feinberg & Papalambros 2015, 2017) that consider uncertainties (Kang, Bayrak & Papalambros 2018; Lee, Kang & Lee 2019) can be applied.

The optimization proceeds iteratively across producers. After maximizing the overall profit of a focal producer, other competitors optimize their profit using the same process that the 'optimized' producer followed. These sequential optimizations proceed until no players (producers) can find a better design (i.e., one that increases profit). This results in a Nash equilibrium, a 'solution concept' widely deployed in marketing and engineering design research (Luo *et al.* 2007; Shiau & Michalek 2009*b*; Kang *et al.* 2016). Here during the initial iteration, it is assumed that producers decide on *all* decision variables; for subsequent iterations, they decide only on product/service prices and channels. In other words, because product design decisions are slow and costly to alter, it is presumed that producers first decide product attributes, and then engage in (iterative, sequential) optimization for prices and channels for both services and products.

4. Application to the tablet and eBook market

4.1. Market setting

The proposed framework is demonstrated via tablet (product) and eBook (service) designs. Because the main purpose of this study is illustrative, market assumptions are deliberately generic, transparent, and simple, as follows. First, four main producers are selected, each of which operates in both the tablet and eBook markets: (1) Kindle/Amazon Kindle books, (2) Nook/Barnes & Noble (B&N), (3) iPad/iBooks, and (4) Nexus/Google Play books. The study focuses on single product designs (as opposed to product family designs), and therefore assumes that each producer optimizes for a single 'flagship' tablet with full-color display. For eBook services, price distributions across the four eBook markets are based on the real observed prices of 20 bestseller eBooks in each market available from a verified, published source (Gilbert 2012); the PS channel structure is based on the market situation at the time price data collection. In addition, the assumption is that when a customer shops for an eBook from her or his tablet's producer, she or he does so via an in-tablet app but uses a web-based interface for eBooks from other competitors (Bläsi & Rothlauf 2013; Ritala *et al.* 2014).

Table 1 summarizes the market setting for the study, with four flagship tablets and four eBook markets. The eBook prices shown are averages of 20 bestsellers. For example, Amazon's price of \$9.78 compares favorably with those for B&N (\$9.98), iBooks (\$10.41), and Google Play (\$10.14). The binary indicators listed in Table 1 indicate whether a channel exists between tablet and eBook markets. Note, for example, that the PS channel is asymmetric: iPad users can access all four eBook services (Row 3 of 4), while iBooks does not supply eBook services to competitors (Column 3 of 4).

4.2. Demand modeling

Two choice-based conjoint surveys were conducted, for the tablet and eBook, sequentially. 152 respondents in the United States (US) were surveyed using Amazon's Mechanical Turk (Amazon 2012*a*) in conjunction with Sawtooth Software's CBC (Choice-Based Conjoint) Hierarchical Bayes Module (Orme 2013); this sample size is comparable to those used in prior studies in the area (e.g., Michalek *et al.* 2005, with $n = 184$). Respondent demographics were broadly consistent with the US in general: 41% male, 59% female; 20% were 15–24 years of age, 49% 25–34, 16% 35–44, and 15% older than 45; 72% and 58% of the respondents reported tablet and eBook use experiences, respectively. Analogous figures for the US (Census 2012; Pew Research 2013) are: tablet users are 47% male and 53% female; 18% are 15–24 years of age, 19% 25–34, 24% 35–44, and 40% are over 45. These deviations between sample and population demographics are non-significant.

For the tablet choice-based conjoint survey, five attributes – compatible eBooks, tablet brands, price, display size, and storage – were included, as shown in Table 2. Respondents were asked to suppose that they were considering purchasing a tablet, with the specific objective that they could read eBooks, and that their tablet choices would determine which of the multiple compatible eBook services would be available to them. The survey began with an 'education' page that ensured participants understood the nature of the eBook/tablet format, co-branding, and other key elements of the market system; for example, when the tablet brand is Kindle HD, the compatible eBook options always included Amazon (i.e., ones along the diagonal in Table 1). As is typical, each choice set included a small number (in this case, three) of tablet profiles along with a 'none' option (that is, the 'no-choice option' in which the customer chooses none of the PS options).

Previous respondents from the tablet survey were surveyed again. They were told to suppose that they had bought a tablet, and then wanted to purchase an eBook. For the eBook choice-based conjoint survey, three attributes of known importance were included – eBook market, eBook price, and ease of shopping – and shown in Table 3. Subjects were told that the prices for the same book can vary across markets. As mentioned earlier, customers can buy a book from their tablet producer's market via an in-tablet app, or from another seller using a web-based store. This reflects the reality that using your tablet brand's eBook market is simply more convenient than buying from a competitor. As in the tablet conjoint, each choice set included three eBook profiles, and the option of choosing 'none.'

Table 2. Part-worths for tablet attribute levels

Attributes	Levels	Mean	STD	Importance
Compatible eBooks	Amazon	−0.86	1.16	30.5%
	B&N	−3.12	0.92	
	iBook	−3.10	1.41	
	Google Play	−2.60	1.01	
	Amazon, B&N	1.03	0.90	
	Amazon, iBook	0.97	0.88	
	Amazon, Google Play	1.11	0.97	
	B&N, iBook	−1.28	1.11	
	B&N, Google Play	−1.06	0.83	
	iBook, GooglePlay	−1.22	1.23	
	Amazon, B&N, iBook	2.33	0.87	
	Amazon, B&N, Google Play	2.30	0.97	
	Amazon, iBook, Google Play	2.05	0.89	
	B&N, iBook, Google Play	0.33	1.14	
	Amazon, B&N, iBook, Google Play	3.12	0.89	
Tablet brand	Kindle	0.62	1.76	19.3%
	Nook	−0.91	1.39	
	iPad	0.91	2.39	
	Nexus	−0.62	1.60	
Tablet Price	$129	3.41	3.25	28.2%
	$199	2.31	1.82	
	$299	0.32	0.89	
	$399	−1.98	1.98	
	$499	−4.06	2.85	
Display Size	7″	−0.48	0.83	9.8%
	7.9″	−0.13	0.74	
	8.9″	0.04	0.63	
	9.7″	0.10	0.84	
	10″	0.48	0.77	
Storage	8 GB	−1.77	1.40	12.2%
	16 GB	−0.54	0.88	
	32 GB	0.37	0.48	
	64 GB	0.78	0.76	
	128 GB	1.16	1.15	
None		−1.72	3.78	

Using HB estimation (as per Section 3.2), individual preference functions were quantified for each of the 152 respondents. Markov Chain Monte Carlo (MCMC) draws were 'thinned' to every tenth; the burn-in was 50,000 (these were discarded); and the inference proceeds from the final 50,000 draws, which were used to obtain preference part-worths. Tables 2 and 3 list estimated part-worths for each level, and the average relative importance for each attribute. Cubic spline interpolation allows the estimation of continuous preference functions from the discrete part-worths used in the study (see Michalek *et al.* 2011). Lastly, the profit

Table 3. Part-worths for eBook attribute levels

Attributes	Levels	Mean	STD	Importance
eBook market	Amazon	1.33	2.26	42.6%
	B&N	−0.65	1.31	
	iBook	−0.41	1.41	
	Google Play	−0.27	1.56	
eBook price (bestseller)	$8.99	3.63	3.86	39.5%
	$9.99	1.20	1.07	
	$10.99	−1.92	2.10	
	$11.99	−2.91	2.77	
Ease of shopping[a]	By app	1.61	2.43	17.9%
	By web-based store outside app	−1.61	2.43	
None		−3.33	3.07	

a When tablet and eBook market are from the same producer, eBooks can be purchased using an in-tablet app.

values are calculated using the means of the market response distribution based on the preference parameters of these 152 customers.

The conjoint survey was supplemented by follow-up questions aimed at assessing eventual service demand, e.g., 'Suppose you buy a new tablet now. How long do you intend to use it?' and 'Suppose you use the eBook service, how often are you likely to purchase eBooks?' The mean and standard deviation of the period of product ownership were 4.4 years and 2.7 years, respectively; analogous values for the frequency of eBook purchase were 19.2 and 15.8 books per year, respectively. These data were used in calculating individual-level service demand.[1] Recall that the price data of 20 eBooks were used (Gilbert 2012), some of which were the same across the four markets, while others differed. Average prices were used for optimization purposes.

Since tablets are multi-purpose products, estimating the market 'share' and size for tablets among eBook users is challenging. Summary statistics can provide benchmarks: 457 million eBooks were sold in 2012 (Wilson 2014), 25% of the eBooks are read on tablets (BWMBooks 2012), and the average number of eBooks read (among those who read electronically) is 24 books per year (Rainie 2012). Based on this data, a rough estimate of the projected tablet demand used for eReading is 4.76M (i.e., 457M $\times$ 25%/24). Because this is an input figure that 'scales linearly' within the model, improved estimates of the market size can be easily included in the methodology.

4.3. Cost and optimization modeling

To put our method to use, producers must build their own costing models. To this end, prior studies of tablet cost modeling are adapted (Wang, Kannan & Azarm 2011) focusing on display and memory storage costs:

[1] Individual service demand can be calculated by eliminating $I^{-1}\sum_{i=1}^{I}$ from Eq. (6), so the sum is only over the $\mathbf{T}_i$ observations for individual i. For example, if individual i purchases 19 eBooks per year, and she or he uses a tablet for 3 years, $\mathbf{T}_i = 19 \times 3 = 57$.

$$C_{d_j} = C_{d0} q_{d_j}^{b_1} z_{d_j}^{b_2} \tag{19}$$
$$C_{m_j} = C_{m0} z_{m_j} \tag{20}$$

where C_{d_j} is the cost of LCD display j, C_{d0} is \$50 (of variable cost, used as a basis value), q_{d_j} is overall demand for displays, z_{d_j} is display size in inches, b_1 and b_2 are parameters (estimated in prior work at -0.1032 and 0.7965, respectively), C_{m_j} is cost of flash memory j, C_{m_0} is \$4 (of variable cost), and z_{m_j} is memory size in Gigabytes (GB); any of these values can be updated as newer information becomes available. Display costs follow economies of scale, although here other costs are considered to be constant with respect to demand/production, including costs for batteries, integrated circuits, and 'miscellaneous,' which are assumed to be \$115 in total (as per Wang *et al.* 2011). EBook prices can themselves be broken down into margins, royalty fees, taxes, and delivery costs. Since royalty fees make up the majority of an eBook's price (Amazon 2012*b*), only the royalty fee is considered as the cost of eBook service provision, and the iBooks' royalty rate, 70% is used (Mill City Press 2012).

4.3.1. Decision variables and optimization

Figure 2 is referred to again for an overview of the nature of the decision space and overall optimization strategy. Optimization can be achieved in various ways, and the general procedure is agnostic, to what is used. However, the procedure described below has the virtue of scaling well in the number of PS-producing firms. At its center, is an iterative process that checks whether equilibrium conditions are met at every pass. In broad schematic, at every pass, each of the four producers must enact two types of Yes/No decisions: (1) on each of the services for the other three producers (they must always offer their own service); and (2) on whether to offer its service on the other three platforms. This entails eight options which enable other services to be allowed on its product, and eight options which enable products to carry the producer's own services. These total 64, in all. To choose among these 64 options – each of which requires that all other design elements are optimized – each of the four producers optimizes (as detailed subsequently). After all the four producers have done this, equilibrium conditions are checked; if they are not met, iteration continues. [As mentioned above, it is also possible to perform a one-shot optimization for all $(64)^4 = 16777216$ ensuing possibilities, but this number grows exponentially in the number of producers – with k producers, there $2^{2k(k-1)}$ possibilities – and is prone to local maxima.]

The decision variables are the PS channels ($z_1, \ldots, z_{16} = 0$ or 1), tablet price (\$129 $\leqslant z_{17} \leqslant$ \$499), display size ($7 \leqslant z_{18} \leqslant 10$), memory storage size ($8 \leqslant z_{19} \leqslant 128$), and eBook price change ($-\$2 \leqslant z_{20} \leqslant +\$2$). The PS channel decisions are binary decision variables. Because there are four products and four services, the PS channel matrix, as mentioned previously, is 4 by 4, so the space of possible channel combinations has the size $2^{(4\times4)} = 65,536$. However, some of these are impermissible: the PS channels between the same producers (i.e., on the diagonal) must be set to 1, and a producer can control only its channels so that each producer has possible PS channel options of $2^6 = 64$. Procedurally, as depicted in Figure 2, each producer optimizes its decision sequentially so that the tablet brand and the eBook market brand are optimized in order. As discussed earlier, in terms of PS channel acceptance between competitors, *removing* a PS channel does not require the other party's agreement, while *adding* a PS channel is possible only

Table 4. Sequential optimization scenarios

Scenarios	Sequential optimization order			
	First	Second	Third	Fourth
Exclusive channel	Amazon	B&N	Apple	Google
Optimal channel-S1	Amazon	B&N	Apple	Google
Optimal channel-S2	Google	Apple	B&N	Amazon
Optimal channel-S3	B&N	Google	Amazon	Apple
Optimal channel-S4	Apple	Amazon	Google	B&N
Non-exclusive symmetric channel	Amazon	B&N	Apple	Google

when neither player's profits are harmed. Profit optimization is achieved subject to this PS channel constraint in addition to the tablet and eBook design boundary constraints.

For the equilibrium calculation, optimization is carried out sequentially; this is repeated until the optimal design decisions of all producers have converged, and profit cannot be enhanced by further changes. Previous producers' (optimal) decisions are used for the next producer's optimization, as parameters of the demand model. Because product features cannot be changed frequently, it is assumed that producers first decide on all decision variables, including product attributes, and secondarily decide on only product/service prices and channels.

The study compares six different scenarios varying in the type of channel and optimization orders as shown in Table 4. The first and last scenarios are used as the baseline to compare with optimal channel scenario. Since there could be a first mover advantage in the game, four optimal channel scenarios are set (S1, S2, S3, and S4) with different sequential optimization orders.

An exclusive channel scenario is the case where there is no channel among competitors, and a non-exclusive symmetric channel scenario is the case where all competitors are fully connected through channels, as explained in Section 3.2. These two scenarios fix channels, and then optimize other decision variables in order to compare them with the scenarios that find optimal channels. In the pilot test, when channels are not decision variables, the sequential optimization order does not affect the results significantly. Therefore, the exclusive channel and non-exclusive symmetric channel scenarios use the same optimization order as S1. Optimal channel scenarios are the cases that optimize all decision variables including channels at the same time. There are 24 cases when four producers make decisions sequentially, but four cases were selected where each producer can experience all orders in balance.

Since the design problem is a mixed-integer optimization one due to discrete channel decisions, all possible channel configurations are examined and the continuous decision variables are optimized for each channel configuration on every optimization pass. The profit optimization problem was solved via SQP (sequential quadratic programming), implemented in MATLAB (MathWorks 2017). Since there are 64 possible PS channel configurations for four producers, enumeration with deterministic algorithms was possible. However, if there are many producers in the market, heuristic optimization algorithms will likely be necessary.

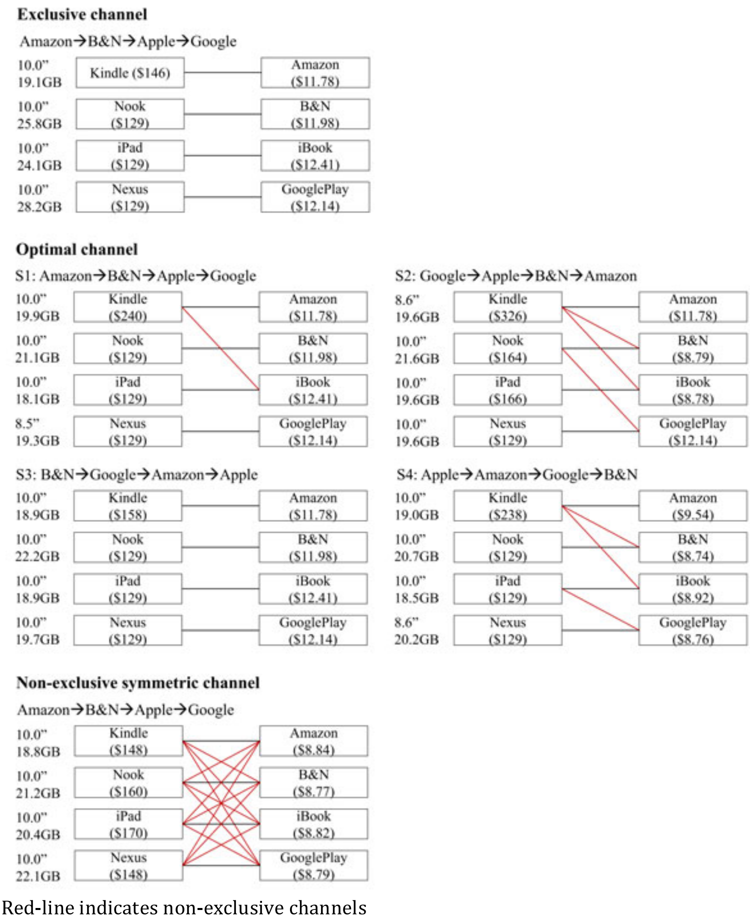

Figure 3. Optimal design decisions for six scenarios.

Owing to high computational costs for performing optimization and validation at the individual level, mean part-worths were calculated and used as inputs to optimization; for validation, the demand was computed at the individual level and then averaged as in Eq. (3). Thus, heterogeneity measured via the HB conjoint model formulation was accounted for at the validation stage, and all reported metrics thereby accommodate it.

5. Discussion: optimization results and implications

The six scenarios in Table 4 were optimized with the initial values shown in Table 1. Figure 3 shows optimal results including the PS channel and product/service attributes of each producer. All results converged to equilibrium. In Figure 3, the red lines indicate inclusive channels between competitors.

For Amazon, in the optimal channel-S1 scenario, the Kindle's optimal price, display size, and storage are \$240, 10″, and 19.9GB, respectively; the optimal eBook price (for Amazon) is \$11.78; and the optimal channel arrangement is for Kindle users to be able to use iBooks, while Amazon supplies eBooks to

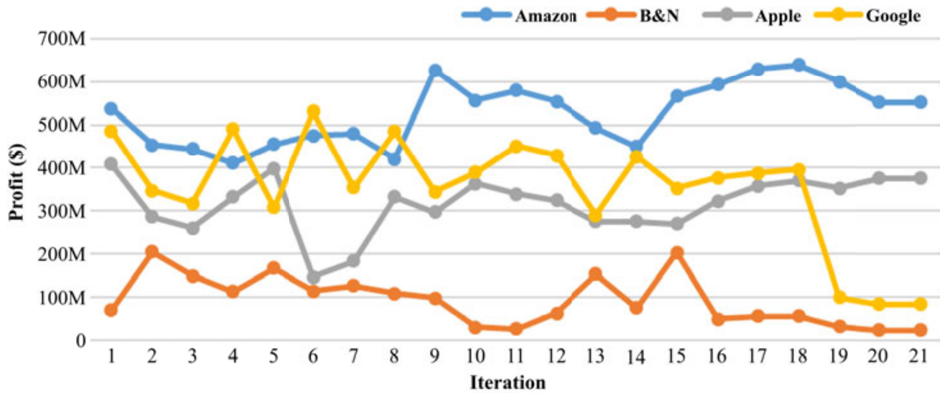

Figure 4. Convergence of sequential profit maximization for optimal channel-S1 scenario.

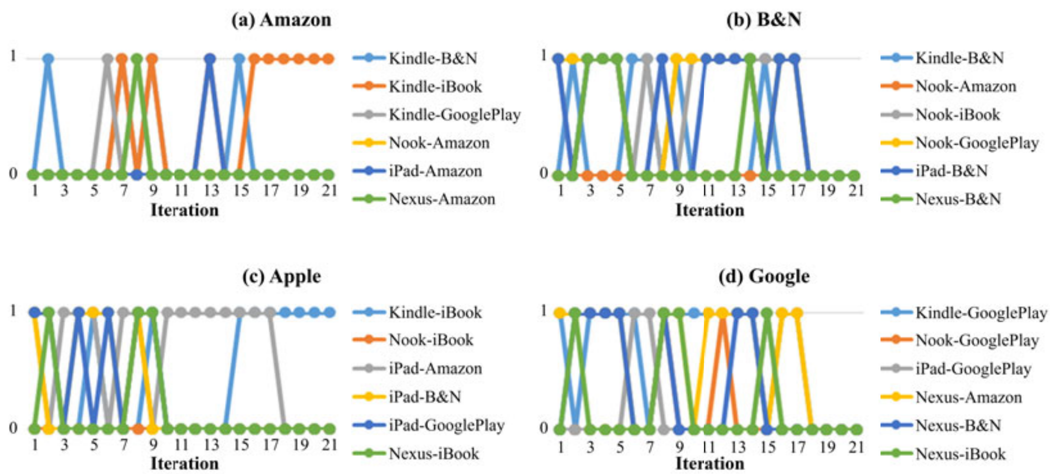

Figure 5. Convergence of channel decisions for optimal channel-S1 scenario.

Kindle-only users. In the optimal channel-S3 scenario, the optimal channel converged to the exclusive channel, although the channel decisions are optimized.

Figure 4 shows how the optimal profit of each producer (optimal channel-S1 scenario) changed and converged over the iteration history, where the x-axis indicates iteration, and y-axis, profit (in dollars). Figure 5 shows the results from each producer's (optimal) channel decisions at that iteration, where 1 indicates that a channel is connected, and 0 indicates that a channel is unconnected in the y-axis. After the 21st iteration, all producers apparently converge indicating that no design change can entail more profits for any of them.

Figure 6(a) shows the achieved overall profits (product + service profits) for each of the producers in the six scenarios. Figure 6(b) shows the product and service profits separately because most product profits are negative. This result shows that most producers sell low-priced products while sacrificing product profits but make up for the loss through service profits, securing service users. Kang *et al.* (2013) showed similar results; besides, it is known that Amazon uses

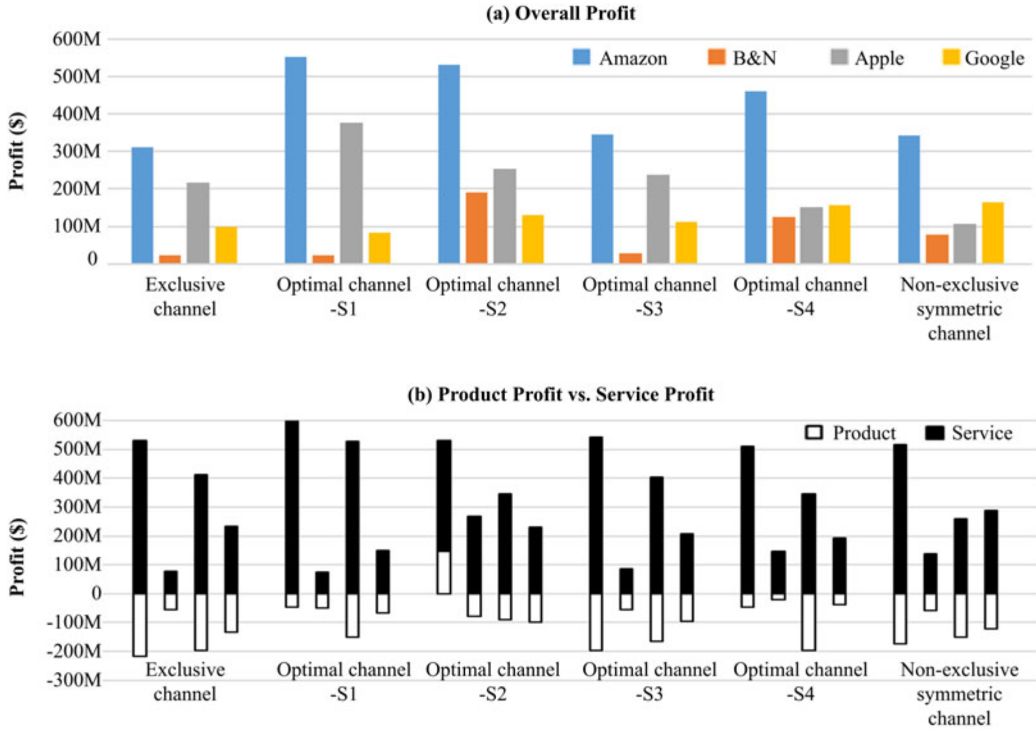

Figure 6. Profits for six scenarios.

the same strategy (Love 2011; Clay 2012). Lastly, Figure 7 shows the optimal prices of tablets and eBooks for the six scenarios, and Table 5 shows the eBook demand for each tablet under different channel scenarios.

Main insights from the optimization results above are discussed as follows.

First, *the decision order affects an equilibrium point when the channel is variable, but the first mover advantage is not guaranteed.* In Figure 3, optimal channel results (S1, S2, S3, and S4) show that the optimal decisions converge at different equilibrium points depending on the decision order. One reason is that the channel decisions are affected by previous channel structures because they are required to get permission from competitors when they want to change channels. In our game, it is shown that the first mover advantage is not guaranteed. In Figure 6, Amazon, B&N, Apple, and Google get the highest profits when they are the first mover (S1), third mover (S2), third mover (S1), and third mover (S4), respectively.

Second, *the difference in brand power stimulates larger profit differentials when the channel is variable.* In Figure 6, optimal channel scenarios have large profit differentials among producers, while fixed channel scenarios such as exclusive channels and non-exclusive symmetric channels have comparably small profit differentials among producers. The reason is that, when producers with high brand power (brand preference) such as Amazon (eBook market) and iPad (tablet) have a choice of channel, they can utilize competitors' products/services effectively by controlling channels (see Tables 2 and 3 for brand preference).

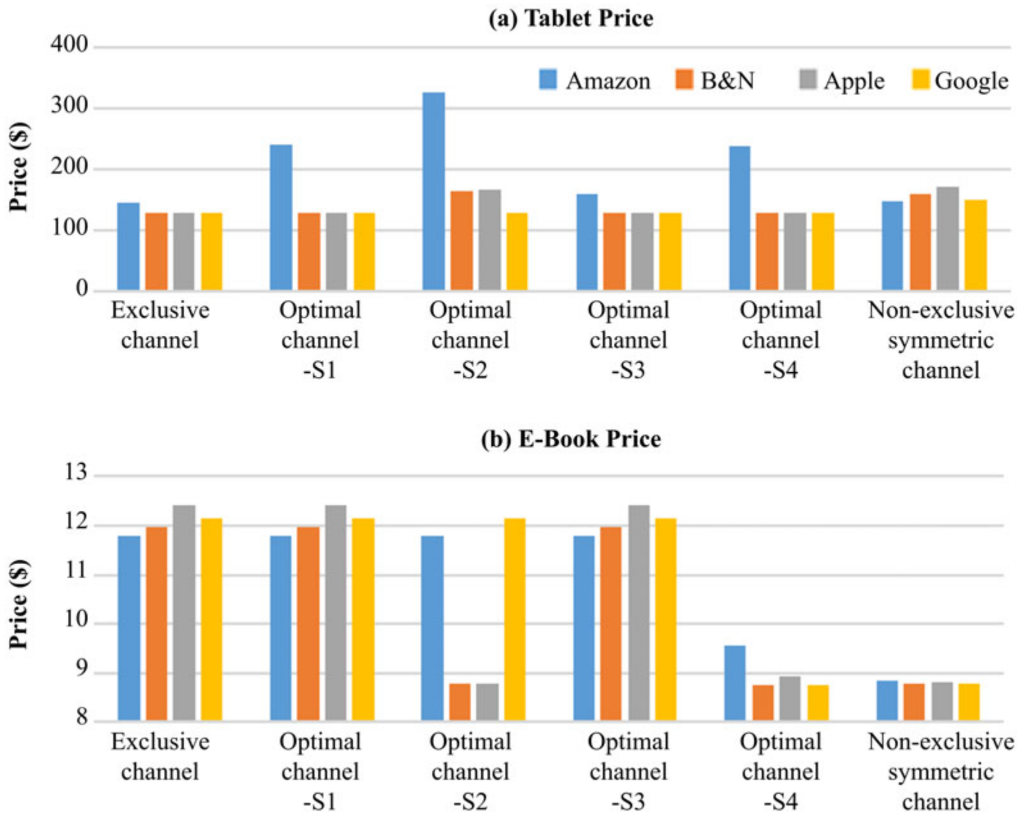

Figure 7. Optimal price decisions for six scenarios.

Third, *a product with high brand power pursues an inclusive channel, while a service with high brand power pursues an exclusive channel.* Amazon, with the highest brand power yields the highest profits in all scenarios. In all optimal channel scenarios, Amazon sells eBooks *only* to Kindle – the only 'exclusive arrangement' obtained – whereas the others sell to their competitors. The main distinction in the results is therefore between Amazon/Kindle and the other three: Amazon/Kindle pursues a highly inclusive strategy by which eBooks are allowed on its platform (Kindle), but a highly exclusive one in terms of whom they will sell their eBooks to, i.e., only themselves. Whether this can be generalized to other market settings is a matter of speculation, but it can be rigorously examined using the methods developed here.

Fourth, *service has a lower price in the more inclusive channels.* In Figure 7(b), a non-exclusive symmetric channel has much lower eBook prices than an exclusive channel. When comparing optimal channel scenarios, relatively inclusive channels (S2, S4) have lower eBook prices than relatively exclusive channels (S1, S3). The results demonstrate that inclusive channels promote competition and reduce service price. On the other hand, the analysis of tablet prices shows that a non-exclusive symmetric channel has a higher tablet price than an exclusive channel. In optimal channel scenarios, relatively inclusive channels (S2, S4) have higher tablet prices than relatively exclusive channels (S1, S3). This is because

Table 5. eBook service usage for each tablet

	Tablet	eBook demand for each tablet			
		Amazon	B&N	iBook	Google Play
Exclusive channel	Kindle	100%	—	—	—
	Nook	—	100%	—	—
	iPad	—	—	100%	—
	Nexus	—	—	—	100%
	Sum	100%	100%	100%	100%
Optimal channel-S1	Kindle	100%	—	**29%**	—
	Nook	—	100%	—	—
	iPad	—	—	71%	—
	Nexus	—	—	—	100%
	Sum	100%	100%	100%	100%
Optimal channel-S2	Kindle	100%	**40%**	**30%**	—
	Nook	—	60%	—	8%
	iPad	—	—	70%	—
	Nexus	—	—	—	92%
	Sum	100%	100%	100%	100%
Optimal channel-S3	Kindle	100%	—	—	—
	Nook	—	100%	—	—
	iPad	—	—	100%	—
	Nexus	—	—	—	100%
	Sum	100%	100%	100%	100%
Optimal channel-S4	Kindle	100%	**77%**	**24%**	—
	Nook	—	23%	—	—
	iPad	—	—	76%	**65%**
	Nexus	—	—	—	35%
	Sum	100%	—	100%	100%
Non-exclusive symmetric channel	Kindle	59%	**18%**	**10%**	**17%**
	Nook	**7%**	42%	**5%**	**9%**
	iPad	**25%**	**25%**	77%	**19%**
	Nexus	**9%**	**15%**	**8%**	55%
	Sum	100%	100%	100%	100%

Bold indicates eBook service demand of competitors' tablets.

when the channel is inclusive, customers can use more services through the tablet, so the tablet's value increases.

Fifth, *the proposed framework helps decide which competitors the focal firm should cooperate with.* From the results, it is shown that cooperation between Kindle and iBooks is necessary. In Figure 3, the channel between Kindle and iBooks appears in the optimal decision of most scenarios such as S1, S2, and S3. This demonstrates that this cooperation is positive for both Amazon and Apple's profits. On the other hand, the results show that cooperation between Amazon–Google, and Apple–B&N may not be attractive, as they are never seen to cooperate in the optimal results.

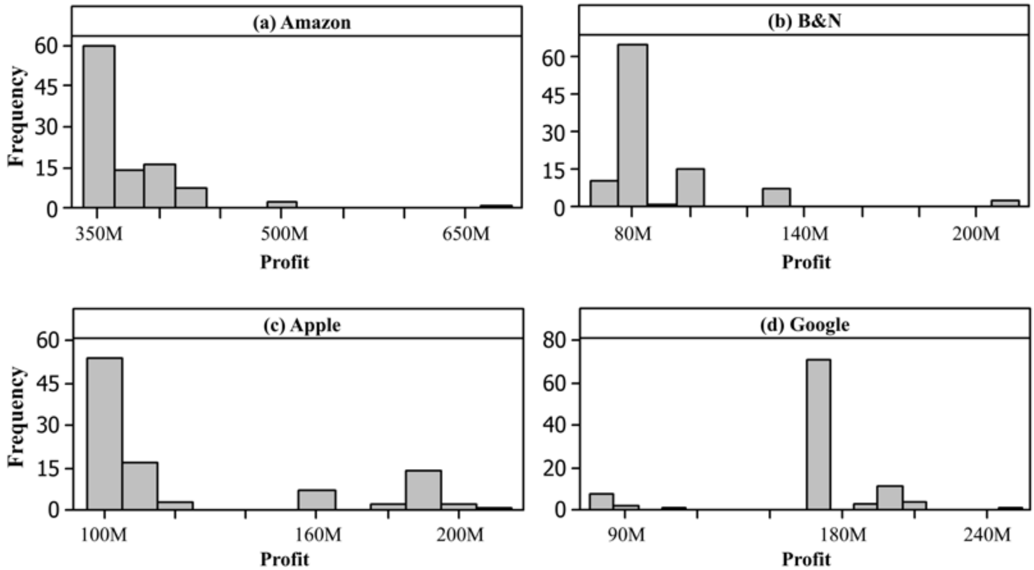

Figure 8. Equilibrium points for the non-exclusive symmetric channel scenario.

Sixth, *the proposed framework helps analyze the customer inflow between products and services.* The proposed demand model determines where the service users (and profits) 'come from.' In optimal channel-S1 scenario of Table 5, since iBooks supplies eBooks not only to iPad, but also to Kindle, 29% of iBooks users come from Kindle. In a non-exclusive symmetric channel, only 42% of B&N users come from Nook users, and the other 58% of B&N users come from competitors' tablets.

Lastly, *there exist multiple equilibrium points, but the majority of the optimization results converge to one equilibrium point*. Since channel structures are listed and other variables for each channel structure are optimized, channel decisions do not affect optimality. Thus, one needs to check whether other decision variables converge to a social trap which is a low-level equilibrium point inferior to another equilibrium point in that it yields lower levels of profit for all the players. In the proposed framework, optimization was carried out sequentially, i.e., the previous iteration's optimal results were used as the initial values for the next iteration. Random initial values are generated in each iteration and sequential optimization is conducted. In the non-exclusive symmetric channel scenario, 100 optimization runs are tested, and Figure 8 shows the histogram of profit results for these runs. Approximately 60% of the tests converge with the same profits as those computed under the proposed framework. These results show that depending on initial values, it is possible to reach a social trap that yields lower overall profits, and the designer should check whether the equilibrium point is indeed a social trap or not.

Although a variety of other factors (such as procurement and contractual costs, maintaining an adequate variety of titles, offline sales of physical books, etc.) would need to be incorporated for a complete analysis of these four publishers, it is nonetheless recommended that they do not settle on identical (that is, symmetric) service channel arrangements at equilibrium, reflecting upon the differences in the firms' input values into the PS channel optimization problem. One must underscore the various assumptions made to restrict attention to the focal variables (e.g., the lack of black-and-white tablets), which dictate that the results should be extrapolated with caution to the actual market for these four producers. However, the simulation results suggest that the proposed model yields results with reasonable face validity, and can help decision makers understand market behavior and, via market simulation, the anticipated effects of changes in both product/service attribute values, and contractual channel structures.

6. Conclusion: implications, limitations, and future research

Over the last decade, an increasing number of products have become more than the sum of their parts, capable of availing of an array of *services* provided by the products' producers as well as their rivals. When a consumer chooses a cell phone, for example, she or he must envision which apps it can run, and therefore understand the degree of choice and competition in that related, service-based marketplace. Traditional demand models, primarily from marketing, operations, and engineering design, can decompose both the service and product decisions and help optimize them separately. Difficulties arise, however, when these decisions are conjoined and necessarily dependent with product choice preceding service access.

This paper has proposed a modeling framework to support complex decision-making in PS channels. The framework is designed to optimize several disparate, but interacting elements – the PS channels, product prices, product attributes, service prices, and service attributes – jointly, using the objective of overall service and product profits. Notably, it does so for three distinct multi-channel structures: *exclusive*, *non-exclusive asymmetric*, and *non-exclusive symmetric*. Such a framework helps producers understand how PS channel decisions affect not only their own customer demand and profit patterns, but also those of other market players. An extensive simulation and optimization study, using summary market information (e.g., prices), and conjoint choice data for both tablets and eBooks, illustrated how the model can be used for a real product category, and how channel structures affect demands and profit levels for a producer's products and related services.

The proposed framework is expected to be used for PS design planning in a company that supplies products and the associated services. The optimization results for the tablet and eBook market provide some insights to early stage design as follows:

First, a decision order affects an equilibrium point when the channel is variable, but the first mover advantage is not guaranteed. A designer does not need to rush to make a decision, but has to watch other competitors' channel decisions in the market closely. Second, a difference in brand power stimulates larger profit differentials when the channel is variable. If the focal company has higher brand power than its competitors, a designer should utilize competitors' products/services actively by varying the channel. Third, a product with high brand power pursues an inclusive channel, while a service with high brand power pursues an exclusive channel. A designer should examine the brand power of product and service respectively, and make different channel strategies for the product and service. Fourth, service has the lower price in the more inclusive channels. A designer should balance between service price and product price according to the channel. Fifth, the computed results help decide which competitors the focal firm should cooperate with. Before deciding on the product/service attribute specifications at an early design stage, a designer should try to negotiate with competitors that complement the product/service, and then decide on specifications based on the cooperation results. Sixth, similarly, the computed results help analyze customer inflows between products and services. A designer should observe closely customer inflows from competitors' products, and reinforce the positive channels.

We view the proposed framework as evolutionary building firmly on widely used techniques in marketing, design, and operations. The novel feature of the framework is to integrate techniques developed in cognate literatures: First, the demand model accommodates the actual, sequential nature of the choice of product and multiple associated services; previous customer choice research focused on a single choice of product or PS bundle. Second, the PS channel structure was accommodated via decision variables instead of predetermined parameters; previous distribution channel research in this area largely examined price optimization under a given channel structure. Lastly – and it is believed this is a methodological innovation with the potential for broad application – the proposed framework considers competitors' profit changes as (non-negativity) constraints, owing to the fact that PS channels are shared decisions requiring acceptance from both product producers and service providers.

Future work can test this framework in different product classes and contractual contexts to determine its general applicability and robustness for different PSS. The framework can be extended to product or service family design, although this would require detailed knowledge of consumer preference heterogeneity and cost-sharing models, using firms' internal production data.

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