Manuscript submitted to Design Science

Designing Profitable Joint Product-Service Channels

Namwoo Kang
Assistant Professor
K-School
Korea Advanced Institute of Science and Technology (KAIST)
291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea
nwkang@kaist.ac.kr (corresponding author)

Fred M. Feinberg
Handleman Professor of Management
Ross School of Business
Professor of Statistics
University of Michigan
701 Tappan Street, Ann Arbor, MI, 48109
feinf@umich.edu

Panos Y. Papalambros
James B. Angell Distinguished University Professor
Department of Mechanical Engineering
University of Michigan
2350 Hayward Street, Ann Arbor, MI 48109
pyp@umich.edu

Designing Profitable Joint Product-Service Channels

Abstract

Consumer choices of services and the product platform that delivers them, such as apps and mobile devices or eBooks and eReaders, are becoming inextricably interrelated. Market viability demands product-service combinations be compatible across multiple producers and service channels, and 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, and so optimizing producers' contingent product, service, 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 is proposed to optimize integrated services and products for each scenario. Optimization results can provide guidelines for strategies that are mutually profitable for partner-competitor firms. An e-book service and tablet example, using market-level information from four firms (Amazon, Apple, B&N, GooglePlay) and conjoint-based product-service choice data, illustrates the approach using a scalable sequential optimization algorithm. The example results suggest that firms in a market equilibrium can differ markedly on the services they should seek to provide via other firms' products, and demonstrate the interrelationship among marketing, services, and product design.

Keywords: products; services; channel design; conjoint analysis; product-service systems

1 Introduction

Integration of services and products enhances both profitability and sustainability of innovating firms. An oft-cited example concerns the interrelation of digital services delivered via tablets, e.g., App Store over iPad, or Amazon through Kindle. The importance of product-service integration extends well beyond handheld devices (Brady et al. 2006, Hudson et al. 2011) with some early definitions emerging, such as "a marketable set of products and services capable of jointly fulfilling a user's need" (Mont 2002) to achieve more economic value than conventional product-oriented businesses (Baines et al. 2009, Roy and Baxter 2009). When jointly designing services, products, and their channels to role played by 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 didn't make *services*." (Jeff Bezos quoted in [Hudson et al. 2011]).

Product-service (PS) channels require compatibility between services and products from the *customer's* perspective, and cooperation with a competitor's service and product from the *producer's* perspective. Thus, SP distribution channels differ substantially from conventional ones 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., and App store) 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, the PS channel structure is itself a design decision (hence amenable to optimization), whereas analyses for traditional channels typically assume a predetermined fixed structure.

To operate and compete successfully in an integrated product-service 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 and Krieger 1991, Moore et al. 1999), with ancillary applications to optimal service design (Pullman and Moore 1999, Easton and Pullman 2001). Research in the operations management and engineering design fields have extended this approach to multi-disciplinary design comprising engineering, manufacturing, and policy (Michalek et al. 2005, Lewis et al. 2006, Frischknecht et al. 2010). Although much previous research in profit-maximizing design has focused on either the service or the product aspect in isolation, some has addressed service and product design jointly, mainly in after sales and related services like scheduled maintenance and repair (Cohen and 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, and Kahn's (2009) review of drivers of success in new product development, only about a tenth of the firms were primarily service-oriented, while a third were some sort of mixture of services and products. The latter firms have a complex array of decisions to make regarding not only the attributes of their products, but also which services to offer, whether to license those services to other firms, 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.

In summary, producers must have foresight about service offerings since these drive primary consumer product choice and a firm's overall profitability. Here we focus on two issues: (i) compatibility between services and products from the customer's perspective, and (ii) strategic cooperation among competitors' services and products. We thereby analyze and model a broad class of product-service markets, characterized by several core assumptions:

(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., purchase through a service platform); and
(4) Channel decisions among competitors require contractual agreements.

Despite the variety of decisions across this market set-up, they can all 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. In this article we show how to leverage game-theoretic techniques to establish and determine market equilibria for various common market structures, and then illustrate the (equilibrium) solution method using real data from tablets and e-book services to calibrate quantities of managerial importance.

We now discuss the key trade-offs in PS channel design decisions.

A simple example helps to illustrate the interconnectedness of the service and product design optimization problems. When a product is launched, the producer must determine its price, which might be approached with standard techniques (e.g., conjoint and a time-discounted or finite-horizon profit model). For PS channels, product price setting must consider the demand for associated services, but also what might happen if a lower initial product price spurs demand not only for the producer's own services but also for competitors' services that can be accessed through its device. If the channel is exclusive (my customers can only access my services on my devices), 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, 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 product-service choice and demand far more complex to model. Since the particular PS channel availability is a shared decision variable, firms need to understand how 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 e-book 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/GooglePlay (Google) supply both e-book services and associated core tablet products. Assuming all PS channels were exclusive, Kindle users could avail only of Amazon e-books and Amazon can supply e-books 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 e-book market, as Amazon's App store lacks an iBook app; yet Amazon supplies e-book 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 iBook but also Amazon e-books, but iBook supplies e-book services to only the iPad (Bläsi and Rothlauf 2013; Ritala, Golnam, and Wegmann 2014).

Channels and customer choice. The effect of PS channel structure on customer choices is clear from the fact that customers choose services from multiple providers, that is, other than the one explicitly provided by the manufacturer of their equipment. This effect cuts both ways: choice of product is influenced by which services will be available when 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 product choice and service demand. For example, an Amazon customer who has many Amazon e-books does not need to buy a Kindle specifically: she has other options, such as the iPad Kindle app. Analogously, an iPad user does not need to buy all, or indeed any, e-books through iBook, because other iPad-compatible options, like Amazon, are available.

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 from Apple to do so, and porting the software to other operating systems might therefore lower 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 share for a product and for its formerly exclusive services.

Adding and deleting channels. This sharing of PS channel decision is affected by competitors' decisions in at least two major ways. First and most obvious, 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 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* (the commonly-used economics term meaning 'all other things being unchanged'). 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 e-books (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 so that Kindle app users could no longer shop Amazon e-books directly; instead, iPad users need to follow the more laborious route of shopping Amazon e-books from a web-based store outside the app, sync them with the app on iPad, and then access them. In short, ease of use for services can vary according to competitors' PS decisions. Notably, PS channels differ critically from "mixed source" applications (e.g., Casadesus-Masanell and Llanes 2011) where the question is one of "opening up" a platform to development by others, not contractually licensing it for mutual profitability.

In summary, in order to coordinate product-service 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 to support e-books from another firm if the arrangement is profitable to that firm. In the modeling approach presented in this article we will use this insight – to our knowledge for the first time – to impose constraints on possible contractual solutions. It is important to 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, then fed into the SP 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 and Shugan 1983, McGuire and Staelin 1983, Lee and Staelin 1997, Sudhir 2001, Luo et al. 2007, Cai et al. 2012), design (Williams et al. 2008, Shiau and Michalek 2009), and systems (see, e.g., Jun et al. 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, not channels selected for joint optimization. Here, we extend the purview of these prior works to consider the types of channel structures coming to dominate online commerce and their joint implications for product design and marketing.

The remainder of the paper is organized as follows. Section 2 describes related work in product-service systems, and Section 3 introduces the associated design profit maximization framework. In Section 4, we illustrate the proposed method in an application to the aforementioned tablet and e-book services design example and discuss results. Section 5 offers conclusions, limitations, and direction for future research.

2 Theoretical Framework: Related Prior Research

Systems comprising services and products have appeared in prior literature in various disciplines. So-called "product-service systems" were introduced by Goedkoop (1999), defining "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 product-service ecosystems (Mont 2002, Baines et al. 2009, Roy and Baxter 2009); full reviews of the recent literature appear in Beuren et al. (2013) and Reim et al. (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 and reduce costs and environmental impact. 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 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 for financial service "products" (e.g., Thornton and White 2001, Lee 2002).

In marketing, product design research focused on profit optimization has a rich history (e.g., Moore et al. 1999, Green, Krieger, and Wind 2001). One major input into such methods is the quantification of consumer preferences and choice shares, typically achieved via conjoint-based methods. Because demand can be written as a function of product attributes and price, conjoint thereby allows optimization for various metrics like sales, share, 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 and Moore 1999, Easton and 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 and consumption, perishability, inability to stockpile, etc. – so that operations management techniques are especially amenable to handling service capacity and demand management (Pullman and 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 and Moore 1999, Easton and Pullman 2001). Several articles have addressed service and product characteristics together, though not in PS channels specifically. For example, Cohen and 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 into the "operating difficulty" of meeting customer demand patterns. Kang et al. (2013) proposed an integrated optimization framework to co-design products (e.g., tablets) and services (e.g., e-books and cloud services) to maximize overall profit.

Real product design decisions cannot be made based only on marketing considerations. The marketer and engineer must consider the trade-offs between marketable design and feasible design (Michalek et al. 2005, Michalek et al. 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" 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).

Profit optimization of multi-player channels is typically game theoretic, with the equilibrium condition that no player can gain by altering his/her decisions. Since each channel player's decision can affect the other channel player's profit and subsequent actions, it is important to understand the relationships between channel decisions, an observation going back at least to Jeuland and Shugan (1983). Sudhir (2001) further categorized these relationships according to manufacturer-manufacturer interaction, manufacturer-retailer interaction, retailer pricing rule, demand functional form, and wholesale price information availability. Sadeghi and Zandieh (2011) developed a two-player non-cooperative game framework for product portfolios while considering customer–engineering interactions, while Cai et al. (2012) addressed the combination of exclusive channel and revenue sharing strategies for the complementary goods markets.

In channels research specifically, the use of internet-based sales mechanisms has emerged as a critical topic (Hsaio and Chen 2013), and some engineering design research (Williams et al. 2008, Shaiu and Michalek 2009) has begun addressing the distribution channel to optimize a product design for suppliers' profit, subject to enhanced profitability of retailers. Shiau and Michalek (2009) focused on product design and the 'conventional' distribution channel via a game-theoretic approach. Aribarg and Foutz (2009) addressed category-based choice modelling for complementary products in a study of cell phones and service plans, but in the context of a single choice of a product-service bundle, as opposed to sequential choices of product 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. By contrast, here we consider the channel structure as a *variable* that interrelates with all other variables, and allow asymmetries in service provision and sequential consumer choices. Game theoretic 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 Market setting

Here we detail the market setting for the integrated product-service business model addressed in this paper. Fig. 1 depicts several representative PS channel structures involving two producers. Service choice examples are also shown, according to the PS channel structure.

[FIGURE 1 ABOUT HERE]

We underscore several key properties of the types of systems depicted in Fig. 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 might be items in a web store, such as a particular book or app, so 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 – we can always conjoin them to create a master list with matched indices, and will do so later on.]

4) Because the products are presumed to provide similar core benefits, each customer who buys 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:

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

- 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.

- 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.

We assume 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 e-book service market, p_A and $\mathbf{s}_A$ can be the Kindle and Amazon market, respectively; p_B and $\mathbf{s}_B$ can be iPad and iBook markets, respectively. That is, $\{s_{A1}, s_{A2}, s_{A3}, \ldots, s_{AM}\}$ are e-books in the Amazon market and $\{s_{B1}, s_{B2}, s_{B3}, \ldots, s_{BM}\}$ are e-books in the iBook market. In practice, M, the number of total potential books, can number in the millions. Note that s_{At} and s_{Bt} are the same book, where t = 1, 2, 3, ..., M, and can either can take on a value of 1, if the book is available, or 0 if it is not. In the service and product market, book price and shopping method can be different. Each customer can purchase a different number of e-books for a different period of product ownership.

3.2 Demand and profit modeling under the PS channel

We model services and products based on the market set-up described above, with a demand model that can be modified for different market settings. We adopt the latent (to the researcher) consumer utility concept underlying random-utility-based discrete choice models (Green and Krieger 1996), which have come to dominate both theoretical and applied work in the marketing field, as has Hierarchical Bayes (HB) choice-based conjoint (Rossi and Allenby 2003, Gustafsson, Herrmann, and 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 continuized 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 coefficient 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 Fig. 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 a channel is connected (as depicted by lines in Fig. 1); 0 if 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 of 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 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 logit form, which is particularly amenable to gradient and elasticity computation:

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

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

Product demand can be calculated, for various market scenarios, based on heterogeneous customer preference models. Either total or averaged-across-participants demand 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 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; estimation of service attributes part-worths proceeds analogously to that for products. Note, however, that the setting is somewhat more complex, for the following reasons: (1) service alternative options depend on product choice; (2) services consist of subservices; and (3) service choice occurs 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 attributes 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 usual 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 for subservices (e.g., one e-book 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:

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

where q_{s_h} is service demand of service option s_h, μ indicates (as before) 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., e-book purchase history).

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

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

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

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

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

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 that Eq. (9) has one more term than Eq. (10) because service $\mathbf{s}_A$ can be used by both p_A and p_B.

Based on this demand model, 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, Π_{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 then to optimize the sum of service and product profits.

3.3 Product-Service Design Framework

Based on the demand system above, we propose a framework to optimize profit for product-service design, depicted schematically in Fig. 2. 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. These variables are set for the competitor, then optimized for the focal firm. Note that 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 detail.)

[FIGURE 2 ABOUT HERE]

As discussed earlier, the PS channel is a binary design variable, so that 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 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. Product demand is calculated based on product price, product attributes, and service compatibility as per Eq. (1) to (3). Using individuals' potential services sets, service demand is calculated based on service prices, service attributes, the PS channel, and product demand, through Eq. (4) to (6). Product profit and service profit are calculated using price, cost, and demand for services and products, through Eq. (11) and (12).

A notable feature of the proposed framework is that it uses a competitor's profit change as a constraint: When 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. That is, a producer can only reasonably propose channels to a competitor that will enhance that competitor's profit. For service and product constraints, three types – boundary, equality, or inequality – can be enacted. For feasibility constraints (e.g., whether a product's components can fit in its case), engineering or operation simulation models can be applied (e.g., Kang et al. 2015, 2017). Optimization proceeds iteratively across producers: After maximizing the overall profit of a focal producer, other competitors optimize their profit with 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, Shaiu and Michalek 2009, Kang et al. 2016). Here we assume that, during the initial iteration, producers decide on *all* decision variables; for subsequent iterations, they decide only on product/service prices and channels. That is, because product design decisions are slow and costly to alter, we presume that producers first decide on product attributes, then engage in (iterative, sequential) optimization for prices and channels for both services and products.

4 Results: Application to Tablets and E-books

4.1 Market setting

The proposed framework is demonstrated via tablet (product) and e-book (service) designs. Because the main purpose of this study is illustrative, market assumptions are deliberately generic, transparent, and simple, as follows. First, we selected four main producers, each of which operates in both tablet and e-book markets: (1) Kindle / Amazon Kindle books, (2) Nook / Barnes & Noble (B&N), (3) iPad / iBook, and (4) Nexus / GooglePlay 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 e-book services, price distributions across the four e-book markets are based on real observed prices of 20 best-seller e-books 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, we assume that when a customer shops for an e-book from her tablet's producer, she does so via an in-tablet app, but uses a web-based interface for e-books from other competitors' (Bläsi and Rothlauf 2013, Ritala et al. 2014).

Table 1 summarizes the market setting for the study, with four flagship tablets and four e-book markets. The e-book prices shown are averages of 20 best-sellers so, for example, Amazon's price of $9.78 compares favorably with those for B&N ($9.98), iBook ($10.41), and GooglePlay ($10.14). The binary indicators listed in Table 1 indicate whether a channel exists between tablet and e-book markets. Note, for example, that the PS channel is asymmetric: iPad users can access all four e-book services (row 3 of 4), while iBook does not supply e-book services to competitors (column 3 of 4).

Table 1: Market setting for e-book / tablet application

Product (Tablet)	Service (e-book market)			
	Amazon $9.78 (2.14) [a]	B&N $9.98 (1.81)	iBook $10.41 (1.64)	GooglePlay $10.14 (2.32)
Kindle, $169, 7", 16GB	1	0	0	0
Nook, $149, 7", 16GB	0	1	0	0
iPad, $399, 9.7", 16GB	1	1	1	1
Nexus, $229, 7", 16GB	1	1	0	1

(a) Prices and figures in parentheses refer to average prices and standard deviations, respectively, across 20 best-seller books.

4.2 Demand modeling

We conducted two choice-based conjoint surveys, for tablet choice and e-book choice, sequentially. 152 US respondents were surveyed using Amazon's Mechanical Turk (Amazon 2012a) in conjunction with Sawtooth Software's CBC (Choice-Based Conjoint) Hierarchical Bayes Module (Orme 2013); this sample size is comparable with 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 respondents reported tablet and e-book 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 e-books, tablet brand, 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 of being able to read e-books, and that their tablet choices would determine which of multiple compatible e-book 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, compatible e-book 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"(that is, the "no choice option" in which the customer chooses none of the product-service options).

Table 2: Attribute levels and relative importance in tablet choice

Attributes	Levels	Estimated Importance
Compatible e-books	**15 levels**: {Amazon} / {B&N} / {iBook} / {GooglePlay} / {Amazon, B&N} / {Amazon, iBook} / {Amazon, GooglePlay}/ {B&N, iBook} / {B&N, GooglePlay} / {iBook, GooglePlay} / {Amazon, B&N, iBook} / {Amazon, B&N, GooglePlay} / {Amazon, iBook, GooglePlay} / {B&N, iBook, GooglePlay} / {Amazon, B&N, iBook, GooglePlay}	30.5%
Tablet brand	**4 levels**: Kindle HD / Nook HD / iPad / Nexus	19.3%
Tablet price	**5 levels**: $129 / $199 / $299 / $399 / $499	28.2%
Display size	**5 levels**: 7" / 7.9" / 8.9" / 9.7" / 10"	9.8%
Storage	**5 levels**: 8GB / 16GB / 32GB / 64GB / 128GB	12.2%

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

Table 3: Attribute levels and relative importance in e-book choice		
Attributes	**Levels**	**Estimated Importance**
E-book market	**4 levels**: Amazon / B&N / iBook / GooglePlay	42.6%
E-book price (best-seller)	**4 levels**: \$8.99 / \$9.99 / \$1.99 / \$11.99	39.5%
Ease of shopping $^{(a)}$	**2 levels**: By app / By web-based store outside app	17.9%

(a) When tablet and e-book market are from the same producer, e-books can be purchased by an in-tablet app.

Using HB estimation (as per Section 3.2), individual preference functions were quantified for each of the 152 respondents. MCMC draws were 'thinned' to every tenth; burn-in was 50,000 (these were discarded); and inference proceeds from the final 50,000 draws, which were used to obtain preference part-worths. Tables 2 and 3 list average relative importance for each attribute, while Table 4 lists estimated part-worths for each level separately. Lastly, cubic spline interpolation allows the estimation of continuous preference functions from the discrete part-worths used in the study (see Michalek et al. 2011).

[TABLE 4 ABOUT HERE]

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 "Supposing you use the e-book service, how often are you likely to purchase e-books?" Mean and standard deviation of the period of product ownership were 4.4 years and 2.7 years, respectively; analogous values for frequency of e-book purchase were 19.2 and 15.8 books per year, respectively. These data were used in calculating individual level service demand.[1] Recall that we used price data on 20 e-books (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 e-book users is challenging. Summary statistics can provide benchmarks: 457 million e-books were sold in 2012 (Wilson 2014), 25% of e-books are read on tablets (BWMBooks 2012),

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

and the average number of e-books read (among those who read electronically) is 24 books per year (Rainie, 2012). Based on this data, a rough estimate of projected tablet demand used for e-reading is 4.76M (i.e., 457M $\times$ 25% / 24). Because this is an input figure that 'scales linearly' within the model, improved estimates of market size can be easily slotted into the methodology.

4.3 Cost and optimization modeling

To put our method to use, producers must input their own costing models. Here, we adapt prior studies of tablet cost modeling (Wang et al. 2011) focusing on display and memory storage costs:

$$C_{d_j} = C_{d_0} q_{d_j}^{b_1} z_{d_j}^{b_2} \tag{13}$$

$$C_{m_j} = C_{m_0} z_{m_j} \tag{14}$$

where C_{d_j} is the cost of LCD display j, C_{d_0} 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); we stress that any of these values can be updated as newer information becomes available. Display costs follow economies of scale, although here other costs are considered 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). E-book prices can be themselves be broken down into margin, royalty fees, taxes, and delivery costs. Since royalty fees make up a majority of an e-book's price (Amazon 2012b), we consider only the royalty fee as the cost of e-book service provision, and used iBook's royalty rate, 70% (Mill City Press 2012).

4.3.1 Decision Variables and Optimization

We refer again to Fig. 2 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 which is used. However, the one described below has the virtue of scaling well in the number of product-service-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 8 decisions for which other services allow on its product, and 8 on which products to allow to carry its own services, for 64 in all. To choose among these 64 options – each of which requires that all other design elements be optimized – each of the four producers optimizes (as detailed subsequently). After all 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 ($\$129 \leq z_{17} \leq \$499$), display size ($7 \leq z_{18} \leq 10$), memory storage size ($8 \leq z_{19} \leq 128$), and e-book price change ($-\$2 \leq z_{20} \leq +\$2$). The PS channel decisions are binary decision variables. Because we have four products and four services, the PS channel matrix, as mentioned previously, is 4 by 4, so the space of possible channel combinations has size $2^{(4\times 4)} = 65{,}536$. 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 $2^6 = 64$. When the number of permissible channel configurations is relatively small, as here, it's possible to attempt to optimize all other design variables in each of the configurations on every optimization pass; but this would still require the use of a sophisticated algorithm and be less efficient than including the channel structure as part of the algorithm directly. Procedurally, as depicted in Fig. 2, each producer optimizes its decision sequentially so that tablet brand and e-book 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 when neither player's profits are harmed. Profit optimization is achieved subject to this PS channel constraint in addition to tablet and e-book design boundary constraints.

For the equilibrium calculation, optimization is carried out in order (determined at random) of Amazon, B&N, Apple, and Google; 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, we assume that producers first decide on all decision variables, including product attributes, and secondarily decide only on product/service prices and channels. Since the design problem is a mixed integer optimization, the overarching profit optimization problem was solved via genetic algorithms (GA), implemented in MATLAB (MathWorks 2017). [Specifically, each optimization pass in the GA involved six binary variables – to whom will you license your services (3), and which services (3) will you allow on your device – and four attributes (price, display, storage, eBook price); population size was set at 50, which was sufficient given rapid convergence; crossover fraction was 0.8; migration was forward; migration fraction was .2, and function tolerance was set 1E-06.] Owing to high computational costs for performing all optimization and validation at the individual level, mean part-worths were calculated and used as inputs for optimization; for validation, demand was computed at the individual-level, then averaged, as per Eq. (3). Thus, heterogeneity, as 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 for eBook market

Fig. 3 shows how the optimal profit of each producer changed and converged over the iteration history, where the *x*-axis indicates iteration and *y*-axis profit (in dollars), the latter resulting from each producer's (optimal) design decisions at that iteration. At the 11^{th} iteration, all producers had apparently converged; that is, no design change can entail more profit for any. Figs. 4 and 5 similarly suggest that all optimal decision values have converged. Note again that product attributes are optimized first, while product/service prices and channel decisions are re-optimized at each subsequent iteration.

[FIGURES 3 – 6 AND TABLE 5 ABOUT HERE]

Fig. 6 depicts optimal design decisions, including the PS channel and product/service attributes of each producer, where initial values are shown in Table 1. For Amazon, the Kindle's optimal price, display, and storage are $396.3, 10", and 18.4GB, respectively; optimal e-book price (for Amazon) is $9.95; and the optimal channel arrangement is for Kindle users to be able to use all competitors' e-book services, while Amazon supplies e-books to only Kindle users. Table 5 lists market responses of optimal decisions, where the values shown are means of the market response distribution based on 152 (heterogeneous) customer preference parameters. Optimal profits result when each producer optimizes its own situation; however, because the channel is not exclusive, service profit can arise not only from the same producer's product, but also competitors' products. For example, B&N supplies e-books to Nook and Nexus, so that 95% of service profit comes from Nook users and 5% of service profit comes from Nexus users. 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 in a full analysis for these four publishers, it is nonetheless instructive that they do not settle on identical (that is, symmetric) service channel arrangements at equilibrium, reflecting differences in the firms' input values into the PS channel optimization problem.

The proposed demand model can also help determine where the service profit 'comes from'. Market shares of services and products in each case are shown in the last two columns of Table 5. We must underscore that the various assumptions made to restrict attention to the focal variables (e.g., the lack of black-and-white tablets) dictate that the results should be extrapolated with caution to the actual market for these four producers. However, the simulation results do 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 structure.

Although Fig. 6 contains a wealth of information regarding the particularities of this specific market system, it is useful to focus on the "major take-aways" regarding the structure of the obtained solution. Consider first what each firm produces: Amazon (Kindle) allows you to buy from all other producers, while the other platforms restrict you to three others. Conversely, each platform allows itself on at most two devices: Amazon sells *only* to Kindle – the only "exclusive arrangement” obtained – whereas the others each sell to two (always including its own as one of them). The main distinction in the results is therefore between Amazon/Kindle and the other three: Amazon/Kindle pursues a highly inclusive strategy in terms of which eBooks are allowed on its platform (Kindle), but a highly exclusive one in terms of whom they will sell their eBooks to: only themselves. We speculate that this may occur due to Kindle eBooks’ relatively high brand liking (see Table 4) of -0.86, vs. B&N = -3.12, iBook = -3.10, and GooglePlay = -2.60, which is a very large gap on the logit scale. Whether this generalizes to other market settings is a matter of speculation, but could be rigorously examined using the methods developed here.

6 Conclusion: Implications, Limitations, and Future Research

Over the last decade, more and more 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 must envision which apps it can run, and therefore 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 are necessarily dependent, with product choice preceding service access.

This article proposed a modeling framework to support complex decision-making in Product-service (PS) channels. The framework is designed to optimize over several disparate, but interacting, elements – 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., for prices) and conjoint choice data for both tablet and e-books, 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. Indeed, the model’s solution graphically demonstrates (Fig. 3) how each producer was able to obtain larger profits over baseline (based on their current design specifications), after optimization.

We view the proposed framework as evolutionary, building firmly on widely-used techniques in marketing, services, and engineering design. In that light, there are a number of novel features of the framework that serve to unify aspects of the techniques developed in those cognate literatures. First, the demand model in this framework accommodates the actual, sequential nature of choice of product and multiple associated services; previous customer choice research had, by contrast, focused on a single choice of a product or a product-service bundle. Second, the PS channel structure was accommodated via decision variables instead of pre-determined parameters; previous distribution channel research in this area has largely examined price optimization under a given channel structure. Lastly – and we believe this to be 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 would do well to test this framework in different product classes and contractual contexts, to determine its general applicability and robustness throughout product-service systems. Moreover, the proposed framework can be extended to product or service family design, although this will require detailed knowledge of consumer preference heterogeneity and cost-sharing models, informed by firms' internal production data.

7 Financial support

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

References

Amazon. 2012a. Amazon mechanical Turk. http://www.mturk.com.

Amazon. 2012b. Kindle direct publishing. http://kdp.amazon.com/self-publishing.

Anderson, C. 2009. *Free: The future of a radical price*. Random House.

Aribarg, A., N. Z. Foutz. 2009. Category-based screening in choice of complementary products. *Journal of Marketing Research*, 46(4), 518-530.

Baines, T., H. Lightfoot, J. Peppard, M. Johnson, A. Tiwari, E. Shehab, M. Swink. 2009. Towards an operations strategy for product-centric servitization. *International Journal of Operations & Production Management*, 29(5), 494-519.

Barczak, G., A. Griffin, K. B. Kahn. 2009. Perspective: trends and drivers of success in NPD practices: results of the 2003 PDMA best practices study *. J. Prod. Innovation Management*, 26(1), 3-23.

Beuren, F. H., M. G. G. Ferreira, & P. A. C. Miguel. 2013. Product-service systems: a literature review on integrated products and services. *Journal of Cleaner Production*, 47 (May), 222-231.

Bläsi, C., F. Rothlauf. 2013. On the interoperability of eBook formats. *Report for European Booksellers Federation, EU Commissioner for the Digital Agenda,* April.

Brady, T., A. Davies, M. Hobday. 2006. Charting a path toward integrated solutions. MIT *Sloan Management Review*, 47(3) 39-48.

BWMBooks. 2012. eBook market 2012. http://www.bwmbooks.com.

Cai, G., Y. Dai, S. X. Zhou. 2012. Exclusive channels and revenue sharing in a complementary goods market. *Marketing Science*, 31(1) 172-187.

Casadesus-Masanell, R. and G. Llanes. 2011. Mixed source. *Management Science*, *57*(7), 1212-1230.

Census. 2012. Age and sex composition in the United Sates: 2012. Tech. rep., US Census Bureau.

Cohen, M. A., S. Whang. 1997. Competing in service and product: a product life-cycle model. *Management Science*, 43(4) 535-545.

Easton, F. F., M. E. Pullman. 2001. Optimizing service attributes: The seller's utility problem. *Decision Sciences*, 32(2) 251-276.

Frischknecht, B. D., K. Whitefoot, P. Y. Papalambros. 2010. On the suitability of econometric demand models in design for market systems. *Journal of Mechanical Design*, 132(12) 121007.

Gilbert, J.. 2012. Where To Buy The Cheapest eBooks: Amazon vs. iBooks vs. Google Play vs. Barnes & Noble. Huffington Post, 17 October.

Goedkoop, M. et al. 1999. Product service systems, ecological and economic basics. Tech. rep., Report for Dutch Ministries of Environment (VROM) and Economic Affairs (EZ).

Green, P. E., A. M. Krieger, Y. Wind. 2001. Thirty years of conjoint analysis: Reflections and prospects. *Interfaces*, 31(3 supplement) S56-S73.

Green, P. E., A. M. Krieger. 1991. Product design strategies for target-market positioning. *J. Prod. Innovation Management*, 8(3) 189-202.

Green, P. E., A. M. Krieger. 1996. Individualized hybrid models for conjoint analysis. *Management Science*, 42(6) 850-867.

Gustafsson, A., A. Herrmann, F. Huber. 2013. *Conjoint measurement: methods and applications*. Springer Science & Business Media.

Hudson, C., C. Fudge, J. Rae. 2011. From products to services: Understanding the new rules of engagement. *Design Management Review*, 22(4) 46-53.

Jeuland, A. P., S. M. Shugan. 1983. Managing channel profits. *Marketing Science*, 2(3) 239-272.

Jun, G.T., Ward, J.R. and Clarkson, P.J. 2010. Systems modelling approaches to the design of safe healthcare delivery. *Ergonomics,* 53(7) 829-847.

Kang, N., F. M. Feinberg, P. Y. Papalambros. 2013. A Framework for Enterprise-driven Product Service Systems Design. Proceedings of the 19th International Conference on Engineering Design, Seoul, Korea, Aug 4-Aug 7.

Kang, N., F. M. Feinberg, P. Y. Papalambros. 2015. Integrated Decision Making in Electric Vehicle and Charging Station Location Network Design. *Journal of Mechanical Design*, 137(6) 061402.

Kang, N., Ren, Y., Feinberg, F. M., P. Y. Papalambros. 2016. Public Investment and Electric Vehicle Design: A Model-based Market Analysis Framework with Application to a USA-China Comparison Study. *Design Science*, 2, e6.

Kang, N., Feinberg, F. M., P. Y. Papalambros. 2017. Autonomous Electric Vehicle Sharing System Design. *Journal of Mechanical Design*, 139(1) 011402.

Lee, J. 2002. A key to marketing financial services: the right mix of products, services, channels and customers. *Journal of Services Marketing*, *16*(3) 238-258.

Lee, E., R. Staelin. 1997. Vertical strategic interaction: Implications for channel pricing strategy. *Marketing Science*, 16(3) 185-207.

Lewis, K. E., W. Chen, L. C. Schmidt. 2006. Decision making in engineering design. ASME Press, NY.

Luo, L., P. K. Kannan, B. T. Ratchford. 2007. New product development under channel acceptance. *Marketing Science*, 26(2) 149-163.

MathWorks. 2017. Mixed integer optimization. www.mathworks.com/help/gads/mixed-integer-optimization.html

McGuire, T. W., R. Staelin. 1983. An industry equilibrium analysis of downstream vertical integration. *Marketing Science*, 2(2) 161-191.

Michalek, J. J., F. M. Feinberg, P. Y. Papalambros. 2005. Linking marketing and engineering product design decisions via analytical target cascading. *J. Prod. Innovation Management*, 22(1) 42-62.

Michalek, J. J., P. Ebbes, F. Adigüzel, F. M. Feinberg, P. Y. Papalambros. 2011. Enhancing marketing with engineering: Optimal product line design for heterogeneous markets. *International Journal of Research in Marketing*, 28(1) 1-12.

Mill City Press. 2012. Setting an eBook price & understanding eBook royalties. http://www.millcitypress.net.

Mont, O. K. 2002. Clarifying the concept of product-service system. *Journal of Cleaner Production*, 10(3) 237-245.

Moore, W. L., J. J. Louviere, R. Verma. 1999. Using conjoint analysis to help design product platforms. *J. Prod. Innovation Management*, 16(1) 27-39.

Orme, B. 2013. The CBC System for Choice-Based Conjoint Analysis. Technical Paper Series. Sawtooth Software.

Pew Research. 2013. Tablet ownership 2013. http://pewinternet.org/Reports/2013/Tablet-Ownership-2013.aspx.

Pullman, M. E., W. L. Moore. 1999. Optimal service design: integrating marketing and operations perspectives. *International Journal of Service Industry Management*, 10(2) 239-261.

Rainie, L. et al. 2012. The rise of e-reading. Technical report, Pew Research Center's Internet & American Life Project. http://libraries.pewinternet.org/2012/04/04/the-rise-of-e-reading.

Reim, W., V. Parida, & D. Örtqvist. 2015. Product–Service Systems (PSS) business models and tactics–a systematic literature review. *Journal of Cleaner Production*, 97 (June), 61-75.

Ritala, P., A. Golnam, A. Wegmann. 2014. Coopetition-based business models: The case of Amazon. com. *Industrial Marketing Management*, *43*(2), 236-249.

Rossi, P. E., G. M. Allenby. 2003. Bayesian statistics and marketing. *Marketing Science*, 22(3) 304-328.

Roy, R., D. Baxter. 2009. Product-service systems. *Journal of Engineering Design*, 20(4) 327-328.

Sadeghi, A., M. Zandieh, 2011. A game theory-based model for product portfolio management in a competitive market. *Expert Systems with Applications*, *38*(7), pp.7919-7923.

Shi, Y., Qu, T., L.K Chu. 2016. A dynamic Stackelberg game model for portfolio procurement. *Industrial Management & Data Systems*, *116*(3), pp.350-368.

Shiau, C. N., J. J. Michalek. 2009. Should designers worry about market systems? *Journal of Mechanical Design*, 131(1) 011011.

Smith, D.J. 2013. Power-by-the-hour: the role of technology in reshaping business strategy at Rolls-Royce. *Technology Analysis & Strategic Management* , **25** (8), pp. 987-1007.

Sudhir, K. 2001. Structural analysis of manufacturer pricing in the presence of a strategic retailer. *Marketing Science*, 20(3) 244-264.

Thornton, J. and L. White. 2001. Customer orientations and usage of financial distribution channels. *Journal of services Marketing*, *15*(3), pp.168-185.

Vasantha, G. V. A., R. Roy, A. Lelah, D. Brissaud. 2012. A review of product-service systems design methodologies. *Journal of Engineering Design*, 23(9) 635-659.

Verma, R., G. M. Thompson, W. L. Moore, J. J. Louviere. 2001. Effective design of products/services: An approach based on integration of marketing and operations management decisions. *Decision Sciences*, 32(1) 165-194.

Wang, Z., P. K. Kannan, S. Azarm. 2011. Customer-driven optimal design for convergence products. *Journal of Mechanical Design*, 133(10) 101010.

Williams, N., S. Azarm, P. K. Kannan. 2008. Engineering product design optimization for retail channel acceptance. *Journal of Mechanical Design*, 130(6) 061402.

Wilson, T. D. 2014. The E-Book Phenomenon: A Disruptive Technology. *Information Research: An International Electronic Journal*, *19*(2), n2.

Zhang, S., Lee, C.K.M., Wu, K. K.L. Choy. 2016. Multi-objective optimization for sustainable supply chain network design considering multiple distribution channels. *Expert Systems with Applications*, *65*, pp.87-99.

Figures 1-6 and Tables 4-5

Table 4: Part-worths for e-book attribute levels

Attributes	Levels	Mean	STD	Importance
Compatible e-books	Amazon	-0.86	1.16	30.5%
	B&N	-3.12	0.92	
	iBook	-3.10	1.41	
	GooglePlay	-2.60	1.01	
	Amazon, B&N	1.03	0.90	
	Amazon, iBook	0.97	0.88	
	Amazon, GooglePlay	1.11	0.97	
	B&N, iBook	-1.28	1.11	
	B&N, GooglePlay	-1.06	0.83	
	iBook, GooglePlay	-1.22	1.23	
	Amazon, B&N, iBook	2.33	0.87	
	Amazon, B&N, GooglePlay	2.30	0.97	
	Amazon, iBook, GooglePlay	2.05	0.89	
	B&N, iBook, GooglePlay	0.33	1.14	
	Amazon, B&N, iBook, GooglePlay	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	8GB	-1.77	1.40	12.2%
	16GB	-0.54	0.88	
	32GB	0.37	0.48	
	64GB	0.78	0.76	
	128GB	1.16	1.15	
None		-1.72	3.78	

Table 5: Market responses of optimal decisions

Producer	Overall Profit ($)	Product Profit ($)	Service Profit ($)	Service Profit from (%)	Product M/S (%)	Service M/S (%)
Amazon	759M	312M	447M	Kindle: 100%	Kindle: 47%	Amazon: 38%
				Nook:	Nook: 14%	B&N: 29%
				iPad:	iPad: 12%	iBook: 17%
				Nexus:	Nexus: 13%	GooglePlay: 16%
B&N	297M	-138M	435M	Kindle:	Kindle: 27%	Amazon: 25%
				Nook: 95%	Nook: 43%	B&N: 38%
				iPad:	iPad: 11%	iBook: 18%
				Nexus: 5%	Nexus: 7%	GooglePlay: 19%
Apple	437M	155M	282M	Kindle: 7%	Kindle: 19%	Amazon: 32%
				Nook:	Nook: 24%	B&N: 24%
				iPad: 93%	iPad: 39%	iBook: 23%
				Nexus:	Nexus: 8%	GooglePlay: 22%
Google	388M	577M	331M	Kindle: 11%	Kindle: 18%	Amazon: 35%
				Nook:	Nook: 9%	B&N: 18%
				iPad:	iPad: 25%	iBook: 19%
				Nexus: 89%	Nexus: 38%	GooglePlay: 27%

Figure 1: Examples of market settings

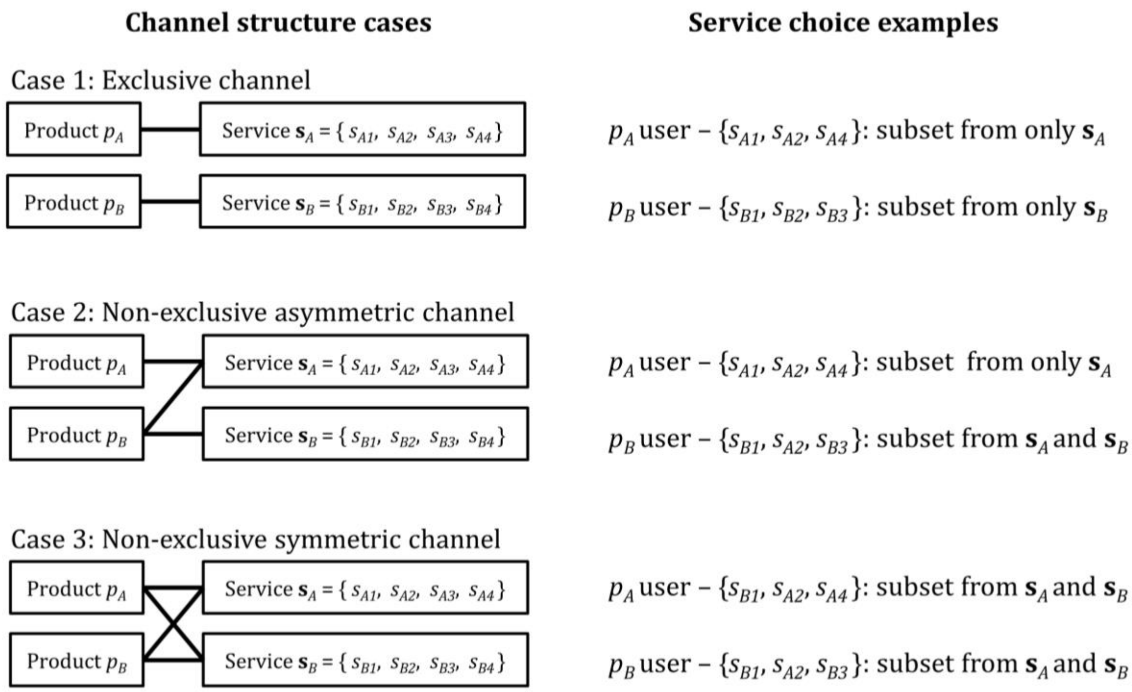

Figure 2: Profit maximization framework for product-service design

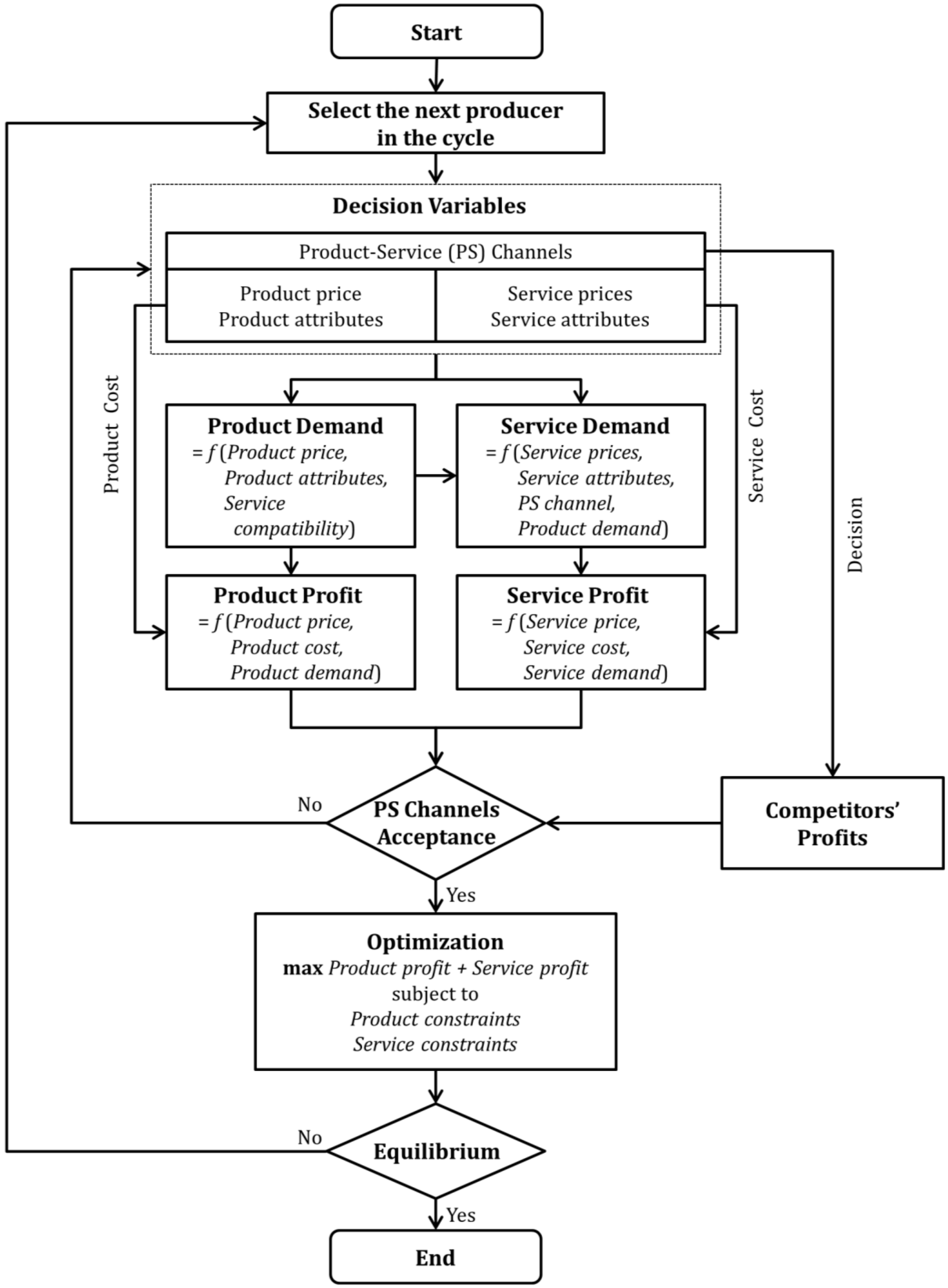

Figure 3: Sequential profit maximizations for four producers

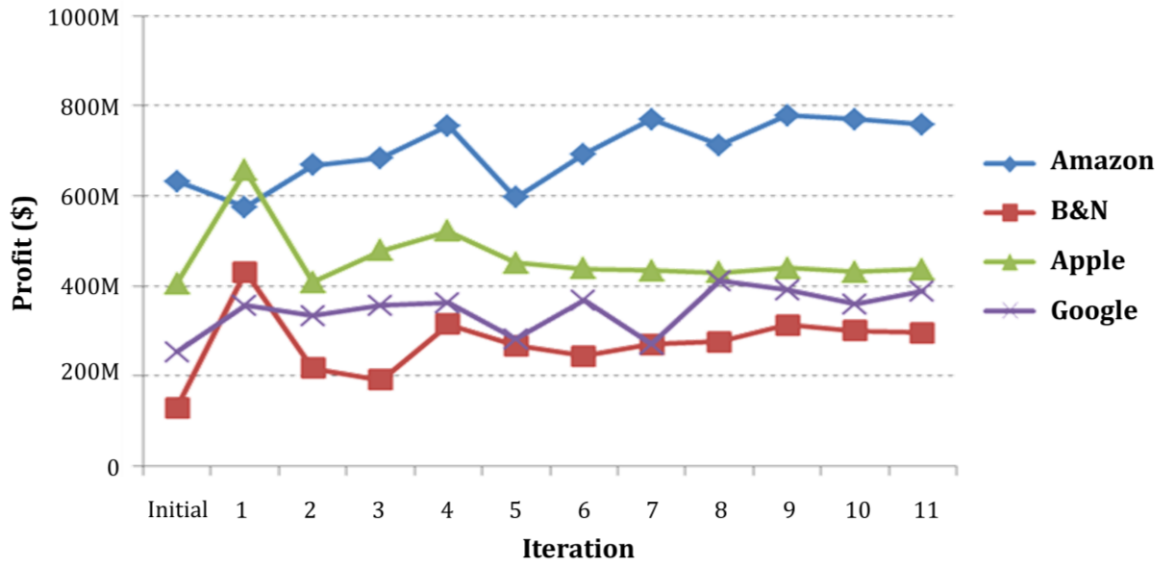

Figure 4: Convergence of price decisions for each producer

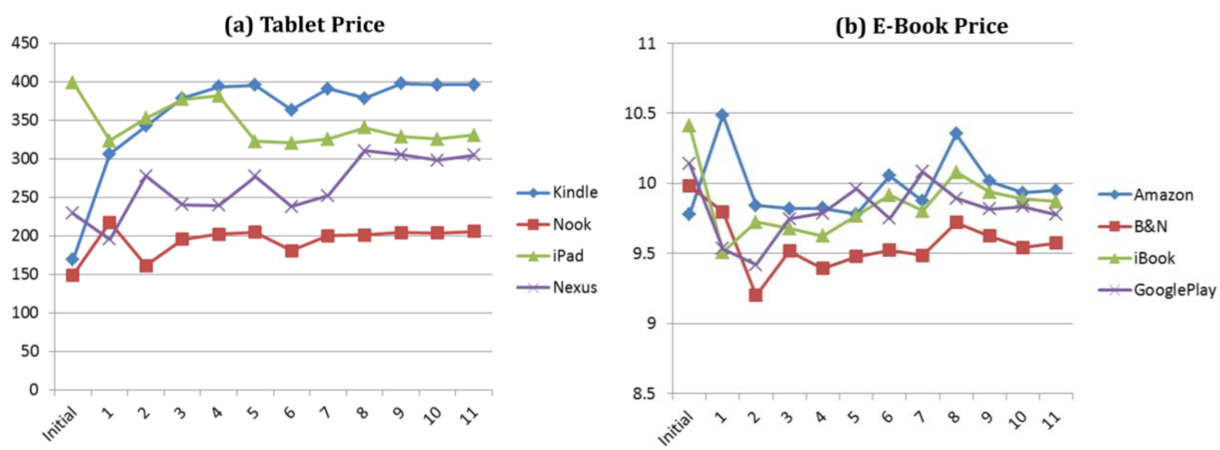

Figure 5: Convergence of channel decisions for each producer

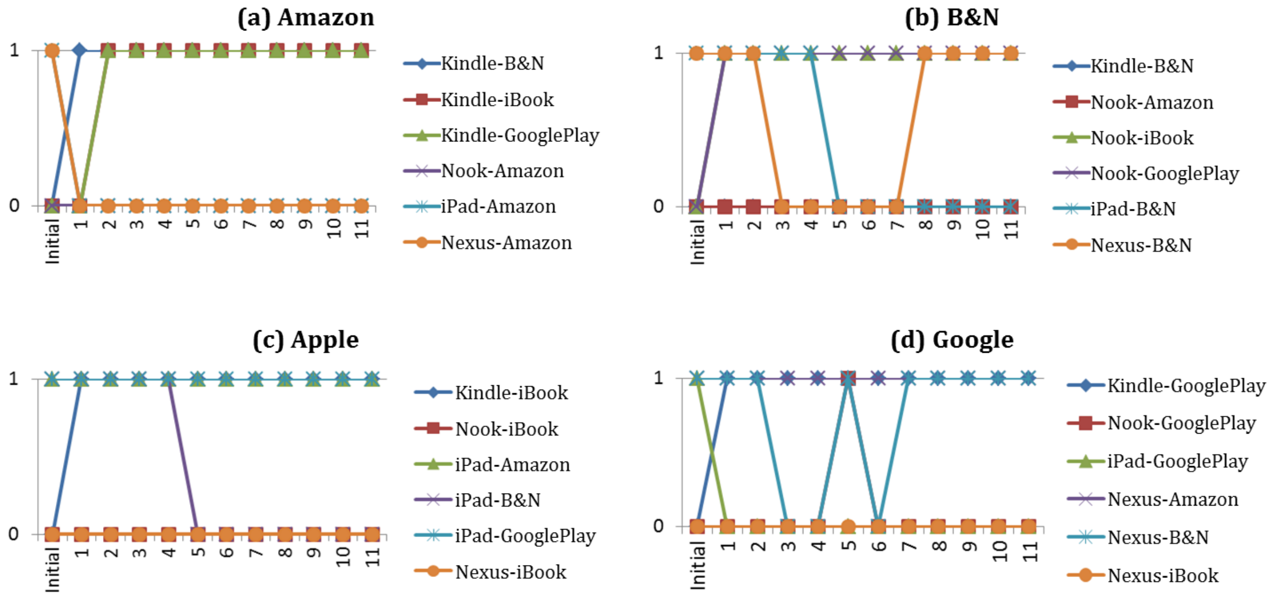

Figure 6: Optimal design decisions for each producer