A Pricing Model for the Internet of Things Enabled Smart Service Systems

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Abstract
How can firms price their products and services, as their ecosystems get smarter? In order to answer this question, this paper provides a stylized model and its expansion to characterize industries that have become smarter and connected through the introduction of smart devices, a.k.a. the Internet of Things. First, we propose a basic model for a duopolistic multi-sided market with externality effects. Next, we expand this model to a case that considers cross-market network externalities. Our results reveal that, even if Internet of Things technologies facilitate complex multi-sided markets, there is a strategic pricing solution for firm profits. Moreover, a strategic firm can benefit from aforementioned cross-market externalities in terms of higher market share and equilibrium prices.

This study not only contributes to the theories of pricing information goods, but also provides a guideline for practitioners who make pricing and other strategic decisions for the Internet of Things enabled goods and services.

1. Introduction

In our homes and businesses, we increasingly enjoy the benefits of machine-to-machine communication, such as the automatic ordering of car services by our cars when a certain mileage is reached or the signaling for copier repair to our office maintenance team when a jam occurs. As we increasingly add machines to our home and office spaces that have communication capabilities then there is greater potential for machines to interact with each other and share data. This creates an opportunity for technologies to make more and better-informed decisions for us. The connection between machine communication and decision making capability is at the core of Internet of Things (IoT), a term used to represent the “integration of the physical world with the virtual work of the Internet” [1, 2]. The IoT network therefore draws on shared information between devices to increase the efficiency and effectiveness of customer services and products.

The IoT synergizes multiple markets that disrupt the way products and services are monetized and managed. That is, a firm could offer products and services that are from seemingly separate markets in an IoT network. This may include products such as durable goods, consumable goods and services such as advertising and maintenance. To investigate the network externalities created by the IoT, researchers have focused on two-sided markets [3, 4]. For example, Amazon.com provides smart refrigerators and grocery management services. Whereas a smart refrigerator will monitor the food types and supply within the fridge, the food management services will signal the grocer of replenishment needs. A provider, such as Amazon Fresh may then ship the groceries from the store to the customer’s house.

Recently researchers have provided a number of business models that can help firms strategize their approach as a provider of one or more products and services enabled through smart service systems [5]. The different business models suggest that a single company may choose to address multiple markets that connect as an IoT. Yet, as a burgeoning area of research and practice, it is still unclear how to best price offerings in a business model that address complementary markets within the IoT to attract the most market share. Indeed, researchers suggest that attracting all sides of the market will depend on finding effective pricing models [6, 7].

Because of the seamless relationships between the market offerings, the price competition between firms serving multiple markets using the IoT is not straightforward. This study includes an analytical model of price competition between two firms competing in multiple markets (e.g., durables, services, and consumables) over two time periods. We find equilibrium conditions that provide a base model of pricing competition for the IoT. Then, we extend the model by considering the nuances of network externalities obtained by firms providing multiple types of offerings. As such, we consider a multi-sided market where externalities explain competitive pricing and market share across two firms.
2. Literature Review

2.1 Internet of Things

The Internet of Things (IoT) is based on four simple components. The first layer of the IoT is comprised of the “Things,” that consist of technological components. The components may include refrigerators, cars, shopping carts, and other devices with data processing capabilities. While in the past, these everyday objects were incapable of decision-making or data collection abilities, the premise behind IoT, is that these objects are transformed into computing mediums through the integration of special hardware.

The second layer of the IoT contains the hardware that enables the “Things” to use the Internet for communications. This hardware is integrated into the everyday objects at our work and home in order to collect data and transmit it over the Internet. There are various hardware components available including integrated circuits, SIM cards, and sensor. For example, hardware providers include Honeywell, Akita electronics, and Samsung.

The third layer of the IoT is made up of the Internet products and services. This layer is comprised of hardware, software and service providers that enable information from the technological components to traverse the Internet. Internet products may include switches, routers, modems and other networking software required to provide Internet services. Internet services may include Internet access providers and other web storage and consumer offerings. For example, access providers may include Comcast, Frontier, CenturyLink that serve both commercial and residential consumers.

The fourth layer of the IoT include the platforms that provide the intelligence to analyze the transmitted data and make decisions. The platform level is central to a fully functional IoT; that is, the other layers are inconsequential until decisions and subsequent actions can be made from the data collected. For example, the analysis of inventory within the refrigerator may generate a grocery list and even a placed order at the consumer’s favorite grocer. As such, the platform layer removes the management of decisions and actions from consumers and therefore creates value for the consumer.

This layer is also responsible for tracking and storing data in order to provide insights and preemptive decisions over time. The platforms may employ local database options or be in the cloud. For example, commercially available platforms include Intelligent Systems from Microsoft and Internet of Everything from Cisco. This final layer of the IoT is the most complex because it binds the other components from all other layers. Specifically, it collects the data from the ‘Things’, applies analysis and intelligence to generate a decision, and transmits it to other ‘Things’ via the hardware and Internet.

2.2 Competing in Multiple Markets

The IoT enables the connection between a number of products and services that address many consumer needs, and therefore, many sides of an IoT enabled market. As such, researchers have sought to elucidate different business models that represent combinations of ownership issues [5]. In particular, researchers suggest that companies may address one or more side of the market. Figure 1 demonstrates the multi-sided nature of the IoT enabled market.

![Figure 1. Market Sides in the IoT Network](image-url)

Herein, we consider the way a company may address one or more sides of the IoT enabled market, to benefit from the externalities created by capturing market share from more than one side. To model the interactions within a multi-sided market, researchers have focused on the externalities within two-sided enterprises [3]. The definition of a two-sided market is “one in which 1) two sets of agents interact through an intermediary or platform, and 2) the decisions of each set of agents effects the outcomes of the other set of agents, typically through an externality” [8]. For example, a smart copier may be purchased by a company, with data collected and provided to the device informing maintenance service providers and consumable sellers. Researchers have considered two-sided markets to study different strategies for addressing different market sides (e.g., [7]).
strategies of interest include freemium models where a discount or free offering is provided to one side of the market [9]. Another approach is to change the underlying layer of the IoT, such as using proprietary platforms versus open source platforms [10]. Taken together these models have helped demonstrate ways companies can address multiple sides of the market.

Building on past considerations, we further consider the way competition within a two-sided market may unfold when externalities are present. That is, on the one hand, independent companies may address different sides of the market. Indeed, researchers suggest that network externalities develop over time and therefore may deter companies from entering multiple sides of the market at once [11]. As such, many multi-sided markets are addressed by independent organizations, such as the use of Frigidaire smart fridges to send data to Amazon Fresh for grocery delivery. In such a scenario, each firm may be the market leader for its offering, and exist as a virtual monopoly. These companies may benefit from focusing on core capabilities, yet their profit comes from only one side of the market.

However, on the other hand, companies may provide offerings to both sides of a market. For example, such a scenario may occur if Amazon.com designs and sell smart-refrigerators that connect to the Amazon Fresh online grocery service. In such a scenario, each firm may be the market leader for its offering, and exist as a virtual monopoly. These companies may benefit from focusing on core capabilities, yet their profit comes from only one side of the market.

In our model setup, there are two firms in j market sides with asymmetric market shares: $0 \leq q^a_0 < 0.5 < q^a_0 \leq 1$

The asymmetric market share assumption benefits the model in two ways. First, it provides a more realistic representation of current IoT-enabled markets. Second, it covers a wider range of theoretical scenarios than an equal-market-share case.

We also assume that, in the market setting above, there is a continuum of customers uniformly distributed between firms a and b. This horizontal differentiation (which indicates that IoT-enabled service characteristics across a market side are fixed) is due to inherent characteristics of IoT services (such as customer taste, ease of operation, configurability, compatibility and security perception) rather than the physical location.

### 3.1 Basic Model

In our model setup, there are i firms in j sides of the market. Multi-sided markets develop over time, generally with the introduction of a disruptive technology because network externalities require time to affect a market. [11] For example, it took Amazon.com years to develop a viable electronic book reader platform and benefit from synergies on both sides (e-reader and e-book) of the publication market. Therefore, most multi-sided markets start with independent organizations serving each side. The best representation of a pre-competition multi-sided market is the case where firms independently serve separate sides of the market [5]. In short, in the basic model, we consider that cross-market externalities do not come into effect. On the other hand, information goods inherently exhibit network externalities within a market [14]. Therefore, in the basic model we consider IoT services to exhibit delayed positive network externalities despite the fact that cross-market externalities do not exist.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>$u$</td>
<td>Customers’ utility</td>
</tr>
<tr>
<td>$i$</td>
<td>Firm index: $i \in {a, b}$</td>
</tr>
<tr>
<td>$t$</td>
<td>Period: $t \in {0,1,2}$</td>
</tr>
<tr>
<td>$c_x$</td>
<td>Cost of switching: $c_x \sim U[0, \theta]$</td>
</tr>
<tr>
<td>$e$</td>
<td>Network effect on $u$</td>
</tr>
<tr>
<td>$j$</td>
<td>Market side index: $j \in {1, 2, 3}$</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Marginal shifting cost</td>
</tr>
<tr>
<td>$p^i_t$</td>
<td>Price of firm $i$ in period $t$</td>
</tr>
<tr>
<td>$q^i_t$</td>
<td>Quantity sold by firm $i$ in period $t$</td>
</tr>
<tr>
<td>$x^i$</td>
<td>Distance from buying the service from firm $i$</td>
</tr>
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</table>

The IoT-enabled market are served by two firms ($a$ and $b$) with asymmetric initial market shares:

The notation used in this paper is in Table 1.
We consider a two-period pricing game with two firms. Price $p_i^t$ represents the price of firm $i$ in period $t$. Customers make purchase decisions based on their utilities. The term $x^t_i$ is the distance of the customer buying the service from firm $i$. In addition, the term $c_s$ represents any costs incurred to switch. The initial picture looks as shown in figure 1:

![Figure 1. Illustration of the initial condition for the basic model](image)

For simplicity, we denote $e_{11}$ as $e$, and omit the subscript $j$ in $p_{ij}^t$ and $q_{ij}^t$. The net utility of the indifferent customer for firm $a$ in the second period can be characterized as:

$$
\begin{align*}
    u - \alpha x^a - p_a^2 + e q_a^2 &= \\
    u - \alpha(1 - x^a) - p_a^2 - c_s + e q_a^2
\end{align*}
$$

The indifferent customer determines new market shares for firm $a$ and $b$ at the end of the second period. We use backward induction to find equilibrium prices and quantities sold to represent market shares. First, we start with the second period solution, and then we solve the maximization problem for the first period profits to find equilibrium prices and quantities sold. As mentioned in table 1, $q_i^t$ denotes quantity sold by firm $i$ in period $t$.

The net utility of firm $b$’s indifferent customer in the second period is:

$$
\begin{align*}
    u - \alpha x^b - p_b^2 + e q_b^2 &= \\
    u - \alpha(1 - x^b) - p_b^2 - c_s + e q_b^2
\end{align*}
$$

We can determine the new allocation of market share for firm $a$ and $b$ at the end of the second period by determining the quantity of switching customers. To find market shares for the second term, we start by identifying customers who switch:

Customers will switch from firm $a$ to firm $b$ when $c_s^a < \alpha(2x^a - 1) + p_a^2 - p_b^2 + e(q_b^2 - q_a^2)$.

Similarly, firm $b$ customers switch to firm $a$ when $c_s^b < \alpha(1 - 2x^b) - p_a^2 + p_b^2 + e(q_a^2 - q_b^2)$. Please note that switching cost can be different for each customer since it is a distribution. Such switching costs bring additional trade-offs over the heterogeneity of tastes. For example, consider two customers where one is closer to firm $a$ in tastes. Normally we would expect the closer customer to stay with firm $a$ and the farther customer to switch, however, if the closer customer’s switching cost is low, and the farther customers switching cost is high, then the farther customer can stay with the firm because of high switching costs and the closer customer may switch to the rival’s service.

We assume that $\alpha < p_a^2 - p_b^2$ to avoid the negative probability of switching and an interior location $x$ for the customer. This assumption not only improves tractability in the general model, but also it is a better representation of reality. Price $p$ in our model includes inherent penalties of switching, therefore a customer’s switching cost will be less than the price difference, or else the customer would not switch. These conditions are checked for all possible cases (negative and positive) of optimal solutions.

Let $n_{ij}$ be the quantity of customers who bought from $i$ in period $t - 1$, and firm $k$ in period $t$, in market side $j$. For example, customers who switched to firm $b$ from firm $a$ in period 2 are represented as $n_{2a}^b$. Therefore, customers staying with firm $a$ can be found through the following calculation:

$$
\begin{align*}
n_{2a}^b &= \int_0^{q_a^2} \left( \int_0^{\frac{\theta}{e}} \frac{1}{\theta} \, ds \right) \, dx \\
&= \frac{q_a^2 (\alpha(1 - q_a^2) - p_a^2 + p_b^2 + e(q_a^2 - q_b^2)^2 + \theta)}{\theta}
\end{align*}
$$

Customers switching from firm $a$ to $b$:

$$
\begin{align*}
n_{2a}^a &= q_a^2 - n_{2a}^b \\
&= \frac{q_a^2 (\alpha(q_a^2 - 1) + p_a^2 - p_b^2 - e(q_a^2 - q_b^2)^2)}{\theta}
\end{align*}
$$

Customers staying with firm $b$:

$$
\begin{align*}
n_{2b}^b &= \int_0^{q_b^2} \left( \int_0^{\frac{\theta}{e}} \frac{1}{\theta} \, ds \right) \, dx \\
&= \frac{(q_b^2 - 1)(q_a^2 (\alpha + e) - q_b^2 e + p_a^2 - p_b^2 + \theta)}{\theta}
\end{align*}
$$

Customers switching from firm $b$ to firm $a$:
First order conditions give us equilibrium prices as:

\[ p_{2a}^* = \frac{(1 + q_1^a) \theta + e(2q_1^a - 1)(q_1^a - q_2^b)}{3} \]

\[ p_{2b}^* = \frac{(2 - q_1^a) \theta - e(2q_1^a - 1)(q_1^a - q_2^b)}{3} \]

Equilibrium quantities sold are:

\[ q_{2a}^* = \frac{(1 + q_1^a)}{3} \]

\[ q_{2b}^* = \frac{(2 - q_1^a)}{3} \]

As a result of the second period profit maximization, we obtain profits as a function of quantities sold in the first period:

\[ \pi_{2a}^* = \frac{(e(2q_1^a - 1)(q_1^a - q_2^b) + (1 + q_1^a)\theta)^2}{9\theta} \]

\[ \pi_{2b}^* = \frac{(e(2q_1^a - 1)(q_1^a - q_2^b) - (2 - q_1^a)\theta)^2}{9\theta} \]

For the first period maximization problem, we follow a process similar to the second period. First, we identify the indifferent customers to find switching costs \( c_i \) in terms of \( x^i \) and prices.

The net utility of the indifferent customer for firm \( a \) in the first period is:

\[ u - \alpha x^a - p_1^a + eq_1^a = u - \alpha(1 - x^a) - p_1^a - c_2 + e q_1^b \]

The net utility of firm \( b \)'s indifferent customer is:

\[ u - \alpha(1 - x^b) - p_1^b + eq_1^a = u - \alpha x^b - p_1^b - c_2 + e q_1^b \]

Subsequently, we solve the maximization problem for the first period profits to find equilibrium prices and quantities sold. Tracing previous steps shows that there are optimal pricing strategies for firm \( a \) and \( b \) in the basic model.

**Theorem:** There exists a solution for the maximum revenue in IoT-enabled markets, thus there are rational pricing strategies for firms \( a \) and \( b \).

### 3.2 Pricing with Cross-Market Externalities

Under the assumption that positive network externalities are present across sides of the market, we introduce a more sophisticated parameter \( e \). In this case, \( e_{hj} \) represents the delayed positive network externalities of the quantity sold in market side \( h \) on market side \( j \). This externality means that the utility of the consumer benefits from a compatible service sold in a connected market. For example, when a firm such as Amazon.com sells a smart refrigerator, it has the potential to affect grocery sales of Amazon Fresh. A smart fridge eliminates the need for manual grocery ordering. This benefit creates value both for the fridge consumer and for the firm’s grocery side.

The main challenge for such a platform is to get the pricing right. In our second case, we develop a pricing strategy when cross-market externalities are enabled though technologies such as IoT. Here is an illustration of how cross-market externalities affect our model.
4. Conclusion

Advances in information technologies provided us with smart services that exhibit complex interactions. Cross-market externalities such as the ones in the Internet of Things (IoT) enabled markets are an example of these complex properties. For example, making refrigerators smart, can connect refrigerator manufacturers and grocers, as well as advertisers, and farmers. In our study, we developed a model incorporating both within-market and cross-market externality effects in an industry that has multiple sides. To our knowledge, this is the first model about multi-sided markets. Therefore, this study also contributes to the e-Commerce literature as the first multi-sided IoT-enabled markets model.

On the other hand, practitioners in sides of the IoT enabled market are challenged in developing viable pricing models in such complex business scenarios. Practitioners currently use pricing models developed for conventional service models. This study offers a new approach, supported by a novel model, for pricing smart services enabled by the IoT.

Our findings suggest that, even with the presence of positive and delayed network externalities in a multi-sided market, there is a solution for the optimal revenue. Moreover, we find that cross-market externalities provide opportunities for those firms who are willing to operationalize their pricing and market share strategies around them. Specifically, firms that are willing to identify cross-market externalities can benefit in terms of higher market share and prices. Perhaps firms such as Apple or Google already benefit from externalities by instinctually creating ecosystems with multiple sides. If there is such a phenomenon, we explain the rationale behind it with an analytical model.

The main limitations of this research are due to the analytical modeling methodology we employed. First, arguments and propositions in this study have not been tested empirically and they are bound by the model assumptions. For example, we anticipated network externalities would be positive, which is aligned with the e-Commerce and economics literature [3, 12, 14, 15]. However, in real life we observe a diminishing rate of return for the externality effect, and even sometimes it is negative. Indeed, an example for negative network externalities has been the departure of young social media users from Facebook when parents became users and sent friend requests to their children.

Finally, but maybe the most importantly, data collected from such smart devices would lead to micro-segmentation and advanced marketing methods that would target individual customers rather than
wide segments. Analyzing the data collected from IoT-enabled devices, firms can direct promotions to extract a higher utility from consumers. To summarize, our model can be improved by considering synergies other than positive network externalities among the sides of an IoT enabled smart services market.

Each one of the limitations in this study provides an opportunity for a future research direction. First, in this study, we use a relatively simplified model of the network externality concept. Our model could be improved by considering a more sophisticated form (probably concave) externality function. Second, the model is based on two periods. Extending the time horizon to include multiple periods can provide additional insights into the impact of network externalities on customers’ utility functions. Finally, validation of our findings creates an opportunity for an empirical study for the pricing of IoT enabled smart service systems.
5. References


