How Can Substitution and Complementarity Effects Be Leveraged for Broadband Internet Services Strategy?

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Abstract

With growth in mobile Internet services, the relationship between mobile and fixed broadband has become an issue in telecom firm strategy. Previous research focused on aggregate penetration for mobile and fixed broadband services. Our research analyzes the economic relationship between mobile and fixed broadband services at the household level, as a basis for how senior managers should rethink their strategy approach. Using data on broadband services subscriptions, we examine how changes that occur for mobile broadband services bandwidth (MBB) affect changes in fixed broadband bandwidth (FBB) services subscriptions, inclusive of new subscriptions – and vice versa. We explore the different cross-effects and asymmetric patterns of event-driven bandwidth changes. Mobile and fixed broadband services are complementary: both affect the consumption of the other. Our findings offer useful information for marketing strategy and broadband services promotion, such as bundling strategy based on bandwidth changes, and segmentation based on the bandwidth changes in both services.

1. Introduction

With the development of devices such as smartphones and tablets, the adoption of mobile Internet services has grown rapidly [12]. The average growth rate for mobile Internet services during the first eleven quarters after their launch was eleven times faster than for Internet adoption of desktop computing, for example [14]. The growth of mobile Internet traffic has become a complex challenge to the broadband services business model in retail telecommunications, and mobile broadband services are a major new revenue source for services providers. In contrast, fixed broadband penetration in most developed countries has reached the point of saturation. Key industry players, such as Verizon and AT&T, offer both types of services, so they must align their strategies for mobile and fixed services.

Understanding the interaction between fixed and mobile broadband is critical to retain and acquire customers, and deliver the right customer experience. Their interaction has not been clearly understood yet though. Meanwhile, there has been explosive growth in mobile broadband subscriptions, but somewhat declining interest in fixed broadband services. And various reports have forecasted that mobile broadband will displace fixed broadband soon [13, 17], but the number of subscribers using both is still increasing [18].

The substitution of mobile for fixed broadband services has been the subject of some debate. Prior research mostly has focused on comparing aggregate penetration rates for mobile and fixed broadband services at the national level [11, 22]. And various authors have suggested ways to think about making broadband policy effective in developed and developing countries. They have not offered insights on how subscribers choose among the various services though. So there have been mixed results on the relationship between the broadband services. We aim to contribute new knowledge by identifying the effects of these services at the subscriber level and providing strategies for these services.

To assess the interactions between mobile and fixed broadband, we will leverage data on variation in the bandwidths selected by individual users for their services. We ask: How can we identify whether changes in the use of mobile broadband bandwidth lead to substitution and complementarity effects in subsequent consumption of fixed broadband services? We use *bandwidth* as a measure of consumer preferences, and examine how the consumption of *mobile broadband bandwidth* (MBB) affects changes in consumption of *fixed broadband bandwidth* (FBB) – and vice versa. This enabled us to find out how consumer choice for one service depends on consumer choice for the other.

We use broadband Internet services subscription data for anonymized customers from a retail telecom services firm in Singapore, related to consumer choices for mobile and fixed broadband services. This enabled us to control for the order of events related to services subscription changes between mobile and fixed broadband bandwidth in our estimation work.

2. Fixed and Mobile Phone Technologies

In the telecom literature, many authors have dis-

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cussed the relationship between mobile and fixed-line telephone services. For example, Sung and Lee [21] focused on the substitution effects of mobile for fixed-line services. Other studies have sought to empirically validate the substitution effect in terms of the cross-elasticity of demand between mobile and fixed-line phone services [1, 7, 9, 15, 19]. Substitution can be explained by the relative decline in mobile network costs, network effects, and improved service quality. Others have suggested complementarity effects from mobile phone services [2].

Due to the short time that mobile broadband services have been available in the market, there have not been many studies on the relationship between fixed and mobile services substitution. Several research papers and industry reports have made predictions about the relationship between mobile and fixed broadband though. For example, Srinuan et al. [20] showed that prices in Sweden strongly affect the market's interest in broadband connections. Several studies also have predicted complementarities for mobile Internet services on broadband Internet services [5, 16].

3. Research Setting and Data

3.1. The Research Setting

We next discuss the research setting and customer decisions pertaining to broadband Internet services subscriptions. We collected data on mobile and fixed broadband Internet services, and measured service quality with bandwidth to represent download speed. This is relevant because subscribers generally prefer greater speed for downloading than for uploading. Download speeds for fixed broadband services range from 2 to 100 megabits per second (mbps); mobile broadband services have lower speeds of operation. Mobile customers can use USB-connected wireless modems for Internet access via their laptops [6]. In contrast to fixed broadband services, which are often sold using flat-rate pricing based on relative speed, mobile broadband services are offered at fixed prices for a given level of bandwidth speed, a data download capacity, and possibly a charge for excessive data usage. The research sponsor offers download speeds from 1.2 to 42 mbps, with a stated data cap.

3.2. The Data

Our data cover June 1, 2007 to May 31, 2012, and describe customer subscription changes for fixed and mobile broadband services. They include 99,653 households that subscribed to fixed broadband services and 37,078 mobile broadband subscribers. Our empirical analyses of the interactions between fixed and mobile broadband services are based on their mutual dependency. We observe variation in consumer choices for: whether consumers subscribed to both services; what bandwidths they selected; and the sequences of their subscription changes.

We identified three categories of changes in subscriptions: new subscriptions; changes from one service to another; and termination of a service. Our data include 125,080 fixed broadband subscription changes and 40,964 mobile broadband services changes. Also, 2,253 households made switches in their fixed broadband services while they were subscribed to mobile broadband services. In contrast, 3,732 households made adjustments to their mobile broadband services while they were subscribed to fixed broadband services.

We also collected download speeds and caps, prices, and smartphone versus feature phone types from the sponsor's website. Subscribers can select the bandwidth they will use from among eleven alternatives in fixed and mobile broadband services. Our dependent variables are the changes in bandwidth subscriptions for both services. We traced customers' changes for selected bandwidth subscriptions for both services. The data caps in mobile broadband services go from 0 to 30 gigabytes.

4. Empirical Models

We developed a number of empirical models to represent changes in subscriptions for fixed and mobile broadband services. We will present a subset of the results we obtained to date, to create an appropriate balance between the presentation of our quantitative findings, and their discussion, interpretation and assessment. We also will offer additional commentary on what the empirical results tell us about firm strategy for fixed and mobile broadband services. (See Appendix Table A1 for our modeling notation.)

4.1. Preferences for Bandwidth of Services

The first pair of models examines how changes in fixed (or mobile) broadband bandwidth depend on the bandwidth choice in the other service. To assess the presence of substitution and complementarities, we estimated customer preferences based on their consumption of different types of broadband services and their different bandwidths. Customers also experience uncertainty about the effective download speeds for a given level of bandwidth; it takes time and repeated use to learn the true performance of the bandwidth of services to which they subscribe [3, 10]. It is hard to evaluate service quality due to the wide range of bandwidths available. The quality that customers perceive with their current bandwidth subscriptions affects subsequent changes they make in the bandwidth they choose.

For the empirical analysis, we first identified the time when customers changed their bandwidth in fixed or mobile broadband services. To capture the changes in FBB and MBB separately, we estimated two different models using changes in bandwidth for the fixed (or mobile) mobile broadband services for customer i as the dependent variables: $\Delta Bandwidth\_FB_i$, and $Bandwidth\_MB_i$. We will refer to the model that uses $\Delta Bandwidth\_FB_i$ as its dependent variable as the *FBB Switching Model* (Model 1), and the one using $\Delta Bandwidth\_MB_i$ as the *MBB Switching Model* (Model 2).

$$\Delta Bandwidth\_FB = \beta_0 + \beta_1 Price\_FB + \beta_2 Bandwidth\_MB + \beta_3 DataCap + \beta_4 Duration\_MB + \delta_1 Smartphone + \delta_2 Duration\_SM + \gamma_1 Age + \gamma_2 Gender + \gamma_3 DwellingType + \gamma_4 Region + \gamma_5 Time + \varepsilon \quad (1)$$

$$\Delta Bandwidth\_MB = \beta_0 + \beta_1 Price\_MB + \beta_2 Bandwidth\_FB + \beta_3 Duration\_FB + \delta_1 Smartphone + \delta_2 Duration\_SM + \gamma_1 Age + \gamma_2 Gender + \gamma_3 DwellingType + \gamma_4 Region + \gamma_5 Time + \mu \quad (2)$$

We view the bandwidth of the mobile or fixed broadband service that a customer was using at the time of making a service change ($Bandwidth\_MB_i$, $Bandwidth\_FB_i$) as a main effect. Through this main effect, we expect to capture how the quality of the current mobile or fixed broadband service leads to a change in the other type of broadband service. For customers who did not subscribe to another type of service when they changed bandwidth in a service, we set the variables $Bandwidth\_MB_i$ or $Bandwidth\_FB_i$ to 0. Since mobile broadband services have data download caps, we used the data cap of the mobile broadband service that the customer had in use ($DataCap_i$) for the FBB Switching Model. For both models, we also distinguished between the duration of usage of bandwidth for the other type of service not involved in the subscription ($Duration\_MB_i$, $Duration\_FB_i$). This controls for the customer's experience. We also adopted the price of the broadband service in use before a bandwidth change occurred ($Price\_FB_i$, $Price\_MB_i$).

Our model is based on the assumption that both fixed and mobile broadband services can substitute for one another. We also consider the possibility that phone-based Internet access affects the change in bandwidth. We use a variable to indicate whether a customer was subscribed to smartphone services ($Smartphone_i$) when switching to fixed broadband services. The duration of smartphone services use ($Duration\_SM_i$) further controls for how much experience a customer has with smartphone services.

Besides the main independent variables, we use other demographic variables to control for individual effects. Customer Age_i and $Gender_i$ are controls for the propensity to adopt higher quality technology. Customer $DwellingType_i$ and $Region_i$ of residence are wealth-level indicators. More wealth increases the likelihood of an upgrade of the household's broadband bandwidth.

A subscription for broadband services is usually accompanied by a two-year contract. The number of remaining months in a contract may be important in holding up a customer's decision to make a bandwidth change. However, instead of controlling for contract time remaining, we captured each household's subscription changes during five years, a longer period than what any of the sponsor's contracts would have required. We observed that most households made a change or two in each broadband service during the period that we studied.

We used a cross-sectional regression model and the household-level as our unit of analysis. We also controlled for the effect of the time when bandwidth changes occurred. We identified broadband bandwidth subscription change events that occurred before December 1, 2009, the day smartphone services were introduced in Singapore, as being members of the reference group. The availability of smartphones was a triggering event that drove rapid growth in mobile data traffic. We considered customer changes in mobile and fixed broadband bandwidth subscriptions for six-month periods after smartphones entered the market. Table 1 shows descriptive statistics for our data.

4.2. The Cross-Effects of Bandwidth Changes

We next assess changes observed in customers' mobile (or fixed) broadband bandwidth subscriptions as a main effect relative to subsequent changes in the other type of broadband bandwidth subscription. This is the basis for how we will explain substitution and complementarity effects across the mobile and fixed broadband services. A typical approach is to use a cross-price elasticity estimation to demonstrate substitution or complementarity effects between two different products [4]. The use of this indicator is based on the assumption that a change in the quantity demanded is entirely due to a price change [8]. Our focus is to observe each customer's sequence of bandwidth changes in fixed and mobile broadband rather than the customer's price sensitivity relative to the two services.

Recognizing the directions of the interactions between the two services, we also applied two different equations, similar to the first set of models. In Equation 3, the *MBB-to-FBB Model*, the change in MBB subscription is the prior event and the change in FBB subscription is the subsequent event. In Equation 4, the *FBB-to-MBB Model*, the two change-related events are reversed.

Table 1. Descriptive statistics

VARIABLE	MEAN	STD. DEV.
Fixed broadband bandwidth changes (125,080 obs.)		
$\Delta Bandwidth\_FB$	20.88	35.29
$Price\_FB$	11.99	25.69
$Bandwidth\_MB$	0.10	1.39
$DataCap$	0.06	1.23
$Duration\_MB$	5.56	58.24
$Smartphone$	0.08	0.28
$Duration\_SM$	43.14	197.58
Mobile broadband bandwidth changes (40,964 obs.)		
$\Delta Bandwidth\_MB_i$	4.45	9.06
$Price\_MB_i$	5.33	17.84
$Bandwidth\_FB_i$	2.91	12.97
$Duration\_FB_i$	34.98	152.30
$Smartphone_i$	0.11	0.31
$Duration\_SM_i$	53.35	206.87

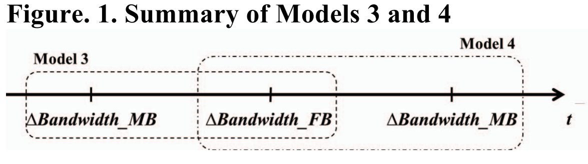
Equations 3 and 4 use largely the same explanatory variables as Equations 1 and 2. We use the difference in a specific broadband bandwidth subscription as the main explanatory variable. For the MBB-to-FBB Model, we use the difference in the downloadable data cap for the mobile broadband service. Also, we include the $TimeGap_i$ between the prior and subsequent events to control the time lag between the two events. Through this variable, we also capture the households that changed their mobile and fixed broadband services at the same time, with $TimeGap_i = 0$). Models 3 to 4 are shown below:

$$\begin{aligned}\Delta Bandwidth\_FB = {} & \beta_0 + \beta_1 \Delta Price\_FB \\ & + \beta_2 \Delta Bandwidth\_MB + \beta_3 \Delta DataCap \\ & + \beta_4 TimeGap + \delta_1 Smartphone \\ & + \delta_2 Duration\_SM + \gamma_1 Age + \gamma_2 Gender \\ & + \gamma_3 DwellingType + \gamma_4 Region + \gamma_5 Time + \nu \end{aligned} \tag{3}$$

$$\begin{aligned}\Delta Bandwidth\_MB = {} & \beta_0 + \beta_1 \Delta Price\_MB \\ & + \beta_2 \Delta Bandwidth\_FB + \beta_3 TimeGap \\ & + \delta_1 Smartphone + \delta_2 Length\_SM + \gamma_1 Age \\ & + \gamma_2 Gender + \gamma_3 Dwelling\_Type + \gamma_4 Region \\ & + \gamma_5 Time + \omega \end{aligned} \tag{4}$$

The changes in fixed and mobile broadband may be endogenous due to simultaneity. Our analysis is to assess how much change occurred in consumption of bandwidth of fixed (mobile) broadband services after changes to mobile (fixed) broadband bandwidth occurred. Figure 1 summarizes Models 3 and 4.

Figure. 1. Summary of Models 3 and 4



5. Results

5.1. Customer Preferences for Bandwidth

Appendix Table A2 presents results for the FBB and MBB Switching Models 1 and 2. The results of the FBB Switching Model (the second column) show that, as a customer subscribes to higher mobile broadband bandwidth, a household will increase fixed broadband bandwidth (0.683, $p < 0.01$). This indicates that MBB is positively related to FBB. This makes sense: customers with higher MBB services are likely to be heavy consumers of data. This suggests that a customer's experience with higher MBB also will lead to demand for higher FBB.

Although our model assumes that the variable for mobile broadband bandwidth ($Bandwidth\_MB_i$) is continuous, the bandwidth of the mobile broadband services that our data represent is based on the definitions of the service plans. In our data, customers can choose one out of five options for mobile broadband bandwidth (1.2, 2.1, 7.2, 21, 42 mbps). So we used a categorical variable for MBB (1.2, 2.1, 7.2, more than 21 mbps). The estimation results show that customers who subscribed to higher MBB tended to switch to higher FBB. This is consistent with the results of our original regression, which assumed that $Bandwidth\_MB_i$ is a continuous variable.

The MBB Switching Model's results show a positive effect of FBB on increases in MBB (0.035, $p < 0.01$). Like in the FBB Switching Model, customers who subscribe to higher FBB also require higher MBB, which reflects heavy-use consumer preferences. We used a regression model with a categorical variable for $Bandwidth\_FB_i$ (less than 10, less than 50, less than 100, and less than 1,000 mbps). This also shows positive effects of FBB on changes in MBB. For the other control variables, we obtained similar results as those for the FBB Switching Model.

We also confirmed the positive effect of smartphone services on the changes in FBB and MBB. This result shows that experience with Internet services involving mobile devices encourages demand for higher bandwidth when laptop or desktop computers are used. After controlling for the effect of smartphone services, the interactions that we estimated between MBB and FBB services remain the same.

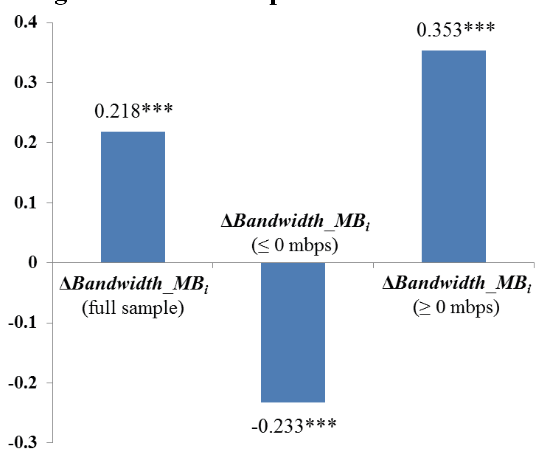
The other control variables also were significant in both models. The data cap on mobile broadband services subscriptions showed a positive effect (0.988, $p < 0.01$) on changes in FBB. The price of subscribed broadband services negatively impacted changes in broadband bandwidth subscriptions (-0.846, $p < 0.01$ in Model 1; -0.282, $p < 0.01$ in Model 2). The duration of usage for MBB negatively affected changes in FBB subscriptions. The duration of fixed broadband services usage also showed a negative effect on the changes in MBB. We infer that, as customers adapt to and learn about using mobile broadband services, they will decrease FBB.

For the demographic and time effects, both models showed similar results. (We suppressed these in the Appendix Tables A2 and A3 to save space). The younger generation and wealthier customers tended to upgrade both their FBB and MBB services more. We also observed that bandwidth upgrades gradually increased after smartphone services were introduced on December 1, 2009.

5.2. Cross-Effects with Bandwidth Changes

We further explored the consequences of subscription switching by utilizing bandwidth changes for both broadband services and viewing their occurrences as events in sequence. (See Appendix Table A3 for the results of Models 3 and 4.) Overall, we observed evidence for complementarity effects between MBB and FBB. [1] This implies that increases in MBB were associated with upgrades in subscribers' FBB services – and vice versa. It also is interesting to note that positive (and negative) changes in MBB show complementarity (and substitution) effects. (See Figure 2.)

Figure 2. Effects of MBB subscription changes on changes in FBB subscriptions

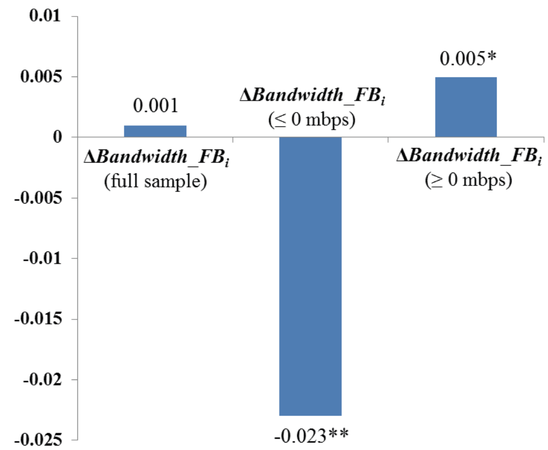


Note: MBB-to-FBB Model with different samples. (1) $\Delta Bandwidth\_MB \leq 0$: 125,083 obs.; (2) $\Delta Bandwidth\_MB \geq 0$: 122,554 obs. Signif.: *** $p < .01$, ** $p < .05$, * $p < .10$.

The increase in MBB showed some complementary effects with respect to FBB. But when MBB decreased, the results showed substitution effects instead. The results of the FBB-to-MBB Model also showed similar patterns in fixed to mobile broadband bandwidth subscription changes. (See Figure 3.)

[1] Multicollinearity was not a problem. We used likelihood ratio tests to compare the full and reduced models, excluding variables for smartphone effects. The χ^2 likelihood ratio and adjusted R^2 showed the full model is better.

Figure 3. Effects of FBB subscription changes on changes in MBB subscriptions



Note: FBB-to-MBB Model with different samples. (1) $\Delta Bandwidth\_FB \leq 0$: 41,115 obs.; (2) $\Delta Bandwidth\_FB \geq 0$: 37,554 obs. Signif.: *** $p < .01$, ** $p < .05$, * $p < .10$.

To summarize, customer subscriptions involving MBB only have positive effects on changes in a customer's FBB subscriptions. In addition, observing positive and negative changes in MBB is helpful to assess the direction of changes in FBB as well. This assertion also holds for changes in FBB services.

6. Discussion

Managers can use our results in several ways that touch on retail telecom strategy. The relationship between fixed and mobile broadband bandwidth gives rise to these business strategies: (1) *customer segmentation* that leverages bandwidth choices for mobile versus fixed broadband services; and (2) more *refined bundling* to take advantage of the discovery of the revealed preferences of customers for different bandwidth levels for broadband Internet services.

First, a benefit from applying our findings will come from understanding a customer's needs for broadband services. From Models 1 and 2, we saw that customer bandwidth choices in mobile and fixed broadband services are positively correlated. This implies that customers who use relatively high mobile broadband bandwidth are likely to change their subscriptions to have greater bandwidth in fixed broadband services too. The same is true for fixed and mobile broadband services in reverse: more fixed broadband capability engenders a need on the customer's part to use higher bandwidth mobile services.

The services' mutual dependency provides mangers with a general basis for exploring optimal pricing. For example, considering the positive mutual dependency and the low marginal cost of mobile services provision, service providers can offer free mobile broadband services with low bandwidth to customers who use fixed broadband services. Then the increased profitability of the fixed broadband services may be greater than the extra cost incurred for the mobile services, leading to increased total profit.

Second, our results in Models 3 and 4 show that the firm should consider customizing its bundling of mobile and fixed broadband services for different customers. When a household customer of both services increases the bandwidth of one of its subscribed broadband services, the customer will be likely to increase bandwidth in the other. With this complementary relationship, a bundle that offers high bandwidth in both services should appeal to such customers. By the same token, when we observe a customer downgrading the bandwidth of a broadband service, the services provider can proactively respond to the customer's decision by leveraging the substitution relationship between the two services. If the profitability in the broadband service to be downgraded is smaller than in the other service, the provider can increase its profit. But, if the profitability of the broadband service to be downgraded is greater than that in the other service, then the manager will need to develop a more attractive custom bundle, possibly with some discount, to limit the diminution in the customer's *average revenue per user* (ARPU).

Third, we can segment customers based on asymmetric patterns of bandwidth changes, as in the strategy evaluation framework in Table 2.

Table 2. Customer Segmentation for Changes in Fixed and Mobile Broadband Services Bandwidth

Observed Event	Expected Event in the Other Service	Customer Segments	Bundle Strategy	Average Revenue per User
Increase in FBB	Increase in MBB	Bandwidth seekers Mobility seekers	Bundle with highest mobile broadband bandwidth	Can increase by offering additional upgrade in both services
Decrease in FBB		Mobility seekers	Bundle with increased MBB and decreased FBB Increase MBB with some discount	Will improve if the increased ARPU for mobile broadband services is higher than the decreased ARPU for fixed broadband services
Increase in MBB	Increase in FBB	Bandwidth seekers Mobility seekers	Bundle with highest fixed broadband bandwidth	Can increase by offering additional upgrade in both services
Decrease in MBB		Bandwidth seekers	Bundle with increased FBB and decreased MBB Increase FBB with some discount	Will improve if the increased ARPU for fixed broadband services is higher than the decreased ARPU for mobile broadband services

The results from Models 3 and 4 suggest that service providers can expect changes in one type of broadband services to occur based on observed change in the other type of broadband services. This segmentation is also directly connected to customized bundles. Customers who upgrade their bandwidth for mobile (or fixed) broadband services can be classified as *bandwidth seekers* and *mobility seekers* based on how they upgrade their bandwidth in the other broadband service. An example is that customers who downgrade their fixed broadband bandwidth services are likely to increase their mobile broadband bandwidth. These customers are less interested in high-speed Internet services and less worried about prices because they upgraded their mobile broadband services with a higher unit cost in mbps terms and downgraded their fixed broadband services with a lower unit cost per mbps. We can classify such customers as mobility seekers.

On the other hand, customers who downgrade their mobile broadband bandwidth can be expected to upgrade their fixed broadband bandwidth. These customers care less about mobile Internet services and want high-speed Internet services with lower unit cost per mbps. We can infer that these customers pursue less mobility, and probably want to use fixed broadband services for their home networks. We classify these customers as bandwidth seekers.

Customer segmentation helps service providers to set up customized bundling strategies. For customers who are both bandwidth and mobility seekers, bundles with the highest bandwidth and a small price cut will be attractive. The operational cost for each broadband service does not depend on bandwidth. So migration to higher speed services is a strategy to increase marginal revenue. For mobility seekers, providers can develop a new bundle comprising increased mobile broadband bandwidth and decreased fixed broadband bandwidth. For bandwidth seekers, on the other hand, providers need to offer a bundle with increased fixed broadband bandwidth and decreased mobile broadband bandwidth. The unit cost per mpbs is usually higher in mobile broadband services than fixed broadband services. So providers may need to offer more discounts to bandwidth seekers than mobility seekers. Although our suggestions do not address how much each strategy contributes to revenue, they still offer guidance on the relationship between fixed and mobile broadband services with customers in mind.

7. Conclusion

The main purpose of this research has been to examine substitution and complementarity effects between fixed and mobile broadband services in terms of bandwidth. We assessed customer preferences for choosing different types of broadband services. We also collected data on customer subscription histories, and showed evidence for both substitution and complementarity effects with fixed and mobile broadband services bandwidth. We found that fixed and mobile broadband bandwidth complement one other, but act as substitutes if one of them decreases due to the micro-behavior of customer choices. Overall, our results were helpful in producing insights regarding how to motivate customers to maximize mobile Internet use.

We note some limitations. First, our results are based on data that describe customer subscription histories. They consist of all household-level services subscription changes during a five-year period. We sought to examine the effects of prior services and bandwidth changes on subsequent services and bandwidth change choices. As we move this research forward, we will expand our efforts to study individual household differences with broadband Internet services bandwidth choices in greater detail.

Second, our use of cross-sectional data did not allow us to identify or exploit differences in subscription changes at the household level. We currently have additional data collection under way so we can cover enough time to use panel data econometric methods. This will support more refined estimation.

Third, our empirical models were specified to support the analysis of interactions between fixed and mobile broadband subscription changes. For service providers, this kind of analysis can assist with the prediction of what the next changes will be after observing the current changes in a household's services and bandwidth choices. Our current modeling approach is limited in its capacity to let us delve more deeply into this issue though. Why so? Because the models we have used are not able to explain why a customer makes changes in the bandwidth of the household's fixed or mobile broadband without dealing more directly with endogeneity via simultaneity of the underlying services choices. To achieve clarity with the empirical estimation for this aspect of the business problem, we are currently exploring candidates for the inclusion of an instrumental variable that can strengthen our approach to explaining services subscription changes. We also are considering to recast our analysis as a natural experiment and to apply difference-in-differences estimation methods.

Fourth, we also tried different measurements for the dependent and independent variables in our models. Instead of using bandwidth changes in the MBB-to-FBB and FBB-to-MBB models, we categorized the changes as upgrades (1), no changes (0), and downgrades (-1), and estimated multinomial logit models. The results also showed complementarities between mobile and fixed broadband bandwidth changes. We will develop this approach further.

Fifth, we recognize that our strategy recommendations in this research are still a work-in-progress, especially related to how the details of what we suggest are able to be tied back to our empirical modeling results. By analyzing quality changes in broadband services at the household level, we were able to suggest several business strategies related to customer segmentation and some ways to more effective bundle different broadband services. Though the quality of a service that is offered is typically proportional to its price, we have not yet explored how customer ARPU increased after subscription changes were made in fixed and mobile broadband services at the household level. To achieve more managerial insights, we must incorporate richer analysis of the price of bandwidth in fixed and mobile broadband sin the empirical model that we have estimated.

Finally, we will look at how interactions between fixed and mobile broadband Internet services contribute revenue to service providers. By pursuing these issues in our ongoing work, the insights from this research will be of greater interest to senior managers and telecom strategists.

Acknowledgment and Data Disclaimer

This research was done under a binding non-disclosure agreement with the corporate sponsor, requiring the anonymization of all data that were used and analyzed. No personally-identifiable information about customers has been disclosed or shared. This research was supported by the Singapore National Research Foundation under the International Research Centre @ Singapore Funding Initiative, administered by the Interactive Digital Media Programme Office (IDMPO). Rob Kauffman acknowledges support from the Lee Kuan Yew Faculty Fellowship for Research Excellence.

References

[1] Ahn, H., Lee, M.H. An Econometric Analysis of the Demand for Access to Mobile Telephone Networks. *Info. Econ. Pol*., 11(3), 1999, 297-305.

[2] Albon, R. Fixed-to-Mobile Substitution, Complementarity and Convergence. *Agen.*, 13(4), 2006, 309-322.

[3] Bolton, R.N., Lemon, K.N. A Dynamic Model of Cus-

tomers' Usage of Services: Usage as an Antecedent and Consequence of Satisfaction. *J. Mkt. Res.*, 36(5), 1999, 171-186.
[4] Boyabatlı, O., Kleindorfer, P., Koontz, S.R. Integrating Long-Term and Short-Term Contracting in Beef Supply Chains. *Mgmt. Sci*., 57(10), 2011, 1771-1787.
[5] De Reuver, M., Ongena, G., Bouwman, H. Should Mobile Internet Be an Extension to the Fixed Web? Fixed-Mobile Reinforcement as Mediator between Context of Use and Future Use. *Telem. and Inform.*, 30(2), 2014, 111-120.
[6] Ergen, M. Mobile Broadband: Including WiMAX and LTE. Springer, Berkeley, CA, 2009.
[7] Garbacz, C., Thompson, H.G. Universal Telecommunication Service: A World Perspective. *Info. Econ. Pol.*, 17(4), 2005, 495-512.
[8] Gillespie, A. *Foundations of Economics*. Oxford University Press, Oxford, UK, 2011.
[9] Grajek, M., Kretschmer, T. Usage and Diffusion of Cellular Telephony, 1998–2004. *Intl. J. Ind. Org.*, 27(2), 2009, 238-249.
[10] Iyengar, R., Ansari, A., Gupta, S. A Model of Consumer Learning for Service Quality and Usage, *J. Mktg. Res.*, 44(4), 2007, 529-544.
[11] Kim, Y., Lee, J.D., Koh, D. Effects of Consumer Preferences on the Convergence of Mobile Telecom Devices. *Appl. Econ.*, 37(7), 2005, 817-826.
[12] Kumar, A., Liu, Y., Sengupta, J., Divya. Evolution of Mobile Wireless Communication Networks: 1G to 4G. *Intl. J. Electr. Comm. Tech.*, 1(1), 2010, 68-72.
[13] Lind, A., Weber, J., MacGillivery, C. U.S. Consumer Fixed Broadband Displacement by Mobile Broadband 2012-2016 Forecast. IDC, Framingham, MA, 2012.
[14] Murphy, M., Meeker, M. Top Mobile Internet Trends, KPCB Rel. Capital, Menlo Park, CA, 2011.
[15] Narayana, M.R., Substitutability between Mobile and Fixed Telephones: Evidence and Implications for India. *Rev. Urb. Reg. Devel. Stud*., 22(1), 2010, 1-21.
[16] Nielsen, P., Fjuk, A. The Reality Beyond the Hype: Mobile Internet Is Primarily an Extension of PC-Based Internet. *Info. Soc.*, 26(5), 2010, 375-382.
[17] Parsons, D. The Fixed/Mobile Broadband Battle: Is It Time for Smart Broadband? Cisco, San Jose, CA, 2009.
[18] Philpott, M. The Future Broadband: Substitution or Convergence? Ovum, London, UK, 2011.
[19] Rodini, M., Ward, M.R., Woroch, G.A. Going Mobile: Substitutability between Fixed and Mobile Access. *Telecom. Pol.*, 27(5), 2003, 457-476.
[20] Srinuan, P., Srinuan, C., Bohlin, E. Fixed and Mobile Broadband Substitution in Sweden. *Telecom. Pol.*, 36(3), 2012, 237-251.
[21] Sung, N., Lee, Y.H. Substitution between Mobile and Fixed Telephones in Korea. *Rev. Ind. Org.*, 20(4), 2002, 367-374.
[22] Thompson, H.G., Garbacz, C. Economic Impacts of Mobile Versus Fixed Broadband. *Telecom. Pol.*, 35 (11), 2011, 999-1009.

Appendix

Table A1. Notation for Model Variables

NAME	DEFINITION	UNIT
$\Delta Bandwidth\_FB_i$ $\Delta Bandwidth\_MB_i$ $Bandwidth\_FB_i$ $Bandwidth\_MB_i$	Change in fixed broadband bandwidth made by customer *i* Change in mobile bandwidth after customer *i* switches mobile broadband service Customer *i* newly selects to subscribe to fixed broadband service Bandwidth of mobile broadband when customer *i* switches mobile broadband bandwidth	Mbps Mbps Mbps Mbps
$\Delta DataCap_i$	Change in data cap of mobile broadband service after customer *i* switches bandwidth	GB
$Duration\_FB_i$ $Duration\_MB_i$ $Duration\_SM_i$	Duration of fixed broadband service use before customer *i* switches its bandwidth Duration of mobile broadband service use before customer *i* switches its bandwidth Duration of smartphone service use before customer *i* switches its broadband service	Days Days Days
$Price\_FB_i$ $Price\_MB_i$	Price of prior fixed broadband service before customer *i* switches its fixed broadband service Price of prior mobile broadband service before customer *i* switches its mobile broadband service	SGD SGD
$Smartphone_i$	Whether customer *i* already subscribed to smartphone when switching broadband bandwidth	0 or 1
$Time\_Gap_i$	Time between prior/subsequent bandwidth changes by customer *i* in fixed / broadband services	Days
Age_i $Gender_i$, $Region_i$ $Dwelling\_Type_i$ $Time_i$	Customer *i*'s age when bandwidth change made (0: < 30 years; 1: 30 to 49; 2: > 49 years) Customer *i*'s gender, region of residence Customer *i*'s residence type Time when customer *i* switches its broadband service bandwidth	

Table A2. Results: State-Dependent Changes in FBB and MBB Subscriptions

DEPENDENT VARIABLES	FBB SWITCHING MODEL $\Delta Bandwidth\_FB_i$ Coef. (Std. Err.)		MBB SWITCHING MODEL $\Delta Bandwidth\_MB_i$ Coef. (Std. Err.)	
Mobile Broadband Services (MBB) Effects				
Bandwidth_MB	0.683***	(0.060)		
Duration_MB	-0.005***	(0.001)		
DataCap	0.988***	(0.065)		
Price_MB			-0.282***	(0.002)
Fixed Broadband Services (FBB) Effects				
Bandwidth_FB			0.035***	(0.003)
Duration_FB			-0.001***	(0.000)
Price_FB	-0.846***	(0.003)		
Smartphone Services Effects				
Smartphone	4.449***	(0.304)	1.539***	(0.132)
Duration_SM	0.002***	(0.000)	0.001***	(0.000)
Intercept	35.229***	(0.299)	4.566***	(0.196)
N	125,080		40,964	
R^2	38.6%		30.4%	

Note: We suppressed the details of the *Demographic* and *Time* effects variables in the models, since they were not really necessary to support the main findings in this research.

Table A3. Results: Event-Dependent Changes in FBB and MBB Subscriptions

DEPENDENT VARIABLES	MBB-TO-FBB MODEL $\Delta Bandwidth\_FB_i$ Coef. (Std. Err.)		FBB-TO-MBB MODEL $\Delta Bandwidth\_MB_i$ Coef. (Std. Err.)	
Mobile Broadband Services (MBB) Effects				
ΔBandwidth_MB	0.218***	(0.031)		
ΔDataCap	0.008	(0.001)	0.075***	(0.004)
TimeGap	0.000	(0.025)		
Price_MB			0.189***	(0.001)
Fixed Broadband Services (MBB) Effects				
ΔBandwidth_FB			0.001	(0.002)
TimeGap			0.000***	(0.000)
Price_FB	0.620***	(0.001)		
Smartphone Services Effects				
Smartphone	1.160***	(0.185)	0.962***	(0.102)
Duration_SM	0.005***	(0.000)	0.000*	(0.000)
Intercept	-5.438***	(0.190)	-5.438***	(0.190)
N	125,382		41,585	
R^2	77.1%		61.6%	

Note: We again suppressed the details of the *Demographic* and *Time* effects variables in the models. Some observations have multiple prior changes in mobile broadband bandwidth before the subsequent changes occurred. Since we control for *TimeGap*, we treat each prior change as a separate observation. As a result, Model 3 has more observations than Model 1 does. Model 4 also has more observations than Model 2 for similar reasons.