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FTTP Industry Structure: Implications of a Wholesale Retail Split

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Abstract

Fiber to the Premise (FTTP) exhibits characteristics of a natural monopoly industry. However, service level competition is possible in FTTP and can be achieved by a structural separation between network ownership and service provisioning (henceforth, referred to as a wholesale-retail split). A wholesale-retail split interferes with the ability of a network owner to *price discriminate*. While a vertically integrated entity can sell seven different economic goods (voice service, broadband data service, video service, voice-data bundle, voice-video bundle, data-video bundle and triple-play bundle), a dark fiber wholesaler can sell only one good (dark fiber access). A 'lit' wholesaler *may* be able sell the same number of goods as a vertically integrated entity. Significant economies of scope ensure that the marginal cost of provisioning the bundle is much lower than the sum of the marginal costs of provisioning the individual services). If almost all homes have a positive willingness to pay for data service, the bulk of the extractable economic surplus resides in the triple-play bundle. Since the wholesale-retail split does not interferes with the 'dark fiber' wholesaler's ability to extract economic surplus from the triple-play bundle, the inability to price discriminate does not interfere with ability of a dark fiber wholesaler to extract economic surplus vis-à-vis a vertically integrated entity (or a 'lit' wholesaler) and the difference between the profits of a profit maximizing wholesaler and a profit maximizing vertically integrated entity) are modest, at best. In such markets, municipalities or communities that build out FTTP and choose to be wholesalers (i) can realize sustainable prices, (ii) are likely to create greater welfare (due to innovation spurred by retail competition) and (iii) are just as likely to recover costs (vis-à-vis vertically integrated entities). Therefore, contrary to the assertions of some current providers, it is not necessary to vertically integrate and exclude service level competitors in order to generate sufficient revenue to cover an investment in FTTP infrastructure. However, in markets, where a large proportion of homes have a zero willingness to pay for data service (and therefore, desire only video service), the profit maximizing 'dark fiber' wholesaler can be worse off due to its inability to set a video price independently of the bundle price – resulting in a lower optimal bundle price (vis-à-vis a vertically integrated entity) and lower profits. Interestingly, the welfare maximizing 'dark fiber' wholesaler can still create almost the same amount of welfare as a vertically integrated entity, though the distribution of welfare among consumer groups is markedly different. Further, in the presence of a strong (cable) incumbent, the ability to price discriminate gives the vertically integrated entity (or the 'lit' wholesaler) marginally greater ability to compete with the cable incumbent, thereby driving down prices and resulting in (marginally) lower profits for the incumbent (vis-à-vis an incumbent that competes with a 'dark fiber' wholesaler). However, if a large proportion

of homes have zero willingness to pay for data services, not only is the ‘dark fiber’ wholesaler worse off (vis-à-vis a vertically integrated entity), but the lower bundle price set by the ‘dark fiber’ wholesaler makes the incumbent worse off as well (vis-à-vis the incumbent competing against a vertically integrated entity) resulting in bundle consumers enjoying a significantly larger consumer surplus. Finally, a municipal FTTP entrant that seeks to maximize welfare and competes with a profit maximizing (cable) incumbent not only creates welfare for its subscribers, but also enhances the consumer surplus experienced by the subscribers of the (cable) incumbent. For our model parameters, consumer surplus can almost double and service penetration can increase by as much as 60% due to such municipal entry - indicating that welfare maximizing municipal entry ensures that almost every home ends up being served.

1 Introduction

In some communities[1], we observe a single vertically integrated FTTP network owner and (voice, video and data) retail service provider, that can either be profit maximizing (henceforth referred to as the ‘Verizon’ model) or welfare maximizing (henceforth referred to as the ‘Bristol, VA’ model [JK03]). In contrast, either out of choice or due to regulation, we sometimes observe the network owner (or the ‘wholesaler’) leasing facilities to competing service providers (retailers), who then provide voice, video and data service over the shared network (wholesale-retail split). For example, consider a network owned by Grant County, WA, or the city of Stockholm, Sweden, with Qwest providing voice services, Comcast providing video services and AOL providing broadband data services over it. The network owner can either sell dark fiber (henceforth referred to as the ‘Stockholm-Profit’ model or ‘Stockholm-Welfare’ model, depending on whether the wholesaler is profit or welfare maximizing) or ‘lit’ transport (henceforth referred to as the ‘Grant-County-Profit’ model or ‘Grant-County-Welfare’ model).

By virtue of the fact that they are vertically integrated, both ‘Verizon’ and ‘Bristol’ can engage in third degree price discrimination [Var89] by selling seven different economic goods (voice service, broadband data service, video service, voice and video bundle, voice and data bundle, data and video bundle and triple-play bundle service). In complete contrast, ‘Stockholm’ can only wholesale dark fiber: ‘Stockholm’ has no knowledge of what services a retailer provisions over it. ‘Grant County’ (a wholesaler that sells layer 2 ‘lit’ transport services to retail service providers) can price discriminate to a larger extent than ‘Stockholm’ but may still fall short of the number of goods that ‘Verizon’ can sell. Clearly, a wholesale-retail split interferes with the ability of a network owner to price discriminate.

[1] For a discussion on FTTP municipal builds providing open access, see Marvin Sirbu, William Lehr, Sharon Gillett,” Broadband Open Access: Lessons from Municipal Network Case Studies”, Telecommunications Policy Research Conference, 2004

2 Implications of a Wholesale-Retail Split: 2-Service Model

In this section, we examine the implications of a wholesale retail split (and the difference in ability to price discriminate) for producer profits and consumer surplus outcomes of the different industry structures. More specifically we seek to understand the implications of imposing structural separation between infrastructure ownership and service provisioning in FTTP.

2.1 Demand model

In order to compute producer profits and consumer surplus and compare them across the six different industry structures we need to construct models for demand and supply. Consider a 3-space, where the coordinates of each point give the willingness to pay for voice, data and video services for a particular home. For a preliminary analysis, we assume that every home takes voice services; thereby reducing the demand model to 2-space, where the coordinates of each point give the willingness to pay for data service and video service respectively. Let x_1 be the willingness to pay for data service and x_2 the willingness to pay for video service for a particular home: notice that x_1 and x_2 may be correlated. We shall assume the values of x_1 and x_2 for each household are drawn from a correlated bivariate normal distribution—*i.e.* the probability that a particular home has willingness to pay x_1 for data and x_2 for video is given by the bivariate normal probability density function [Wol]:

$$P(x_1, x_2) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}}\exp[-\frac{z}{2(1-\rho^2)}]$$

where,

$$z = \frac{(x_1-\mu_1)^2}{\sigma_1^{\ 2}} - \frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^{\ 2}}$$

and,

μ_1 = mean willingness to pay for data service
μ_2 = mean willingness to pay for video service
σ_1 = standard deviation of willingness to pay for data service
σ_2 = standard deviation of willingness to pay for data service
ρ = coefficient of correlation between the willingness to pay for data and video service respectively for a particular home.

A homeowner can choose to purchase (i) no service, (ii) data service only, (iii) video service only, or (iv) a bundle of data and video service. We define net utility of a transaction as the difference between willingness to pay and price. A homeowner will choose to make a particular purchase only if it has a both a positive net utility and a greater net utility than the other two possible transactions. More formally, if a service provider sets price P_1 for data service, P_2 for video service and P_{12} for the bundle, a home prefers data service only if,

$$x_1 - P_1 \geq 0 \text{.............................}(2.1)$$

$$x_1 - P_1 \geq x_2 - P_2 \text{.....................}(2.2)$$

$$x_1 - P_1 \geq x_1 + x_2 - P_{12} \text{............}(2.3)$$

From (1), (2) and (3),

$$x_1 \geq P_1 \text{............................}(2.4)$$

$$x_2 \leq P_{12} - P_1 \text{.....................}(2.5)$$

Therefore, if Q_1 is the proportion of subscribers that take data service,

$$Q_1 = \int_{-\infty}^{P_{12}-P_1} \int_{P_1}^{\infty} P(x_1, x_2) dx_1 dx_2 \text{..........}(2.6)$$

Similarly, if Q_2 is the proportion of subscribers that take video service,

$$Q_2 = \int_{-\infty}^{P_{12}-P_2} \int_{P_2}^{\infty} P(x_1, x_2) dx_2 dx_1 \text{.........}(2.7)$$

Using similar arguments, a home prefers the bundle over the individual services only if,

$$x_1 + x_2 - P_{12} \geq 0 \text{............................}(2.8)$$

$$x_1 + x_2 - P_{12} \geq x_1 - P_1 \text{....................}(2.9)$$

$$x_1 + x_2 - P_{12} \geq x_2 - P_2 \text{..................}(2.10)$$

From (2.8), (2.9) and (2.10),

$$x_1 + x_2 \geq P_{12} \text{...........................}(2.11)$$

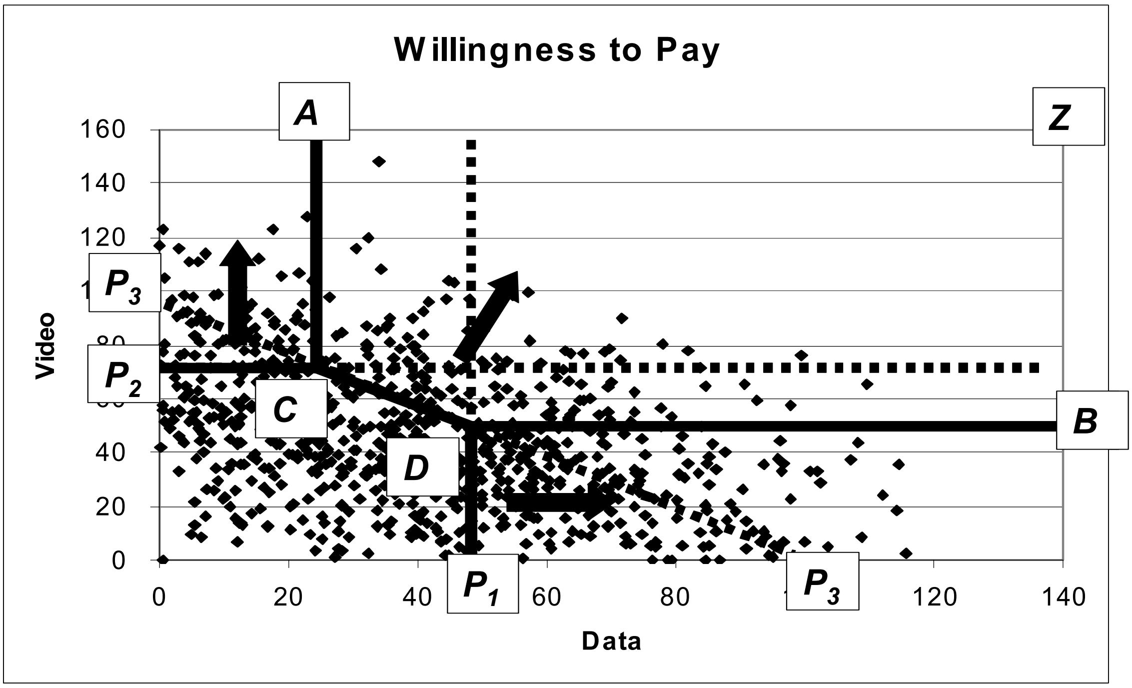
$$x_2 \geq P_{12} - P_1 \text{...........................}(2.12)$$

$$x_1 \geq P_{12} - P_2 \text{...........................}(2.13)$$

Therefore, if Q_{12} is the proportion of subscribers that take the bundle of data and video service,

$$Q_{12} = \int_{P_{12}-P_1}^{\infty} \int_{P_{12}-P_2}^{\infty} P(x_1, x_2) dx_1 dx_2 - \int_{P_{12}-P_1}^{P_2} \int_{P_{12}-x_2}^{P_1} P(x_1, x_2) dx_1 dx_2 \text{..........}(2.14)$$

Figure 2.2 shows a distribution of consumers who have a mean willingness to pay of $35 per month for data ($\mu_1$), $45 per month for video ($\mu_2$) and a coefficient of correlation (ρ) of (-0.5); the areas BDP_1P_3, ACP_2P_3, $ACDBZ$ correspond to the fraction (or proportion) of homes that take data service (Q_1), video service (Q_2) and the bundle (Q_{12}) respectively.



2.2 Supply model

Regardless of how many homes subscribe for any of the services, the network owner has to build out the network to all the Q homes in a market, incurring an annualized (sunk) cost of F [BS05]. Once a home decides to take any service, the network owner (or retail service provider in the 'Stockholm' model) has to deploy the drop loop and provision central office and customer premises equipment at an annualized cost of C_0.

It is further assumed that the annual incremental cost of providing data service is C_1 per home served. This includes the cost of transit, second mile costs of transporting data from the central office to the point of presence of the Internet backbone provider and operations and marketing costs. Providing video services requires setting up a video head end and purchasing rights to content. These costs, in addition to costs of second mile transport from the central office to the head end and costs of operations and marketing constitute the annual incremental cost of providing video service, which is assumed to be C_2 per home served. Clearly the marginal cost of serving a data customer is $C_0 + C_1$, that of serving a video customer is $C_0 + C_2$ and that of provisioning a bundle is $C_0 + C_1 + C_2$. Since, $(C_0 + C_1 + C_2) < (C_0 + C_1) + (C_0 + C_2)$, the marginal cost of supplying the bundle is always less than the sum of the marginal costs of providing the individual services. (It is possible that the incremental costs of providing a bundle are less than the sum of the incremental costs for each of the individual services—due, for example, to economies of scope in operations or marketing—but we ignore this possibility for the present analysis; such economies would only reinforce our conclusions.)

The total cost (per home passed) of providing data service to (a proportion of) Q_1 homes, video service to (a proportion of) Q_2 homes and the bundle to (a proportion of) Q_{12} homes is:

$$C = \frac{F}{Q} + (C_0 + C_1)Q_1 + (C_0 + C_2)Q_2 + (C_0 + C_1 + C_2)Q_{12}$$

2.3 Theoretical models for Industry Structures

2.3.1 Vertically Integrated Industry Structures

'Verizon', being a vertically integrated monopolist, can sell three goods to consumers: data service, video service or the bundle and can therefore set three prices to maximize its profit function. More formally, if 'Verizon' sets a price P_1 for data, P_2 for video and P_{12} for the bundle, and serves (a proportion of) Q_1 data customers (or homes), (a proportion of) Q_2 video customers (or homes) and (a proportion of) Q_{12} bundle customers (or homes), its revenue per home passed (R), cost per home passed (C) and profit (per home passed) functions are:

$$R = P_1Q_1 + P_2Q_2 + P_{12}Q_{12}$$

$$C = \frac{F}{Q} + (C_0 + C_1)Q_1 + (C_0 + C_2)Q_2 + (C_0 + C_1 + C_2)Q_{12}$$

$$\Pr ofit = \frac{-F}{Q} + (P_1 - C_0 - C_1)Q_1 + (P_2 - C_0 - C_2)Q_2 + (P_{12} - C_0 - C_1 - C_2)Q_{12}$$

where, Q_1, Q_2 and Q_{12} are given by equations (2.6), (2.7) and (2.14). Since, all prices are positive and the price of the bundle can never exceed the sum of the prices of the individual services, the optimization problem faced by 'Verizon' can be written as

$$\underset{P_1,P_2,P_{12}}{Maximize} \Pr ofit$$

s.t.,

$$P_1, P_2, P_{12} \geq 0$$

$$P_1 + P_2 \geq P_{12}$$

'Bristol', which is a welfare maximizing vertically integrated monopolist, has revenue and cost functions that are identical to 'Verizon', but instead chooses P_1, P_2 and P_{12} to maximize consumer surplus. The consumer surplus associated with data service per home passed (CS_1), video service per home passed (CS_2) and the bundle per home passed (CS_{12}) are given by:

$$CS_1 = \int_{-\infty}^{P_{12}-P_1} \int_{P_1}^{\infty} (x_1 - P_1)P(x_1, x_2)dx_1dx_2$$

$$CS_2 = \int_{-\infty}^{P_{12}-P_2} \int_{P_2}^{\infty} (x_2 - P_2)P(x_1, x_2)dx_2dx_1$$

$$CS_{12} = \int_{P_{12}-P_1}^{\infty} \int_{P_{12}-P_2}^{\infty} (x_1 + x_2 - P_{12})P(x_1, x_2)dx_1dx_2 - \int_{P_{12}-P_1}^{P_2} \int_{P_{12}-x_2}^{P_1} (x_1 + x_2 - P_{12})P(x_1, x_2)dx_1dx_2$$

$$ConsumerSurplus = CS_1 + CS_2 + CS_{12}$$

Since, all prices are positive and the price of the bundle can never exceed the sum of the prices of the individual services, the optimization problem faced by 'Bristol' can be written as:

$$\underset{P_1, P_2, P_{12}}{Maximize}\; ConsumerSurplus$$

$$s.t.,$$

$$P_1, P_2, P_{12} \geq 0$$

$$P_1 + P_2 \geq P_{12}$$

2.3.2 Wholesale-Retail Split Industry Structures

'Stockholm' sells only one good: dark fiber access from the Central office to each home; hence it has the least 'pricing flexibility' among all the industry structures and can set only one price P_0. We assume that the retail industry is perfectly competitive and therefore all retail service providers make no economic profit. A retailer can buy the dark fiber from 'Stockholm' for P_0 and sell a retail data offering for $P_1 = P_0 + C_0 + C_1$, a retail video offering for $P_2 = P_0 + C_0 + C_2$ or a retail bundle offering for $P_{12} = P_0 + C_0 + C_1 + C_2$. Notice that due to 'Stockholm's decision to sell only dark fiber, the retail price of the bundle exceeds the retail price of the video service by exactly the incremental cost of providing data service (that is, $P_{12} = P_2 + C_1$), while the retail price of the bundle exceeds the retail price of the data service by exactly the incremental cost of providing video service (that is, $P_{12} = P_1 + C_2$).

'Stockholm' generates a revenue (per home passed) of $R = P_0\,(Q_1 + Q_2 + Q_{12})$ and incurs a total cost (per home passed) of $C = F/Q$. Since 'Stockholm' is a 'dark fiber' wholesaler, it does not incur any costs related to the provisioning of the customer premises equipment, the central office equipment, the drop loop and providing data or video services. The profit (per home passed) function of 'Stockholm' is given by

Profit = $P_0\,(Q_1 + Q_2 + Q_{12}) - F/Q$

Where, Q_1, Q_2 and Q_{12} are given by

$$Q_1 = \int_{-\infty}^{C_2} \int_{P_0+C_0+C_1}^{\infty} P(x_1, x_2) dx_1 dx_2$$

$$Q_2 = \int_{-\infty}^{C_1} \int_{P_0+C_0+C_2}^{\infty} P(x_1, x_2) dx_2 dx_1$$

$$Q_{12} = \int_{C_2}^{\infty} \int_{C_1}^{\infty} P(x_1, x_2) dx_1 dx_2 - \int_{C_2}^{P_0+C_0+C_2} \int_{P_0+C_0+C_1+C_2-x_2}^{P_0+C_0+C_1} P(x_1, x_2) dx_1 dx_2$$

The consumer surplus (per home passed) associated with data service (CS_1), video service (CS_2) and the bundle (CS_{12}) are given by:

$$CS_1 = \int_{-\infty}^{C_2} \int_{P_0+C_0+C_1}^{\infty} (x_1 - P_0 - C_0 - C_1) P(x_1, x_2) dx_1 dx_2$$

$$CS_2 = \int_{-\infty}^{C_1} \int_{P_0+C_0+C_2}^{\infty} (x_2 - P_0 - C_0 - C_2) P(x_1, x_2) dx_2 dx_1$$

$$CS_{12} = \int_{C_2}^{\infty} \int_{C_1}^{\infty} (x_1 + x_2 - P_0 - C_0 - C_1 - C_2) P(x_1, x_2) dx_1 dx_2$$

$$- \int_{C_2}^{P_0+C_0+C_2} \int_{P_0+C_0+C_1+C_2-x_2}^{P_0+C_0+C_1} (x_1 + x_2 - P_0 - C_0 - C_1 - C_2) P(x_1, x_2) dx_1 dx_2$$

$$ConsumerSurplus = CS_1 + CS_2 + CS_{12}$$

Since, prices are positive, the optimization problem faced by 'Stockholm Profit' can be written as

$$\underset{P_0}{Maximize} \Pr ofit$$

$$s.t.,$$

$$P_0 \geq 0$$

The optimization problem faced by 'Stockholm Welfare' can be written as

$$\underset{P_0}{Maximize}\, ConsumerSurplus$$

$$s.t.,$$

$$P_0 \geq 0$$

'Grant County' can set two prices P_{01} and P_{02} for data capability and video (or bundle) capability respectively. If Q_1 (is the proportion of) homes (that) take data service, Q_2 (is the proportion of) homes (that) take video service and Q_{12} (is the proportion of) homes (that) take the bundle, 'Grant County Profit' generates a revenue (per home passed) of $R = P_{01}Q_1 + P_{02}(Q_2 + Q_{12})$ and incurs a total cost (per home passed) of $C = F/Q + C_0 (Q_1 + Q_2 + Q_{12})$. Since 'Grant County' is a wholesaler providing layer 2 transport services, it does not incur any costs related to providing data or video services. The profit (per home passed) function of 'Grant County Profit' is given by

Profit = $(P_{01} - C_0)\, Q_1 + (P_{02} - C_0)\,(Q_2 + Q_{12}) - F/Q$

Where, Q_1, Q_2 and Q_{12} are given by

$$Q_1 = \int_{-\infty}^{P_{02}-P_{01}+C_2} \int_{P_{01}+C_0+C_1}^{\infty} P(x_1, x_2)\, dx_1 dx_2$$

$$Q_2 = \int_{-\infty}^{C_1} \int_{P_{02}+C_0+C_2}^{\infty} P(x_1, x_2)\, dx_2 dx_1$$

$$Q_{12} = \int_{P_{02}-P_{01}+C_2}^{\infty} \int_{C_1}^{\infty} P(x_1, x_2)\, dx_1 dx_2 - \int_{P_{02}-P_{01}+C_2}^{P_{02}+C_0+C_2} \int_{P_{02}+C_0+C_1+C_2-x_2}^{P_{01}+C_0+C_1} P(x_1, x_2)\, dx_1 dx_2$$

Since, all prices are positive and the price of the data capability can never exceed the price of the video (or bundle) capability[2], the optimization problem faced by 'Grant County Profit' can be written as

$$\underset{P_{01}, P_{02}}{Maximize}\ \Pr ofit$$

s.t.,

$$P_{01}, P_{02} \geq 0$$

$$P_{02} \geq P_{01}$$

'Grant County Welfare' has identical revenue and cost functions as 'Grant County Profit', but instead chooses P_{01} and P_{02} to maximize consumer surplus. The consumer surplus (per home passed) associated with data service (CS_1), video service (CS_2) and the bundle (CS_{12}) are given by:

$$CS_1 = \int_{-\infty}^{P_{02}-P_{01}+C_2} \int_{P_{01}+C_0+C_1}^{\infty} (x_1 - P_{01} - C_0 - C_1) P(x_1, x_2)\, dx_1 dx_2$$

$$CS_2 = \int_{-\infty}^{C_1} \int_{P_{02}+C_0+C_2}^{\infty} (x_2 - P_{02} - C_0 - C_2) P(x_1, x_2)\, dx_2 dx_1$$

$$CS_{12} = \int_{P_{02}-P_{01}+C_2}^{\infty} \int_{C_1}^{\infty} (x_1 + x_2 - P_{02} - C_0 - C_1 - C_2) P(x_1, x_2)\, dx_1 dx_2$$

$$- \int_{P_{02}-P_{01}+C_2}^{P_{02}+C_0+C_2} \int_{P_{02}+C_0+C_1+C_2-x_2}^{P_{01}+C_0+C_1} (x_1 + x_2 - P_{02} - C_0 - C_1 - C_2) P(x_1, x_2)\, dx_1 dx_2$$

$$ConsumerSurplus = CS_1 + CS_2 + CS_{12}$$

The optimization problem faced by 'Grant County Welfare' can be written as

2 Otherwise retail service providers would provision data service over the cheaper video capability

$$\underset{P_{01},P_{02}}{Maximize}\ ConsumerSurplus$$

$s.t.,$

$$P_{01}, P_{02} \geq 0$$

$$P_{02} \geq P_{01}$$

If P_1^v, P_2^v and P_{12}^v are the respective retail prices for data, video and the bundle in the vertically integrated industry structures (say Verizon), and P_1, P_2 and P_{12} are the respective retail prices of data, video and the bundle in 'Grant County Profit' (say), figure 3 graphically shows the implications of the wholesale retail split. The pricing inflexibility imposed by the wholesale retail split ensures that the price of the retail video service is much higher in 'Grant County Profit' vis-à-vis 'Verizon' ensuring that 'Grant County Profit' has a lower number of video-only customers.

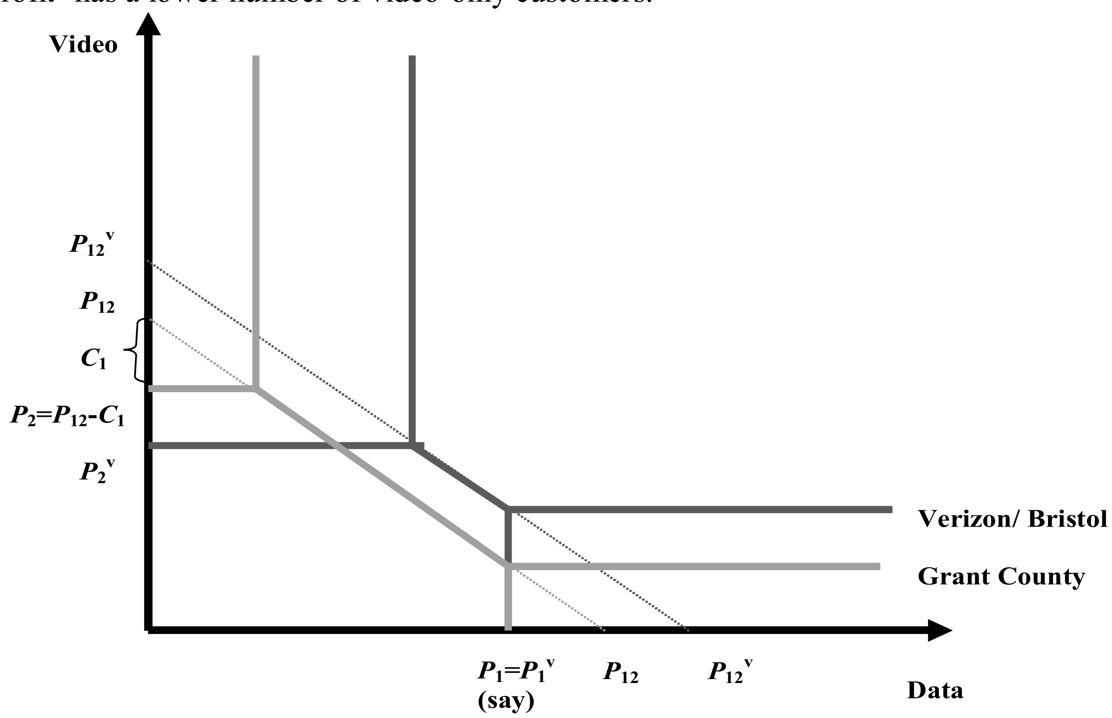


Figure 2.2: Implications of a Wholesale Retail Split

Similarly, the pricing inflexibility arising from 'Stockholm's decision of selling only dark fiber ensures that the price of the retail data and retail video services is much higher in 'Stockholm' vis-à-vis 'Verizon' ensuring that 'Stockholm' has a lower number of data-only and video-only customers. We observe the welfare implications of this pricing inflexibility in the next section.

2.4 Model Results

For the base case, we assume that the network serves an urban market that has 10,000 homes and is characterized by the following model parameters.

Parameter	Value	Explanation
Q	10,000 homes	
μ_1	\$35/ home/ month	
μ_2	\$45/ home/ month	
σ_1	\$10/ home/ month	
σ_2	\$10/ home/ month	
F	\$50,000/ month	Capital cost of \$800 per home for fiber amortized over 25 years at 5% cost of capital
C_0	\$8/ home/ month	Capital cost of \$200 per home for installation of the drop (amortized over 25 years at 5% cost of capital) and \$400 for OLT and CPE (amortized it over 5 years at 5% cost of capital)
C_1	\$20/ home/ month	
C_2	\$30/ home/ month	
ρ	$-1 < \rho < +1$	

Figure 2.3 Parameter values for the base model

Figure 2.4 shows that the total welfare per home passed (sum of consumer and producer surplus) generated by the welfare maximizing industry structures ('Bristol', 'Grant County Welfare' and 'Stockholm') is higher than the total welfare (per home passed) generated by the profit maximizing counterparts 'Verizon' and 'Grant County Profit' by about \$2 - \$5 per month per home. It is interesting to note that for values of ρ higher than 0.75, all the welfare maximizing industry structures create almost the same amount of total welfare (and similarly the profit maximizing industry structures create almost an identical amount of total welfare). This is due to the fact that for values of ρ above 0.75, most customers seek the bundle. Since the wholesale retail split does not interfere with the ability of the wholesaler to extract the economic surplus[3] associated with the bundle, the outcomes are very similar for 'Verizon' and 'Grant County Profit' and for 'Grant County Welfare', 'Bristol' and 'Stockholm'.

For other values of ρ, 'Bristol' generates only marginally greater welfare (per home passed) than 'Grant County Welfare' and 'Stockholm Welfare' of less than \$0.10 per month per home (while, 'Grant County Welfare' and 'Stockholm Welfare' have almost identical welfare outcomes). The welfare difference between 'Bristol' and 'Grant County Welfare' or 'Stockholm Welfare' remains almost the same as ρ decreases because though 'Bristol' serves many more video subscribers (than 'Grant County Welfare') due to its ability to set a lower video price independently of the bundle price, in order to meet the cost recovery constraint 'Bristol' has to set a higher bundle price – the welfare effects of each action balance each other out. Finally, figure 5 also shows that 'Verizon' creates

[3] By surplus we refer to the area between the supply and the demand curves. Alternatively, this is also the maximum profit that can be extracted by a firm that has the ability to engage in first degree price discrimination.

marginally higher welfare (less than $0.10 per month per home) over 'Grant County Profit'.

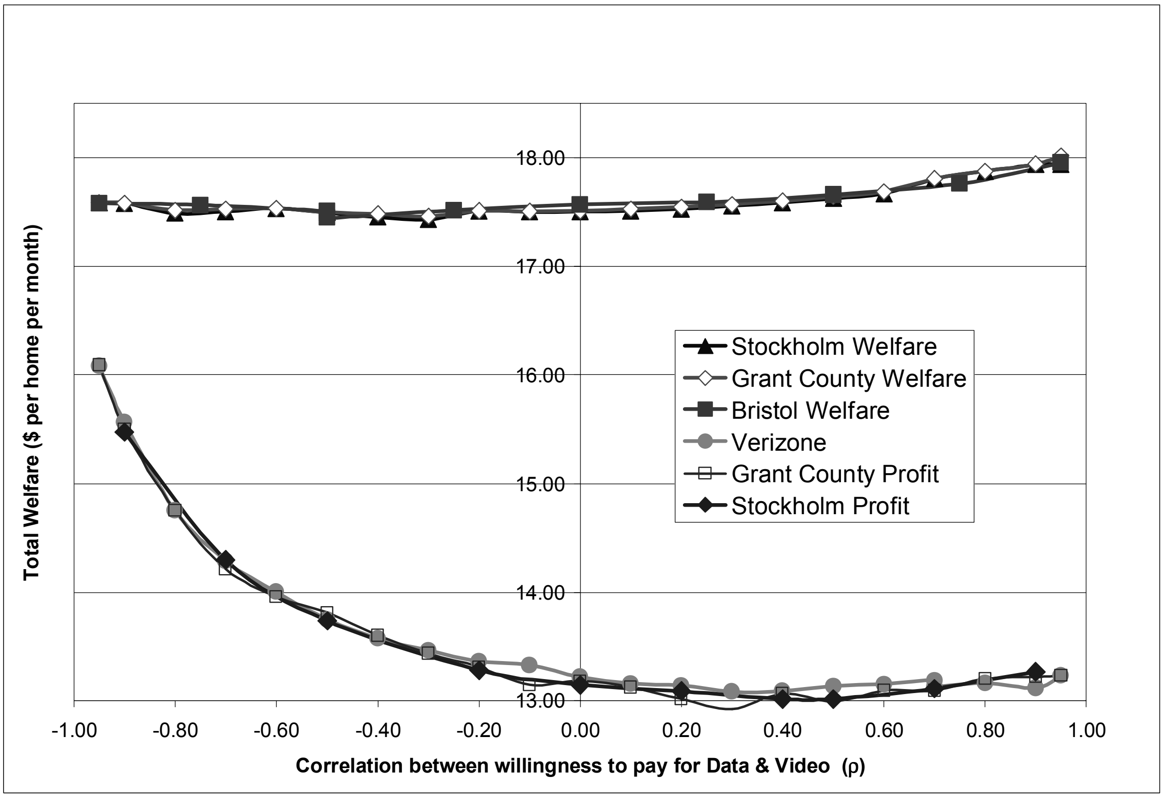


Figure 2.4: Total Welfare (per home passed) for all Industry Structures

'Verizon' and 'Grant County Profit' have very similar consumer surplus outcomes and marginally different profitability outcomes (Figure 2.5), in spite of having very different prices (Figure 2.6). The profit maximizing pricing strategy of 'Verizon' entails lowering the prices of the individual data and video services while increasing the price of the bundle as ρ increases from -1 to +1. Intuitively, this is because at values of ρ closer to -1, there are more users that seek the individual services (and hence higher prices for individual services are profit maximizing), while at values of ρ closer to +1 more users seek the bundle (and hence a higher price for the bundle is profit maximizing).

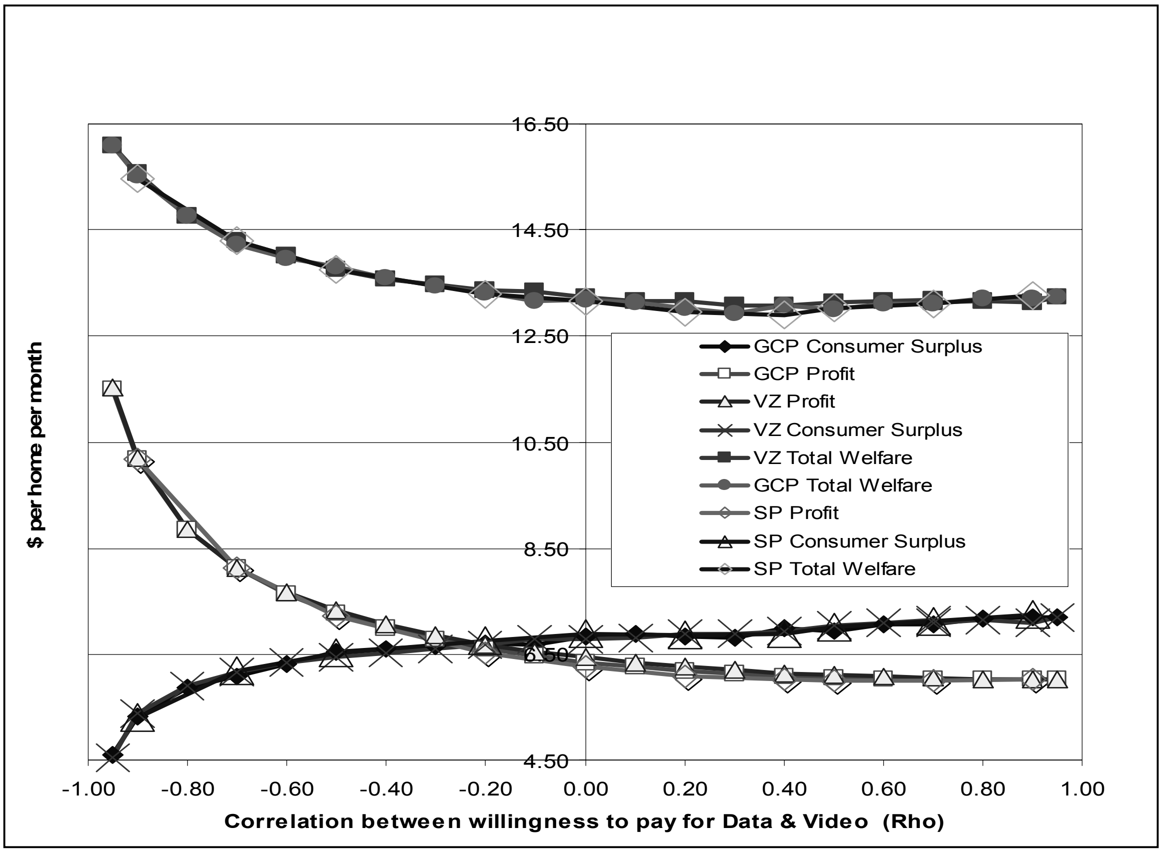


Figure 2.5: Comparison between 'Verizon' and 'Grant County Profit' (Profit per home passed and Consumer Surplus per home passed)

Figure 2.6 further shows that while the price of data set by both entities tends to be remarkably similar, 'Grant County Profit' has a lower bundle price (lower by about $0.20 per home per month) but a much higher video price (higher by up to $8 per home per month since it is tied to the bundle price). The consumer surplus outcomes are very similar because the decrease in consumer surplus from the video service (resulting from the much higher video price and fewer video subscribers) in the case of 'Grant County Profit' is roughly compensated by the increase in consumer surplus from the bundle (resulting from the marginally lower bundle price). Consumer Surplus always increases with ρ because as ρ goes to +1, there are a lot more homes with high willingness to pay. Since consumer surplus experienced by a particular home is the difference between its willingness to pay and the price, homes with high willingness to pay have a bigger impact on consumer surplus.

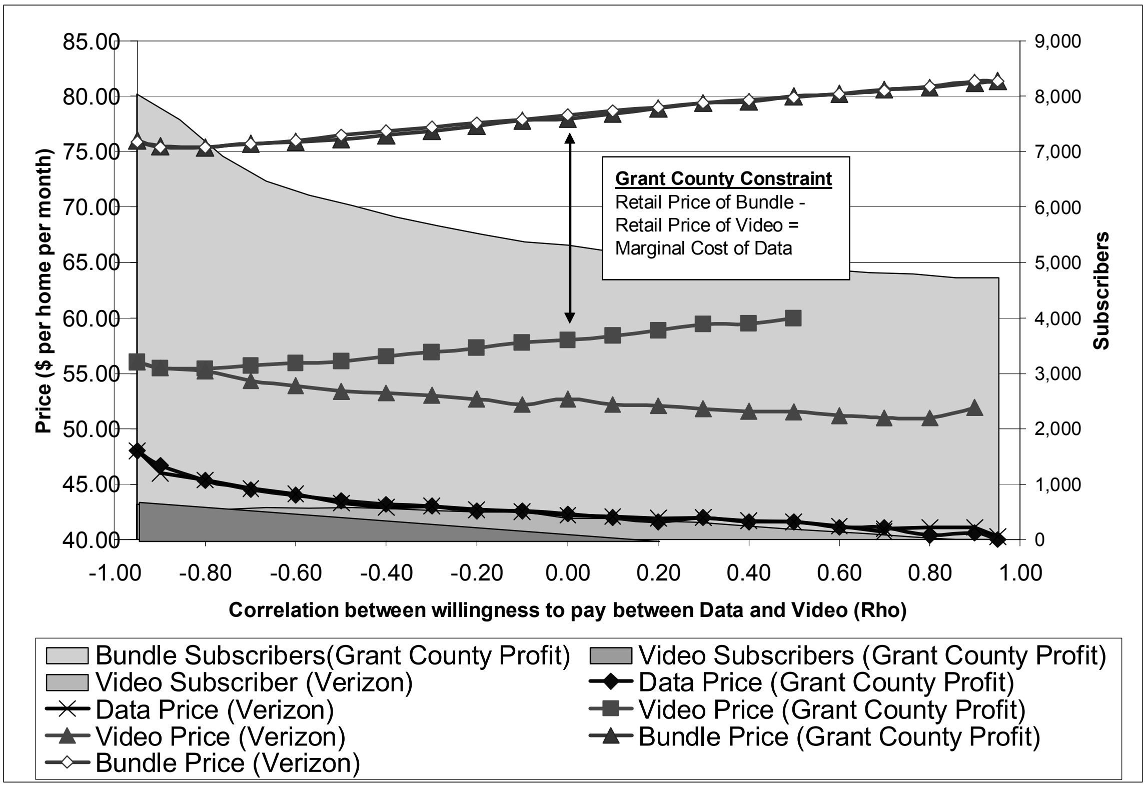


Figure 2.6: Comparison between 'Verizon' and 'Grant County Profit' (Prices and Number of Subscribers)

'Verizon' has marginally higher profit (about \$0.10 per home passed per month for $-0.75 < \rho < 0.75$) vis-à-vis 'Grant County Profit' due to its greater ability to price discriminate. For reasons already stated, for ρ greater than 0.75, the profits generated by 'Verizon' and 'Grant County Profit' are almost identical. For ρ less than -0.75, the similarity in profit outcomes is due to the similarity in the price of the video service for both industry structures[4] (though the movement of the video price is in opposite directions – that is, 'Verizon's video price is decreasing and 'Grant County Profit's video price is increasing with increasing ρ). When ρ is closer to -1, both 'Verizon' and 'Grant County Profit' are able to serve a significantly higher number of subscribers resulting in higher profit and higher total welfare compared to the scenarios where ρ is closer to +1.

The marginal difference in profit between 'Grant County Profit' and 'Verizon' (of only around \$0.10 per subscriber per home passed) for the base case is a consequence of the cost structure of the industry, resulting in economies of scope in supplying the bundle. Recall that the marginal cost of supplying the bundle is less than the sum of the marginal

[4] The value of ρ (= -0.75) at which the video prices of both industry structures is equal appears to be influenced by our choice of model parameters. For $\rho > 0.75$ the 'Verizon' video price is decreasing while the 'Grant County Profit' video price is increasing.

costs of providing the individual services. This ensures that for a normal[5] distribution of willingness to pay, most of the extractable economic surplus[6] lies in the bundle vis-à-vis the individual services. Since the wholesale retail split interferes with the ability of the wholesaler to extract the surplus associated with the video service (and not the bundle) the difference in profits is not very significant as the extractable economic surplus associated with the video-only service, especially for our choice of parameters, is modest.

Extending the above argument, the difference in profit between 'Verizon' and 'Grant County Profit' should increase with an increase in extractable economic surplus associated with the video service. The extractable surplus associated with the video service increases with (a) increase in mean willingness to pay for video service (μ_2), (b) decrease in mean willingness to pay for data service (μ_1), (c) decrease in the incremental cost of provisioning video service (C_2) and (d) increase in the incremental cost of provisioning data service (C_1). Figure 8 shows how the difference in profit varies with different values for μ_1 keeping the other model parameters fixed at F = \$50,000 per month, C_0 = \$8 per home per month, C_1 = \$10 per home per month, C_2 = \$30 per home per month and μ_2 = \$45 per home per month. As expected the extractable surplus associated with the video service is the highest for the lowest value of μ_1 (= \$15 per home per month) and by the same token the difference between the profit of 'Verizon' and 'Grant County Profit' is maximum (about \$0.30 per home passed per month) for this value of μ_1. For μ_1 = \$25 per home per month, the difference in profits turns out to be about \$0.10 per home passed per month, while the profits are almost identical for μ_1 = \$35 per home per month.

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[5] We have also investigated uncorrelated uniform and exponential distributions of willingness to pay with little change in our conclusions.

[6] By extractable surplus we refer to the area between the supply and the demand curves. Alternatively, this is also the maximum profit that can be extracted by a firm that has the ability to engage in first degree price discrimination. Notice that for the bundle, the mean willingness to pay is $\mu_1 + \mu_2$, but the cost of supplying the bundle is $C_0 + C_1 + C_2$, this ensures that majority of the extractable surplus resides in the bundle.

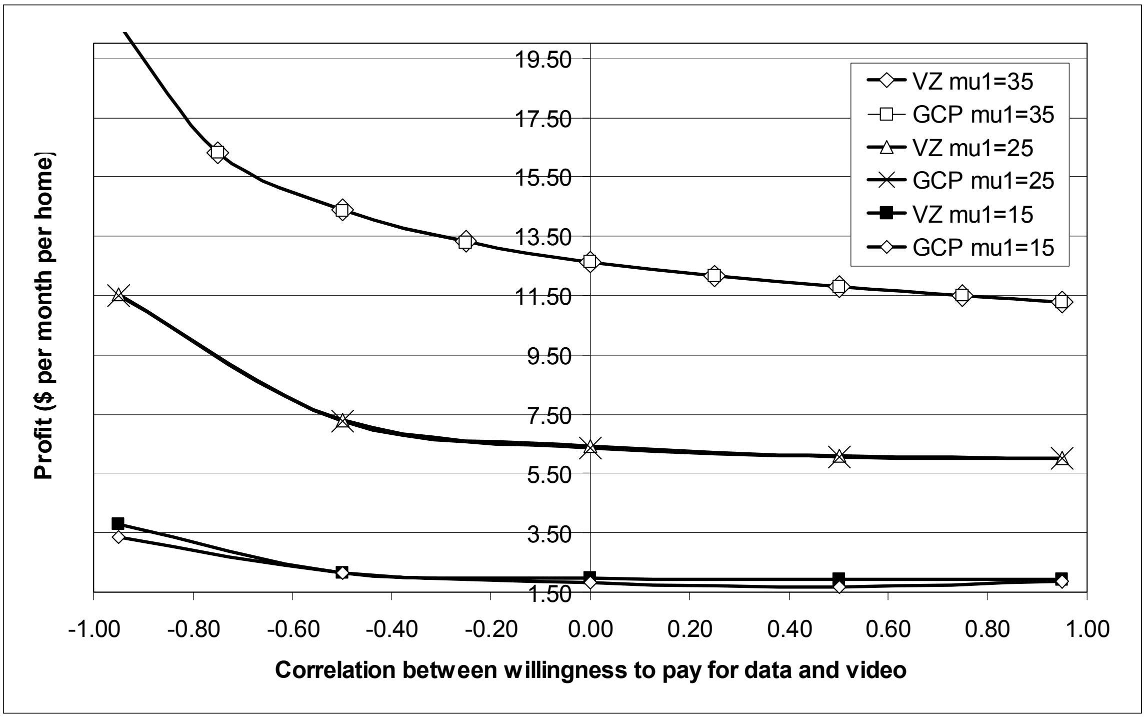

Figure 2.7: Comparing profits (per home passed) of 'Verizon' and 'Grant County Profit' for different values of μ_1.

2.4.1 Alternative Demand Scenario

Our current choice of model demand parameters ensures that all homes have a positive willingness to pay for both, video, and data services. While, this may be largely true for video service and this is borne out by the fact that a large proportion (70%) of homes subscribe to cable television[7] and an even larger proportion of homes (>90%) own a television set[8]. However, in some markets, it may not be unusual for many homes not to have a personal computer[9]. In addition, households may exhibit a greater variance in their willingness to pay for broadband data service. We model the alternative demand scenario by choosing the mean willingness to pay for video service to be $25 per home per month and the standard deviation to be $25 per home per month (thereby ensuring that more than 15% of homes have a zero willingness to pay for data service).

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7 Statistical abstract of the United States

8 The total number of US households with TV sets is 108 million according to Nielsen Media Research, U.S. Television Household Estimates, 2003-04.

9 Statistical abstract of the United States

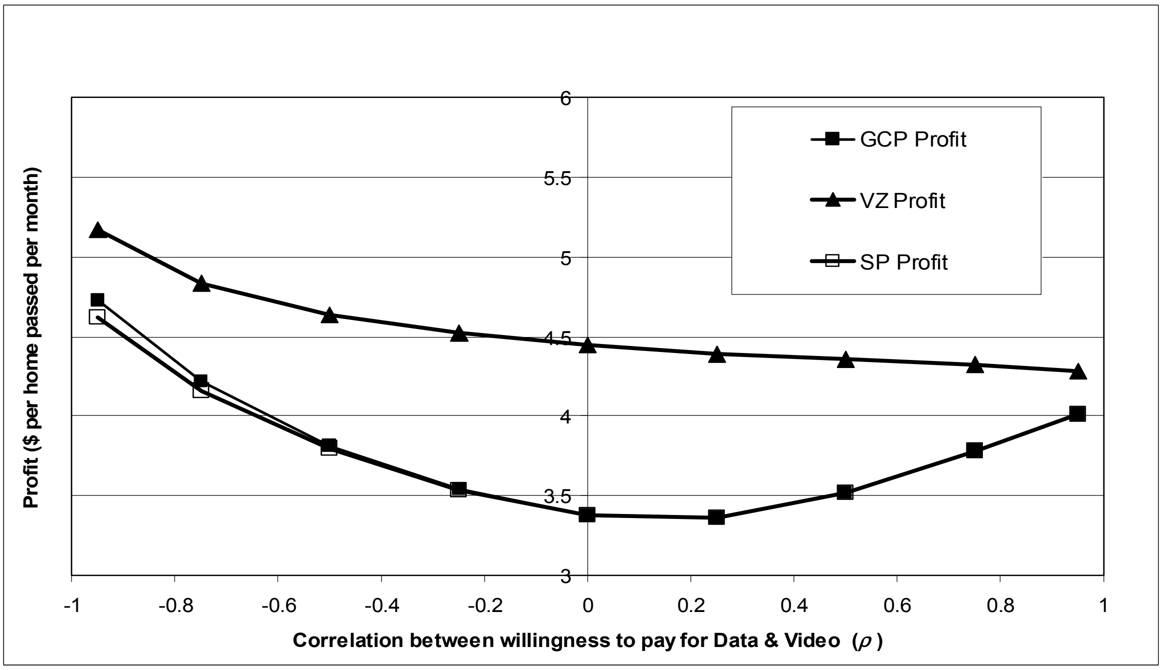

Figure 2.8 Profit outcomes of Verizon, Grant County Profit and Stockholm Profit under alternative demand scenario

Under these demand conditions, figure 2.8 shows that 'Grant County Profit' and 'Stockholm Profit' has a significantly lower (by up to $1.10 per home passed per month) profit than 'Verizon'.

This is due to the fact that a significant number of homes desire only video service and as figure 2.9 shows 'Stockholm Profit' (and 'Grant County Profit) cannot set a lower price for video service independently of the bundle price. Consequently, in order to serve only video customers, 'Stockholm Profit' has to set a relatively low price for the 'dark fiber' which results in a lower bundle price and lower profit margin on the bundle.

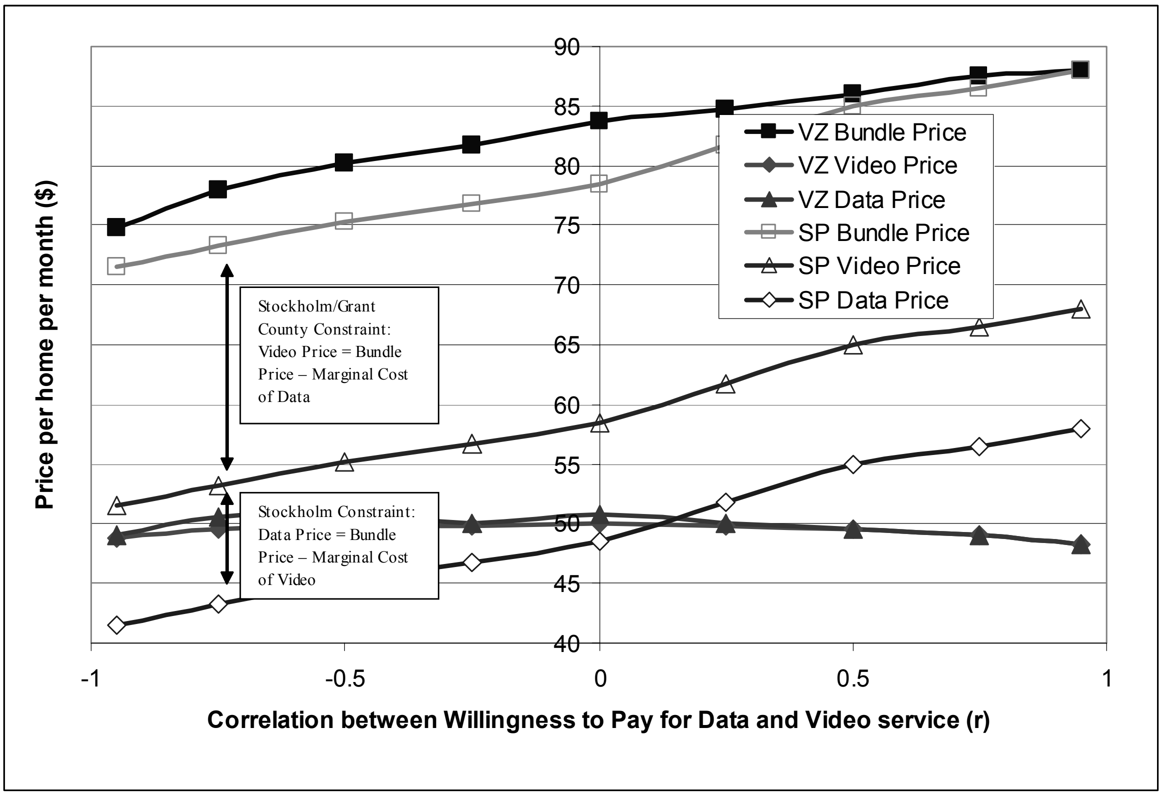

Figure 2.9 Price of services by Industry Structures for alternative demand scenario

Interestingly, however, as figure 2.10 shows, 'Stockholm Welfare' is not much worse off vis-à-vis 'Bristol' even in the alternative demand scenario. 'Bristol' is able to create only up to $0.25 per home per month more welfare compared to 'Stockholm Profit' in spite of the additional pricing flexibility. While 'Bristol' drops its video (and data) price below that charged by 'Stockholm Welfare' to serve more video (and data) customers and thereby create more welfare, it is forced to raise the bundle price (over the price charged by 'Stockholm Welfare') in order to meet the cost recovery constraint. This results in some loss of welfare for 'Bristol's bundle customers and ensures that the gap between the welfare created by 'Bristol' and 'Stockholm Welfare' remains modest.

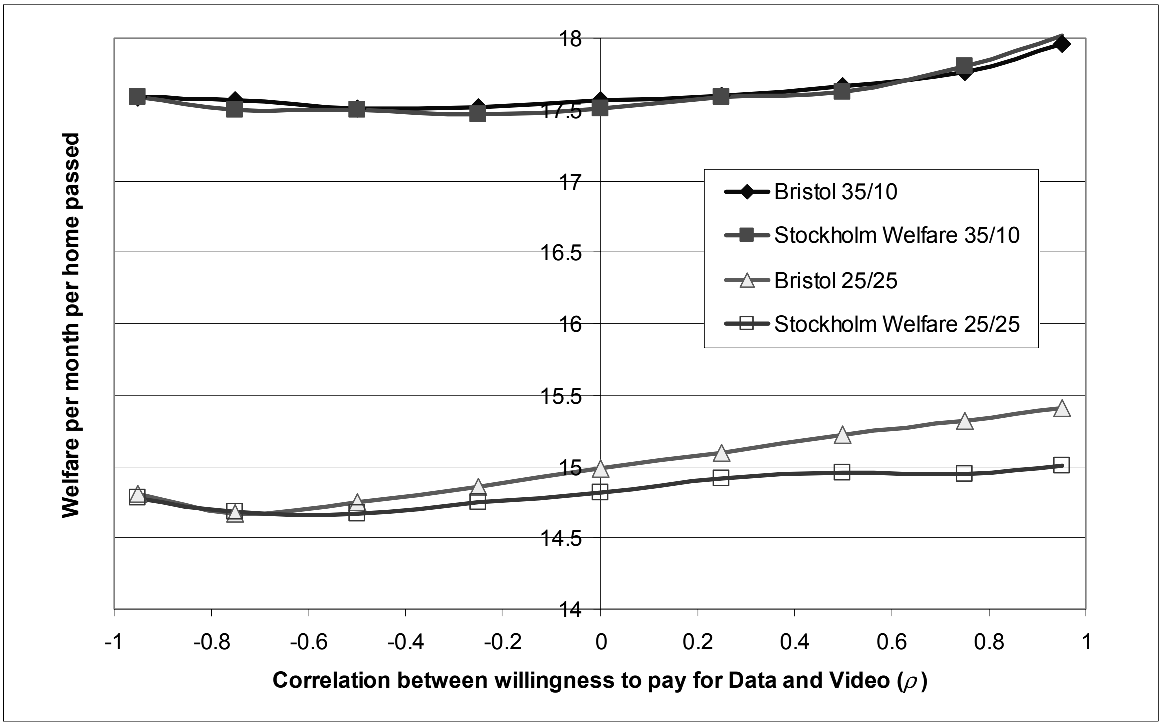

Figure 2.10 Welfare outcomes for 'Bristol' and 'Stockholm Welfare' for both demand scenarios

2.5 Policy Implications

These observations have two very important policy implications: (i) Municipalities that are considering building out FTTP to maximize welfare can largely do so without being vertically integrated (and may even choose to be 'dark fiber' wholesalers). Since 'Bristol' creates less than $0.25 of additional welfare per home passed per month over 'Grant County Welfare' and 'Stockholm' (even in the alternative demand scenario), it is conceivable that the additional welfare that subscribers experience due to increased product diversity and improved service resulting from retail competition (and other innovation in the retail space that our model does not capture) more than compensates for this modest welfare loss. (ii) in scenarios where almost all homes have a positive willingness to pay for data service, FTTP network owners can realize sustainable wholesale prices and are almost as likely to recover costs as vertically integrated providers. Other than markets where a significant fraction of homes have a zero willingness to pay for data service, this finding questions the 'popular' claim that the network owner has to be vertically integrated in order to be profitable and questions the assertion that a wholesale retail split does not provide the right incentives for investment. Since the difference between the total welfare outcomes of 'Verizon' and 'Grant County Profit' is about $0.10 or less per home per month, profit maximizing municipalities that choose to be wholesalers are likely to create more total welfare, assuming that the additional welfare that subscribers experience by the virtue of retail competition more than compensates for $0.10 welfare loss (per home passed). In markets where a large fraction of homes have a zero willingness to pay for data service, a wholesaler may choose to be a 'lit' wholesaler over a 'dark fiber' wholesaler and sell an asymmetric video capability to ensure the same level of profitability.

3 3-service Model

Extending the model from two to three services does not change our results. In a 3-service model vertically integrated entities "Verizon" and "Bristol" can now sell seven[10] possible product bundles - (i) voice, (ii) video, (iii) data, (iv) video-voice, (v) data-voice, (vi) data-video, and (vii) data-video-voice triple play bundle. Stockholm, on the other hand, can set only one price for dark fiber access.

3.1 Model Assumptions

While a vertically integrated entity like Verizon can sell seven possible product bundles, it can set only set five independent prices: for (i) the data service (or data-voice bundle), (ii) video service, (iii) voice service, (iv) video-voice bundle and (v) triple play bundle (or data-video bundle). This is because:

(i) a home that buys broadband data service can now purchase VoIP services from firms such as Vonage. If were are to assume that the VoIP market will be competitive and the incremental prices of VoIP services will get driven down to the marginal cost, one can say that Verizon cannot set the price of its data-voice bundle independently of its broadband data offering. For this purposes of this analysis, we assume that $P_{13}=P_1+C_3$, where P_{13}, P_1 and C_3 are the price of the data-voice bundle, data service and the marginal cost of providing voice services respectively.

(ii) a home that buys a data-video bundle can now purchase VoIP services from firms like Vonage and consume a triple play bundle. Using the same argument as above, 'Verizon' cannot set the price of its triple play bundle independently of its data-video bundle. In fact, for this purposes of this analysis, we assume that $P_{123}=P_{12}+C_3$, where P_{123}, P_{12} and C_3 are the price of the data-video-voice triple bundle, data-video bundle and the marginal cost of providing voice services respectively.

Table 3.1 provides a summary of parameters values assumed for this section. Note that the only three additions to the parameters used in the two service model are: the mean willingness to pay for voice service (μ_3), the standard deviation of willingness to pay for voice service (σ_3) and the marginal or incremental cost if providing voice service (C_3).

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[10] When a broadband data connection allows a home to purchase VoIP services from firms like Vonage, a vertically integrated entity like "Verizon" can set prices independently for only five product bundles (i) data (or data-voice bundle) service (ii) video service (iii) voice service (iv) video-voice bundle service and (v) data-video-voice bundle (or data-video bundle) service

	Value	Explanation
Q	10,000 homes	
μ_1	\$35/ home/ month	
μ_2	\$45/ home/ month	
μ_3	\$25/home/month	Average monthly price for unlimited local calling[11]
σ_1	\$10/ home/ month	
σ_2	\$10/ home/ month	
σ_3	\$10/home/month	
C_1	\$20/home/month	
C_2	\$30/home/month	
C_3	\$5/home/month	Voice services have a low marginal cost on a broadband network
ρ_f	$0 < \rho_f < 1$	

Figure 3.1 Parameter values for the 3-service model

3.2 Model Results

Figure 3.1 shows that there is at most a 6% difference in profits between Verizon and Stockholm. Interestingly, as figures 3.1 and 3.2 indicate, very similar profit outcomes are obtained for 'Verizon' and 'Stockholm' with a different subscriber mix. Stockholm can generate almost the same profit as 'Verizon' by serving primarily triple play customers and a very small number of data-voice bundle customers, while Verizon serves fewer triple play customers but a much larger number of data-voice and video-voice customers. When all homes have a positive willingness to pay for all three services, the additional pricing flexibility does not help Verizon because dropping the prices of the 2-service bundles with the intention of increasing profits allows it to gain data-voice and video-voice customers mainly at the expense of triple play customers.

11 www..verizon.com

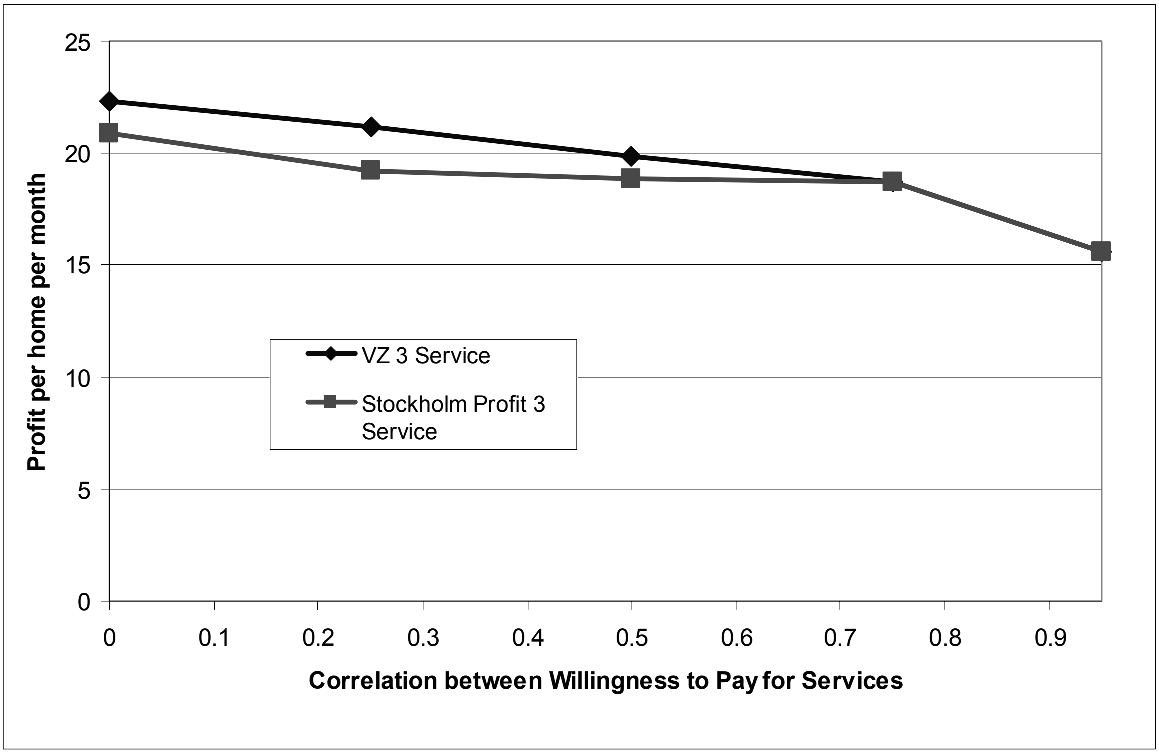

Figure 3.1 Comparison between 'Verizon' and 'Stockholm' (Profit per home passed)

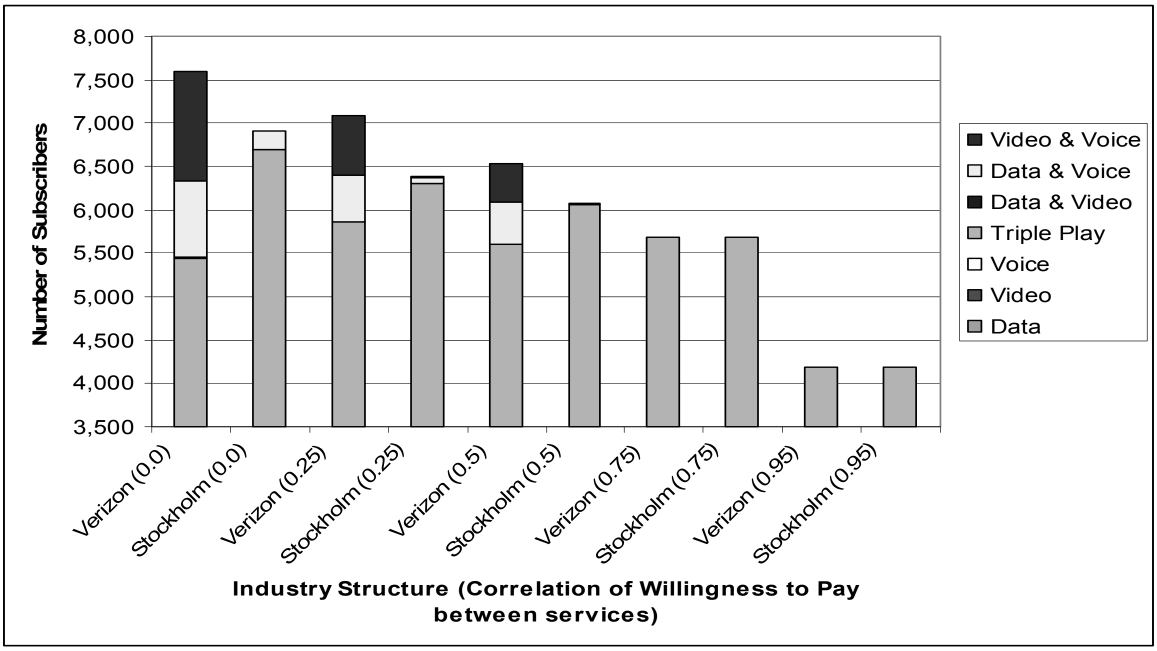

Figure 3.2 Comparison of subscriber mix (Verizon vis-à-vis Stockholm)

In a demand scenario where a significant number of homes have a zero willingness to pay for data service, lowering the price for the data-voice, video-voice and data-video bundles will enable Verizon to serve customers that presumably Stockholm does not serve. Therefore in such a demand scenario, one can expect Stockholm to have substantially lower profits compared to Verizon as already shown by the 2-service models that have been studied for the single service provider case and the duopoly case. The 3-service model does confirm our hypothesis that when all homes have a positive willingness to pay for data, video and voice services, the profit outcomes of Verizon and Stockholm are quite similar. Since Grant County can set prices for more bundles compared to Stockholm, the difference between Grant County's profit and Verizon's profit can be expected to be even less.

4 Duopoly Competition

The network owner may not be a monopolist in many markets. In this section we consider the implications of a wholesale retail split in the presence of inter modal competition with an incumbent (say, in the form of a Cable MSO), where the FTTP network owner has lower pricing flexibility to start with.

While we expect our conclusions from the single provider 2-service model to remain largely intact, one reason for considering the duopoly model is to understand what impact the FTTP provider's ability to price discriminate (or the lack thereof) has on the profitability of the (cable) incumbent. We would like to know if the (cable) incumbent is significantly more profitable competing against 'Stockholm'[12] vis-à-vis competing against 'Verizon' (even though 'Verizon' may not be significantly more profitable than 'Stockholm'). If so, we would see overall consumer surplus reduced as a consequence.

We also consider the case of an FTTP incumbent faced with an entrant also using FTTP technology.

4.1 Bertrand's Paradox

To avoid Bertrand's paradox [Tir98], we assume that the FTTP entrant and the (cable) incumbent offer differentiated services. Video services can be differentiated by content (the channel line-up and video on demand content) and quality (High Definition Television vis-à-vis Standard Definition Television), while data services can be differentiated by quality (downstream and upstream data rates). In fact, if we are to assume that the incumbent is a cable MSO, it is possible that the legacy (albeit upgraded) cable network makes it difficult for the cable MSO to offer a product that is identical to the FTTP offering[13].

4.2 Duopoly Demand model with Product Differentiation

We assume that the (cable) incumbent offers two individual services broadband (cable modem) data and video (cable TV) and the data-video (cable) bundle and the FTTP service provider(s)[14] competes with the incumbent in these services (by offering FTTP data, FTTP video and a data-video FTTP bundle). The incumbent (cable MSO) and the FTTP service provider (may) use different technologies to provision these services, the incumbent's (cable modem) data service may not be a perfect substitute for the FTTP data service (and

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[12] thereby leading to significantly lower consumer surplus

[13] As an example, one can imagine that while the FTTP entrant can offer High Definition Video on Demand services due to the fact that there is more capacity on a FTTP network, the cable MSO may be able to offer richer SDTV content due to its long standing relationships with content producing studios.

[14] In the wholesale-retail split industry structure, the retailers compete with Cable MSO in the retail data, video and data-video bundle markets.

likewise for video) and it is therefore conceivable that a particular home has a different willingness to pay for the incumbent's (cable modem) data service and FTTP data service (and likewise for video). For the demand model for the duopoly case, consider a 4-space, where the coordinates of each point give the willingness to pay for FTTP data (x_1), FTTP video (x_2), incumbent's (cable modem) data (x_3) and incumbent's (cable TV) video (x_4) services for each home: notice that x_1, x_2, x_3 and x_4 may be correlated. We shall assume the values of x_1, x_2, x_3, and x_4 for each household are drawn from a correlated quadrivariate normal distribution—*i.e.* the probability that a particular home has willingness to pay x_1 for data and x_2 for video is given by the quadrivariate normal probability density function $P(x_1, x_2, x_3, x_4)$. In order to simplify the problem, we assume[15] that, the correlation coefficients $\rho_{12} = \rho_{34} = \rho_{23} = \rho_{14} = 0$ and $\rho_{13} = \rho_{24} = \rho_f$. The quadrivariate normal probability density function then simplifies to:

$$P(x_1, x_2, x_3, x_4) = \frac{1}{2\pi\sigma_1\sigma_3\sqrt{1-\rho_f^{\,2}}}\exp[-\frac{z_{13}}{2(1-\rho_f^{\,2})}]\frac{1}{2\pi\sigma_2\sigma_4\sqrt{1-\rho_f^{\,2}}}\exp[-\frac{z_{24}}{2(1-\rho_f^{\,2})}]$$

where,

$$z_{13} = \frac{(x_1-\mu_1)^2}{\sigma_1^{\,2}} - \frac{2\rho_f(x_1-\mu_1)(x_3-\mu_3)}{\sigma_1\sigma_3} + \frac{(x_3-\mu_3)^2}{\sigma_3^{\,2}}$$

$$z_{24} = \frac{(x_2-\mu_4)^2}{\sigma_2^{\,2}} - \frac{2\rho_f(x_2-\mu_4)(x_2-\mu_4)}{\sigma_2\sigma_4} + \frac{(x_2-\mu_4)^2}{\sigma_4^{\,2}}$$

and,

μ_1 = mean willingness to pay for FTTP data service
μ_2 = mean willingness to pay for FTTP video service
μ_3 = mean willingness to pay for incumbent's (cable modem) data service
μ_4 = mean willingness to pay for incumbent's (cable TV) video service
σ_1 = standard deviation of willingness to pay for FTTP data service
σ_2 = standard deviation of willingness to pay for FTTP video service
σ_3 = standard deviation of willingness to pay for cable modem data service
σ_4 = standard deviation of willingness to pay for cable TV service
ρ_f= coefficient of correlation between the willingness to pay between FTTP data and incumbent's (cable modem) data service which is assumed to be the same as the coefficient of correlation between the willingness to pay between FTTP video and incumbent's (cable TV) video service. ρ_f is therefore a measure of differentiation between the products offered by the two firms. We assume[16] that ρ_f varies from 0 to 1, where $\rho_f = 1$ implies that the products are perfect substitutes and $\rho_f = 0$ implies that the products are well differentiated.

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[15] Since we have already studied the impact of correlation between willingness to pay for data service and video service for each home in the single provider 2-service model, we assume that the willingness to pay for data and video service for each home is uncorrelated. Also, we assume that the willingness to pay for the incumbent's data service and the FTTP video service for each home is uncorrelated. Likewise, the willingness to pay for the incumbent's video service and the FTTP data service for each home is also assumed to be uncorrelated.

[16] We believe that it is unlikely that ρ_f can assume negative values as that would mean that a home that values FTTP data service highly has a very low willingness to pay for the incumbent's data service. Such a situation is considered highly improbable.

A homeowner can choose to purchase (i) no service, (ii) FTTP data service only, (iii) FTTP video service only, (iv) FTTP data and video bundle service (v) incumbent's (cable modem) data service (vi) incumbent's (cable TV) video service, or (vii) a (cable) incumbent's data and video bundle service. We define net utility of a transaction as the difference between willingness to pay and price. A homeowner will choose to make a purchase only if it has a both a positive net utility and a greater net utility than the other six possible transactions. More formally, if a FTTP service provider sets price P_1 for FTTP data service, P_2 for FTTP video service, P_{12} for the FTTP bundle and an incumbent (Cable MSO) sets price P_3 for data service, P_4 for video service, P_{34} for the data-video bundle, a home prefers FTTP data service only if,

$$x_1 - P_1 \geq 0 \text{..........(4.1)}$$
$$x_1 - P_1 \geq x_2 - P_2 \text{..........(4.2)}$$
$$x_1 - P_1 \geq x_1 + x_2 - P_{12} \text{..........(4.3)}$$
$$x_1 - P_1 \geq x_3 - P_3 \text{..........(4.4)}$$
$$x_1 - P_1 \geq x_4 - P_4 \text{..........(4.5)}$$
$$x_1 - P_1 \geq x_3 + x_4 - P_{34} \text{..........(4.6)}$$

From (4.1), (4.2), (4.3), (4.4), (4.5) and (4.6),

$$x_1 \geq P_1 \text{..........(4.7)}$$
$$x_1 \geq x_2 - P_2 + P_1 \text{..........(4.8)}$$
$$x_2 \leq P_{12} - P_1 \text{..........(4.9)}$$
$$x_3 \leq x_1 + P_3 - P_1 \text{..........(4.10)}$$
$$x_4 \leq x_1 + P_4 - P_1 \text{..........(4.11)}$$
$$x_3 + x_4 \leq x_1 + P_{34} - P_1 \text{..........(4.12)}$$

We see that[17], (4.7) + (4.9) => (4.8) and (4.7) + (4.9) + (4.10) + (4.12) => (4.11). Therefore we have,

$$x_1 \geq P_1 \text{..........(4.13)}$$
$$x_2 \leq P_{12} - P_1 \text{..........(4.14)}$$
$$x_3 \leq P_3 - P_1 + x_1 \text{..........(4.15)}$$
$$x_4 \leq P_{34} - P_1 - x_3 + x_1 \text{..........(4.16)}$$

Therefore, if Q_1 is the proportion of subscribers that take FTTP data service,

$$Q_1 = \int_{P_1}^{\infty} \int_{-\infty}^{P_{12}-P_1} \int_{-\infty}^{P_3-P_1+x_1} \int_{-\infty}^{P_{34}-P_1+x_1-x_3} P(x_1, x_2, x_3, x_4)\, dx_4 dx_3 dx_2 dx_1 \text{..........(4.17)}$$

[17] See Appendix for proof

Similarly, if Q_2 is the proportion of subscribers that take FTTP video service,

$$Q_2 = \int_{P_2}^{\infty} \int_{-\infty}^{P_{12}-P_2} \int_{-\infty}^{P_3-P_2+x_2} \int_{-\infty}^{P_{34}-P_2+x_2-x_3} P(x_1,x_2,x_3,x_4)dx_4dx_3dx_1dx_2 \text{..........}(4.18)$$

Similarly, if Q_3 is the proportion of subscribers that take cable modem data service,

$$Q_3 = \int_{P_3}^{\infty} \int_{-\infty}^{P_{34}-P_3} \int_{-\infty}^{P_2-P_3+x_3} \int_{-\infty}^{P_{12}-P_3+x_3-x_2} P(x_1,x_2,x_3,x_4)dx_1dx_2dx_4dx_3 \text{..........}(4.19)$$

Similarly, if Q_4 is the proportion of subscribers that take cable modem data service,

$$Q_4 = \int_{P_4}^{\infty} \int_{-\infty}^{P_{34}-P_3} \int_{-\infty}^{P_2-P_4+x_4} \int_{-\infty}^{P_{12}-P_4+x_4-x_2} P(x_1,x_2,x_3,x_4)dx_1dx_2dx_3dx_4 \text{..........}(4.20)$$

Using similar arguments, a home prefers the FTTP bundle over the FTTP individual data and video services,

$$x_1 + x_2 - P_{12} \geq 0 \text{..........}(4.21)$$
$$x_1 + x_2 - P_{12} \geq x_1 - P_1 \text{..........}(4.22)$$
$$x_1 + x_2 - P_{12} \geq x_2 - P_2 \text{..........}(4.23)$$
$$x_1 + x_2 - P_{12} \geq x_3 - P_3 \text{..........}(4.24)$$
$$x_1 + x_2 - P_{12} \geq x_4 - P_4 \text{.........}(4.25)$$
$$x_1 + x_2 - P_{12} \geq x_3 + x_4 - P_{34} \text{.........}(4.26)$$

From (4.21) – (4.23) and (4.27), we have

$$x_1 + x_2 \geq P_{12} \text{..........}(4.28)$$
$$x_1 \geq P_{12} - P_2 \text{..........}(4.29)$$
$$x_2 \geq P_{12} - P_1 \text{..........}(4.30)$$
$$x_3 \leq P_3 - P_{12} + x_1 + x_2 \text{..........}(4.31)$$
$$x_4 \leq P_4 - P_{12} + x_1 + x_2 \text{..........}(4.32)$$

(4.28), (4.29), (4.30), (4.31) and (4.32) ensure that the conditions (4.22) and (4.26) hold. Therefore, if Q_{12} is the proportion of subscribers that take data-video bundle,

$$Q_{12} = \int_{P_{12}-P_1}^{\infty} \int_{P_{12}-P_2}^{\infty} \int_{0}^{P_4-P_{12}+x_1+x_2} \int_{0}^{P_3-P_{12}+x_1+x_2} P(x_1,x_2,x_3,x_4)dx_3dx_4dx_1dx_2$$
$$- \int_{P_{12}-P_1}^{P_2} \int_{P_{12}-x_2}^{P_1} \int_{0}^{P_4-P_{12}+x_1+x_2} \int_{0}^{P_3-P_{12}+x_1+x_2} P(x_1,x_2,x_3,x_4)dx_3dx_4dx_1dx_2 \text{..........}(4.32)$$

Therefore, if Q_{23} is the proportion of subscribers that take data service,

$$Q_{34} = \int_{P_{34}-P_3}^{\infty} \int_{P_{34}-P_4}^{\infty} \int_{0}^{P_2-P_{34}+x_3+x_4} \int_{0}^{P_1-P_{34}+x_3+x_4} P(x_1,x_2,x_3,x_4)dx_1dx_2dx_3dx_4$$

$$- \int_{P_{34}-P_3}^{P_4} \int_{P_{34}-x_4}^{P_3} \int_{0}^{P_2-P_{34}+x_3+x_4} \int_{0}^{P_1-P_{34}+x_3+x_4} P(x_1,x_2,x_3,x_4)dx_1dx_2dx_3dx_4 \text{..........(4.33)}$$

4.3 Supply model

The FTTP supply model is assumed to be the same as in Section 2. The incumbent's (Cable MSO) supply model has some significant differences:

(i) We will assume that the cost that the incumbent (Cable MSO) incurred in building out the cable plant has been largely recovered – however, there is a capital expenditure of upgrading the cable network (U) which needs to be recovered from the revenues that accrue henceforth.

(ii) Since the cable network is already built to each home, no drop loop needs to be laid and no ONU (optical network unit) needs to be installed. However, it may still be necessary to do a truck roll (and incur a cost C_t, which is likely much lower than C_0) when a user signs up for service, which provides some economies of scope for bundle provisioning.

(iii) The incremental cost of providing (cable modem) data service (C_3) includes the (amortized) cost of a cable modem (and Cable Modem Termination System – CMTS ports), in addition to the second-mile costs incurred by the FTTP network provider.

(iv) The incremental cost of providing cable TV service (C_4) includes the (amortized) cost of a digital video set-top box[18], however since the Cable MSO already has a head-end (the costs of which have presumably been recovered), the cost C_4 is likely to be lower in the case of the cable MSO (vis-à-vis C_2).

The cost of providing cable modem data service to Q_3 homes, FTTP video service to Q_4 homes, the FTTP bundle to Q_{34} homes, is:

$$C = U + (C_t + C_3)Q_3 + (C_t + C_4)Q_4 + (C_t + C_3 + C_4)Q_{34}$$

4.4 Models for Industry Structures under duopoly competition

[18] If the Cable MSO provides analog video, then there is no additional cost for the set-top box.

4.4.1 Vertically Integrated FTTP Service provider

'Verizon', being a vertically integrated, can sell three goods to consumers: data service, video service or the bundle and can therefore set three prices to maximize its profit function. More formally, if 'Verizon' sets a price P_1 for data, P_2 for video and P_{12} for the bundle, and serves (a proportion of) Q_1 data customers (or homes), (a proportion of) Q_2 video customers (or homes) and (a proportion of) Q_{12} bundle customers (or homes), its revenue per home passed (R), cost per home passed (C) and profit (per home passed) functions are:

$$R = P_1Q_1 + P_2Q_2 + P_{12}Q_{12}$$

$$C = \frac{F}{Q} + (C_0 + C_1)Q_1 + (C_0 + C_2)Q_2 + (C_0 + C_1 + C_2)Q_{12}$$

$$VZprofit = \frac{F}{Q} + (P_1 - C_0 - C_1)Q_1 + (P_2 - C_0 - C_2)Q_2 + (P_{12} - C_0 - C_1 - C_2)Q_{12}$$

where, Q_1, Q_2 and Q_{12} are given by equations (4.17), (4.18) and (4.32).

Similarly, the incumbent (cable MSO) can sell three goods to consumers: cable modem data service, cable TV service or the data-video bundle and can therefore also set three prices to maximize its profit function. More formally, if the cable MSO sets a price P_3 for cable modem data service, P_4 for cable TV service and P_{34} for the bundle, and serves (a proportion of) Q_3 data customers (or homes), (a proportion of) Q_4 video customers (or homes) and (a proportion of) Q_{34} bundle customers (or homes), its revenue per home passed (R), cost per home passed (C) and profit (per home passed) functions are:

$$R = P_3Q_3 + P_4Q_4 + P_{34}Q_{34}$$

$$C = \frac{U}{Q} + (C_t + C_3)Q_3 + (C_t + C_4)Q_4 + (C_t + C_3 + C_4)Q_{34}$$

$$Cableprofit = \frac{-U}{Q} + (P_3 - C_t - C_3)Q_3 + (P_4 - C_t - C_4)Q_4 + (P_{34} - C_t - C_3 - C_4)Q_{34} \quad \text{..........(4.34)}$$

where Q_3, Q_4 and Q_{34} are given by equations (4.19), (4.20) and (4.33).

Since, all prices are positive and the price of the bundle can never exceed the sum of the prices of the individual services, the optimization problem faced by 'Verizon' can be written as

$$\underset{P_1, P_2, P_{12}}{Maximize}\, VZprofit$$

$$s.t.,$$

$$P_{12} \geq P_1 \geq 0$$

$$P_{12} \geq P_2 \geq 0$$

$$P_1 + P_2 \geq P_{12}$$

Simultaneously, the incumbent (cable MSO) solves its optimization problem:

$$\underset{P_3,P_4,P_{34}}{Maximize}\, Cableprofit$$

$s.t.,$

$$P_{34} \geq P_3 \geq 0$$

$$P_{34} \geq P_4 \geq 0$$

$$P_3 + P_4 \geq P_{34}$$

The duopoly game between 'Bristol' and the incumbent is also relevant because it models the situation where a welfare maximizing municipal FTTP entrant competes against a profit maximizing (cable) incumbent. 'Bristol' has revenue and cost functions that are identical to 'Verizon'.

$$R = P_1Q_1 + P_2Q_2 + P_{12}Q_{12}$$

$$C = \frac{F}{Q} + (C_0 + C_1)Q_1 + (C_0 + C_2)Q_2 + (C_0 + C_1 + C_2)Q_{12}$$

$$Bristolprofit = \frac{-F}{Q} + (P_1 - C_0 - C_1)Q_1 + (P_2 - C_0 - C_2)Q_2 + (P_{12} - C_0 - C_1 - C_2)Q_{12}$$

Instead of maximizing revenue, 'Bristol' maximizes consumer surplus with a cost recovery constraint. Bristol's Consumer Surplus is given by the following expressions:

$$CS_1 = \int_{P_1}^{\infty} \int_{-\infty}^{P_{12}-P_1} \int_{-\infty}^{P_3-P_1+x_1} \int_{-\infty}^{P_{34}-P_1+x_1-x_3} (x_1 - P_1)P(x_1,x_2,x_3,x_4)dx_4dx_3dx_2dx_1$$

$$CS_2 = \int_{P_2}^{\infty} \int_{-\infty}^{P_{12}-P_2} \int_{-\infty}^{P_3-P_2+x_2} \int_{-\infty}^{P_{34}-P_2+x_2-x_3} (x_2 - P_2)P(x_1,x_2,x_3,x_4)dx_4dx_3dx_1dx_2$$

$$CS_{12} = \int_{P_{12}-P_1}^{\infty} \int_{P_{12}-P_2}^{\infty} \int_{0}^{P_4-P_{12}+x_1+x_2} \int_{0}^{P_3-P_{12}+x_1+x_2} (x_1 + x_2 - P_{12})P(x_1,x_2,x_3,x_4)dx_3dx_4dx_1dx_2$$

$$- \int_{P_{12}-P_1}^{P_2} \int_{P_{12}-x_2}^{P_1} \int_{0}^{P_4-P_{12}+x_1+x_2} \int_{0}^{P_3-P_{12}+x_1+x_2} (x_1 + x_2 - P_{12})P(x_1,x_2,x_3,x_4)dx_3dx_4dx_1dx_2$$

$$ConsumerSurplus = CS_1 + CS_2 + CS_{12}$$

Bristol's maximization problem can be written as:

$$\underset{P_1,P_2,P_{12}}{Maximize}\, ConsumerSurplus$$

$s.t.,$

$$P_{12} \geq P_1 \geq 0$$

$$P_{12} \geq P_2 \geq 0$$

$$P_1 + P_2 \geq P_{12}$$

$$Bristolprofit \geq 0$$

Simultaneously, the incumbent (cable MSO) chooses P_3, P_4, P_{34} to maximize its profit function given by 4.34.

4.4.2 Wholesale-Retail Split Industry Structures

We assume that 'Stockholm' can set one price P_0 for dark fiber access. A retailer can buy the dark fiber from 'Stockholm' for P_0 and sell a retail data offering for $P_1 = P_0 + C_0 + C_1$, a retail video offering for $P_2 = P_0 + C_0 + C_2$ or a retail bundle offering for $P_{12} = P_0 + C_0 + C_1 + C_2$ (refer to section 2.3.3 for details).

'Stockholm' generates a revenue (per home passed) of $R = P_0 (Q_1 + Q_2 + Q_{12})$ and incurs a total cost (per home passed) of $C = F/Q$. Since 'Stockholm' is a 'dark fiber' wholesaler, it does not incur any costs related to the provisioning of the customer premises equipment, the central office equipment, the drop loop and providing data or video services. The profit (per home passed) function of 'Stockholm' is given by

$$\text{Profit} = P_0 (Q_1 + Q_2 + Q_{12}) - F/Q$$

Where, Q_1, Q_2 and Q_{12} are given by

$$Q_1 = \int_{P_0+C_0+C_1}^{\infty} \int_{-\infty}^{C_2} \int_{-\infty}^{P_3-P_0-C_0-C_1+x_1} \int_{-\infty}^{P_{34}-P_0-C_0-C_1+x_1-x_3} P(x_1,x_2,x_3,x_4)\,dx_4\,dx_3\,dx_2\,dx_1$$

$$Q_2 = \int_{P_0+C_0+C_2}^{\infty} \int_{-\infty}^{C_1} \int_{-\infty}^{P_3-P_0-C_0-C_2+x_2} \int_{-\infty}^{P_{34}-P_0-C_0-C_2+x_2-x_3} P(x_1,x_2,x_3,x_4)\,dx_4\,dx_3\,dx_1\,dx_2$$

$$Q_{12} = \int_{C_2}^{\infty} \int_{C_1}^{\infty} \int_{0}^{P_4-P_0-C_0-C_1-C_2+x_1+x_2} \int_{0}^{P_3-P_0-C_0-C_1-C_2+x_1+x_2} P(x_1,x_2,x_3,x_4)\,dx_3\,dx_4\,dx_1\,dx_2$$

$$- \int_{C_2}^{P_0+C_0+C_2} \int_{P_0+C_0+C_1+C_2-x_2}^{P_1} \int_{0}^{P_4-P_0-C_0-C_1-C_2+x_1+x_2} \int_{0}^{P_3-P_0-C_0-C_1-C_2+x_1+x_2} P(x_1,x_2,x_3,x_4)\,dx_3\,dx_4\,dx_1\,dx_2$$

The optimization problem faced by 'Stockholm Profit' can be written as

$$\underset{P_0}{Maximize}\ \mathrm{Pr}\,ofit$$

$$s.t.,$$

$$P_0 \geq 0$$

Since the consumer surplus (per home passed) associated with data service (CS_1), video service (CS_2) and the bundle (CS_{12}) are given by:

$$CS_1 = \int_{P_0+C_0+C_1}^{\infty} \int_{-\infty}^{C_2} \int_{-\infty}^{P_3-P_0-C_0-C_1+x_1} \int_{-\infty}^{P_{34}-P_0-C_0-C_1+x_1-x_3} (x_1 - P_0 - C_0 - C_1) P(x_1,x_2,x_3,x_4) dx_4 dx_3 dx_2 dx_1$$

$$CS_2 = \int_{P_0+C_0+C_2}^{\infty} \int_{-\infty}^{C_1} \int_{-\infty}^{P_3-P_0-C_0-C_2+x_2} \int_{-\infty}^{P_{34}-P_0-C_0-C_2+x_2-x_3} (x_2 - P_0 - C_0 - C_2) P(x_1,x_2,x_3,x_4) dx_4 dx_3 dx_1 dx_2$$

$$CS_{12} = \int_{C_2}^{\infty} \int_{C_1}^{\infty} \int_{0}^{P_4-P_0-C_0-C_1-C_2+x_1+x_2} \int_{0}^{P_3-P_0-C_0-C_1-C_2+x_1+x_2} (x_1 + x_2 - P_0 - C_0 - C_1 - C_2) P(x_1,x_2,x_3,x_4) dx_3 dx_4 dx_1 dx_2$$

$$- \int_{C_2}^{P_0+C_0+C_2} \int_{P_0+C_0+C_1+C_2-x_2}^{P_1} \int_{0}^{P_4-P_0-C_0-C_1-C_2+x_1+x_2} \int_{0}^{P_3-P_0-C_0-C_1-C_2+x_1+x_2} (x_1 + x_2 - P_0 - C_0 - C_1 - C_2) P(x_1,x_2,x_3,x_4) dx_3 dx_4 dx_1 dx_2$$

$$ConsumerSurplus = CS_1 + CS_2 + CS_{12}$$

Similarly the optimization problem faced by ‘Stockholm Welfare’ can be written as

$$\underset{P_0}{Maximize}\, ConsumerSurplus$$

$$s.t.,$$

$$P_0 \geq 0$$

$$P_0(Q_1 + Q_2 + Q_{12}) - \frac{F}{Q} \geq 0$$

In both cases, the incumbent (cable MSO) chooses prices P_3, P_4, and P_{34} to maximize its profit function given by 4.34.

Clearly, the profit (and consumer surplus) outcomes for ‘Verizon’ (and ‘Bristol’) and ‘Stockhom Profit’ (‘Stockholm Welfare’) are the upper and lower bounds of the profit (and consumer surplus) that a ‘lit’ wholesaler like ‘Grant County’ can generate. Therefore, for the duopoly case, we limit our study to ‘Verizon’ and ‘Stockholm’ only.

4.5 Model Results

We study the implications for ‘Verizon’ and ‘Stockholm’ when (i) all homes have a positive willingness to pay for data service and (ii) when a significant fraction of homes (15-20%) have a zero willingness to pay for data service. Further, we study duopoly competition under (i) asymmetric costs (where the incumbent has a superior cost position vis-à-vis the FTTP entrant, as we would expect an incumbent cable MSO to have) and (ii) symmetric costs (where both have the same cost structure). Following are the demand model parameters:

	Value	Explanation
Q	10,000 homes	
μ_1	Scenario I: \$35/ home/ month Scenario II \$25/home/month	Scenario I: All homes have a positive willingness to pay for data service. Scenario II: Significant fraction of homes have a zero willingness to pay for data service
μ_2	\$45/ home/ month	
μ_3	Scenario I \$35/ home/ month Scenario II \$25/home/month	On an average, homes have the same willingness to pay for the data service offered by the incumbent and FTTP data service. However, depending on the value of □$_f$, a particular home may have different values for the willingness to pay for incumbent data service and FTTP data service.
μ_4	\$45/ home/ month	See above.
σ_1	Scenario I \$10/ home/ month Scenario II \$25/home/month	Scenario I: All homes have a positive willingness to pay for data service. Scenario II: Significant fraction of homes have a zero willingness to pay for data service
σ_2	\$10/ home/ month	
σ_3	Scenario I \$10/ home/ month Scenario II \$25/home/month	σ_3 is always assumed to be equal to σ_1
σ_4	\$10/ home/ month	σ_4 is always assumed to be equal to σ_2
ρ_f	0 < □$_f$ < 1	

The supply model assumptions are as follows:

F	\$50,000/ month	We have assumed a capital cost of \$800 per home for installation of the fiber resulting in a total capital expenditure of \$8 million (amortized over 25 years at 5% cost of capital)
C_0	\$8/ home/ month	We have assumed a capital cost of \$200 per home for installation of the drop (amortized over 25 years at 5% cost of capital) and a cost of \$400 for OLT and CPE (amortized it over 5 years at 5% cost of capital)
C_1	\$20/ home/ month	
C_2	\$30/ home/ month	
U	Asymmetric Cost Scenario: \$35,000/ month Symmetric Cost Scenario: \$50,000/month	Asymmetric Cost Scenario: Capital cost of upgrading the cable network is assumed to be \$500 per home resulting in a total capital expenditure of \$5 million (amortized over 25 years at 5% cost of capital). Symmetric Cost Scenario: See above for choice of F.
C_t	Asymmetric Cost Scenario: \$2/ home/ month Symmetric Cost Scenario: \$8/ home/ month	Asymmetric Cost Scenario: Since an ONT is required for a cable network, the only cost is that of a truck roll – assumed to be \$150 (amortized it over 5 years at 5% cost of capital). Symmetric Cost Scenario: See above for choice of C_0
C_3	\$20/ home/ month	For simplicity assumed to be same as C_1
C_4	\$30/ home/ month	For simplicity assumed to be same as C_2

Figure 4.1 shows the profitability of all entities under symmetric costs and the demand scenario where all homes have a positive willingness to pay for data services. As expected the profits of all entities, 'Verizon', 'Stockholm Profit', the incumbent (competing with 'Verizon' and with 'Stockholm Profit') decreases with an increase in ρ_f - evidence of the fact that as products become less differentiated, price competition intensifies and profits

decline. Indeed, if the services offered are identical, Bertrand's paradox assures us that neither firm is profitable, which our results confirm. The difference between the profits per home passed of 'Verizon' and 'Stockholm Profit' is less than $0.10 (i.e. a difference of less than 5%). This is consistent with the intuition we developed in the single service provider model – the bulk of the extractable economic surplus lies in the bundle and lack of ability to price discriminate does not hinder the ability to extract the surplus. For the same reason, the incumbent competing against 'Stockholm Profit' does only marginally better than the incumbent competing against 'Verizon' – there is less than $0.15 (7%) difference in profitability.

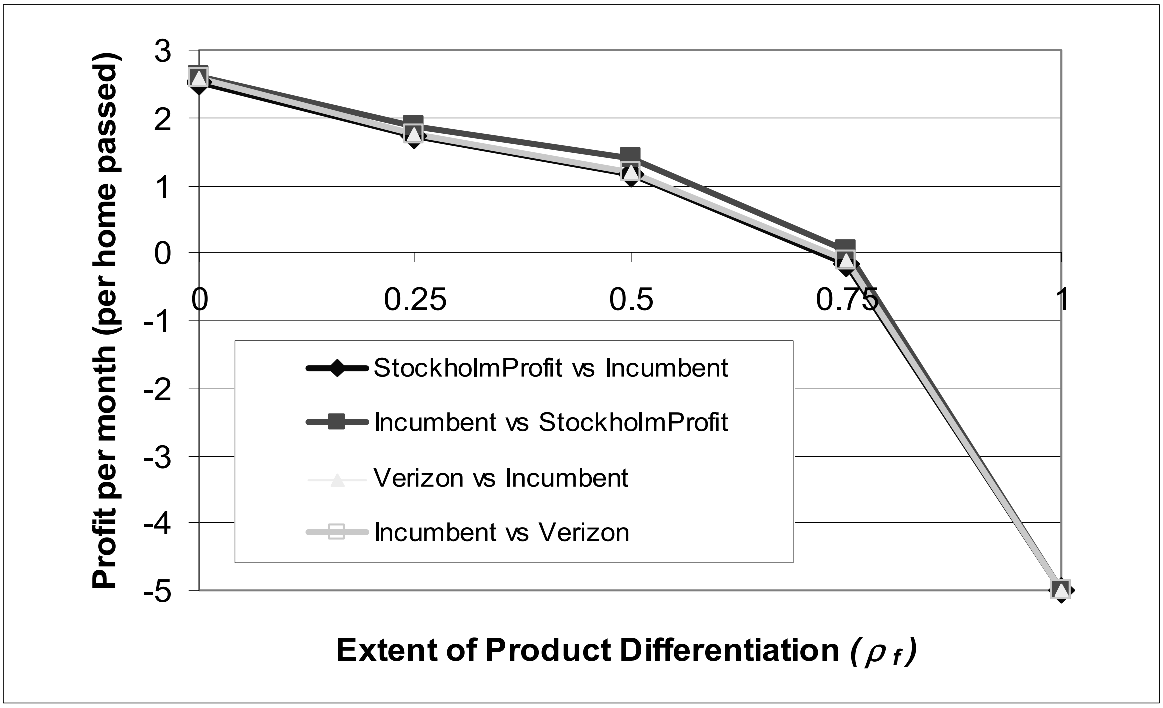

Figure 4.1 Profitability of 'Verizon', 'Stockholm Profit' and the incumbent under Demand Scenario I

Under the other demand scenario (where 15% of homes do not own a computer and have a zero willingness to pay for data service), 'Verizon' generates up to $0.70 (or 25%) more profit than 'Stockholm Profit' (figure 4.2). This is due to the fact that 'Stockholm' cannot set the price of video independently from that of the bundle and the resulting optimal bundle price ends up being much lower than the bundle price of 'Verizon'. For this reason, the incumbent competing against 'Stockholm Profit' is forced to lower its bundle price vis-à-vis the incumbent competing against 'Verizon' – and instead of being able to take advantage of 'Stockholm Profit's inability to price discriminate, it ends up being less profitable (per home passed per month) than the incumbent competing against 'Verizon' by $0.25 (or 10%). Consequently, the bundle consumers in the 'Stockholm Profit' versus incumbent duopoly game enjoy a significantly higher consumer surplus. The duopoly game with asymmetric costs reinforces these conclusions. Therefore, our duopoly competition analysis shows that an incumbent is not able to take much of an advantage of a wholesale-retail split to boost its profits.

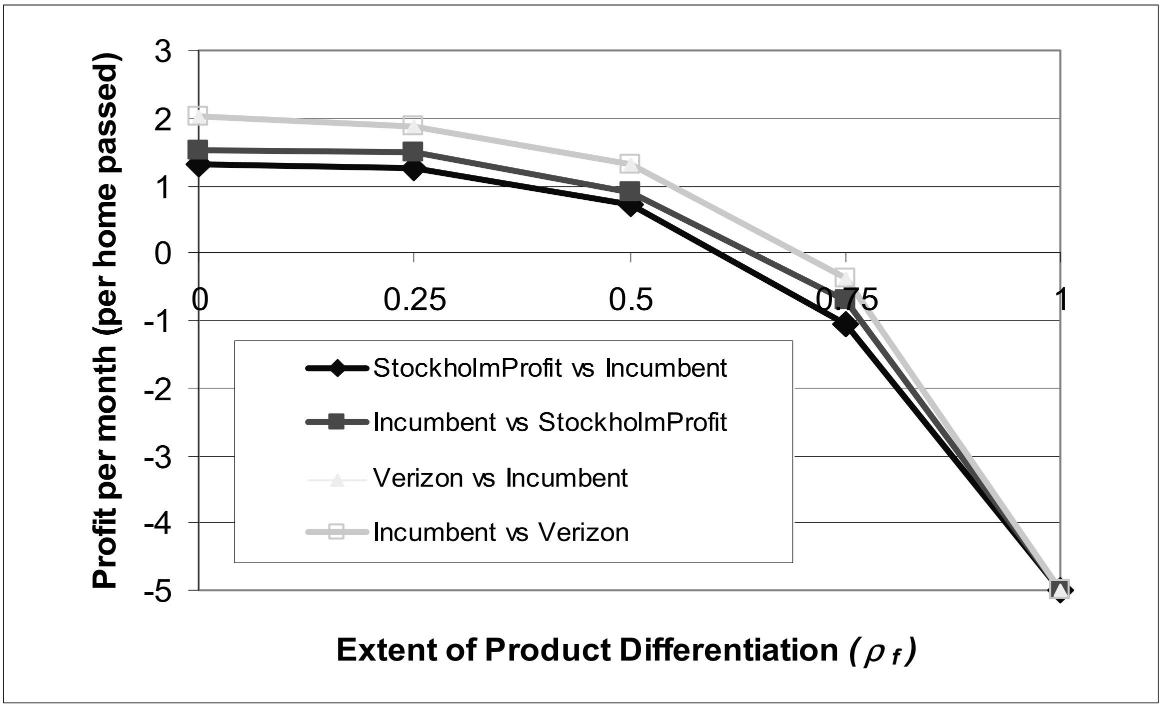

Figure 4.2 Profitability of 'Verizon', 'Stockholm Profit' and the incumbent under Demand Scenario II

The results of the duopoly game between a welfare maximizing[19] FTTP entrant ('Bristol' and 'Stockholm Welfare') and a profit maximizing incumbent (under the demand scenario where 15% of homes have a zero willingness to pay for data) are summarized in figures 4.3 and 4.4. For the welfare game, we assume that the profit maximizing incumbent has a superior cost structure (asymmetric costs), otherwise a welfare maximizing entrant can easily drive a profit maximizing incumbent out of business. With our asymmetric cost assumptions, the entrant cannot recover its costs for values of ρ_f greater than 0.5. Figure 4.3 confirms that even under such a demand scenario, 'Stockholm Welfare' can create almost as much welfare as 'Bristol' – the difference in welfare being about \$0.50 (or ~5%)[20] per home passed per month.

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[19] With a cost recovery constraint

[20] Recall that under the same demand scenario, 'Verizon' is 25% more profitable

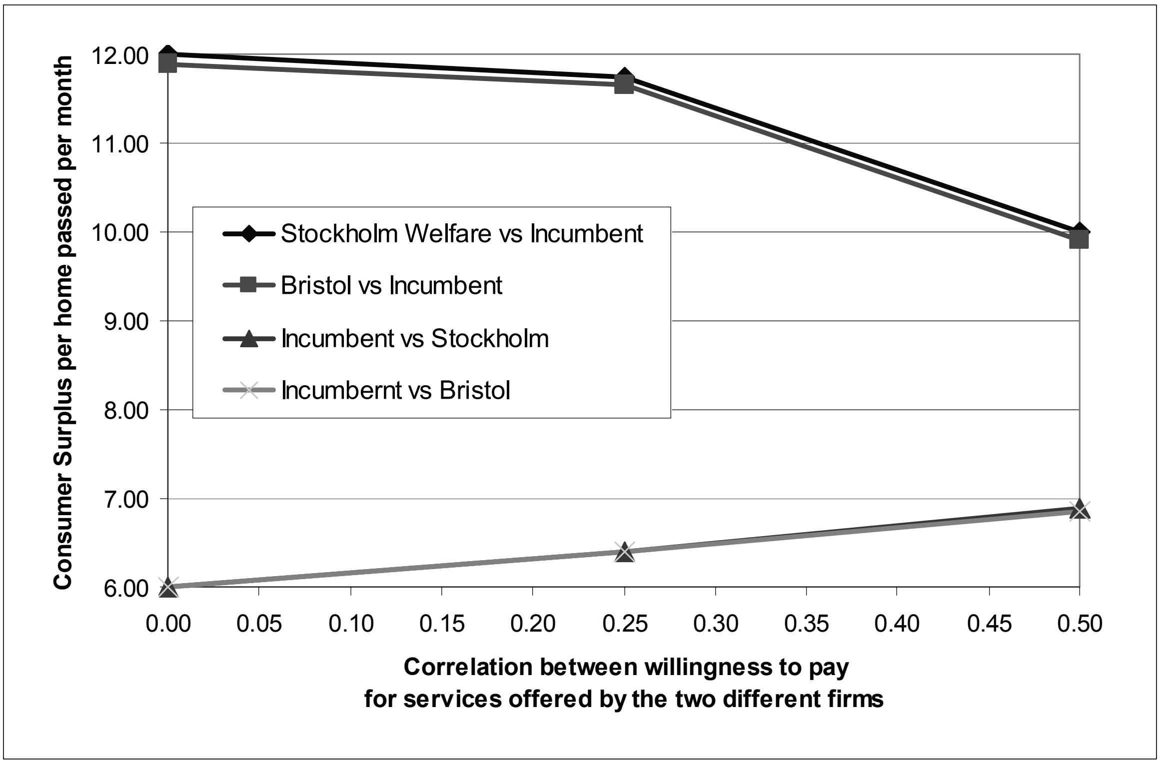

Figure 4.3 Consumer Surplus of 'Bristol', 'Stockholm Welfare' and the incumbent under Demand Scenario II

The consumer surplus generated by the FTTP entrant decreases with ρ_f because as the products gets less differentiated fewer homes get served by FTTP. On the other hand, the consumer surplus of the incumbent increases slightly with ρ_f because its profit decreases and so its consumers enjoy more of the surplus. Given that this particular game is of interest to municipalities building out FTTP, figure 4.4 sheds some light on the welfare implications of municipal entry. A municipal FTTP entrant that maximizes welfare not only creates welfare for its consumers, but also enhances the consumer surplus experienced by the consumers of the incumbent. For our model parameters, consumer surplus increases by as much as \$5.40 per home passed per month for $\rho_f = 0$ (a 130% increase) and \$2.10 per home passed per month for $\rho_f = 0.5$ (a 90% increase) due to municipal entry. Total welfare (also includes the profits of the incumbent) increases by about \$6 per month per home passed (or 36%) for $\rho_f = 0$ and \$2 per month per home passed (or 12%) for $\rho_f = 0.5$. Service penetration rises from 57% to almost 90%, indicating that welfare maximizing municipal entry ensures that almost every home ends up being served (figure 4.5). Since we have not estimated the demand and supply curves precisely, these numbers provide some indication of potential benefits municipal broadband can provide by way of increased consumer surplus to customers of both the municipal FTTP network and the incumbent. This evidence supports the argument that even if the municipal network were to be unprofitable and had to be funded out of increased taxes, the consumer surplus resulting from such an entry could far outweigh the effect of increased taxation. Precisely estimating those benefits for different markets promises to be an interesting area of future empirical research.

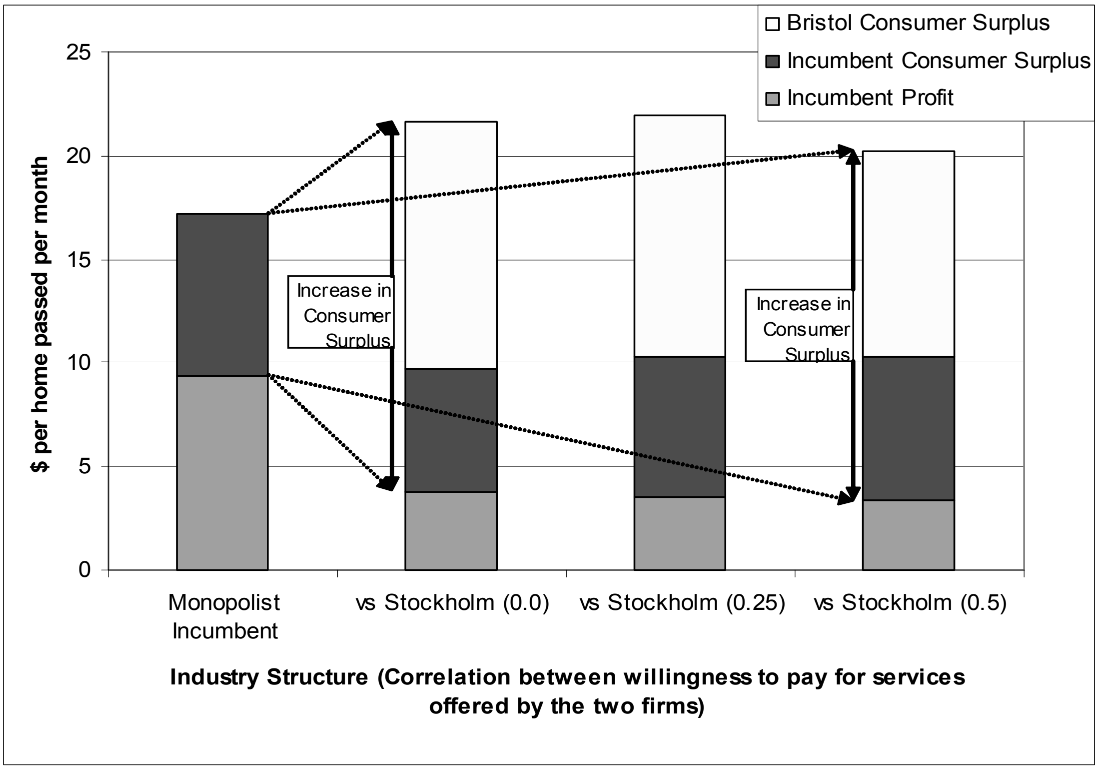

Figure 4.4 Welfare implications of municipal FTTP entry

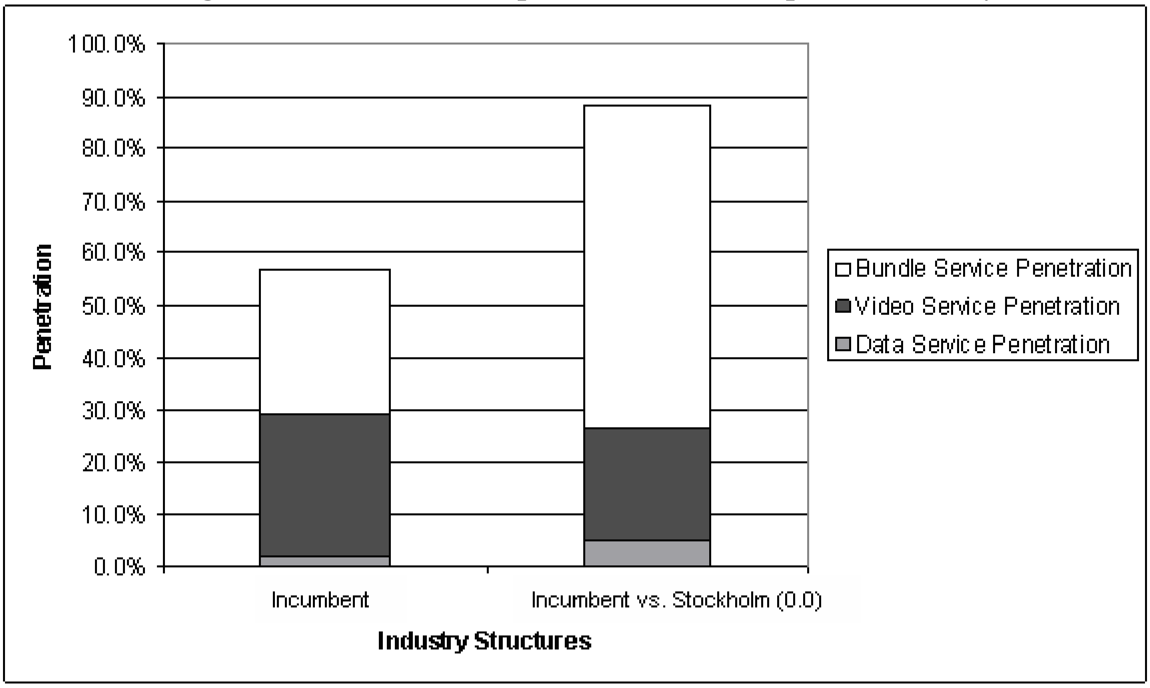

Figure 4.5 Implications of municipal FTTP entry for service penetration

5 Caveats

So that the model remains tractable and can provide transparent insights into the problem, we have made some certain simplifying assumptions. In this section, we discuss some of the limitations of the model.

5.1 Caveats

First, we assume the retail market (in the wholesale-retail split industry structures) to be perfectly contestable and competitive. However, we know that there are entry barriers, especially for the video business where a retailer needs to construct a video head end and get access to content. This will most likely result in oligopolistic competition (with the extreme case of a retail monopoly) that could cause (some degree of) double marginalization, thereby reducing welfare relative to a perfectly competitive retail market.

We assume the incremental costs, C_1 and C_2, are the same in both vertically integrated and competitive retail cases. Also, we assume layer 2 costs, C_0, are the same whether supplied competitively (in the case of 'Stockholm') or by the wholesaler. Competition should drive down all these costs relative to the vertically integrated case.

While the model captures the economies of scope in bundle provisioning due to C_0, it is possible that the incremental costs of providing a bundle are less than the sum of the incremental costs for each of the individual services - due, for example, to economies of scope in operations or marketing - but we ignore this possibility for the present analysis; such economies would only reinforce our conclusions.

In this model we assume only three services – voice, video and data services and bundles resulting from the combinations of these – i.e. service providers set a maximum of 7 prices. In reality, it is possible that service providers may segment the market further by selling different voice, video and data products (e.g. offer different tiers of video programming) and actually set a much higher number of prices.

Further, the model assumes that all revenues accrue from end customers and not from application service providers. While this correctly captures the business model of FTTP service providers today, depending on the outcome of the network neutrality debate, this could very well be different in the future. Though our model clearly shows that it is not necessary to charge application service providers in order to recover costs, it is conceivable that the wholesale retail split may interfere with the ability of the network owner to extract surplus from an application service provider (for example, it may be easier for a vertically integrated entity to extract a portion of advertising revenue from Google vis-à-vis a wholesaler). While we think this is an important problem to study, it is out of scope in the context of the present analysis.

Finally, if we relax our assumption that the wholesaler sells only symmetric capacity, it is easy to see the wholesaler can indeed price discriminate to the same extent as a vertically integrated entity by selling a video capability that has high downstream bandwidth (say 4 Mbps) but very low upstream bandwidth (say a few Kbps that would be insufficient to support broadband data and severely compromise the broadband data experience). In general, there may be other technical choices that a wholesaler can make that would increase its ability to price discriminate.

5.2 Technology and Price Discrimination – Strategies for 'Grant County'

The extent to which 'Grant County' can price discriminate depends largely on the technological choices that 'Grant County' makes. Earlier we assumed that 'Grant County' cannot set the price of the video service capability independently of its data-video bundle capability because the downstream capacity associated with a video capability is sufficient to provision a data-video bundle (as well as a data-voice-video bundle). Especially in the demand scenario where a significant proportion of homes have a zero willingness to pay for data service, any strategies that 'Grant County' can use to set the same number of prices as 'Verizon' will make 'Grant County' as likely to recovers costs as 'Verizon'.

(i) Asymmetric Capacity: If 'Grant County' sells symmetric upstream and downstream capacity it cannot set separate prices for the video service capability and the video-voice bundle capability. With respect to the five prices that 'Verizon' can independently set, 'Grant County' can set prices independently only for (i) data service capability (or data-voice bundle capability), (ii) voice service capability and (iii) the triple play bundle capability (or the data-video bundle capability). This is because the amount of bandwidth associated with the video service capability is sufficient for a home to use it for a video-voice bundle, a data-video bundle or a triple play service. However, if 'Grant County' were to sell asymmetric capacity, it can sell a video capability that has a high downstream bit-rate (~5Mbps) but a very low upstream bandwidth (a few Kbps). Provisioning asymmetric capacity is one way in which 'Grant County' can also set five prices – *i.e.* price discriminate to same extent as 'Verizon'.

(ii) Multicasting: Instead of selling unicast capability, if 'Grant County' sells multicast video capability, it could be very difficult for a retailer to use the video capability and provision data and voice service over it due to insufficient bandwidth between the remote terminal and the central office. This is relevant only to active star architectures[21].

(iii) Finally, 'Grant County' can also manipulate packet delay and jitter on the network in order to prevent certain applications from running without their explicit knowledge, but this may create adverse problems.

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[21] Multicasting is relevant in PONs to the extent that (i) the PON provider is doing IPTV and not a video overlay, and (ii) it economizes in the middle mile.

However, Grant County could find it difficult to price discriminate to the same extent as Verizon if, for example, broadband data service consumed is 10 Mbps (or higher). Grant County would find it hard to provide only data service capability, data-voice bundle capability or data-video bundle capability. This is because, at 10 Mbps the data capability would have enough bandwidth to support voice, video and data applications and a retailer could buy such a data capability from the wholesaler and provision a triple bundle or a data-video bundle or a data-voice bundle over it.

6 Conclusion and Future Research

Fiber to the Premise (FTTP) exhibits characteristics of a natural monopoly industry. However, service level competition over a shared network is possible in FTTP and can be achieved by a structural separation between network ownership and service provisioning, also referred to as a wholesale-retail split. Three different models of service level competition are possible (i) dark fiber unbundled network element (UNE) based (the network owner wholesales dark fiber), (ii) wavelength UNE based (the network owner wholesales wavelengths) and (iii) higher layer based open access (the network owner wholesales transport capacity).

Feasibility of service level competition depends on the architecture of the shared FTTP network and technology choices of the network owner (also referred to as the wholesaler). While a home-run architecture supports all models of competition, a single wavelength PON supports only higher layer open access. An optimal fiber aggregation point (OFAP) based network, which aggregates distribution fiber from ~100 homes for a rural deployment and ~200 homes for an urban deployment is the lowest cost architecture that supports all models of competition. It also provides the network owner with at least two valuable real-options (at a modest cost): (i) option to defer investment in central office OLT ports and (ii) option to phase in new technology. Accounting for the benefits that accrue from the option to defer investment in central office OLT ports, the OFAP architecture is has the lowest cost among all FTTP architectures – this demonstrates that a network owner does not need to incur any additional costs to build out an architecture that enables service level competition via dark fiber.

A wholesale-retail split interferes with the ability of a network owner or wholesaler to *price discriminate*. Vertically integrated entities can engage in third degree price discrimination and sell seven possible product bundles - (i) voice, (ii) video, (iii) data, (iv) video-voice, (v) data-voice, (vi) data-video, and (vii) data-video-voice triple play bundle. In complete contrast, a dark fiber wholesaler can set only one price for dark fiber access. A ‘lit’ wholesaler *may* be able sell the same number of goods as a vertically integrated entity depending on its technological choices.

In spite of interfering with a wholesaler's ability to price discriminate, a wholesale-retail split is economically feasible. A wholesaler can recover its cost and as long as a significant number of homes do not have a zero willingness to pay for broadband data service, a wholesaler is almost as profitable as a vertically integrated entity. This is because the bulk of the extractable economic surplus resides in the triple-play bundle due to significant economies of scope in provisioning the bundle. Since the wholesale-retail split does not interferes with the 'dark fiber' wholesaler's ability to extract economic surplus from the triple-play bundle, the inability to price discriminate does not interfere with the ability of a dark fiber wholesaler to extract economic surplus vis-à-vis a vertically integrated entity (or a 'lit' wholesaler) and the difference between the profits of a profit maximizing wholesaler and a profit maximizing vertically integrated entity) are modest, at best. In such markets, municipalities or communities that build out FTTP and choose to be wholesalers (i) can realize sustainable prices, (ii) are likely to create greater welfare (due to innovation spurred by retail competition) and (iii) are just as likely to recover costs (vis-à-vis vertically integrated entities). Therefore, contrary to the assertions of some current providers, it is not necessary to vertically integrate and exclude service level competitors in order to generate sufficient revenue to cover an investment in FTTP infrastructure. However, in markets, where a large proportion of homes have a zero willingness to pay for data service (and therefore, desire only video service), the profit maximizing 'dark fiber' wholesaler can be worse off due to its inability to set a video price independently of the bundle price – resulting in a lower optimal bundle price (vis-à-vis a vertically integrated entity) and lower profits. Interestingly, the welfare maximizing 'dark fiber' wholesaler can still create almost the same amount of welfare as a vertically integrated entity, though the distribution of welfare among consumer groups is markedly different.

Even in the presence of a (cable) incumbent that offers voice, video and data services, a wholesaler is as likely to recover its costs as a vertically integrated entity. The ability to price discriminate gives the vertically integrated entity only marginally greater ability to compete with the cable incumbent and does not drive down prices or incumbent profits by much. In the case of a dark fiber wholesaler, if a large proportion of homes have zero willingness to pay for data services, not only is the 'dark fiber' wholesaler worse off (vis-à-vis a vertically integrated entity), but the profit maximizing dark fiber price set by the 'dark fiber' wholesaler results in a lower bundle price that makes the incumbent worse off as well (vis-à-vis the incumbent competing against a vertically integrated entity) resulting in bundle consumers enjoying a significantly larger consumer surplus.

Finally, a municipal FTTP entrant that seeks to maximize welfare and competes with a profit maximizing (cable) incumbent not only creates welfare for its subscribers, but also enhances the consumer surplus experienced by the subscribers of the (cable) incumbent. For our model parameters, consumer surplus can almost double due to such municipal entry. Service penetration rises from 57% to almost 90%, indicating that welfare maximizing municipal entry ensures that almost every home ends up being served. Even if the municipal network were to be unprofitable and had to be funded out of increased taxes, the consumer surplus resulting from such an entry could far outweigh the effect of increased taxation.

6.1 Some ideas for Future Research

The FTTP engineering cost model is based on first mile costs only. As an area of future research, the conclusions (especially around natural monopoly) can be strengthened by extending the model to include operations costs and second mile costs of FTTP networks.

The impact of the wholesale retail split is predicated on the assumption that all revenues accrue only from end customers – however, in a world without network neutrality (where the network owner charges application services providers), an area of further research could involve studying the impact of the wholesale retail split for advertising and other revenues that network owners may seek to extract from application service providers.

Further, we have assumed that the retail markets are perfectly competitive. A possible area of research could involve examining second mile and operations costs and estimating possible number of retailers that might serve a particular market and assess the impact of the wholesale retail split in the presence of oligopolistic competition between a few retailers (instead of assuming perfect retail competition).

While we have assumed a service provider can set at most 7 prices, in reality a service provider can segment the market further and offer multiple voice, video and data products (as an example, a service providers could provide many tiers of video programming). Another area of possible empirical research could be around studying the impact of the wholesale retail split when a service provider sells many different products and services targeted towards multiple market segments.

Since we have not estimated the demand and supply curves empirically, the stated benefits of municipal entry are illustrative. Precisely estimating the increased consumer surplus to consumers of both the municipal FTTP network as well as of the incumbent for different markets promises to be an interesting area of future empirical research.

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