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The Effect of a Satellite Internet Provider on a Landline Telecommunication Duopoly

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Abstract

The world is more connected than ever before with the average household owning 10 connected devices (Verizon, 2018). To connect the unconnected Ericsson (2016) suggests Internet satellites will play an important role. The purpose of this thesis is to understand how Internet satellites effect the telecommunication market using Hotelling (1979) spatial location model to examine equilibrium price and profits in duopoly and triopoly, investigate what happens when the quality of the Internet satellites increases, and identify how location choice impacts the model's result. Extending previous research, the model provides similar result for both linear and quadratic transportation costs. Moreover, the market power effect dominates so both Hotelling's (1929) Principle of Minimum Differentials and d'Asperemont et al.'s (1979) Principle of Maximum Differential breaks down and the Internet providers preferred location is between the extremes and the centre of the "linear city."

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1 Introduction

People are increasingly online and connected. Connectivity in daily life; ordering food, watching a film on Netflix, or chatting with friends, is more interweaved than ever before. According to Verizon (2018) ”the average household has 10 connected devices, a number that continue to rise every year.” In the Euromonitor International’s (2016) Global Consumer Trends Survey more than half of the respondents answered they would be lost without Internet access. Similarly, Boumphrey and Bremer (2017) identified connected consumers as a megatrend towards 2030. In other words, peoples life increasingly depends on usage of telecommunication products and services, and global telecommunication providers are expected to continue to grow in the future. Sallomi and Lee (2018) identified satellites, and development of high-speed mobile services such as 5G and 4G as prominent market segments. The two leading telecommunication providers, China Mobile Limited (2018) and Verizon (2018), both develops international standards for 5G architecture through landline Internet access.

The landline telecommunication market is analysed using Hotelling model of spatial competition, adding a satellite Internet provider without transportation cost. The framework is considered when two of the Internet providers are located at the interval boundaries, while the third Internet provider is located along the interval boundaries. The research aim is to explore how the satellite Internet provider effects the competition in the telecommunication market. For the purpose of this research three objectives were created to guide the research process:

- Examine equilibrium prices and profits in the telecommunication market
- Investigate what happens when the quality of the Internet satellites increases
- Identify how location choices impact the result of the model

Spatial competition is well researched (see Salop, 1979; Economides, 1989; Rochet and Tirole, 2003; Chawla et al., 2006; Buechel Roeh). However, less is known about how satellite Internet influence spatial competition of a landline telecommunication duopoly.

Hotelling's (1929) "linear-city" captures horizontal product differentiation in "a market as an extended region" (Hotelling, 1990, p. 45). Using linear transportation costs, he established the Principle of Minimum Differentiation as an equilibrium concept where firm approach each other and share the marked equally. d'Aspermont et al. (1979) criticised the model not being subgame perfect equilibrium because of the Bertrand paradox. In other words, when firms producing perfect substitutes are located next to each other they find it more profitable to take away the rival's entire business by undercutting prices. Moreover, d'Aspermont et al. (1979) modified Hotelling's "linear-city" with quadratic transportation costs introducing the opposing phenomenon vertical differentiation, a result of the Principle of Maximum Differentiation (Prescott and Visscher, 1977; Griva and Vettas, 2011), where higher quality products sell at higher prices since consumers differ in their willingness to pay (Shaked and Sutton, 1982; 1987; Pepall, Richards and Norman, 2011).

In Hotelling's model location was originally interpreted geographically as transportation costs. Lancaster (1966) and Hinloopen & Martin (2013) emphasise that Hotelling model extends to any choice of product characteristics such as durability, quality, or product R&D, and transportation costs can therefore have various interpretations. Hotelling assumed that location like price could be altered costlessly. However, Prescott and Visscher (1977) argue most relocation costs are substantial, involving moving plant site or changing consumer imaging using advertising. Therefore is it more reasonable to model the firms as making location decisions once. For the purpose of this research transportation costs have a geographical interpretation as distance travelled.

The results show that adding a third satellite Internet provider to the duopoly model with linear transportation costs soften the competition between Internet provider 1 and 2, henceforth IP_1 and IP_2, and simplifies the location analysis. Spatial location is therefore analysed without mixed strategies. The literature has provided troublesome result analyse location choices (see Hotelling 1929; D'Aspremont et al., 1979; Salop, 1979; Economides, 1989). Competing indirectly through Internet provider 3 (IP_3), neither IP_1 nor IP_2 want to locate at the centre of the "linear city" to avoid price competition. Optimal range of location is towards the centre so the indifferent consumer is found at the interval border where the Internet providers do not have any incentive to move as it does not effect demand. Therefore do both Minimum Differentiation explored by Hotellinger (1929) and the Principle of Maximal Differential developed by d'Aspremont et al. (1979) break down. This research is theoretically different from previous research (see Economides, 1993; Brenner, 2001; Larralde et al., 2009), extending the model by adding a satellite Internet provider both linear and quadratic transportation costs give the same result.

The literature that follows from Hotelling (1929) is immense. Extensions include the circular city (Salop, 1979; Economides, 1989), graphs (Buechel Roeh, 2014), nonlinear transportation costs (D'Aspremont et al., 1979; Economides 1986), sequential entry (Prescott and Visscher, 1977; Chawla et al., 2006), quantity competition (Hamilton et al, 1994), competition with more than two firms (Shaked and Sutton, 1982; Lancaster, 1989; Brenner, 2001), and two-sided platform (Rochet and Tirole, 2003; Armstrong, 2006; Economides and Tåg, 2012; Hagiu and Hałaburda, 2014). The majority of the literature ignores the number of firms influence on the equilibrium outcome only considering duopoly markets. However, Salop (1979) examines an oligopoly model of the circular city with n firms. The circular model is a "good paradigm for some characteristics such as colour" as it describes "the choice of consumers distributed along the coastline of a lake" (Economides, 1993, p. 304). For most goods, as with provision of Internet, it is more appropriate to use a line interval as space since simplicity and symmetry of the circular model cannot sufficiently compensate for lack of appropriate structure.

To answer the research questions the paper is organised as follows. The next section outlines the development of the telecommunication industry and section 3 describes the main characteristics of the model. Section 4, the analysis, presents the solution to the model with two and three Internet providers respectively, before location choices are examined in section 5. Finally, section 6 presents the research conclusion and relates the research to the research objectives. Moreover, it discusses the limitations of the study and offers recommendations for future studies. All proofs of the results are given in the appendices.

2 From landline telecom to satellite Internet

Before the emergence of the Internet, telecommunication had a clear meaning in terms of telephony; voice communication, allowing people to communicate over a distance (National Research Council, 2006; Mitel, 2018). As technology developed, the telephone industry evolved into transmission of not only voice, but also data, image, and video today described as telecommunication. Mobile phones importance for data transfers (National Research Council, 2006) is emphasised by Sallomi and Lee (2018) in Deloittes' Technology, Media and Telecommunications Predictions. They estimated mobile penetration rates among adults in developed countries to surpass 90 per cent by the end of 2023. Similarly, World Bank Group (2016) predicted that on average 8 in 10 in the developing world own a mobile phone. To put it differently, "the poorest households are more likely to have access to mobile phones than to toilets or clean water" (World Bank Group, 2016, p. v), highlighting smartphones position as the primary access to digital services (Gruber et al., 2011).

As with the development of the telephony, the Internet has evolved at an exponential rate (Hadjitheodosiou, Ephremides and Friedman, 1999; Wittig, 2009; Kim et al., 2011). The Internet's development is illustrated by the numer of users more than tripling from 1 billion in 2005 to 3.2 billion in 2015 (World Bank, 2016), and surpassing 4.1 billion users in December 2017 equivalent to 54,4 per cent of the World's population. The highest Internet penetration rate is found in North America with 95 per cent, followed by Europe with 85.2 per cent. Africa and Asia are found on the bottom with 35.2 per cent and 48.1 per cent respectively (Internet World Stats, 2018). Sprague et al. (2014) argue the Internet will become even more valuable and widespread in the coming years, particularly in countries that have not yet reached a critical mass of online users.

There are mainly two benefits of increased connectivity: economic growth and information access. First considering economic growth, Gruber et al.'s (2011) research found mobile telecommunications contribution to annual GDP growth to be 0.026 in low mobile penetration countries compared to 0.048 in high mobile penetration countries. This was later emphasised by Zuckerberg (2014), Sprague et al. (2014) and West (2014; 2015a; 2015b). Furthermore, countries with low penetration rates experience a double disadvantage as high mobile penetration yields incentives for further investment. In other words, these countries face lower growth due to lower mobile coverage, and therefore lower incentives for further development of mobile networks. Second, access to information enhances empowerment by timely providing research tools for education and health (Gruber et al., 2011; West, 2014; 2015a; 2015b).

Although the number of Internet users has grown quickly, the Internet is by no means universal. 45.6 per cent of the World's population is still offline (Internet World Stats, 2018); have not used the Internet in the past 12 months (Sprague et al., 2014), and cannot participate in the digital economy (Zuckerberg, 2014; World Bank Group, 2016). Sprague et al. (2014) and Wittig (2009) argue parts of the population risk being left behind, a disadvantage that they might never overcome. Therefore is it important to connect the unconnected to accelerate both economic and social growth (Zuckerberg, 2013; 2014; Deloitte, 2014; West, 2015a) by creating favourable conditions for technology (World Bank Group, 2016). More specifically, to deliver universal Internet access World Bank Group (2016) highlights the importance of investment in infrastructure, price for mobile phones and data, and competition in telecommunication markets.

The increased Internet population has been fuelled by two factors (Sprague et al., 2014); infrastructure and price for mobile phones and data, serving as barriers to connectivity if not addressed (West, 2015a). First, infrastructure, the growing demand for Internet spurred mobile network operators to invest in speed and bandwidth to bring digital services to a wider range of people. Moreover, urbanisation and Internet penetration is highly correlated since urban areas typically have better Internet infrastructure due to higher population density (Wittig, 2009; Sprague et al., 2014). Second, prices for both mobile phone and data have been shrinking since the introduction of mobile phones in the consumer market in 1983 (Sprague et al., 2014). However, for people with little disposable income it is still costly to access data (Zuckerberg, 2013; West, 2014; 2015a). In other words, digital infrasturcture have to be expanded and costs reduced to increase Internet penetration and enable affordable services (West, 2015a). In that context, Ericsson (2016) emphasised that satellite's could play an important role providing Internet access to the extremely rural population.

The idea of using satellite constellations to provide wireless telecommunication services is not new. Clark (1945) in Wireless World proposed a constellation of satellites to provide full equatorial coverage of the Earth. Satellite-constellation-based systems are already used for applications such as: navigation and position, and low-bit-rate communication- and messaging data services (Wood, Pavlou and Evans, 2001). To improve digital infrastructure in remote areas Google launched Project Loon trying to promote Internet through balloons (Wu and Yoo, 2007). Facebook, on the other hand, investigated whether drones could be an effective infrastructure solution and concluded satellites might be more efficient and cost effective (Zuckerberg, 2014). Satellites not only expand the digital infrastructure, but also have the advantage of "solving the expensive last-mile issue" (Hadjitheodosiou, Ephremides and Friedman, 1999, p. 2), offering global coverage in remote, rural, urban and inaccessible areas (Wood, Pavlou and Evans, 2001; Wood, 2001; Wood et al., 2001; Chen, 2005; Wittig, 2009; West, 2015a).

Recognising the research gap in relation to spatial competition and Internet satellites, Whetten (1989, p. 491) argues "the mission of a theory development is to challenge and extend existing knowledge, not simply rewrite it." It is therefore essential to ask the right "what," "how," and "why" questions. During the review of the literature, the following research questions were developed:

- How do Nash equilibrium results vary from duopoly to triopoly markets when a satellite Internet provider enters the market?
- What happens in the telecommunication markets as quality of Internet provider 3 increases?
- Why is location choices for rivals of the satellite Internet important in the telecommunication market?

3 The Model

In an economy with homogeneous goods, a generalised Hoteling's (1929) model of spatial competition with linear utility is used to evaluate the effect of a satellite Internet provider entering a telecommunication duopoly. This paper follows the standard approach of a noncooperative game structured in two stages. In the first stage the Internet providers simultaneously choose location which is assumed fixed at the interval boundaries corresponding to the Principle of Maximum Differentiation.[2] After choosing location, price competition takes place.

Consumers are constrained to buy one unit of Internet access and are distributed uniformly around the world (Pepall, Richards and Norman, 2011) allowing demand to be represented by a line of consumers with total mass equal one. Internet provider 1 and 2; IP_1 and IP_2, provides landline Internet access, and Internet provider 3 (IP_3) provides Internet satellites. Location of IP_1 and IP_2 are symmetric at the extreme of the linear city $[0, 1]$ at $x = 0$ and $x = 1$. IP_3, on the other hand, is located along the linear city $x \in [0, 1]$. In addition to different locations, the Internet providers supply products with different quality. Although the IP_3 expands Internets' bandwidth by introducing Internet satellites extending the market coverage, the satellites deliver lower quality Internet than IP_1 and IP_2. The quality of IP_1 and IP_2 are $q_1 = q_2 = 1$ and IP_3's quality is $q_3 \leq 1$ where higher quality increases consumers' willingness to pay.

The Internet provider's location indicates the consumer's utility for accessing the Internet. Consumers have reservation price Vq_i; dependent on quality, for a good located at his position. Although fixed and marginal costs are normalised to zero, if the good is located elsewhere linear transportation cost, t, incurs per unit of distance "travelled." For the homogeneous products of IP_1 and IP_2 transportation costs affect consumers decision-making process. As IP_3 has Internet satellites located along the "linear city" consumers valuation are linear, not influenced by transportation costs. Consumers are endowed with

[2] Optimal location choice is analysed in section 5.

the following utility functions separable in reservation price

$$u(IP_1, p_1, q_1 = 1, x) = V - p_1 - tx \tag{1}$$

$$u(IP_2, p_2, q_2 = 1, x) = V - p_2 - t(1 - x) \tag{2}$$

$$u(IP_3, p_3, q_3, x = 0) = Vq_3 - p_3 \tag{3}$$

$$u(NO) = 0 \tag{4}$$

where (1), (2), and (3) represent the utility functions of customers buying from Internet provider 1, 2, and 3 respectively. (4) is the utility of not buying any goods. Furthermore, IP_i indicates the respective Internet provider, and p_i the price. Transportation costs, t, increase linearly with distance. The term $V > 0$ can be interpreted as customers valuation, only if V exceeds the sum of price and transportation costs does the consumer buy the good.

4 Analysis

The model is first solved for two Internet providers and then extended with a third Internet provider. Before the researcher evaluate what happens if IP_3's quality exceeds one, the equilibrium conditions of both price and profit are discussed.

4.1 Two Internet providers - duopoly

The model with two Internet providers is a standard Hotelling model (see Triole, 1988). A simultaneous move game where IP_1 and IP_2 simultaneously, but independent of each other make strategic choices about location. The game is solved by Nash equilibrium, so no one Internet provider can change strategy and be better off given the other Internet provider's strategy. Consumers living along the linear city $x \in [0, 1]$ obtains utility (1) and (2) from buying Internet access from IP_1 and IP_2 respectively, and (4) from not accessing the Internet. At $x_{1,2}$ the location where utility (1) equals (2) the consumer is indifferent between buying Internet from IP_1 and IP_2, which is represented by

$$u_1(IP_1, p_1, q_1 = 1, x) = u_2(IP_2, p_2, q_2 = 1, x) \to x_{1,2} = \frac{p_2 - p_1}{2t} + \frac{1}{2}$$

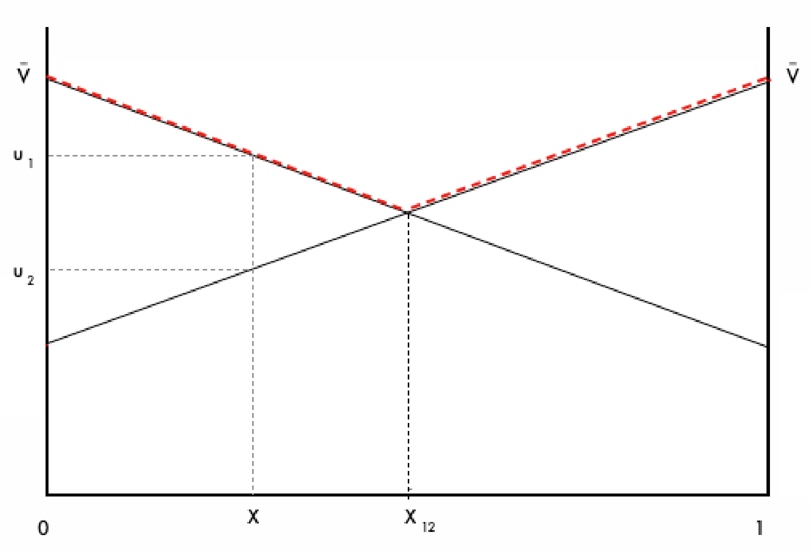


Figure 1: Consumers utility in duopoly

Figure 1 illustrates consumers utility levels (1) and (2) as a function of location. Consumers reservation price is high relative to the Internet provider's price so the market is fully covered and all customers buy Internet access. At location x the utility levels u_1, IP_1's Internet, and u_2, IP_2's Internet, are compared. The consumer's willingness-to-pay for IP_1's product is greater than its willingness-to-pay for IP_2's product since $u_1 > u_2$ so the customer prefer to buy Internet access from IP_1. Furthermore, given the distributional assumptions and the indifferent consumer's location, consumer's demand are $D_1(p1, p_2) = x_{1,2}$ and $D_2(p_1, p_2) = 1 - x_{1,2}$. The Internet providers respective demand functions are

$$D_1(p_1, p_2) = x_{1,2} = \frac{1}{2} + \frac{p_2 - p_1}{2t}$$

and

$$D_2(p_1, p_2) = 1 - x_{1,2} = \frac{1}{2} - \frac{p_2 - p_1}{2t}$$

To find Nash equilibrium Internet provider i chooses p_i to maximise its profit $\pi_i = p_i D_i$

given the price p_j charged by its rival. When marginal cost of production is normalised to zero, differentiating the Internet providers profit with respect to price yields

$$\begin{cases} \frac{1}{2} + \frac{p_2 - 2p_1}{2t} = 0 \\ \frac{1}{2} - \frac{2p_2 - p_1}{2t} = 0 \end{cases} \Rightarrow \begin{cases} p_2 - 2p_1 + t = 0 \\ p_1 - 2p_2 + t = 0 \end{cases} \Rightarrow \begin{cases} p_1 = t \\ p_2 = t \end{cases}$$

The Internet providers obtain the following equilibrium prices and profits

$$p_1 = p_2 = t$$

$$\pi_1(p_1, p_2) = \pi_2(p_1, p_2) = \frac{t}{2}$$

where profits are decreasing in t. The indifferent consumer buys Internet access if

$$u_1(IP_1, p_1, q_1 = 1, x) \geq 0 \rightarrow V - p_1 - tx \geq \rightarrow V \geq \frac{3}{2}t$$

Even though the Internet access delivered by IP_1 and IP_2 is physically identical products, as transportation cost increases so do the product differentiation. At the extremes of the "linear city" maximal differentiation is achieved. If the Internet provider's are located at the same location; minimal differentiation, the model reduces to standard Bertrand price competition. Whether the consumers buy Internet access is dependent on the reservation price. Only if the sum of price and transportation costs do no exceed the consumer's valuation does the consumer buy the good, $V \geq \frac{3}{2}t$. For proof see Appendix 1.

4.2 Three Internet providers - Triopoly

To evaluate the effect of Internet satellites in the telecommunication market the duopoly model is extended to a triopoly model. Doing so allows the researcher to discuss the case of three Internet providers in the location space. In a similar manner as in the duopoly, $x_{1,3}$ and $x_{2,3}$ are the locations where the consumer is indifferent between IP_1 and IP_3, and IP_2 and IP_3 respectively. In the triopoly, the indifferent consumers at location x_{12} is not considered as quality of IP_3 is assumed sufficiently high for the Internet provider to enter the market.

$$u(IP_1, p_1, q_1 = 1, x) = u(IP_3, p_3, q_3, x = 0) \rightarrow x_{1,3} = \frac{V(1-q_3) - p_1 + p_3}{t}$$

$$u(IP_2, p_2, q_2 = 1, x) = u(IP_3, p_3, q_3, x = 0) \rightarrow x_{2,3} = \frac{-V(1-q_3) + p_2 - p_3 + t}{t}$$

where $V(1-q_3) = r$ is the quality discount, the utility difference between buying Internet access from IP_1 or IP_2, and IP_3. The quality discount is reversely related to IP_3's quality. In other words, as q_3 increases the quality discount decreases and vise versa. Moreover, when r is positive; q_3 is less than one, the Internet providers compete in a triopoly market. If r is negative; q_3 is greater than one, all consumers are going to switch to IP_3 constructing a monopoly market. The location of the indifferent consumers are therefore rewritten in terms of r

$$x_{1,3} = \frac{1}{t}r + \frac{1}{t}(p_3 - p_1)$$

and

$$x_{2,3} = 1 - \frac{1}{t}r + \frac{1}{t}(p_2 - p_3)$$

For IP_3 to have positive demand, it is assumed that $x_{1,3} < x_{2,3}$. The Internet providers respective demand functions are

$$D_1(p_1, p_2, p_3) = x_{1,3} = \frac{1}{t}r + \frac{1}{t}(p_3 - p_1)$$

and

$$D_2(p_1, p_2, p_3) = 1 - x_{2,3} = \frac{1}{t}r + \frac{1}{t}(p_3 - p_2)$$

and

$$D_3(p_1, p_2, p_3) = x_{2,3} - x_{1,3} = 1 - \frac{2}{t}r + \frac{1}{t}(p_1 + p_2 - 2p_3)$$

When the marginal cost of production is normalised to zero, the Internet provider chooses p_i to maximise its profits given the price charged by its rivals. The Internet providers obtain the following equilibrium prices and profits

$$\begin{cases} \frac{1}{t}r + \frac{1}{t}(p_3 - p_1) = 0 \\ \frac{1}{t}r + \frac{1}{t}(p_2 + p_3) = 0 \\ 1 - \frac{2}{t}r + \frac{1}{t}(p_1 + p_2 - 2p_3) = 0 \end{cases} \Rightarrow \begin{cases} r - 2p_1 + p_3 = 0 \\ r - 2p_2 + p_3 = 0 \\ t - 2r + (p_1 + p_2 - 4p_3) = 0 \end{cases}$$

$$\Rightarrow \begin{cases} p_1 = p_2 = \frac{1}{2}r + \frac{1}{2}p_3 \\ p_3 = \frac{1}{3}t - \frac{1}{3}r \end{cases} \Rightarrow \begin{cases} p_1 = p_2 = \frac{1}{6}t + \frac{1}{3}r \\ p_3 = \frac{1}{3}t - \frac{1}{3}r \end{cases}$$

$$p_1 = p_2 = \frac{1}{6}t + \frac{1}{3}r$$
$$p_3 = \frac{1}{3}t - \frac{1}{3}r$$

$$\pi_1 = D_1 p_1 = \frac{1}{36t}(t + 2r)^2 = \pi_2$$
$$\pi_3 = D_3 p_3 = \frac{2}{9t}(t - r)^2$$

For IP_1 and IP_2 price is positively related to the quality discount hence profit. However, when the quality of the Internet satellites (q_3) increases, profits through prices are decreasing and vice versa. IP_3's price and profit are reversely related to the quality discount. To put it differently, when q_3 increases IP_3's price increases and higher levels of profit are earned by IP_3.

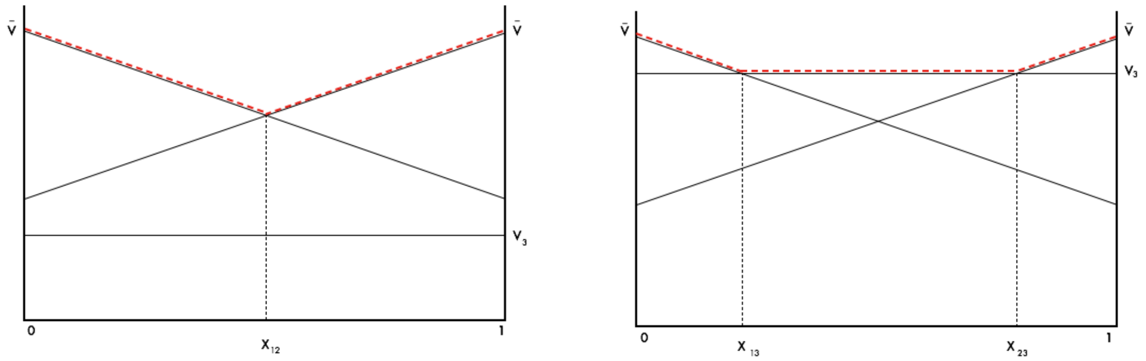
The indifferent consumers buy Internet access if

$$u_1(IP_1, p_1, q_1 = 1, x) \geq 0 \rightarrow 3V - 2r \geq t$$

Whether the consumers buy Internet access is dependent on their reservation price, transportation costs, and quality of IP_3. See Appendix 2 for proof.

4.2.1 Full market coverage

As in the model with two Internet providers, full market coverage is assumed such that the quality discount r is sufficiently small illustrated in figure 2 below. Figure 2a, illustrates the condition $r > t$. IP_3's price is then negative and it gets no customers and will therefore not enter the market. IP_3 provides so low quality Internet that it does not influence IP_1 and IP_2's market share. Contrastingly, figure 2b illustrates the condition $r < t$. In that case, IP_3 price will be positive and it will enter the market lowering IP_1 and IP_2 price hence profits. Then IP_1 and IP_2 do not compete directly with each other, but indirectly through IP_3. As the quality of IP_3 increases it will capture a larger fraction of the market at the expense of IP_1 and IP_2. The difference between figure 2a and 2b is as quality of IP_3 increases, so does its market share.



(a) q_3 Low (b) q_3 High

Figure 2: Market fully covered

Looking at the illustrations above, it seems unrealistic that IP_3 can enter the market without any reaction from its rivals. According to Bain (1959) when IP_1 and IP_2 face threat of entrance are they likely to respond by blockaded-, deterred-, or accommodated entry. Blockaded entry, when the Internet providers compete as there were no threat of entry, occurs if IP_1 and IP_2 have full market coverage and IP_3's quality is low thereby not threatening their market share, which is the case in figure 2a. Another way to respond is for IP_1 and IP_2 to deter entry by lowering price. According to the "limit pricing model" the incumbent firms can discourage entry by sustaining low price over a short period. If the scenario in figure 2b occurs, IP_1 and IP_2 most likely respond by lowering prices to keep IP_3 out of the market. However, if IP_1 and IP_2 find it too costly to deter entry they might instead accommodate entry. Accommodating entry the two Internet providers do not take any actions to keep IP_3 out of the market.

4.3 Discussion of equilibrium results

The Nash equilibrium results of IP_1 and IP_2 in the duopoly are compared with the triopoly at the corner solutions. Low transportation costs, $t = 0$, is considered before high transportation cost, $t = 1$, is examined. The equilibrium result when $t = 0$ cannot be derived, the researcher therefore examines $t = 0.1$ since it is considered sufficiently close to zero. The Internet providers in the duopoly is not dependent on quality of IP_3 such that price equals $p_1 = p_2 = t = 0.1$. Similarly, profit in the duopoly equals $\pi_1 = \pi_2 = \frac{t}{2} = \frac{1}{20} = 0.05$. In the triopoly, price and profit is dependent on the quality discount $r = V(1 - q_3)$. If the market coverage $\frac{V}{t}$ is large and quality of IP_3 (q_3) is small such that r is large, IP_3 does not enter the market. Therefore, assuming $r = 0.5$ equilibrium price is $p_1 = p_2 = \frac{11}{60} = 0.1833$ and profit equals $\pi_1 = \pi_2 = \frac{2}{10125} = 0.0002$. In the triopoly, IP_1 and IP_2's price is higher than in the duopoly, while the profit is lower. If IP_3 enters the market both IP_1 and IP_2 lose market to the new rival combined with increased prices, both factors reducing demand hence profit. Even when $r = 0.3$ the same result occurs. For $r = 0.2$, IP_1 and IP_2's price is lower in the triopoly $p_1 = p_2 = \frac{1}{12} = 0.083$ than in the duopoly. Under those circumstances the profits are even lower than previously $\pi_1 = \pi_2 = \frac{1}{12960} = 0.00008$.

Second, the results are evaluated for $t = 1$. In the duopoly $p_1 = p_2 = t = 1$ and $\pi_1 = \pi_2 = \frac{t}{2} = \frac{1}{2}$. In the triopoly when $r = 0.5$ is assumed, equilibrium price equals $p_1 = p_2 = \frac{1}{3} = 0.333$ and profit equals $\pi_1 = \pi_2 = \frac{49}{12960} = 0.0038$. In this case, both price and profit in the triopoly are lower than in the duopoly. While the corner solutions in duopoly are only dependent on transportation costs, t, the solutions in the triopoly are also dependent on the quality discount, r. For price and profit in the triopoly to be greater than the duopoly $r \geq \frac{15}{6}$ so $p_1 = p_2 = 1$ hence $\pi_1 = \pi_2 = \frac{25}{36} = 0.694$. As the quality of IP_3 increases, its market share and profit increases while IP_1 and IP_2's profit diminish.

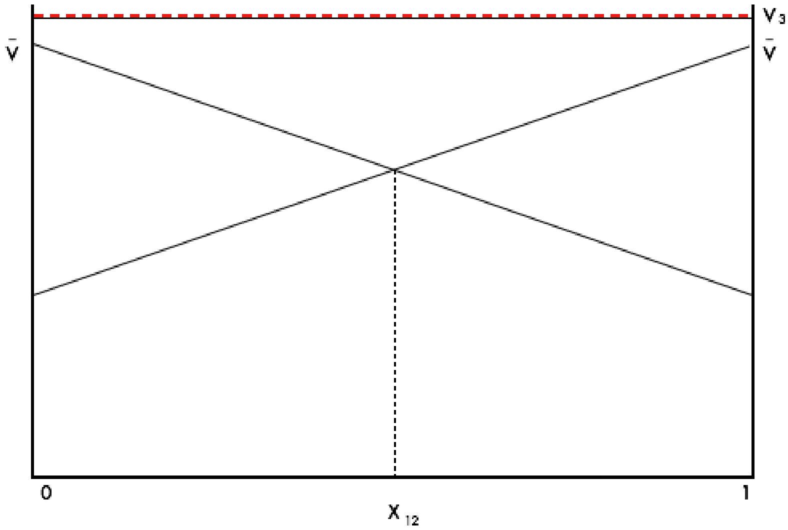


Figure 3: Quality of IP_3 above 1 ($q_3 \geq 1$)

So far IP_3's quality has been assumed $q_3 \in [0, 1]$. The researcher therefore elaborates on IP_3's quality to evaluate the effect on the telecommunication market as the quality increases above one ($q_3 \geq 1$). As illustrated in figure 3 above, if the quality increases above one IP_3 captures the entire market, and IP_1 and IP_2 will not have any customers. According to entry theory by Bain (1959), IP_1 and IP_2 neither accommodate entry nor blockade entry as doing so they risk loosing their entire markets. In other words, IP_1 and IP_2 have incentive to practice entry deterrence when $q_3 \geq 1$ to deter entry by IP_3.

Actions to deter entry can include limiting pricing or signalling. First, limiting pricing as entry deterrence involves IP_1 and IP_2 producing higher or same quality Internet at a lower price. Under those circumstances profits are reduced making it less attractive for IP_3 to enter the market. By undercutting price IP_1 and IP_2 survive in the short run as IP_3 does not have any customers and goes out of business. However, in the long run IP_1 and IP_2 have to increase prices to be profitable. Second, IP_1 and IP_2 can use signalling to influence IP_3's entrance decision. Since IP_3 makes assumptions about cost structure based on price and output levels, IP_1 and IP_2 can use its cost structure as a signal. By charging a price less than monopoly level, IP_1 and IP_2 signal low cost and efficiency to IP_3. Although entry deterrence is costly for IP_1 and IP_2, the alternative of going out of business in the long run might justify it in the short run.

5 Location choice

Until now the Internet provider's location choice have been assumed fixed. In the framework of spatial competition the Internet providers strategically choose location to attract consumers. In the two stage game, price is determined in the second stage of the model making the results sensitive to modelling parameters (Stuart, 2004). While the transportation function is the most familiar example of sensitivity illustrated by d'Asperemont et al., (1979). Location choice is another example of sensitivity, which has been troublesome in the literature (see Hotelling, 1939; d'Asperemont et al., 1979; Economedies, 1993; Brenner, 2001). Allowing for endogenous location, competitors location and transportation costs influence the Internet providers most profitable location.

Since IP_1 and IP_2 are located inside the "linear city" utility functions (1), (2), and (3) are generalised so the consumers are endowed with the following utility

$$u(IP_1, p_1, q_1 = 1, x_1) = V - p_1 - t|x - x_1| \tag{5}$$

$$u(IP_2, p_2, q_2 = 1, x_2) = V - p_2 - t|x - x_2| \tag{6}$$

$$u(IP_3, p_3, q_3, x = 0) = Vq_3 - p_3 \tag{7}$$

The indifferent consumers are identified at two points, one low and one high. In other words, the Internet provider located at x_i has indifferent consumers at x_i^- and x_i^+. The indifferent consumers are specified as

$$u(IP_1, p_1, q_1 = 1, x_{1,3}^-) = u(IP_3, p_3, q_3, x_{1,3}^-) \rightarrow V - t\left|x_1 - x_{1,3}^-\right| - p_1 = Vq_3 - p_3 \rightarrow$$

$$x_{1,3}^- = x_1 - \frac{r}{t} - \frac{1}{t}(p_3 - p_1)$$

$$u(IP_1, p_1, q_1 = 1, x_{1,3}^+) = u(IP_3, p_3, q_3, x_{1,3}^+) \rightarrow V - t\left|x_{1,3}^+ - x_1\right| - p_1 = Vq_3 - p_3 \rightarrow$$

$$x_{1,3}^+ = x_1 + \frac{r}{t} + \frac{1}{t}(p_3 - p_1)$$

$$u(IP_2, p_2, q_2 = 1, x_{2,3}^-) = u(IP_3, p_3, q_3, x_{2,3}^-) \rightarrow V - t\big|x_2 - x_{2,3}^-\big| - p_2 = Vq_3 - p_3 \Rightarrow$$

$$x_{2,3}^- = x_2 - \frac{r}{t} - \frac{1}{t}(p_3 - p_2)$$

$$u(IP_2, p_2, q_2 = 1, x_{2,3}^+) = u(IP_3, p_3, q_3, x_{2,3}^+) \rightarrow V - t\big|x_{2,3}^+ - x_2\big| - p_2 = Vq_3 - p_3 \rightarrow$$

$$x_{2,3}^+ = x_2 + \frac{r}{t} + \frac{1}{t}(p_3 - p_2)$$

The demand function for Internet provider i is specified in terms of both x_i^- and x_i^+, giving the respective demand functions

$$D_1 = x_{1,3}^+ - x_{1,3}^- = \frac{2}{t}r + \frac{2}{t}(p_3 - p_1)$$

and

$$D_2 = x_{2,3}^+ - x_{2,3}^- = \frac{2}{t}r + \frac{2}{t}(p_3 - p_2)$$

and

$$D_3 = x_{1,3}^- + (x_{2,3}^- - x_{1,3}^+) + (1 - x_{2,3}^+) = 1 - \frac{4}{t}r + \frac{2}{t}(p_1 - p_3) + \frac{2}{t}(p_2 - p_3)$$

As before the Internet provider i chooses p_i to maximise its profits $\pi_i = D_i p_i$. Marginal profits therefore yields

$$\begin{cases} \frac{2}{t}(p_1 - p_3) - \frac{2}{t}r = 0 \\ \frac{2}{t}(p_2 - p_3) - \frac{2}{t}r = 0 \\ 1 - \frac{4}{t}r + \frac{2}{t}(p_1 - 2p_3) + \frac{2}{t}(p_2 - 2p_3) = 0 \end{cases} \Rightarrow \begin{cases} r - 2p_1 + p_3 = 0 \\ r - 2p_2 + p_3 = 0 \\ t - r + 2(p_1 + p_2 - 4p_3) = 0 \end{cases}$$

$$\Rightarrow \begin{cases} p_1 = p_2 = \frac{1}{2}r + \frac{1}{2}p_3 \\ p_3 = \frac{1}{6}t - \frac{1}{3}r \end{cases} \Rightarrow \begin{cases} p_1 = p_2 = \frac{1}{12}t + \frac{1}{3}r \\ p_3 = \frac{1}{6}t - \frac{1}{3}r \end{cases}$$

The Internet providers obtain the following equilibrium prices and profits

$$p_1 = p_2 = \frac{1}{12}t + \frac{1}{3}r$$

$$p_3 = \frac{1}{6}t - \frac{1}{3}r$$

$$\pi_1 = \frac{2}{t}\left(\frac{1}{12}t + \frac{1}{3}r\right)^2 = \pi_2$$

$$\pi_3 = \frac{4}{t}\left(\frac{1}{6}t - \frac{1}{3}r\right)^2$$

Where IP_1 and IP_2's price is again positively related to the quality discount, r. Contrastingly, IP_3's price is negatively related to the quality discount.

The indifferent consumer is then estimated as the demand is generated at the interval $x \in [0, 1]$. An infinite small change in price influence the number of consumers purchasing Internet access. Either the consumer will continue to buy Internet access from the current Internet provider and standard income and substitution effect applies, or the consumer will leave the market (Novshek & Sonnenschein, 1978). In other words, the indifferent consumer buy Internet access if

$$u(IP_1, p_1, q_1 = 1, x_{1,3}^{-}) \geq u(IP_3, p_3, q_3, x_{1,3}^{-}) \rightarrow 4r \geq -t$$

where the customer valuation expressed with the the quality discount is greater than or equal to negative transportation costs.

Under endogenous location the researcher then estimates the range of location for IP_1 and IP_2 to examine optimal location. Previously the Hotelling model assumed fixed location for both of the Internet providers. However, it is now assumed that one Internet provider's location is fixed at unity, while the other is located along the interval border. Which provides the following result. For Internet provider 1 the lower bound is estimated when $x_{1,3}^{-} \geq 0$ and the upper bound when $x_{1,3}^{+} \leq 1$, which gives

$$\frac{1}{12} + \frac{1}{3t}r \leq x_1 \leq \frac{11}{12} - \frac{1}{3t}r \tag{8}$$

When $x_{2,3}^{-} \geq 0$ and $x_{2,3}^{+} \leq 1$, symmetry of the Internet providers gives

$$\frac{1}{12} + \frac{1}{3t}r \leq x_2 \leq \frac{11}{12} - \frac{1}{3t}r \tag{9}$$

Using that $x_{2,3}^{-} - x_{1,3}^{+} \geq 0$ because of the competition effect (Larralde et al., 2009)

$$x_2 - x_1 \geq \frac{2}{3t}r + \frac{1}{6}$$

implies

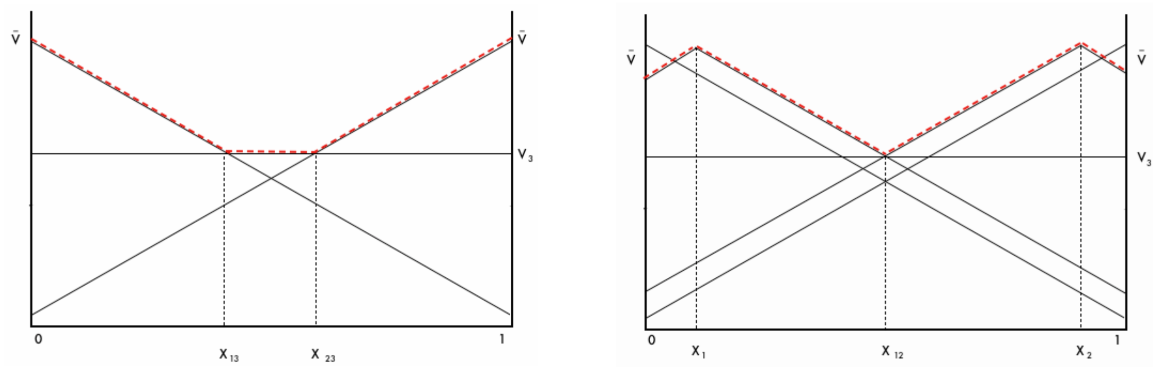
$$x_1 \leq x_2 - \frac{2}{3t}r - \frac{1}{6}$$

Hence it must be that

$$\frac{5}{6} - \frac{2}{3t}r \geq x_2 - x_1 \geq \frac{1}{6} + \frac{2}{3t}r \tag{10}$$

The range of the Internet provider's optimal location choice is estimated in equation (8) and (9). Because of the competition effect, equation (10) must be satisfied. For proof see Appendix 3.

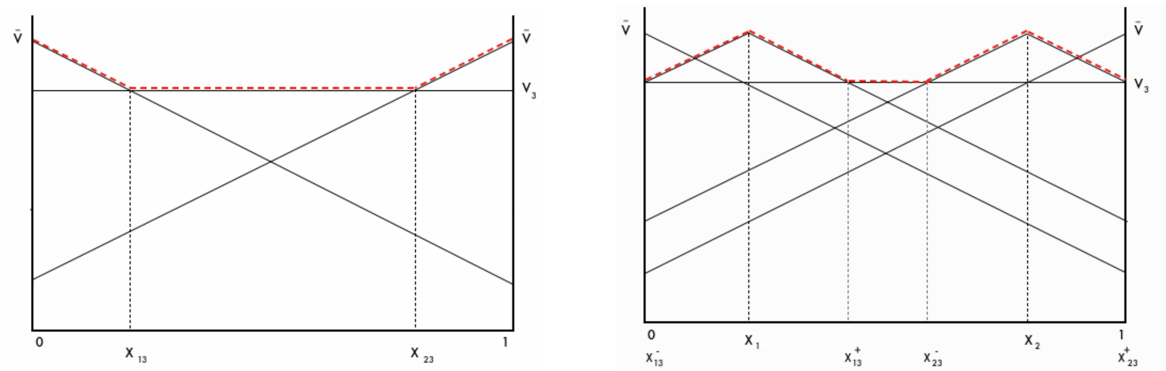
The Internet providers optimal location choices are illustrated in figure 4 when IP_3's quality, q_3, is low. In figure 4a when IP_1 and IP_2 are located at the extremes of the "linear city" they have incentive to change location to keep the market a duopoly. Allowing for endogenous location, figure 4b, IP_1 and IP_2 split the entire market and increase their market share. To put it differently, IP_1 and IP_2 locate at x_1 and x_2 respectively, rather than the extremes of the linear city to increase profits.



(a) Location at the interval boundaries (b) Location along the interval space

Figure 4: q_3 Low

Similarly, figure 5 illustrate the Internet providers optimal location choices when q_3 is high. When IP_1 and IP_2 are located at the extremes of the "linear city" in figure 5a, they compete indirectly through IP_3. By changing location towards the centre, as seen from figure 5b, IP_1 and IP_2 double their profits. Neither Internet provider wants to locate at the centre to avoid price competition. Therefore, the Internet providers locate towards the centre so the indifferent consumer is found at the interval border. At this location the Internet providers do not have any incentive to move further as it does not have any effect on demand hence neither price nor profit.



(a) Location at the interval boundaries (b) Location along the interval space

Figure 5: q_3 High

Allowing endogenous location for IP_1 and IP_2 lowers the Internet providers price and profits. When the Internet providers change location towards the centre of the "linear city" to increase their market share and double their profits, the Principle of Maximal Differential developed by d'Aspremont et al. (1979) breaks down. Furthermore, competition between IP_1 and IP_2; the corner firms, toughens the closer to the centre they locate and to avoid price competition IP_1 and IP_2 seek differentiation in terms of location. The Internet providers do not have incentive to locate at the centre of the “linear city” and the Principle of Minimum Differentiation, explored by Hotellinger (1929) also breaks down. Optimal location for the Internet providers is to move towards the centre locating along the “linear city”. In figure 4, when q_3 is low, IP_1 and IP_2 locate towards the centre to deter IP_3 from the market and compete directly in a duopoly. On the other hand, when q_3 is high, IP_1 and IP_2 have incentive to locate towards the centre so the indifferent consumer is found at the interval boarder, see inequality (8) and (9), competing indirectly through IP_3 so that inequality (10) is satisfied.

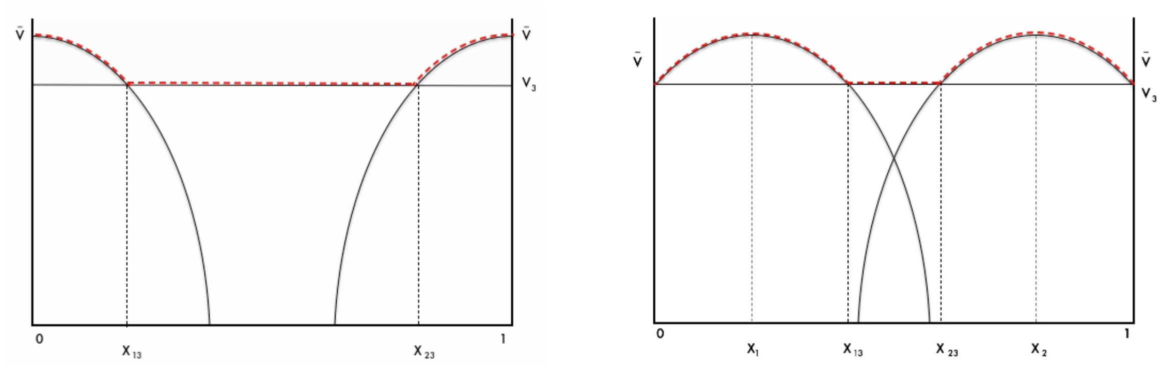
Larralde et al. (2009, p. 343) argue the chosen location a ”result of tension between a competition effect”; the firm locating close to the market centre to steal customers from its rival, ”and a market power effect”, the Internet providers want to be distant from its rivals to soften price competition. Which Brenner (2001) refers to as demand- and strategic price effect. Therefore is the optimal location dependent on the importance of both factors. The consumers view IP_1 and IP_2's products as similar since the market power effect dominates, and the Internet providers prefer to separate to soften price competition. When the entire market is served by three Internet providers, the corner firms IP_1 and IP_2 have incentives to change location from the extremes towards the centre such that neither Principle of Maximum Differentiation nor Principle of Minimum Differentiation hold since the corner firms will benefit from moving marginally towards the market centre.

6 Discussion and conclusion

The study obtains the following result. The first objective was to examine equilibrium prices and profits in the duopoly with the triopoly. This objective was achieved in section three, the analysis. For low transportation costs when $t = 0.1$, the model established for IP_1 and IP_2 that the price in the duopoly was $p_1 = p_2 = 0.1$, which is lower than in the triopoly $p_1 = p_2 = \frac{11}{60} = 0.183$ assuming $r = 0.5$. Profit in the duopoly was $\pi_1 = \pi_2 = \frac{1}{20} = 0.005$ which is higher than in the triopoly $\pi_1 = \pi_2 = \frac{11}{60} = 0.0002$. In other words, under low transportation cost price in the triopoly was higher than in the duopoly, while profit was lower in the triopoly than the duopoly. This is in line with economic theory, when a third competitor enters the market both the rivals market share and profit are lowered. For high transportation costs, $t = 1$, the price in the duopoly was $p_1 = p_2 = 1$ and profit $\pi_1 = \pi_2 = \frac{1}{2}$ compared to $p_1 = p_2 = \frac{1}{3}$ and $\pi_1 = \pi_2 = \frac{49}{12960} = 0.0038$ in the triopoly assuming $r = 0.5$. As transportation costs increased, the Internet providers price and profit in the duopoly was higher than in the triopoly.

The second research objective was to investigate what happens when the quality of the Internet satellites increases, which was met and presented in section 3.3. As quality of IP_3 approached one and increased above one, IP_3 captured the entire market and IP_1 and IP_2 did not have any customers. Entry theory outlined by Bain (1959) suggests rivals facing threat of entry should not accommodate nor block, but deter entry of the potential competitor by lowering prices in the short term.

The third objective was to identify how location choices impact the result of the model, which was explored by relaxing the competition between IP_1 and IP_2 to avoid Bertrand paradox. IP_3 was located along the "linear city" so IP_1 and IP_2 did not compete directly against each other, but indirectly through IP_3. To put it differently, IP_3's role was to soften the competition between the other two Internet providers. Allowing for endogenous location, the researcher found that IP_1 and IP_2 had incentive to change location from the extremes towards the centre, the market power effect, such that the Principle of Maximum Differentiation breaks down. At the same time, the competition effect, locating at the centre toughen competition as the Internet providers steal customers from its rivals, which both Internet providers want to avoid such that the principle of Minimum Differentiation also breaks down. Because of the tension between the market power effect and the competition effect, IP_1 and IP_2 locate between the extreme and the centre; see inequality (8) and (9) satisfying inequality (10), as illustrated in figure 5.



(a) Location at the interval boundaries

(b) Location along the interval space

Figure 6: Quadratic transportation costs

The telecommunication market is then examined when the Internet providers face quadratic transportation costs in figure 6. As can be seen from the graphs, the forces are exactly the same as in the case with linear transportation costs (see figure 5). Both the Principle of Minimum and Maximum Differentiation breaks down as the Internet providers prefer to locate along the "linear city." The result is theoretically different from previous research. Economides (1993) considered an oligopoly model with linear transportation costs, whereas Brenner (2001) and Larralde et al. (2009) studied an oligopoly model with quadratic transportation costs. Expanding previous research, the researcher found the same result for the model with both linear and quadratic transportation costs.

This study makes one contribution to the literature about spatial competition and telecommunication specifically. By exploring spatial competition, it provides insights into Internet satellites in relation to the telecommunication market. Contrary Hotelling (1929) and d'Aspremont et al. (1979), the two Internet providers want to locate along the interval boundaries, see inequality (8) and (9), to soften the competition between IP_1 and IP_2 competing indirectly through the Internet satellites provided by IP_3 satisfying inequality (10). In other words, the market power effect dominates the competition effect. Furthermore, extending the model graphically with quadratic transportation costs (see figure 6) the researcher found that both linear and quadratic transportation costs provide the same results, different from findings by Economides (1993), Brenner (2001), and Larralde et al. (2009).

As with any study there are a number of limitations. First, it is assumed that consumers are distributed in the interval space $x \in [0, 1]$. However, in reality consumer live more dense in some areas like the cities and less in rural areas, which is why the Internet is more easily accessible in more populated areas. Furthermore, fixed and marginal costs are normalised to zero. However, it might be the case that the satellite Internet provider requires higher R&D for the products inducing a higher cost. Second, the model is sensitive to parameter specifications since the game is structured in two stages. Since location is decided upon in the first stage and price in the second stage, the model's outcome is influenced by whether transportation costs are specified as linear (Hotellinger, 1929), quadratic (d'Asperemont et al., 1979), or hybrid. Third, the model used is a simplified model where consumers are distributed along the line in interval space, nevertheless, it is an appropriate structure for modelling Internet providers. Another spatial location model, the circular model, is a good paradigm for continuous characteristics such as colour.

The research revealed that IP_1 and IP_2 facing threat of entrance will react in accordance to one of the entry strategies outlined by Bain (1959). For future research will it be useful to include entry strategies in the model and specifically entry deterrence. Moreover, this study was undertaken with linear transportation costs only illustrating quadratic transportation costs graphically. The research could therefore be replicated with quadratic transportation costs. In conclusion, this study draws attention to the Internet satellites effect on the telecommunication market. However, future studies need to be more comprehensive and distinguish between different entry strategies.

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8 Appendices

8.1 Appendix 1. Two Internet providers, IP_1 and IP_2

Indifferent consumer IP_1 and IP_2

$$u(IP_1, p_1, q_1 = 1, x_{12}) = u(IP_2, p_2, q_2 = 1, x_{12})$$

solves for

$$x_{1,2} = \frac{p_2 - p_1}{2t} + \frac{1}{2}$$

Therefore demand will be

$$D_1(p_1, p_2) = x_{1,2} = \frac{p_2 - p_1}{2t} + \frac{1}{2}$$

$$D_2(p_1, p_2) = 1 - x_{1,2} = \frac{p_1 - p_2}{2t} + \frac{1}{2}$$

The respective Internet provider maximise its profits given the price charged by its rivals.

$$\pi_1(p_1, p_2) = p_1 \left(\frac{p_2 - p_1}{2t} + \frac{1}{2} \right)$$

Because of symmetry

$$\frac{p_2 - 2p_1}{2t} + \frac{1}{2} = 0 \rightarrow p_1 = \frac{p_2 + t}{2} = p_2$$

Nash equilibrium prices

$$p_1 = p_2 = \frac{p_2 + t}{2} = t$$

Nash equilibrium profits

$$\pi_1(p_1, p_2) = p_1 \left(\frac{p_2 - p_1}{2t} + \frac{1}{2} \right) = \frac{1}{2} t = \pi_2$$

Indifferent consumer

$$u(IP_1, p_1, q_1 = 1, x_{12}) \geq 0$$

$$V \geq \frac{3}{2} t$$

8.2 Appendix 2. Three Internet providers

Indifferent consumer IP_1 and IP_3

$$u(IP_1, p_1, q_1 = 1, x_{13}) = u(IP_3, p_3, q_3, x = 0)$$

$$V - p_1 - tx = V q_3 - p_3$$

$$x_{1,3} = \frac{1}{t}(V(1 - q_3)) + \frac{1}{t}(p_3 - p_1)$$

Indifferent consumer IP_2 and IP_3

$$u(IP_2, p_2, q_2 = 1, x_{23}) = u(IP_3, p_3, q_3, x = 0)$$

$$V - p_2 - t(1 - x) = V q_3 - p_3$$

$$x_{2,3} = 1 - \frac{1}{t}(V(1 - q_3)) + \frac{1}{t}(p_2 - p_3)$$

Where $V(1 - q_3) = r$ such that

$$x_{1,3} = \frac{1}{t} r + \frac{1}{t}(p_3 - p_1)$$

$$x_{2,3} = 1 - \frac{1}{t}r + \frac{1}{t}(p_2 - p_3)$$

Consequently will demand be

$$D_1(p_1, p_2, p_3) = x_{1,3} = \frac{1}{t}r + \frac{1}{t}(p_3 - p_1)$$

$$D_2(p_1, p_2, p_3) = 1 - x_{2,3} = \frac{1}{t}r + \frac{1}{t}(p_3 - p_2)$$

$$D_3(p_1, p_2, p_3) = x_{2,3} - x_{1,3} = 1 - \frac{2}{t}r + \frac{1}{t}(p_1 + p_2 - 2p_3)$$

As before, the Internet providers maximise their profits given the rival's price

$$\frac{\partial \pi_1}{\partial p_1} = 0 \rightarrow \frac{1}{t}r + \frac{1}{t}(p_3 - 2p_1) = 0 \rightarrow p_1 = \frac{1}{2}r + \frac{1}{2}p_3 = p_2$$

because of symmetry.

$$\frac{\partial \pi_3}{\partial p_3} = 0 \rightarrow 1 - \frac{2}{t}r + \frac{1}{t}(p_1 + p_2 - 4p_3) = 0 \rightarrow p_3 = \frac{1}{3}t - \frac{1}{3}r$$

Nash equilibrium prices

$$p_3 = \frac{1}{4}t - \frac{2t}{4}r + \frac{t}{4}(p_1 + p_2) = \frac{1}{3}t - \frac{1}{3}r$$

$$p_1 = p_2 = \frac{1}{2}r + \frac{1}{2}p_3 = \frac{1}{6}t + \frac{1}{3}r$$

Profit is maximised given the price charged by the Internet provider's rivals

$$\frac{\partial \pi_1}{\partial p_1} = 0 \rightarrow \pi_1 = \frac{1}{36t}(2r + t)^2 = \pi_2$$

$$\frac{\partial \pi_3}{\partial p_3} = 0 \rightarrow \pi_3 = \frac{2}{9t}(t - r)^2$$

The indifferent consumer only buy Internet access if

$$u(IP_1, p_1, q_1 = 1, x) \geq 0 \rightarrow V - p_1 - tx \geq 0 \rightarrow \frac{1}{2}(3V - t) \geq r$$

8.3 Appendix 3. Location choice

Indifferent consumer IP_1 and IP_3

$$u(IP_1, p_1, q_1 = 1, x_{1,3}^-) = u(IP_3, p_3, q_3, x_{1,3}^-) \rightarrow V - t\left|x_1 - x_{1,3}^-\right| - p_1 = Vq_3 - p_3$$

$$x_{1,3}^- = \frac{1}{t}(p_1 - p_3) - \frac{r}{t} + x_1$$

$$u(IP_1, p_1, q_1 = 1, x_{1,3}^+) = u(IP_3, p_3, q_3, x_{1,3}^+) \rightarrow V - t\left|x_{1,3}^+ - x_1\right| - p_1 = Vq_3 - p_3$$

$$x^+_{1,3} = \frac{r}{t} - \frac{1}{t}(p_1 - p_3) + x_1$$

Indifferent consumer IP_2 and IP_3

$$u(IP_2, p_2, q_2 = 1, x^-_{2,3}) = u(IP_3, p_3, q_3, x^-_{2,3}) \to V - t\left|x_2 - x^-_{2,3}\right| - p_2 = Vq_3 - p_3$$

$$x^-_{2,3} = \frac{1}{t}(p_2 - p_3) - \frac{r}{t} + x_2$$

$$u(IP_2, p_2, q_2 = 1, x^+_{2,3}) = u(IP_3, p_3, q_3, x^+_{2,3}) \to V - t\left|x^+_{2,3} - x_2\right| - p_2 = Vq_3 - p_3$$

$$x^+_{2,3} = \frac{r}{t} - \frac{1}{t}(p_2 - p_3) + x_2$$

The Internet providers respective demand functions are

$$D_1 = x^+_{1,3} - x^-_{1,3} = \frac{p_1 - p_3}{t} - \frac{r}{t} + x_1 - \left(\frac{r}{t} - \frac{p_1 - p_3}{t} + x_1\right) = -\frac{2}{t}(p_3 - p_1) - \frac{2}{t}r$$

$$D_2 = x^+_{2,3} - x^-_{2,3} = \frac{p_2 - p_3}{t} - \frac{r}{t} + x_2 - \left(\frac{r}{t} - \frac{p_2 - p_3}{t} + x_2\right) = -\frac{2}{t}(p_3 - p_2) - \frac{2}{t}r$$

$$D_3 = x^-_{1,3} + (x^-_{2,3} - x^+_{1,3}) + (1 - x^+_{2,3})$$

$$= \left(\frac{p_1 - p_3}{t} - \frac{r}{t} + x_1\right) + \left(\frac{p_2 - p_3}{t} - \frac{r}{t} + x_2 - \left(\frac{r}{t} - \frac{p_1 - p_3}{t} + x_1\right)\right) + \left(1 - \left(\frac{r}{t} - \frac{p_2 - p_3}{t} + x_2\right)\right)$$

$$= 1 - \frac{4}{t}r + \frac{2}{t}(p_1 - p_3) + \frac{2}{t}(p_2 - p_3)$$

Maximising profits yields the following nash equilibrium prices and profits

$$\begin{cases} \frac{2}{t}(p_1 - p_3) - \frac{2}{t}r = 0 \\ \frac{2}{t}(p_2 - p_3) - \frac{2}{t}r = 0 \\ 1 - \frac{4}{t}r + \frac{2}{t}(p_1 - 2p_3) + \frac{2}{t}(p_2 - 2p_3) = 0 \end{cases} \Rightarrow \begin{cases} r - 2p_1 + p_3 = 0 \\ r - 2p_2 + p_3 = 0 \\ t - r + 2(p_1 + p_2 - 4p_3) = 0 \end{cases}$$

$$\Rightarrow \begin{cases} p_1 = p_2 = \frac{1}{2}r + \frac{1}{2}p_3 \\ p_3 = \frac{t}{6} - \frac{1}{3}r \end{cases} \Rightarrow \begin{cases} p_1 = p_2 = \frac{t}{12} + \frac{1}{3}r \\ p_3 = \frac{t}{6} - \frac{1}{3}r \end{cases}$$

$$\pi_1(p_1, p_2, p_3) = p_1\left(-\frac{2}{t}(p_3 - p_2) - \frac{2}{t}r\right) = \frac{2}{t}\left(\frac{1}{12}t + \frac{1}{3}r\right)^2 = \pi_2$$

$$\pi_3(p_1, p_2, p_3) = p_3\left(1 - \frac{4}{t}r + \frac{2}{t}(p_1 - p_3) + \frac{2}{t}(p_2 - p_3)\right) = \frac{4}{t}\left(\frac{1}{6}t - \frac{1}{3}r\right)^2$$

The Indifferent consumer buy Internet access if

$$u(IP_1, p_1, q_1 = 1, x^-_{1,3}) \geq u(IP_3, p_3, q_3, x^-_{1,3}) \to \frac{2}{3}r \geq -\frac{1}{6}t \to 4r \geq -t$$

Location range is first estimated for Internet provider 1, when lower bound is $x_{1,3}^{-} \geq 0$ and upper bound is $x_{1,3}^{+} \leq 1$

$$\frac{1}{12} + \frac{1}{3t}r \leq x_1 \leq \frac{11}{12} - \frac{1}{3t}r$$

Symmetry of the Internet providers when $x_{2,3}^{-} \geq 0$ and $x_{2,3}^{+} \leq 1$ gives

$$\frac{1}{12} + \frac{1}{3t}r \leq x_2 \leq \frac{11}{12} - \frac{1}{3t}r$$

Using that $x_{2,3}^{-} - x_{1,3}^{+} \geq 0$

$$x_{2,3}^{-} - x_{1,3}^{+} \geq 0 \rightarrow x_2 - x_1 \geq \frac{2}{3t}r + \frac{1}{6}$$

which implies

$$x_1 \leq x_2 - \frac{2}{3t}r - \frac{1}{6}$$

Hence it must be that

$$\frac{5}{6} - \frac{2}{3t}r \geq x_2 - x_1 \geq \frac{1}{6} + \frac{2}{3t}r$$