Competition between fixed and mobile broadband access based on mobility and data volume *

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Abstract

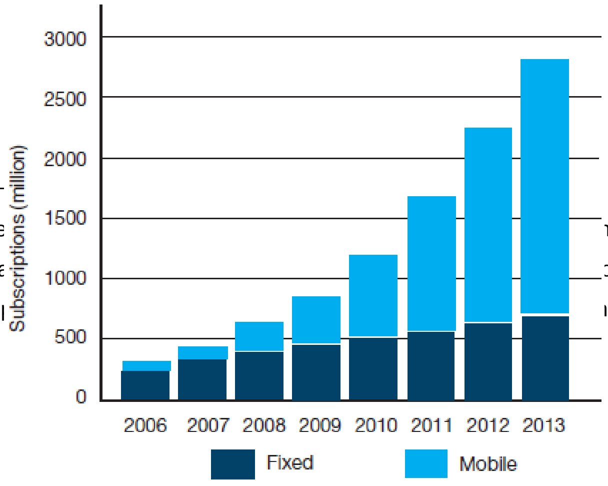
This article proposes a duopoly model based on a model initially introduced by Shubik and Levitan to analyze the competition based on mobility and data volume between fixed and mobile broadband access. By the description of asymmetrical characteristics of fixed and mobile broadband offers and demand functions, Nash equilibrium can be derived through a game where both firms compete in price. This simple model is a first attempt in addressing the issue of partial fixed-mobile substitution. It allows modeling some effects of price interdependence between fixed and mobile markets and is used in a version of the "hypothetical monopolist" test (or SSNIP, Small but Significant and Non-transitory Increase in Price). The comparisons in terms of social welfare between fixed-mobile intermodal competition, fixed perfect competition and mobile perfect competition indicate that the fixed-mobile intermodal competition leads to a higher level of social welfare.

1. Motivation

The progress of mobile broadband has been the major trend in electronic communications in recent years. As spectral efficiency as well as coverage density increase, more and more, mobile networks are becoming potential lower cost competitors to broadband access in remote areas [1]. Thus, peak bandwidth and average throughput via mobile broadband, now allow a wider range of alternative uses to fixed broadband. Mobile is going to be the dominant mode for connecting to the Internet for emerging countries. In most cases, fixed broadband access dominates mobile access. Nevertheless, in some developed countries such as Austria, where there has been a great uptake in mobile broadband since the end of 2006 [2], substitution between mobile and fixed broadband access is now becoming a reality.

Empirical elements

According to certain statistics, it has been predicted that mobile broadband subscriber growth will increase two or three times more than fixed broadband over the next few years.



* Acknowledgeme… homas Cadet and Olivier Chalmeau for useful proofrea… ons.
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Figure 1 : Worldwide estimated number of broadband subscriptions to 2013

The initial motivation for this study comes from the observation in Austria relating to the phenomenon of substitution between fixed and mobile broadband accesses. The table in Annex 1 illustrates that the lowest monthly fee is $22-25/month for fixed access and $11-23/month for mobile access. The lower price and similar nation-wide coverage are certainly major reasons for the widespread adoption of mobile broadband access in Austria. In order to identify the access technologies to be included in the broadband market, the Austrian telecom regulator, RTR, carried out a SSNIP test (Small but Significant Non-transitory Increase in Prices), as a result of which mobile broadband access was indicated as an adequate substitute for fixed ADSL access. Therefore RTR defined the relevant product market as including ADSL access as well as broadband mobile access.

The Austrian case indicates the potential evolution of fixed to mobile broadband access in other countries. It is worth noting that mobile broadband access in Austria is mainly used at home as a fixed access. With the rapid development of mobile broadband devices in recent years, such as Smartphones, 3G USB modems, tablets, 3G SIM integrated PCs, mobile broadband access will greatly increase. The subscription model will go from household based to the individual based which is a very powerful economic growth engine for mobile operators.

Related literature

The competition between fixed and mobile for voice services has been studied in at least six papers [4-9]. Econometric analysis provides some evidence of fixed to mobile substitution effects for voice service at the country level [9], [12],[13]. The work of M.Rodini et al (2003) [9] proves that the extent of fixed-mobile substitution has important regulatory implications toward fixed network unbundling, fixed-mobile vertical separation, and universal service. The work of Wolfgang Briglauer, Anton Schwarz and Christine Zulehner concludes that the retail market for national calls of private users could probably be deregulated due to sufficient competitive pressure generated by mobile sector on the Austrian market [6]. To the author's knowledge, few studies have examined the issue related to fixed-mobile substitution for broadband data access services.
According to the econometric analysis of Distaso et al., inter-modal competition between ADSL, cable access, satellite or fiber optics stimulates broadband adoption [10]. In this paper the issue of fixed-mobile partial substitution is formulated as an interconnected market model used in microeconomics for which a two-player model then a four-player model is established. The concept of utility function and demand function are used to obtain Nash equilibrium. The main objective of this study is to analyze the inter-modal competition resulting from partial substitution between fixed and mobile, and to evaluate fixed-mobile interdependence as well as its effects on consumer surplus and social welfare, as compared to competitive situations when fixed and mobile markets are considered separately.

The remainder of the paper is organized as follows: in section 2 a case study based on a model originally proposed by Shubik and Levitan [11] is introduced. In section 3 efforts are made to determine the equilibrium price for both fixed and mobile broadband accesses in order to obtain the profit for fixed and mobile markets. Various effects of fixed-mobile interdependence are demonstrated in section 4. The social welfare of intermodal competition is determined in section 5 and a comparison to other types of competition without intermodal interaction is made. In section 6 an extended model from two to four players is introduced to consolidate the results of the model with two players which is followed by the conclusion in section 7.

2. The linear model

This paper, inspired by an oligopoly model introduced by Shubik and Levitan in 1980 [11], first defines the characteristics of fixed and mobile broadband access in terms of data volume and mobility and then analyzes price competition between these two types of access.

Area covered by the model in this study

This study does not address the issue of competition between the fixed and mobile voice, due to the abundance of previously mentioned research articles which have already addressed this issue [9-14]. The subscription rate of mobile voice has reached nearly 100% in most developed countries. This means that each consumer has a subscription to mobile voice regardless of the type of data access. In other words, almost each consumer who has a fixed access also has a mobile voice subscription. In parallel, they often have a VoIP or PSTN associated with their fixed access. Just as each consumer with mobile data access has a subscription to mobile voice. Subscriptions to mobile data may be combined with mobile voice. Laying aside the issue of mobile or fixed voice, the model only analyzes the issue of competition between fixed and mobile data accesses. Moreover in the future, voice service may possibly become one of the data services of fixed access and for mobile access in the more distant future.

Fixed and mobile broadband data access can be defined by two characteristics, namely mobility and data volume. Mobile data access provides wider-ranged services than fixed data access, thanks to mobility capabilities: Location Based Services, Internet and email access everywhere, as well as the continuity of broadband access in any circumstances etc. Regarding data volume, fixed broadband is more appropriate to offer unlimited data volume. Mobile broadband is often limited to propose a lower data volume due to the scarcity of radio resources. The utility function is assumed to be quadratic and concave:

(1) $$U = (g_f + v_f)D_f + (g_m + v_m)D_m - \frac{1}{2}(\beta D_f^2 + 2\gamma D_f D_m + \beta D_m^2) - (p_f D_f + p_m D_m)$$

Where ***gf*** and ***gm*** are, respectively, the maximum willingness to pay for mobility for fixed and mobile broadband access. ***vf*** and ***vm*** , respectively, are the maximum willingness to pay for data volume for fixed and mobile broadband access. ***pf*** is the price of fixed access***, pm*** is the price of mobile access. ***Df*** and ***Dm*** are, respectively, aggregate demands for fixed and mobile access.

In this duopoly model, firm *f* offers fixed access and firm *m* offers mobile access, with marginal cost of production *cf* and *cm,* respectively. Without loss of generality, firm *m* offers mobile access with a greater range of mobility services, that is to say, *gm > gf*. Conversely, firm *f* proposes a higher data volume (frequently unlimited data volume), then *vf > vm.*

The substitutability, **γ,** with **γ*=Min[gf,gm]+Min[vf,vm]= gf+vm*** represents the shared elements (substitutable component) between fixed and mobile access (with **γ<*β***). In view of the fact that both accesses are able to provide a reduced level for mobility for instance, *gf,* and a low level of data volume for instance, *vm*. ***β*** represents the satiety of the representative agent towards aggregate demand.

Using Equation (1), inverse demands are given by

(2) $$\begin{aligned} p_f &= (g_f + v_f) - \beta D_f - \gamma D_m \\ p_m &= (g_m + v_m) - \beta D_m - \gamma D_f \end{aligned}$$

It is worth noting that *vm < vf* corresponds to the current capacity of mobile and fixed accesses. *Vm < vf* indicates that the consumer's willingness to pay for mobile data volume is less than that for fixed data volume. On the other hand, the assessed value of mobility, ***gm,*** may be quite similar to that of *gf,* if mobile access is only used at home as a substitute for fixed access. However, if mobile access is used concurrently at home and away from home, mobile access can provide more services than fixed access, such as: Location Based Services, Internet and email access everywhere as well as continuity of broadband access in any circumstance etc. In such a case we obtain *gm > gf.* Substitutability, γ, increases with *(gf+vm),* the shared elements offered by both accesses. Mobile data volume, *vm,* increases with the progress of mobile technologies, thus offering higher substitutability. Willingness to pay for fixed data volume, *vf,* may increase with FTTH, thus increasing the differentiation between fixed and mobile access.

Case study : dominance of mobility, $g_m > v_f$, one access per individual

This case study corresponds to one of the scenarios of broadband access in the future. Until now, the Internet in most countries (except Austria) is mainly accessed at home via fixed broadband (ADSL or cable). In the future, it is assumed that Internet access will grow through mobile broadband devices such as smartphones, 3G USB modems, tablets and 3G SIM integrated PCs. The subscription will become individual-based rather than household-based.

For the purpose of this case study, it is assumed that there is one access per individual. The willingness to pay for mobility services, *gm,* is higher than that of fixed data volume, *vf.* Price, cost and data volume are based on an individual model. A mobile access is, by nature, owned by an individual because of services related to mobility (LBS...). A fixed access is in most cases owned by a household. The individuals of the same household will share the fixed access. Therefore, to convert the household unit to an individual unit, it is necessary to divide the household model price, marginal cost and volume data access by the average number of individuals in a household.

Two important parameters which will evolve with technological progress [1] must be taken into account,

- Mobile data volume will increase thanks to the migration of mobile technology from UMTS to LTE (Long Term Evolution). Mobile networks will have the advantage of a higher LTE spectral efficiency compared to UMTS.
- The range of mobile services will be extended with the development of new mobile services and a widespread adoption of mobile broadband devices.

Moreover, the ever increasing number of fixed subscription migrating to mobile subscription is another parameter which must also be taken into account due to its great impact on a firm's business model.

3. Model resolution

3.1. Price equilibrium

For any two firms (here, fixed and mobile), the profit function of firm *i* ($i = f, m$) is defined as $\Pi i\ (pi, pj) = (pi-ci)\ Di\ (pi, pj)$ for $(j \neq i)$.
A non cooperative equilibrium in prices is given by

$$\Pi i\ (pi^*, pj^*) > \Pi i\ (pi, pj^*)$$

For $pi \geq 0,\ i, j = f, m$. It shall be illustrated in this case study that there is price equilibrium .

Proposition 1: For any two accesses, fixed and mobile with, respectively, *(vf, gf)* and *(vm, gm)*, there is price equilibrium.

Proof :

By applying the following equations, where Πf and Πm represent the profit function of fixed and mobile accesses, the profit of fixed and mobile access can be maximized with respect to pf and pm.

(3)

$$\Pi_f = (p_f - c_f)D_f$$
$$\Pi_m = (p_m - c_m)D_m$$
$$\frac{\partial \Pi_m}{\partial p_m} = 0$$
$$\frac{\partial \Pi_f}{\partial p_f} = 0$$

Using equation (2), the price *pf* and *pm* at equilibrium and the aggregate demand at equilibrium is obtained:

(4)

$$p_f^* = \frac{(2(c_f + g_f + v_f)\beta^2 + (c_m - g_m - v_m)\beta\gamma - (g_f + v_f)\gamma^2)}{(4\beta^2 - \gamma^2)}$$

$$p_m^* = \frac{(2(c_m + g_m + v_m)\beta^2 + (c_f - g_f - v_f)\beta\gamma - (g_m + v_m)\gamma^2)}{(4\beta^2 - \gamma^2)}$$

$$D_f = \frac{\beta(2(-c_f + g_f + v_f)\beta^2 + (c_m - g_m - v_m)\beta\gamma + (c_f - g_f - v_f)\gamma^2)}{4\beta^4 - 5\beta^2\gamma^2 + \gamma^4}$$

$$D_m = \frac{\beta(2(-c_m + g_m + v_m)\beta^2 + (c_f - g_f - v_f)\beta\gamma + (c_m - g_m - v_m)\gamma^2)}{4\beta^4 - 5\beta^2\gamma^2 + \gamma^4}$$

Interpretation of results Equation (4)

Figure 2 illustrates the results on the equilibrium price of Equation (4).

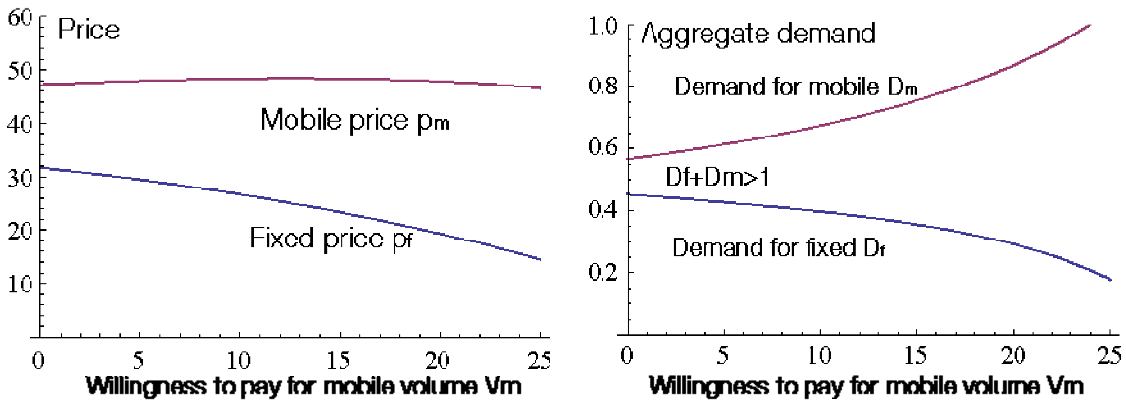

Figure 2: price and demand as a function of willingness to pay for mobile data volume, ***vm***
(with gf=10, vf=50, gm=80, vm=10, cf=10, beta=40)[1]

The price curves, in the graph on the left, illustrate the mobile and fixed prices as a function of the willingness to pay for mobile data volume, *vm*. The mobile price curve indicates that its price remains stable despite the increase of *vm*. However, the curve representing the demand for mobile indicates an important growth for its demand. The downward fixed-price curve illustrates that both fixed price and its demand decrease with willingness to pay for mobile data volume. Consequently substitutability increases with willingness to pay for mobile data volume. The total demand, i.e. the addition of demand for fixed and demand for mobile, may be greater than one (*Df+Dm>1*, market size is normalized to one). This result indicates that demands for fixed and mobile are not exclusive. Some subscribers may have double subscriptions, i.e. fixed and mobile together as a result of the partial substitutability (in other words, their complementarity due to their non-shared elements). It can be concluded that the progress of mobile technology toward LTE will generate a higher data volume, then a higher willingness to pay, and consequently increase the substitutability, in favour of the mobile player.
Figure 3 below illustrates price and aggregate demand behaviour as a function of the willingness to pay for fixed data volume and it is assumed that there is no mobile technological progress.

[1] These values have been chosen to obtain values for prices and aggregate demands, which seem to be understandable values in euros within the European telecom sector

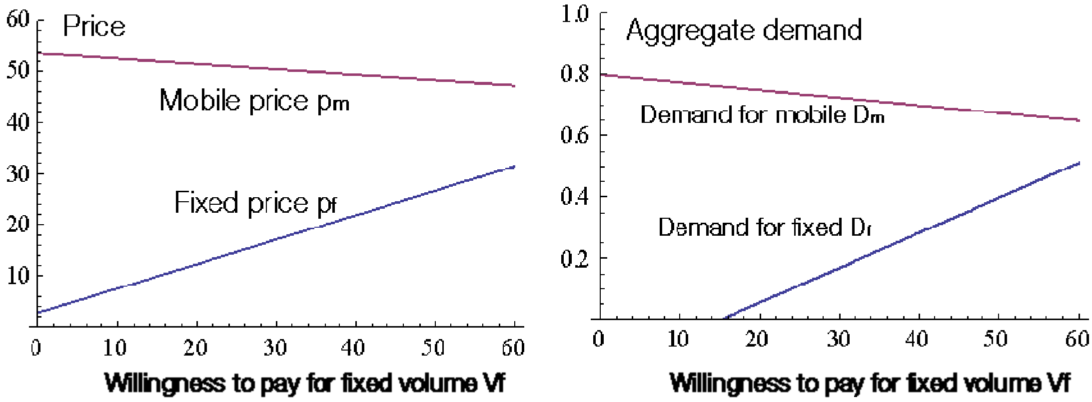

Figure 3: price and demand as a function of willingness to pay for fixed data volume, ***vf***

Fixed data volume increases with the deployment of FTTH. The figure on the left presents the mobile and fixed prices as a function of the willingness to pay for fixed data volume, *vf*. It can be observed that the price for fixed as well as its demand, increase with *vf*. The mobile price curve indicates that the price of mobile slightly decreases with *vf*. The demand curve for mobile on the right illustrates a slight decrease in the demand for mobile. Therefore, it can be concluded that the fixed business may be sustained by the growth of fixed data volume with FTTH. In fact, both fixed and mobile technological progress must be taken into account at the same time, knowing that, in general, mobile progresses more quickly than fixed.

The characteristics of the marginal cost for fixed and mobile access

In the telecom world just now, it is possible to describe marginal cost for mobile and fixed access as follows:

$$c_m = c_m^{subscription} + c_m^{usage}$$
$$c_f = c_f^{suscription} + c_f^{usage}$$

The difference between the fixed and mobile access networks lies in the possibility or not to share resources. For a fixed-line consumer, the resource of the access network is dedicated to him, and can not be shared with another consumer. Whereas for a mobile consumer, the resources of the access network are shared among all users of the same mobile cell. Thus for a mobile operator, the cost of a mobile consumer is primarily related to his usage of the network resources. Thus, it can be assumed that:

$$c_m^{suscription} << c_m^{usage}$$
$$c_f^{subscription} >> c_f^{usage}$$

Therefore, more simplified expressions could be obtained for the marginal costs:

$$c_m = c_m^{usage}$$
$$c_f = c_f^{subscription}$$

Figure 4, an example taken from financial data of telecom companies in France, illustrates this point quite clearly. The marginal costs of a mobile access compared to an ADSL access are typically:

- *cm* = 20 € / month for a mobile access (voice + data)
- *cf* = 22 € / month for an ADSL access

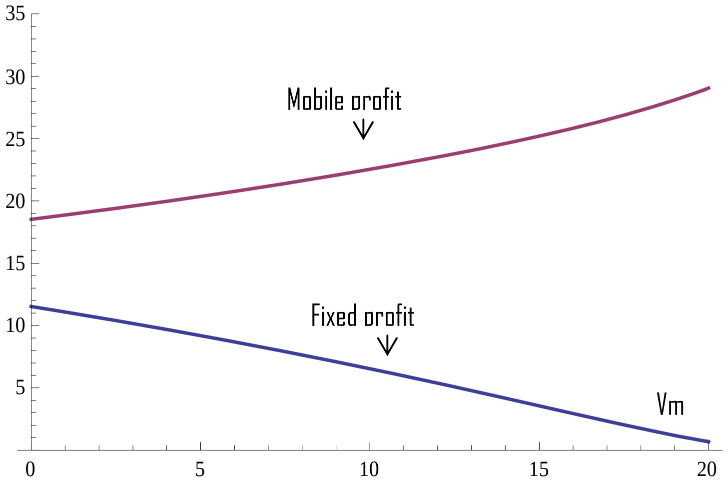

Figure 4: Πf and Πm as a function of willingness to pay for mobile data volume, ***Vm***
(with gf=10 vf=50, gm=80, vm=10, cf=10, cm=20, beta=40)

The variation for Πm and Πf as a function of willingness to pay for mobile data volume, *Vm, can be examined*. In this case study, fixed profit is lower than mobile profit (based on the assumptions of this study). It can then be concluded that the mobile profit is, in most cases, higher than the fixed profit as a result of a higher perceived value of mobility by consumers (e.g. services related to mobility such as LBS, email everywhere etc.). Moreover, the mobile profit increases with Vm due to the fixed-mobile-substitution described above.

4. Some effects of fixed-mobile interdependence

4.1. The effect of a lower marginal cost on one of the two markets

In the following section, the model will be applied to illustrate the effect of a lower marginal cost on one of the two markets: the mobile marginal cost decreases thanks to technological progress. The resolution of the model gives new values for equilibrium prices.

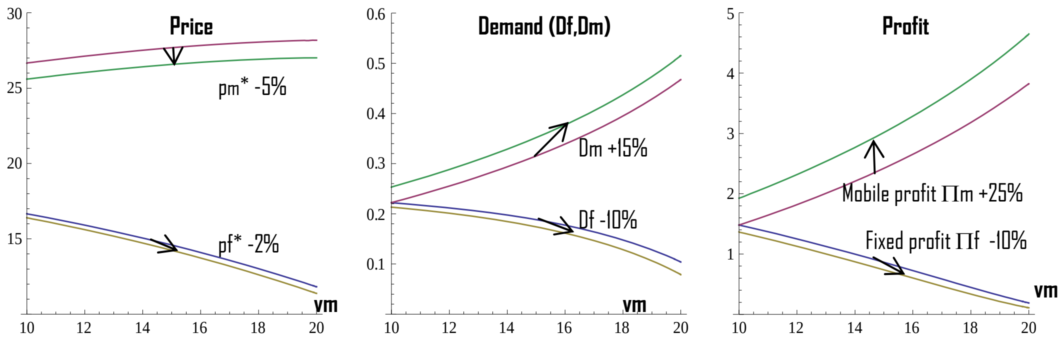

Figure 5: price, demand and profit as a function of *vm* if *cm* is reduced by 10%

Due to a lower mobile marginal cost (10%), the price curve illustrates that the mobile price, thus, decreases by 5% (at *vm=15*) from its initial equilibrium price *pm** and the equilibrium fixed price decreases by 2%.
In the demand curve, the demand for mobile increases by 15% (at *vm=15*). Consequently, the demand for fixed decreases by 10%.
Once again, in the profit curve, the mobile profit increases by 25% but the fixed profit decreases by 10%.
Thus, it can be concluded that technological progress can improve the profit of the mobile access because the mobile operator has made an effort to reduce its marginal cost by integrating the technological progress. Symmetrically, the conclusion is also valid for fixed if the fixed operator reduces marginal cost by integrating technological progress in the fixed domain

4.2. "SSNIP" or "hypothetical monopolist test (HMT)"

The "SSNIP" (Small but Significant and Non-transitory Increase in Price) or "hypothetical monopolist" test (HMT) defines a market as small but significant and non-transitory increase in price. In competition law, the SSNIP test is used to define the relevant market in a consistent way in order to determine whether or not companies have significant market power which would justify government intervention. It is an alternative to any ad hoc definition of the relevant market by means of arguments related to product similarity. The main difficulty in correctly applying the HMT test is caused by the lack of market data and its analysis.

As regards the broadband access market, to identify the access technologies to be included, the Austrian telecom regulator, RTR, carried out a SSNIP test, in which ~ 3000 consumers were interviewed regarding their reactions towards an eventual 10% increase in ADSL prices. 25% of the respondents indicated they would change their type of access, 8% of which would migrate to mobile access. RTR concluded that mobile broadband access was indicated as one of the adequate substitutes for DSL connections.

Below is a simulation of this phenomenon, based on the application of the model. It is worth noting that the concept of SSNIP applies to a perfectly competitive context which is not exactly the case studied here. Nevertheless, it is pertinent to use the concept in order to qualitatively analyze the interaction between fixed and mobile markets.

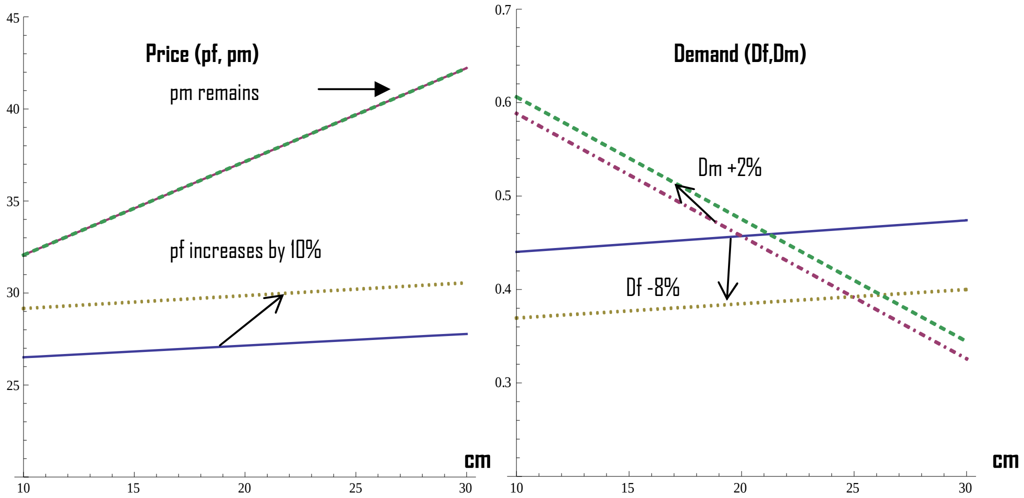

Figure 6 : SSNIP test, ***Df Dm*** as a function of ***cm*** when ***pf*** increases 10%

From the above figure it is apparent that when the fixed access price increases by 10% and mobile prices remain constant, the aggregate demand for mobile, *Dm,* increases by about 2% whereas the aggregate demand for fixed, *Df,* decreases by 8%. The fixed and the mobile data access markets are not two independent markets. Consumers change their consumption patterns due to the partial substitutability between fixed and mobile access. It could then be concluded that the broadband market must be greater than originally assumed.

The above results are obtained by assuming that the fixed price, *pf,* increases by 10% and the mobile price, *pm,* remains unchanged. Now the interdependence between the two markets will be evaluated in order to determine if the fixed price, *pf,* increases by 10% and the mobile market optimizes its price to maximize its profit. The model generates the following results:

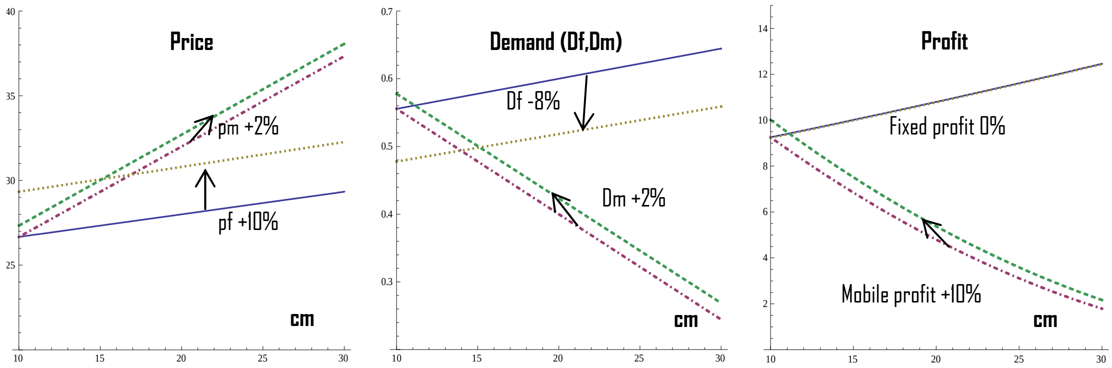

Figure 7 : price, demand and profit as a function of ***cm*** if ***pf*** is 10% higher and ***pm*** is optimized

In the price curves above, the price for fixed has unilaterally increased by 10%, the price for mobile has risen by 2% from its initial equilibrium price into a slightly higher new equilibrium price.
In the demand curve, mobile has increased by 2% whereas fixed has decreased by 8%.
In the profit curve, mobile has increased by 10% whereas fixed profit has only slightly decreased. It can then be concluded that a 10% unilateral price increase in either of the two markets, with respect to its equilibrium price, provides more benefit to the other market.

4.3. Interdependence of a monopoly in the fixed market and perfect competition in the mobile market

In the following section, the model will be applied to illustrate the interdependence of a monopoly in the fixed market and perfect competition in the mobile market. In this configuration, the mobile price is equal to its marginal cost. The fixed market maximizes its profit by setting its price at equilibrium and by taking into account the lowest mobile price (*pm=cm*).

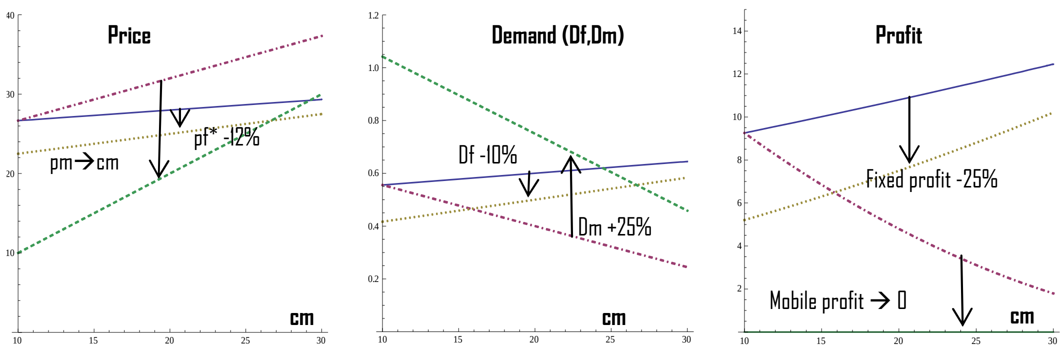

Figure 8 : Impacts of ***pm=cm***: price, demand and profit as a function of ***cm***

In the price curve, mobile moves away from its initial equilibrium price, *pm** to *cm*. The fixed price is optimized with respect to its profit. The new equilibrium price (with *pm=cm)* is lower than its initial equilibrium price, *pf*.*
In the demand curve, mobile increases thanks to its lowest price *pm=cm*. Consequently, the demand for fixed decreases.
In the profit curve, mobile decreases to zero due to the perfect competition and the fixed profit decreases at the same time, as well.
It can then be concluded that a non-regulated fixed market (a monopoly, for example) is indirectly controlled by a competitive mobile market, whenever partial fixed-mobile substitutability exists.

5. Consumer surplus and social welfare

In the following section, the model will be applied to determine the consumer surplus and social welfare of fixed-mobile intermodal competition. Then a comparison of this intermodal competition with other types of competition such as: fixed perfect competition, mobile perfect competition and fixed-mobile perfect intra-modal competition, will be made.

Consumer surplus and social welfare of fixed-mobile intermodal competition

As previously discussed, consumer surplus is determined by the utility function and social welfare is the result of adding the consumer surplus to the profits. The objective is to observe, under different forms of competition, if there is a progression or regression of social welfare.

By applying the utility function defined by Equation (1), consumer surplus, *CS,* and social welfare, *W,* can be determined for the fixed and mobile markets as follows:

$$
\begin{aligned}
CS &= U \\
\Pi_f &= (p_f - c_f)D_f \\
\Pi_m &= (p_m - c_m)D_m \\
W &= CS + \Pi_f + \Pi_m
\end{aligned}
$$

After a series of calculations, the social welfare at equilibrium price is given by

$$
\begin{aligned}
W^* = &\frac{\beta}{2(g_f + v_m - \beta)(g_f + v_m + \beta)((g_f + v_m)^2 - 4\beta^2)^2} \\
&(-2(-c_f\,(g_f + v_m)^2 + (g_f + v_f)(g_f + v_m)^2 + (g_f + v_m)(-c_m + gm + v_m)\beta + 2c_f\,\beta^2 - 2(g_f + v_f)\beta^2)^2 - \\
&2(-c_m\,(g_f + v_m)^2 + (g_f + v_m)^2\,(g_m + v_m) + (-c_f + g_f + v_f)(g_f + v_m)\beta + 2c_m\,\beta^2 - 2(g_m + v_m)\beta^2)^2 + \\
&\beta(2(c_f - g_f - v_f)(c_m - g_m - v_m)(g_f + v_m)^3 + 3(g_f + v_m)^2\,((-c_f + g_f + v_f)^2 + (-c_m + g_m + v_m)^2)\beta - 4((-c_f + g_f + v_f)^2 + (-c_m + g_m + v_m)^2)\beta^3))
\end{aligned}
$$

Comparison of consumer surplus and social welfare of fixed-mobile intermodal competition with other types of competition

1. Fixed perfect competition: in this intra-modal competition, only a fixed offer exists. There may be several firms on the broadband market, but all apply the same price, which is set at fixed marginal cost, i.e. *pf = cf*. The social welfare in this type of competition is given by

$$W_2 = \frac{(g_f + v_f - c_f)^2}{g_f + v_f + \beta}$$

2. Mobile perfect competition: in this intra-modal competition, only a mobile offer exists. There may be several firms on the broadband market, but all apply the same price, which is set at mobile marginal cost, *i.e. pm = cm*. Consumer surplus and social welfare is calculated in the same way as for fixed perfect competition, by replacing the firm *f* by firm *m*. The social welfare in this type of competition is given by

$$W_4 = \frac{(g_m + v_m - c_m)^2}{g_m + v_m + \beta}$$

3. Fixed-mobile perfect intra-modal competition: Since *pf=cf* and *pm=cm*, the fixed aggregate demand, *Df*, and mobile aggregate demand, *Dm*, can be calculated from Equation (2). There is no intermodal competition between fixed and mobile offers. The profits of fixed and mobile are zero. The consumer surplus is determined by Equation (1) with *CS=U, with pf=cf* and *pm=cm*. The social welfare in this type of competition is given by

$$W_5 = \frac{2(c_f - g_f - v_f)(c_m - g_m - v_m)(g_f + v_m) - ((-c_f + g_f + v_f)^2 + (-c_m + g_m + v_m)^2)\beta}{2(g_f + v_m - \beta)(g_f + v_m + \beta)}$$

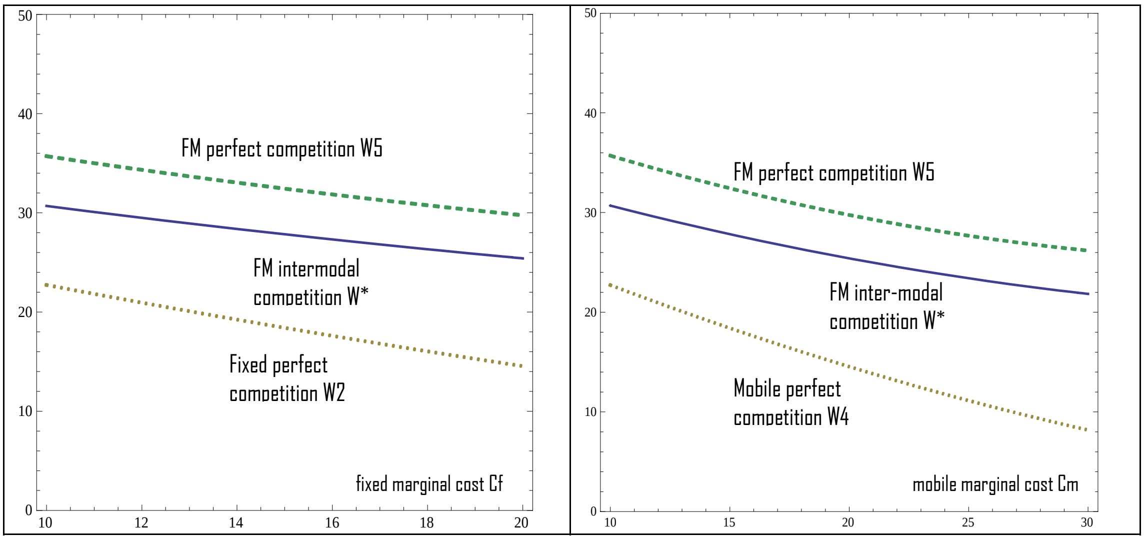

Figure 9: Comparison of social welfare

Figure 9 illustrates that fixed-mobile intermodal competition generates a higher social welfare compared to fixed perfect competition and mobile perfect competition, *W*>W2* & *W*>W4*. Intermodal fixed-mobile competition increases the social welfare compared to intra-modal perfect competition. It can also be observed that the curve for the highest value of social welfare corresponds to that of fixed-mobile perfect intra-modal competition, *W5*, which is a theoretical reference model characterized by its homogeneity, its transparency and fluidity. The comparisons of social welfare are conditioned by the hypotheses of the model.

6. Extended model from two to four players: reduce the effect of collusion by intermodal fixed-mobile competition

In the following section, the model will be extended, from two to four players. By using a four-player model, the robustness of the results obtained by the two-player model can be consolidated and an unobservable effect in the two-player model, i.e. the effect of collusion and the interaction between intermodal competition and collusion, will then be examined.

Four-player model

The four players are, respectively, two fixed firms (firm1 and firm 2) and two mobile firms (firm 3 and firm 4). Two new parameters, γ_f and γ_m, are introduced into the four-player model. For the purposes of this study, γ_f represents the substitutability between two fixed offers and γ_m that for two mobile offers. It is assumed that both fixed firms have the same fixed offer characterized by g_f and v_f and both mobile firms have the same mobile offer characterized by g_m and v_m. The partial fixed-mobile substitutability is again represented by γ where $\gamma= g_f+ v_m$.
An extended utility function is used to generate a new expression for inverse demands. The new utility function is given by

$$U=\sum_{i=1}^{n=4}\alpha_i D_i-\frac{1}{2}(\frac{\beta}{3}D_1^2+2\gamma_f D_1D_2+\frac{\beta}{3}D_2^2)-\frac{1}{2}(\frac{\beta}{3}D_3^2+2\gamma_m D_3D_4+\frac{\beta}{3}D_4^2)-\frac{1}{2}\sum_{i=1}^{2}\sum_{j=3}^{4}(\frac{\beta}{3}D_i^2+2\gamma D_iD_j+\frac{\beta}{3}D_j^2)-\sum_{i=1}^{n=4}p_iD_i$$

Where $\alpha_1=\alpha_2=\alpha_f=g_f+v_f$, α_f represents the maximum willingness to pay for the fixed offer *and* $\alpha_3=\alpha_4=\alpha_m=g_m+v_m$, α_m represents that of the mobile offer. D_1, D_2, p_1, p_2 are, respectively, aggregate demand and price for two fixed firms. D_3, D_4, p_3, p_4 are, respectively, aggregate demand and price for two mobile firms.

This new utility function gives a new expression for inverse demands

$$\begin{aligned}
p_1&=\alpha_f-\beta D_1-\gamma_f D_2-\gamma(D_3+D_4)\\
p_2&=\alpha_f-\beta D_2-\gamma_f D_1-\gamma(D_3+D_4)\\
p_3&=\alpha_m-\beta D_3-\gamma_m D_4-\gamma(D_1+D_2)\\
p_4&=\alpha_m-\beta D_4-\gamma_m D_3-\gamma(D_1+D_2)
\end{aligned}$$

The prices at equilibrium are calculated in the same way as the two-player model (cf. Equation (3) for $i=1,2,3,4$). The aggregate demand and profit of each player are also calculated from the equilibrium prices of the four players. The effects of interdependence of fixed and mobile markets are once again demonstrated with this extended model. The same effects of interdependence are observed and confirmed with the extended model. A higher social welfare in the presence of intermodal competition is confirmed for a second time.

The effect of collusion and its interaction with fixed-mobile substitution

Considering that there is only one player in each market, the effect of collusion between two players of the same market is not observable. However, the effect of collusion (maintained in the fixed market, for example) can be studied with four-player model as well as its interaction with partial fixed-mobile substitution. A two-step procedure will be used to investigate this effect. Firstly, it is assumed that the fixed and the mobile markets are independent, i.e. $\gamma = 0$. The two fixed firms collude to raise joint profits. Then, it is assumed that both markets are no longer independent (i.e. $\gamma \neq 0$). It is precisely the resulting interaction between the effect of collusion and intermodal competition caused by partial fixed-mobile substitutability which is interesting to note.

1. **$\gamma = 0$ fixed and mobile market are independent**

Two sets of curves composed of price, aggregate demand and profit are compared below. The **x** axis of the curves corresponds to the ratio (*pf/ pf**) between fixed price, *pf* with respect to its equilibrium price, *pf**.

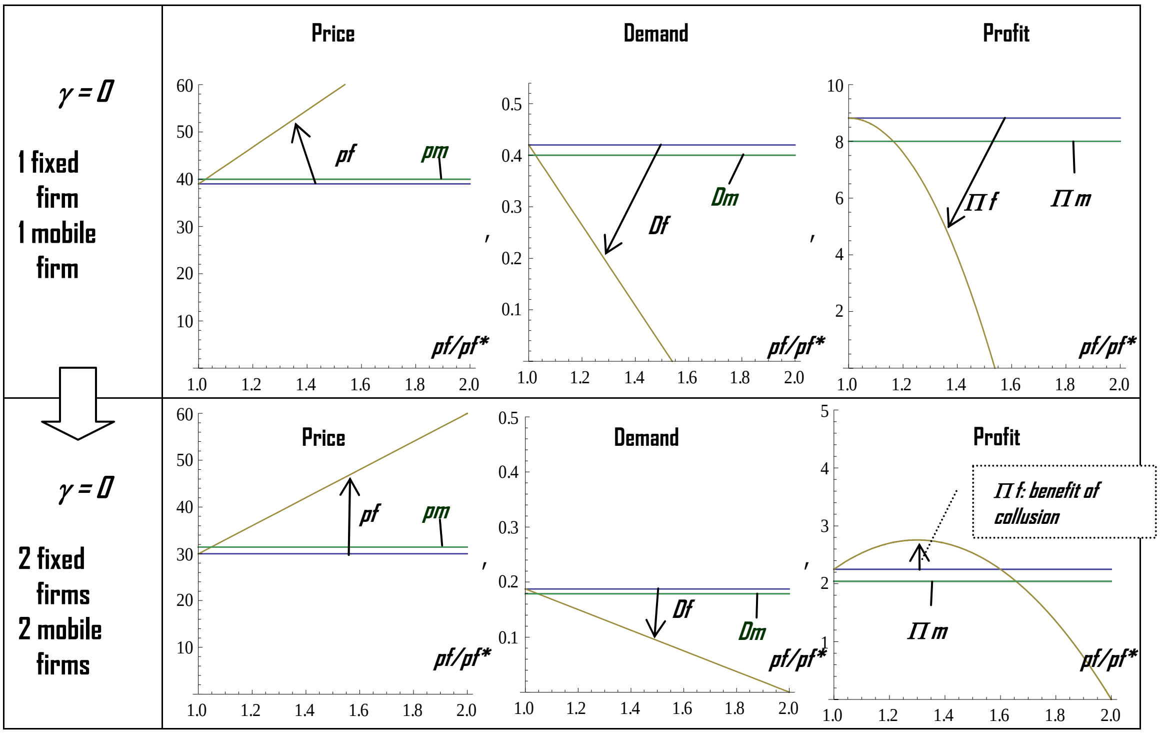

Figure 10 : Effect of collusion when fixed and mobile markets are independent

The first set of curves for price, demand and profit corresponds to the situation where one fixed firm and one mobile firm are active on the market. As $\gamma = 0$, each firm enjoys a monopoly on its respective market. Each firm can set the price at the monopoly equilibrium price to maximize its profit. If the fixed firm deviates its price from its equilibrium position, $pf^* \rightarrow pf$, its aggregate demand, *Df*, and its profit, Πf, decrease when *pf* increases. It can be observed that the *pm*, *Dm* and Πm remain unchanged with the increase of *pf* due to independent markets.

The second set of curves for price, demand and profit corresponds to the situation where two fixed firms and two mobile firms are active on the market. As $\gamma = 0$, there is separately a duopoly competition for respective fixed and mobile markets. Each firm can set the price at the duopoly equilibrium price by taking into account γf (or γm) substitutability between two fixed offers (or two mobile offers). It is known that the equilibrium price and the profit of a monopoly are higher than those of a duopoly. In this case, two fixed firms may benefit from colluding, i.e. jointly increase the fixed price, *pf*. In the profit curves of the second set, it is observed that the profits of the fixed firms rise with the increase of the fixed firms' prices (*pf/pf**). This is the benefit of collusion as a result of the shift from duopoly to monopoly equilibrium price. The benefit of collusion is maximized when the fixed price, *pf*, reaches the monopoly equilibrium price ($pf/pf^*=1.3$ in the profit curve of the second set of figure 10).

2. $\gamma \neq 0$ fixed and mobile markets are not independent

The first set of curves of figure 11 ($\gamma = 0$: 2 fixed firms and 2 mobile firms) will be compared to the second set where intra-modal and intermodal competition coexist ($\gamma \neq 0$: 2 fixed and 2 mobile firms). Through this comparison, the interaction between the effect of collusion and fixed-mobile intermodal competition can be demonstrated.

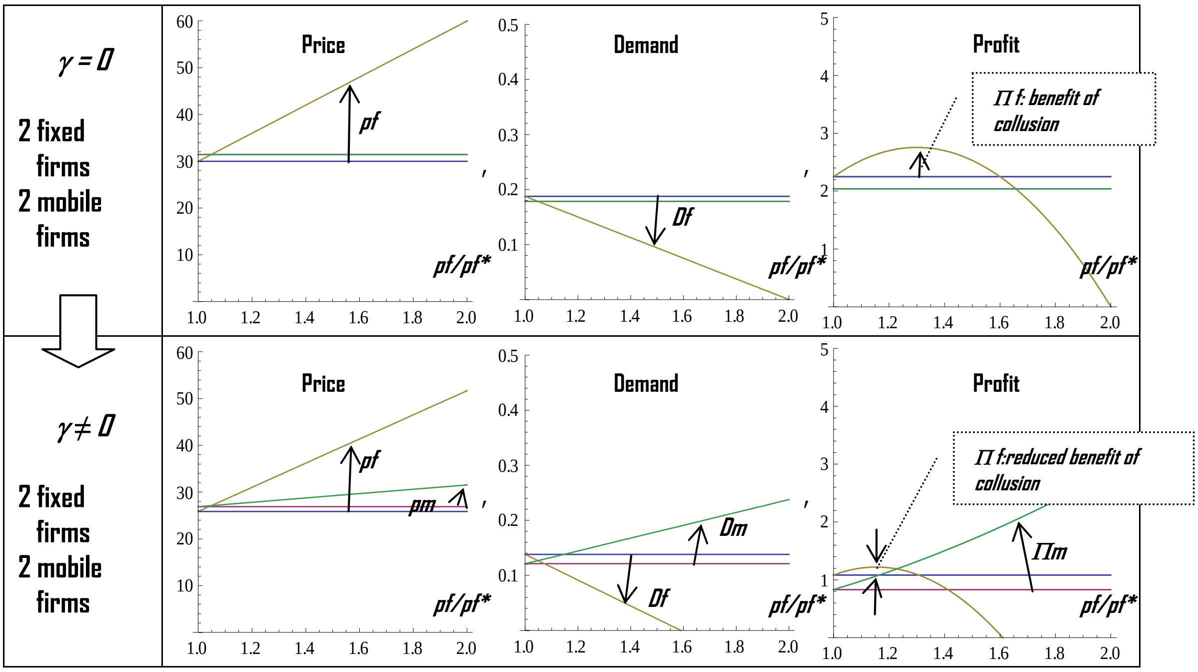

Figure 11 : Effect of collusion reduced by fixed-mobile intermodal competition

The comparison of two price curves for $\gamma = 0$ and $\gamma \neq 0$, respectively, reveals two elements: First, the equilibrium prices, pf^* and pm^*, decrease with increased competition which is both intra-modal and intermodal. Second, mobile prices increase when fixed prices increase, due to the fact that mobile firms aim to optimize their prices in order to maximize their profits.

The aggregate demand curves for $\gamma \neq 0$ indicate that the aggregate demand for the mobile offer increases whereas the aggregate demand for the fixed offer decreases.

The comparison between two profit curves for $\gamma = 0$ and $\gamma \neq 0$, respectively, illustrates that the benefit of collusion is significantly eroded by fixed-mobile intermodal competition. At the same time, the profits of mobile firms increase.

7. Concluding remarks

The oligopoly model, originally introduced by Shubik and Levitan, inspired this study in order to understand the issue of partial substitutability between fixed and mobile data access. This partial substitution is endogenized by using a two-dimensional (mobility and data volume) description of the asymmetric characteristics of mobile and fixed access. This model is also an instrument of qualitative analysis which highlights some effects of interdependence.

From the description of fixed and mobile broadband offers and demand functions, Nash equilibrium can be derived in a game where both firms compete on price. When a mobile operator incorporates technological progress it can reduce its marginal cost and consequently improve its profits. This is also valid for a fixed operator. Based on the SSNIP test principle, a 10% unilateral price increase in either of the two markets with respect to its equilibrium price generates more benefit in favor of the other market. It can be demonstrated that a non regulated fixed market (a monopoly for example) may be indirectly controlled by a more competitive mobile market when partial fixed-mobile substitutability exists. Mobile technological progress increases fixed-mobile substitution, fixed technological progress is an attempt to reduce it. With technological progress, wireless broadband access becomes more competitive versus fixed access. A partial fixed-mobile substitution could be observable worldwide in the future. The development of FTTH, offering a differentiated product, could sustain the fixed business. The comparison of social welfare among fixed-mobile intermodal competition, fixed perfect competition and mobile perfect competition illustrates that the fixed-mobile intermodal competition leads to a higher level of social welfare[2].

The two-player model is extended to a four-player model in order to analyze the configuration of imperfect competition within fixed and mobile markets and then combined with a competition between fixed and mobile, to simulate the situation that the European markets are currently experiencing. It can be assessed that the benefit of collusion on either of the two markets may be reduced by fixed-mobile intermodal competition caused by fixed-mobile partial substitutability. Finally, it can be concluded that the results are robust, via the two and four-player models examined in this paper.

[2] The study began with a two-dimensional Hotelling's model. Shubik's model used in this paper gives qualitatively the same results than that of the Hotelling's model. Therefore we consider it somehow confirm the robustness of the results of this study

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Annex 1: fixed and mobile broadband access prices of Austria in 2009

		Highest monthly fee	*Lowest monthly fee*	**Data volume cap usage**
Fixed	Telecom Austria	$62.67	$24.99	Limited, unlimited
	UPC	$111.78	$23.74	Unlimited
	Tele2	$50.11	$21.98	Limited, unlimited
	iNode (UPC)	$111.78	$22.48	Unlimited
Mobile	Three	$91.37	$10.84	Limited
	A1 (Telecom Austria)	$46.46	$23.23	Limited
	T-mobile	$38.72	$23.23	Limited
	One	$77.44	$15.49	Limited

Austria is a unique case in Europe for the adoption of 3G with high-quality 3G coverage, up to 94% of the population by the operator Hutchison [12]. In 2009, the Austrian telecom regulator (RTR) showed that the number of subscribers in mobile broadband has been increasing rapidly since 2006 and over 1.3 M subscribers in Q4 2009 (40.7% of total broadband access) [13]. These subscribers are partly due to the migration from fixed to mobile which is 10% (5%+5% from ADSL and Cable) to mobile broadband and 13% fixed narrowband to mobile broadband [14].

The fixed-mobile substitution is understandable in the context of Austria. The 3G coverage was 94% by Hutchison, 90% by Mobilkom, 75-80% by T-Mobile and 70% by Orange in 2009. The coverage provided by Hutchison is close to that of ADSL (95%) on a population of 8.3 million. The price for mobile broadband was approximately 1 € / Gbyte / month in 2009. Orange offers 15 € / month for 15 Gbytes/ month. Two years ago the price was 15-20€ / Gbyte per month. Furthermore, the fourth mobile operator Hutchison offers a truly unlimited volume and throughput at 24.90 € / month. Now after this dramatic decline, an OVUM study illustrates that the price of mobile broadband is lower than the fixed [15].