How Much Does Speed Matter in the Fixed to Mobile Broadband Substitution in Europe ?

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Abstract

To date, the few studies examining if and how mobile broadband is constraining the dominance of the fixed broadband market, show that fixed to mobile substitution exists. However none of these studies examines the effect of mobile broadband speed on this substitution. We therefore empirically analyse the impact of mobile broadband speed evolution - through 4G adoption - on fixed to mobile substitution in 18 European countries from 2008 until 2013. The results show this substitution effect is almost doubled when a country adopts 4G. This result implies that progressive deregulation could be conceivable as mobile broadband speed continues to increase. However, the growing competitive pressure from mobile operators also provides fixed operators with incentives to acquire mobile operators. It is therefore imperative for policy makers to preserve mobile-only operators if their objective is to deregulate the market with the aim of having competition improve consumer welfare.

Key words: Mobile, fixed, broadband, substitution, speed, econometrics, Europe, deregulation, competition, ICT.

JEL codes: D43, L43, L86

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1. Introduction

Over the past few years, mobile broadband technologies and speeds have greatly increased in the European Union, reaching an ever larger share of broadband consumers. This increase has implications for broadband market competition. Indeed, mobile broadband is starting to encroach upon the fixed market and if this process becomes sufficiently strong, deregulation of the fixed market may be conceivable.

To date, only a handful of studies have analysed fixed to mobile substitution through empirical research. Although one of these, an early study from Lee et al. (2011), suggests that both technologies complement one another, the most recent studies agree that mobile broadband is to some extent a substitute to fixed broadband. We hypothesize that technological evolution and especially the increasing speed of mobile broadband have played a crucial role in this process of substitution.

When comparing mobile to fixed broadband, we observe that advertised mobile broadband speeds were still lower than fixed counterparts in most EU countries in 2012[5] (see table A1 in the annexes).[6] However, mobile broadband speeds are rapidly increasing. Mobile broadband first consisted of third generation (3G) and later, fourth generation (4G) technology, the latter being faster and more efficient.[7] According to the European Commission digital agenda scoreboard (2013), 3G coverage reached 96.3% of the European population in 2013, while 4G coverage tripled in 2012 to reach 26.2% in 2013.

Like Grzybowski (2014), we hypothesize that this recent evolution in speed and efficiency provides more reasons for consumers to drop fixed broadband in favour of its mobile

[5] http://www.oecd.org/sti/broadband/oecdbroadbandportal.htm

[6] There are however exceptions such as Poland, Greece and Denmark, where the median and average advertised speeds of mobile broadband were above their fixed broadband counterparts. The OECD broadband portal evaluates the advertised speeds which are poor estimations for real speeds.

[7] Depending on the data source, 3G speeds range approximately from 144 kbps to 100 Mbps while 4G speeds range from 40 Mbps to 1 Gbps (for LTE advanced). It is however difficult to estimate the speeds of these different technologies because of the very large difference between theoretical and actual speeds. Moreover, we did not find official sources for 3G and 4G speeds. Information about mobile broadband technologies and speed were found on the following websites:
http://blog.parts-people.com/2012/01/27/4g-imt-advanced-lte-wimax-vs-3g-speed-executive-summary/,
http://4glte.over-blog.com/pages/De_la_2G_a_la_4G-5740669.html,
http://fr.wikipedia.org/wiki/Enhanced_Data_Rates_for_Global_Evolution,
http://fr.wikipedia.org/wiki/Universal_Mobile_Telecommunications_System#D.C3.A9bits_th.C3.A9oriques,
http://en.wikipedia.org/wiki/Evolved_HSPA , http://fr.wikipedia.org/wiki/3G

counterpart. To our knowledge, no previous study has analysed the possible link between broadband speed and this substitution effect.

To complement previous studies on the subject, we test the impact of 4G adoption on fixed to mobile substitution by using the latest mobile broadband data in European countries, robust econometric methods and a broad set of variables. We perform a linear regression over 18 European countries, over the most recent period - from January 2008 until January 2013 – using 6-monthly data. Our results show a much greater substitution effect from fixed to mobile broadband when 4G is adopted in a country than when it is not. Our results provide greater insights into the question of mobile broadband encroachment on its fixed counterpart's current and future dominance.

To explain how we arrived at these results, the paper is organized as follows. Section 2 comments on previous research on the subject. Section 3 discusses the model we used and section 4 discusses the data. Section 5 presents the results which lead to policy implications discussed in section 6. Section 7 concludes.

2. Previous research

Empirical studies on the competitive effects between mobile and fixed broadband are rather scarce and not comprehensive. To the best of our knowledge no empirical study has yet examined whether mobile broadband speed (and related technologies: 3G, 4G) may be a potential determining factor in fixed to mobile broadband substitution.

Many studies have analysed the impact of broadband competition (mainly inter- and intra-platform competition) on broadband penetration, but curiously none has yet examined whether mobile broadband may be a potential competitor to fixed broadband; e.g. Distaso et al. (2006), Höffler (2007), Denni and Gruber (2007), Bouckaert et al. (2010), Gruber and Koutroumpis (2011), Belloc et al. (2012), Dauvin and Grzybowski (2013), Lin and Wu (2013), and many more. The control variables they use are generally the gross national product, the density of population, the level of education, the number of computers per inhabitants and broadband prices. We also use these variables in our empirical model.

Other studies have analysed the competitive effect between mobile broadband and fixed broadband at the aggregated country level but are limited in their time range and their variables. For example, Lee et al. (2011) used data from OECD countries from 2000 to 2008 and analysed the factors that influence the diffusion of fixed and mobile broadband. The authors concluded that fixed and mobile broadband are complementary goods. However, before 2008, mobile broadband was still in its infancy. We can therefore hypothesise that mobile broadband was neither sufficiently widespread[8] nor fast enough to compete with its fixed counterpart. More recently, Grzybowski (2014) analysed fixed to mobile substitution for 27 European countries in the 2005-2010 period and concluded that the spread of 3G decreases the share of "mobile + fixed" households (internet and telephony together) and increases the share of "mobile-only" households. His study is interesting as it concludes that an increase in mobile technologies (the use of 3G) fosters fixed to mobile substitution. However, the author does not differentiate between internet and telephony. Grzybowski (2014) also supposes that if the quality and speed of mobile broadband increase, the number of copper fixed-line connections may be expected to decrease. The author suggests to broadband operators that they could slow down this decline by bundling fixed connection with mobile services. Brenner and Wulf (2014) empirically study ITU[9] Member States for two successive years over the 2007-2011 period, and conclude that a portion of the fixed broadband market capacity has been taken over by mobile broadband services but also that fixed adoption has stimulated mobile adoption. The main limitation of their study is that the authors use relatively complex diffusion models with rigid hypotheses and therefore are not able to include control variables such as demographic and economic dimensions in their model.

Still other studies use data at the household level which limit the study to one country and one year. These studies conclude that fixed to mobile substitution exists. For example, Grzybowski et al. (2014) use survey data from Slovakia in 2011 and estimate, through a computation of demand price elasticities for broadband, that mobile broadband can be considered a strong substitute for its fixed counterpart. The authors also conclude that due to poorly developed fixed broadband technologies in Slovakia, mobile broadband could be a strong alternative to its fixed counterpart, and therefore could be included in the same relevant antitrust market as the latter. Srinuan et al. (2012) studied Swedish household data in 2009 and also computed price elasticities. They showed that mobile broadband can be considered a substitute for fixed broadband in most geographic areas of Sweden, and therefore that both technologies can be considered on the same relevant market at the retail level for these regions.

What we learn from these studies is that the diffusion of mobile broadband may negatively affect the diffusion of fixed broadband – the level of influence depending on the specific region – and therefore may affect the market power of fixed broadband operators. While there may have been complementary goods during the early stage of mobile broadband development (Lee et al., 2011), more recent studies reach the conclusion that mobile broadband

[8] See Figure 2.
[9] International Telecommunication Union.

can be considered a substitute (or a potential substitute) for fixed broadband.[10] This switch in the competitive effects between both technologies is most likely due to the evolution of mobile broadband technologies. Despite Grzybowski pointing out this possibility, to our knowledge, no study has yet studied it empirically. This is why we analyse the impact of 4G adoption on fixed to mobile substitution in this paper.

3. Empirical specifications

The main objective of this study is to analyse the impact of mobile broadband speed evolution - through 4G adoption - on fixed to mobile substitution. To do this we perform an econometric study. To measure broadband diffusion (our dependent variable), we consider, as many others have done, the penetration rate of fixed broadband (hereafter referred to *fixed*). This penetration represents the number of fixed broadband lines per 100 inhabitants. The main explanatory variable is mobile broadband penetration (*mobile*) which is defined as the number of active dedicated data service cards/modems/keys per 100 people. This variable is interacted with a binary variable *fourg* that represents 4G adoption in a given country. *Fourg* takes the value one or zero when 4G technology is adopted or not, respectively, in the specific country. From results in previous studies, one may expect mobile broadband penetration to have a negative impact on fixed broadband penetration and that this impact is even stronger when 4G technology is adopted by the country, as 4G adoption means increased mobile speed.

The control variables we consider are similar to those used in the literature (i.e. regarding the determinants of fixed broadband penetration) and include the following:

- Competition variables
    - Service: the market share of entrants using service-based access (bitstream and resale),
    - Facility: the market share of entrants using facility-based access (full LLU and shared),
    - NE-other: the market share of entrants using technologies other than DSL (cable, wireless, optical fibre, etc.),
    - Incumbent_other: the market share of the incumbent using non-DSL technologies (e.g. cable, optical fibre, etc.),
- GSP: Real Gross State Product per capita (Euro)[11],
- Pop_dens: the number of inhabitants per square kilometre,
- Pc_pen: the number of households having at least one computer per 100 households,

[10] The opposite is not true, as Wulf and Brenner (2014) highlight that mobile adoption could be stimulated by fixed adoption.
[11] The monetary variables were deflated and converted into constant Euro 2005.

- Edu: the percentage of the population aged 15-24 currently in education, and
- Price: the average monthly price of fixed broadband standalone internet access offers.

We do not include previous broadband penetration (Lee and Lee, 2010; Bouckaert et al., 2010) in our model since the use of period dummies and a fixed-effect model enable us to control for the evolution of broadband penetration and for the intercept, i.e. broadband penetration in 2008.[12] Hence, adding previous broadband penetration as an independent variable would be redundant. Moreover it would generate a bias that would imply the need of additional lags of the dependent and independent variables to obtain proper coefficient estimates (Wilkins, 2013).

The specific linear model estimated is the following:

$$Fixed_{i,t} = \beta 0 + \beta 1\ mobile_{i,t-1} + \beta 2\ fourg_{i,t-1} + \beta 3\ (mobile_{i,t-1} * fourg_{i,t-1}) + \beta 4\ service_{i,t-1} + \beta 5\ facility_{i,t-1} + \beta 6\ NE\text{-}other_{i,t-1} + \beta 7\ Incumbent\text{-}other_{i,t-1} + \beta 8\ GSP_{i,t-1} + \beta 9\ pop\_dens_{i,t-1} + \beta 10\ pc\_pen_{i,t-1} + \beta 11\ edu_{i,t-1} + \beta 12\ price_{i,t-1} + u_{i,t}$$

The estimation is based on 6-monthly data from 18 EU countries[13], from July 2008 until July 2012 (plus January 2013 for broadband penetration)[14], with a total of 162 observations.

We do not judge it necessary to include certain diffusion patterns (e.g. the Gompertz and the Logistic models) in the equation, as the slopes of fixed broadband penetration are relatively steady after 2008 (see Figure 1).[15] Moreover, we do not follow the extended Bass[16] model use in Brenner and Wulf (2014) because we want to include control variables in our model.

To avoid simultaneous effects between the dependent and independent variables (and hence endogeneity), we introduce a lag of one period between both variables.[17] We also use a fixed effect model[18] to account for unobserved fixed effects and year's dummies to account for

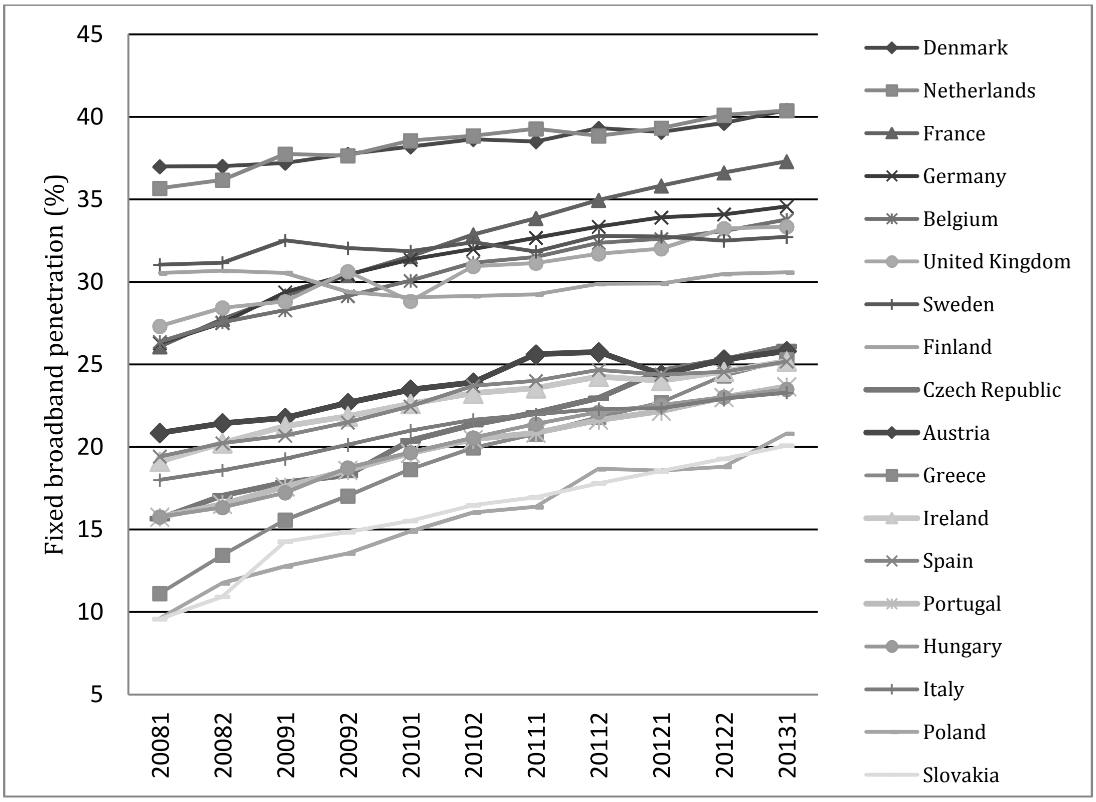
[12] We observe in Figure 1 that the slope depends on the intercept, which the fixed effect takes into account.
[13] These countries are Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherland, Poland, Portugal, United Kingdom, Slovakia, Spain, and Sweden.
[14] Except for population density and PC-penetration, which are based on annual frequency. The missing values were linearly extrapolated.
[15] Lin and Wu (2013) use a Gompertz model and Gruber and Verboven (2001) use a logistic model to take an "S" curve trend into account. These models imply an estimation of the potential numbers of adopters which may bias the estimation as this variable is difficult to estimate.
[16] Bass (1969) models the number of adopters of a product, which has been newly introduced into a market, at time t+1 as a function of the number of adopters in t and the number of potential adopters.
[17] For GSP, the effect of simultaneity may be greater. According to the European Commission, a 10% increase in broadband penetration leads to an increase in the GDP of 1-1.5%. See: http://ec.europa.eu/digital-agenda/en/high-speed-broadband. We therefore introduced (in annex 3, table A5) a lag of two periods instead of one. This did significantly change the results.
[18] The Hausman test between random and fixed effects concludes that H0 (difference in coefficients is not systematic) is not rejected (chi-squared test = 26.65, p-value = 0.15). We therefore used a fixed-effects model.

the trend of the dependent variable. We also control for heteroskedasticity. Moreover, we test mobile broadband for endogeneity (see section 5).

4. The data

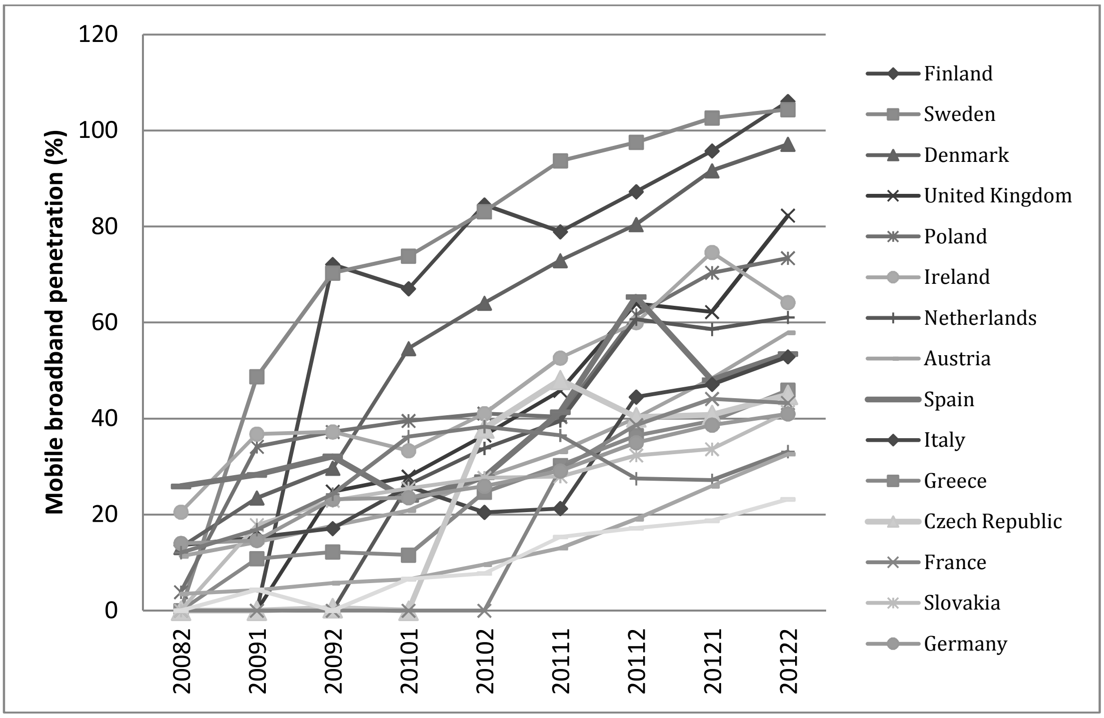
In Figure 1, we analyse the trend of fixed broadband penetration from 2008 to 2013. We observe a relatively steady slope of the evolution of fixed broadband through time. We also observe that this slope depends on the intercept (i.e. broadband penetration in 2008) as the steepest slopes are linked with the lowest intercepts.

Figure 1: Evolution of fixed broadband penetration by country



In Figure 2, we analyse the evolution of mobile broadband penetration between 2008 and 2012. We observe strong increase of mobile broadband penetration for most EU countries in recent years, Finland, Sweden and Denmark being the leaders.

Figure 2: Evolution of mobile broadband penetration by country



Note: mobile broadband penetration may reach levels over 100 percent because some people may have more than one device.

With respect to speed variables in Table 1 (which is a summary of the binary variable *fourg*), 4G technologies were first implemented during the second semester of 2009 in Sweden. Finland, Poland, Denmark and Austria joined Sweden in the second semester of 2010. The 3 remaining countries that had not yet developed 4G in the second semester of 2012 were Spain, Ireland and Slovakia.

Table 1: Number of countries having developed 4G technology (over 18 countries)

2008.1	0
2008.2	0
2009.1	0
2009.2	1
2010.1	1
2010.2	5
2011.1	6
2011.2	6
2012.1	10
2012.2	15

In Figure 1, we observe that fixed broadband penetration in Finland and Sweden did not grow much between 2008 and 2012. It even decreased at some points during that period. These two countries also had the highest mobile broadband penetration rate for the most recent years in our sample. Moreover, they are pioneers in terms of 4G adoption.

Table A1 contains all the information about the sources of our data, and Tables A2 and A3 contain complementary statistics' information (see the Annex).

To conclude, there would appear to be a link in European countries between 4G adoption, the high level of mobile broadband penetration and the slower fixed broadband penetration growth rates.

5. Results

The results are reported in Table 2. Before discussing the key variables, we shall comment briefly on the control variables. We find, as other authors before us do, that the GSP per capita, the percentage of households having a computer and education all have a positive impact on broadband diffusion. It is quite a reasonable result, as a higher level of GSP and more computers lead to a greater demand for broadband, and having more students leads to a higher demand for broadband services (Lin and Wu, 2013). Indirectly, education could be a proxy for government investment in public goods (such as health, education and utilities). It is also quite obvious that a higher broadband price has a negative impact on broadband penetration. Finally, we find a negative coefficient for population density (significant at a 10 percent level).[19]

Moving on to competition variables (on the fixed network), our results provide some useful insights into the ongoing debate on broadband access regulation. First, the coefficients of facility-based access[20] (*facility*) and of non-DSL networks developed by the incumbent (*incumbent-other*) are significantly positive. Instead, service-based access[21] (*service*) has a significantly negative coefficient. The coefficient of new entrants (*NE-other*) is not significant at the 10 percent statistical level. These results suggest that in Europe, facility-based access and, to a lesser extent, the development of non-DSL networks[22] have been conducive to fixed broadband diffusion (something also confirmed by Dauvin and Grzybowski, 2013), unlike service-based access which has slowed down fixed broadband diffusion (also confirmed by Bouckaert et al., 2010).

For the variables of interest, we observe a significantly negative coefficient for mobile broadband and for the interaction term between 4G and mobile broadband. This means that the

[19] This fact can be explained by the use of a fixed-effects model that cancels inter-country differences. We verified this by using a random effects model which resulted in a highly significant and positive coefficient for population density. This is understandable as it is less costly to develop broadband infrastructure in countries with higher population densities.
[20] Full LLU and shared access
[21] Resale and bitstream access
[22] Especially from the incumbent

diffusion of mobile broadband slows down the diffusion of fixed broadband. This effect is even stronger when 4G is adopted in the given country. Unlike some other studies (Grzybowski et al., 2014; and Srinuan et al., 2012), our methodology and the data we collected cannot provide estimations of price elasticities or cross elasticities. Nevertheless, our results are in line with previous research. If we analyse the magnitude of the coefficients of *mobile* (-0.021) and *mobile*fourg* (-0.019), we observe that 4G adoption in a country almost doubles fixed to mobile broadband substitution. In other words, higher mobile speeds greatly encourage consumers to drop fixed broadband in favour of using mobile broadband only for internet access. More specifically, in countries where 4G has been adopted, our results highlight that a rise in mobile broadband penetration of 1 percentage point results in a decrease of fixed broadband penetration of 0.040 (0.021 + 0.019) percentage points. This means that approximately 25[23] new mobile broadband subscriptions are needed – in comparison with 48[24] without 4G - to see a drop of one subscription in the fixed broadband market. These results must be interpreted carefully because, unlike mobile subscription, one fixed subscription usually serves more than one consumer. Hence, if we speak in terms of users (instead of subscriptions), the substitution effect appears to be much greater.[25] It is also important to note that these results do not change significantly irrespective of the robustness test we use.

Finally, 4G adoption in a country seems to enhance broadband penetration as its coefficient is significantly positive. This result is not surprising as 4G deployment is a result of a "technology-friendly regulation" as well as the availability of sufficient means to develop costly technologies. In other words, 4G development may be seen as a proxy for new technologies' deployment on both mobile and fixed networks.

[23] If we consider a 95 % confidence interval, this value ranges from 15 to 67 mobile broadband subscriptions.
[24] If we consider a 95 % confidence interval, this value ranges from 33 to 83 mobile broadband subscriptions.
[25] e.g. if one fixed connection represents 3 users, this means that there is a need of approximately 7 new mobile broadband users – in comparison to 13 without 4G – to see a decrease of one user in the fixed broadband market.

Table 2: Determinants of broadband penetration rate

	Fixed-effect regression Coefficient (Standard error)
$mobile_{i,t-1}$	-0.022*** (0.005)
$fourg_{i,t-1}$	1.286*** (0.438)
$mobile_{i,t-1} * fourg_{i,t-1}$	-0.018** (0.007)
$service_{i,t-1}$	-0.115** (0.040)
$facility_{i,t-1}$	0.126*** (0.029)
$NE\text{-}other_{i,t-1}$	0.071 (0.044)
$Incumbent\text{-}other_{i,t-1}$	0.048* (0.027)
$GSP_{i,t-1}$ *(log)*	3.297** (1.323)
$pop\_dens_{i,t-1}$	-0.057* (0.028)
$pc\_pen_{i,t-1}$	0.094* (0.053)
$edu_{i,t-1}$	0.014*** (0.004)
$price_{i,t-1}$	-0.013*** (0.004)
Regression fit (R^2 - within)	0.918
Number of observations	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%, year dummies are included in the regression.

A final technical comment is in order. A risk of endogeneity may remain despite the fact that we use lags between the dependent and independent variable and a fixed effect model. Mobile broadband penetration may be endogenous if there are simultaneous effects between mobile and fixed broadband penetration (e.g. consumers may choose between mobile and fixed broadband[26]). On the other hand, if both variables (mobile and fixed) have the opposite effect on each other - as Brenner and Wulf (2014) highlight - endogeneity should not be a problem.[27] In any case we tested mobile broadband for endogeneity. To do so, mobile broadband was instrumented with the number of active SIM cards divided by the population.[28] The different

[26] Although previous research as well as our own research here, mainly conclude that a drop in fixed broadband for mobile broadband exists, but that the opposite is not true.
[27] The only problem that could result from such opposite effects is a lower coefficient for mobile broadband.
[28] We tested the instrument and its lag using the over-identifying restrictions test and found the instruments to be valid.

tests for endogeneity[29] underline that mobile broadband is not likely to be endogenous. We can therefore confirm that consumers are more prone to dropping their fixed broadband subscription for a mobile broadband subscription than the opposite.[30]

6. Policy implications

The fact that 4G adoption increases fixed to mobile broadband substitution in Europe may encourage deregulation. More specifically, if mobile operators continue to invest in mobile broadband technologies, this substitution effect is more likely to increase in Europe. Consequently, mobile broadband may increasingly be considered a stronger competitor to fixed broadband and that it will continue to encroach on the market dominance of the latter. It is important to emphasize that this would only be the case if mobile operators had incentives to invest in their own network.

One possible consequence of current mobile broadband development is that fixed operators have great incentives to acquire mobile operators in order to limit competitive pressure from mobile operators. This is currently the situation in many European countries.[31] Indeed, mobile broadband operators are becoming an increasingly greater threat to fixed operators, as they offer increasingly higher speed in addition to mobility, something which fixed operators are not yet able to offer in Europe. Fixed operators therefore have incentives to acquire mobile operators, in order to slow down the decline of fixed broadband (Grzybowski, 2014). This fact could not only limit competition but could also limit investment in mobile technologies.

To conclude, our results are in line with recent studies, as mobile broadband is more likely to be considered to belong to the same retail market as fixed broadband. Our research also suggests that this reality could become even stronger in the future if mobile speeds continue to increase in Europe. Indeed, the development of mobile broadband may gradually allow lower levels of regulation in favour of healthier competition on the broadband market. However, the condition for such a market improvement is that mobile and fixed operators compete with each other. It is therefore important for policy makers to preserve mobile-only operators, if their objective is to let healthy competition gradually replace regulation in order to improve

[29] These tests comprise : 1) an augmented regression test proposed by Davidson and MacKinnon (1993) and 2) a Hausman test as a general specification test. The results of both tests suggested that mobile broadband is not endogenous. Results are shown in the annexes.

[30] Although some other consumers may keep both subscriptions.

[31] E.g. in Belgium, Telenet (a fixed operator) recently bought Base (mobile operator).
http://trends.levif.be/economie/entreprises/pourquoi-le-rachat-de-base-par-telenet-est-vraiment-une-mauvaise-nouvelle/article-opinion-391987.html.
In the UK, Bouygue Telecom (fixed operator) recently bought AA (mobile operator).
http://www.knowyourmobile.com/ee/ee/22887/bt-mobile-launches-ahead-of-bt-ee-buyout.

consumer welfare (through lower prices and better quality). Indeed, we do not see why mobile and fixed broadband could not converge into a unique service (i.e. one single play subscription for all devices) offering high speed and mobility. Fixed broadband infrastructure (DSL, cable and fibre) could gradually offer more mobility (e.g. through hot spots) to compete with mobile broadband. On the other hand, mobile broadband operators could gradually improve their technologies and become faster (to compete with high-speed fixed-line infrastructure). The broadband market could therefore host more operators and let competition progressively replace regulation. Instead we increasingly observe fixed lines operators acquire (or merge with) mobile operators while keeping most consumers dependent on two different services – one offering high speed, the other offering mobility. These mergers and acquisitions have harmful consequences for consumers because they reduce competition and keep consumers dependent on two different services.

7. Conclusion

The increasing importance of mobile broadband in recent years has implications for broadband market competition, as mobile broadband may constrain fixed market dominance.

The few studies on the subject to date show that the diffusion of mobile broadband negatively affects the diffusion of fixed broadband –to varying degrees, depending on the region - and therefore may affect the market power of fixed broadband operators. While there may have been a complementary effect in the early stages of mobile broadband development (Lee et al., 2011), more recent studies reach the conclusion that mobile broadband can be considered as a substitute (or a potential substitute) to fixed broadband. This switch in the competitive effects between both technologies may be due to the evolution of mobile broadband technologies, a possibility put forward by Grzybowski (2014) but, to the best of our knowledge, never previously studied empirically.

To complement previous studies, we analysed the impact of mobile broadband speed evolution - through 4G adoption - on fixed to mobile substitution. We conducted a linear regression over 18 European countries for 6-monthly intervals over the most recent period - from January 2008 until January 2013. Our dependent variable was the penetration rate of the fixed broadband. The main explanatory variable was mobile broadband penetration which was interacted with a binary variable *fourg* (representing the 4G adoption in the given country).

The results showed that 4G adoption in a country almost doubles fixed to mobile substitution. With the evolution of mobile broadband, progressive deregulation may be worth considering on the fixed market. Indeed mobile broadband may be a stronger competitor to fixed broadband if mobile technologies still improve. This result is in line with recent studies' conclusions that mobile broadband should be considered on the same relevant market as fixed broadband – at least for some geographical areas. Our study also highlights that this effect should become stronger in the future if mobile speeds continue to increase in Europe. However, this can only occur if there is sufficient (quality) competition between fixed and mobile operators. Hence, policy makers may have to preserve mobile-only operators if their objective is to deregulate the market to ensure that competition improves consumer welfare.

Although this paper provides new insights on fixed to mobile broadband substitution in Europe, it has its limitations which in turn define a further research agenda. In our study, the proxy of speed of mobile broadband is limited to a binary variable. The scope of the study could be broadened, if access to real mobile broadband speeds were possible. Moreover, we did not include possibly relevant variables in our analysis. Indeed, the quality and speed of the fixed network, as well as the prices of both technologies, may also play a role in the substitution effect we have highlighted. It would therefore be interesting to study these variables.

In this study, we controlled for many variables and different econometric robustness methods. We can therefore conclude that our results are quite robust. Moreover, our results are supported by previous literature highlighting fixed to mobile substitution.

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Annexes

Annex 1: Fixed and mobile download speeds

Table A1: Average and median advertised fixed and mobile download speeds, September 2012 (Mbps)

	Fixed broadband		Mobile broadband	
Country	**Average speed**	**Median speed**	**Average speed**	**Median speed**
United Kingdom	48,947	35,840	6	7.2
Sweden	136,284	30,720	28	20
Spain	41,282	30,720	14	7.2
Slovak Republic	31,985	20,480	20	10.8
Portugal	76,347	30,720	23	14.4
Poland	29,445	10,240	54	42
Netherlands	89,664	61,440	9	14.4
Italy	31,744	20,480	21	14.4
Ireland	22,699	8,192	13	7.2
Hungary	29,245	15,360	14	7.2
Greece	21,888	24,576	30	42.2
Germany	24,880	16,000	22	7.2
France	51,968	30,720	16	14.4
Finland	53,601	15,360	29	7.2
Denmark	52,304	40,000	60	80
Czech Republic	34,509	23,040	16	21.6
Belgium	35,748	30,720	8	3.6
Austria	30,451	20,480	25	12

Source: OECD broadband portal. http://www.oecd.org/sti/broadband/oecdbroadbandportal.htm

Annex 2: Variable sources

Table A2: Variables sources

Variable	Source
Fixed	European union open data portal website http://open-data.europa.eu/en/data/dataset/hdNgCkLHQD1dtsyE93u0Q/resource/80b70098-0581-456a-935e-f3c114ae4630
Mobile	European union open data portal website http://open-data.europa.eu/en/data/dataset/hdNgCkLHQD1dtsyE93u0Q/resource/80b70098-0581-456a-935e-f3c114ae4630
fourg	http://en.wikipedia.org/wiki/List_of_LTE_networks_in_Europe. All sources are cited on this webpage, they come from operators website or national and international news. We verified these sources and they are reliable.
Fixed broadband Competition variables	"working document on broadband access in the EU: situation at 1 July 2008" for 2008; from the "working document on broadband access in the EU: situation at 1 July 2009" for 2009; from the "15th Progress Report on the Single European electronic Communication Market-2009[32]" for January 2010 and from the EC Communication Committee reports on broadband lines in the EU[33] for July 2010 until July 2012.
GSP	Eurostat
Pop_dens	Eurostat
PC_pen	Eurostat
Edu	Eurostat
Price	European union open data portal website http://open-data.europa.eu/en/data/dataset/hdNgCkLHQD1dtsyE93u0Q/resource/80b70098-0581-456a-935e-f3c114ae4630

[32]http://ec.europa.eu/information_society/policy/ecomm/library/communications_reports/annualreports/15th/index_en.htm.

[33] The excel documents are to be found on http://ec.europa.eu/digital-agenda/en/fast-and-ultra-fast-internet-access-analysis-and-data.

Annex 3: Complementary statistics

Table A3: Variables: general statistics

Variable	Mean	Std. Dev.	Min	Max
Fixed	25.57	7.45	9.57	40.11
Mobile	31.29	27.22	0	106.06
fourg	.24	.43	0	1
Service	7.45	5.47	0	28.4
Facility	16.59	14.29	0	55.71
NE-other	28.83	18.38	.13	63.06
Incumbent-other	3.33	6.21	0	27.64
GSP	6162.20	2602.18	1578.55	10816.70
Pop_dens	152.36	115.47	17.5	496.90
PC_pen	73.99	11.96	44	95
Edu	62.18	8.84	0	72.70
Price	51.14	16.77	26.25	107.90

Table A4: correlation matrix of the variables

	Fixed	Mobile	fourg	Service	Facility	NE-other	Incumbent-other	GSP	Pop_dens	PC_pen	Edu	Price
Fixed	1											
Mobile	0.32	1										
fourg	0.28	0.61	1									
Service	-0.07	-0.15	-0.26	1								
Facility	0.26	0.02	-0.03	0.09	1							
NE-other	-0.22	-0.04	0.06	-0.25	-0.82	1						
Incumbent-other	0.31	0.41	0.31	-0.25	-0.19	-0.11	1					
GSP	0.76	0.28	0.16	0.23	0.26	-0.40	0.17	1				
Pop_dens	0.42	-0.25	-0.12	0.07	-0.06	0.14	-0.29	0.17	1			
PC_pen	0.81	0.50	0.36	0.01	-0.04	0.03	0.32	0.69	0.30	1		
Edu	0.28	0.23	0.19	-0.11	-0.35	0.26	0.29	0.07	0.14	0.36	1	
Price	-0.36	-0.14	-0.12	0.05	-0.40	0.34	-0.14	-0.30	0.04	-0.23	0.13	1

Annex 4: Extensions and robustness tests

We test the sensitivity of the results presented in Table 2 in the paper to different features of the model and the variables.

1. Fixed effect versus random effect

We observe that the results are not fundamentally different when using the random effect or the fixed effect. However, the Hausman test results in a Chi^2 of 26.65 and a p-value of 0.15. Hence, we cannot reject the null hypothesis that the differences in coefficients are not systematic. This means the difference between the coefficients of both equations is sufficiently high (even if it does not appear so) to conclude the random effect is not fully consistent. We therefore choose the fixed effect. For this Hausman test, we do not control for heteroskedasticity as it would bias the results.

Table A5: Fixed effect versus random effect

	Fixed effect regression Coefficient (Standard error)	**Random effect regression** Coefficient (Standard error)
$mobile_{i,t-1}$	-0.022*** (0.006)	-0.026*** (0.006)
$fourg_{i,t-1}$	1.286*** (0.347)	1.226*** (0.380)
$mobile_{i,t-1}* fourg_{i,t-1}$	-0.018*** (0.007)	-0.014** (0.007)
$service_{i,t-1}$	-0.115*** (0.028)	-0.121*** (0.029)
$facility_{i,t-1}$	0.126*** (0.021)	0.145*** (0.022)
$NE\text{-}other_{i,t-1}$	0.071*** (0.021)	0.064*** (0.021)
$Incumbent\text{-}other_{i,t-1}$	0.048 (0.033)	0.079** (0.034)
$GSP_{i,t-1}$ *(log)*	3.297*** (0.642)	4.317*** (0.635)
$pop\_dens_{i,t-1}$	-0.057* (0.032)	0.016*** (0.005)
$pc\_pen_{i,t-1}$	0.094** (0.039)	0.185*** (0.034)
$edu_{i,t-1}$	0.014* (0.008)	0.016* (0.009)
$price_{i,t-1}$	-0.013** (0.006)	-0.012** (0.006)
Regression fit (R^2 - within)	0.924	0.841
Number of observations	162	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%, year dummies are included in the regression.

2. GSP: one or two lags

We observe that the results are not fundamentally different with one or two lags for the GSP variable. We can therefore use only one lag in the main equation.

Table A6: GSP (t-2) versus GSP (t-1)

	Fixed effect regression Coefficient (Standard error)	**Fixed effect regression** Coefficient (Standard error)
mobile$_{i,t-1}$	-0.021*** (0.004)	-0.022*** (0.005)
fourg$_{i,t-1}$	1.266*** (0.406)	1.286*** (0.438)
mobile$_{i,t-1}$* *fourg*$_{i,t-1}$	-0.019** (0.008)	-0.018** (0.007)
service$_{i,t-1}$	-0.127*** (0.035)	-0.115** (0.040)
facility$_{i,t-1}$	0.126*** (0.029)	0.126*** (0.029)
NE-other$_{i,t-1}$	0.050 (0.036)	0.070 (0.044)
Incumbent-other$_{i,t-1}$	0.040* (0.023)	0.048* (0.027)
GSP$_{i,t-2}$ *(log)*	3.847*** (1.144)	--
GSP$_{i,t-1}$ *(log)*	--	3.297** (1.323)
pop_dens$_{i,t-1}$	-0.051 (0.031)	-0.057* (0.028)
pc_pen$_{i,t-1}$	0.076 (0.054)	0.094* (0.053)
edu$_{i,t-1}$	0.013*** (0.004)	0.014*** (0.004)
price$_{i,t-1}$	-0.018*** (0.004)	-0.013*** (0.004)
Regression fit (R^2 - within)	0.924	0.918
Number of observations	162	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%, year dummies are included in the regression.

3. Endogeneity tests for mobile broadband

We choose the number of sim cards per inhabitant (*pensim*) as the instrumental variable for the mobile broadband penetration. Indeed, intuitively this instrument seems to be directly correlated with mobile broadband penetration but not with the dependent variable (fixed broadband penetration). In other words *pensim* seems to be correlated with the variable *fixed* only through the variable *mobile*. We also have no reason to suspect any endogeneity of this instrument.

The different tests bellow allow us to judge of the reliability of *pensim* as instrumental variable for *mobile* and then to judge the endogeneity of *mobile*.

The results of the following tests lead to two conclusions:

1) *pensim* appears to be reliable. Indeed, the correlation tests show a clear correlation between *pensim* and *mobile* but we do not observe any direct effect of *pensim* on *fixed*. The other reason to judge pensim as reliable is that, the Hansen J test shows that *this variable* is most probably not endogenous

2) M*obile* is most probably not endogenous. We use two different methods (Augmented regression test and a Hausman test) and both tests highlight that *mobile* is not endogenous.

A. Correlation tests between mobile broadband and the instrumental variable

It follows from Tables A7 and A8 a relatively high correlation between mobile broadband and its instrument (*pensim*).

Table A7: Basic OLS regression between mobile and pensim

VARIABLES	mobile
pensim	1.427***
	(0.151)
Constant	-144.5***
	(19.41)
Observations	162
Number of id	18
R-squared	0.42

Note: significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%.

Table A8: Correlation matrix between mobile and pensim

	mobile	pensim
mobile	1	
pensim	0.4706	1

B. The effect of pensim on fixed broadband

We observe that the coefficient of *pensim* in both cases (with *mobile* and without *mobile* included in the equation) is not significant.

Table A9: The effect of pensim on fixed broadband

	Fixed effect regression Coefficient (Standard error)	**Fixed effect regression** Coefficient (Standard error)
$mobile_{i,t-1}$	-0.034*** (0.005)	--
$fourg_{i,t-1}$	0.475** (0.218)	0.373 (0.274)
$pensim_{i,t-1}$	-0.002 (0.020)	-0.022 (0.024)
$service_{i,t-1}$	-0.119** (0.043)	-0.120** (0.052)
$facility_{i,t-1}$	0.125*** (0.034)	0.118*** (0.034)
$NE\text{-}other_{i,t-1}$	0.064 (0.044)	0.067 (0.047)
$Incumbent\text{-}other_{i,t-1}$	0.022 (0.023)	0.024 (0.034)
$GSP_{i,t-1}$ *(log)*	3.509** (1.511)	3.140** (1.222)
$pop\_dens_{i,t-1}$	-0.047* (0.025)	-0.070* (0.038)
$pc\_pen_{i,t-1}$	0.113* (0.056)	0.156** (0.061)
$edu_{i,t-1}$	0.015** (0.0057)	0.012** (0.006)
$price_{i,t-1}$	-0.012*** (0.004)	-0.011* (0.006)
Regression fit (R^2 - within)	0.913	0.884
Number of observations	162	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%, year dummies are included in the regression.

C. Hansen J test

We test the over-identifying restrictions ("estat overid" in stata). In other words, we test the covariance between the instrument and the error term to confirm if the instrument is not endogenous and hence valid.

For this test we need two instruments, this is why we use *pensim* and its own lag as instruments. The test statistic is not significant (chi squared = 0.71 with a p-value of 0.40); it means *pensim* and the lag of *pensim* are most probably not endogenous. It allows us to test if *mobile* is endogenous or not in the next section.

Table A10: Determinants of broadband penetration rate

	OLS Coefficient (Standard error)
$mobile_{i,t-1}$	-0.031** (0.015)
$fourg_{i,t-1}$	0.535*** (0.198)
$service_{i,t-1}$	-0.119*** (0.025)
$facility_{i,t-1}$	0.126*** (0.016)
$NE\text{-}other_{i,t-1}$	0.066** (0.027)
$Incumbent\text{-}other_{i,t-1}$	0.021 (0.031)
$GSP_{i,t-1}$ (log)	3.556*** (0.935)
$pop\_dens_{i,t-1}$	-0.057*** (0.021)
$pc\_pen_{i,t-1}$	0.138*** (0.036)
$edu_{i,t-1}$	0.014*** (0.004)
$price_{i,t-1}$	0.015*** (0.003)
Regression fit (R^2 - within)	0.994
Number of observations	153
Score chi2(1)	0.71 (p-value = 0.40)

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%. We also use country dummies (in addition to year dummies) as we are not able to use a fixed effect model for this test.

D. Augmented regression test (Davidson and MacKinnon, 1993)

To perform this test, we refer to the different stages proposed by Davidson and MacKinnon (1993). We observe in Table 9 that *residual* is not significant. It means that *mobile* is most probably not endogenous.

Table A11: First stage of the augmented regression test (dependent variable = *mobile*)

	Fixed effect regression Coefficient (Standard error)
pensim	0.662* (0.314)
fourg	3.282 (4.259)
service	0.023 (0.815)
facility	0.231 (0.558)
NE-other	-0.091 (0.578)
Incumbent-other	-0.089 (0.660)
GSP (log)	11.95 (19.49)
pop_dens	0.749 (1.193)
pc_pen	0.749 (1.193)
edu	0.083 (0.091)
price	-0.049 (0.131)
Regression fit (R^2 - within)	0.755
Number of observations	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%, year dummies are included in the regression.

We then save the residuals as a new variable and we insert it in the next equation.

Table A12: Second stage of the augmented regression test (dependent variable =*fixed*)

	Fixed effect regression Coefficient (Standard error)
residual $_{i,\ t-1}$	-0.002 (0.030)
mobile $_{i,t-1}$	-0.031*** (0.005)
fourg $_{i,t-1}$	0.481* (0.252)
service $_{i,t-1}$	-0.119** (0.043)
facility $_{i,t-1}$	0.126*** (0.030)
NE-other $_{i,t-1}$	0.064 (0.046)
Incumbent-other $_{i,t-1}$	0.021 (0.028)
GSP $_{i,t-1}$ *(log)*	3.534** (1.561)
pop_dens $_{i,t-1}$	-0.046 (0.034)
pc_pen $_{i,t-1}$	0.110* (0.060)
edu $_{i,t-1}$	0.015*** (0.005)
price $_{i,t-1}$	-0.012*** (0.004)
Regression fit (R^2 - within)	0.913
Number of observations	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%, year dummies are included in the regression

E. Hausman test: 2SLS versus OLS

To confirm the previous test, we compare the results of both models (2SLS with *pensim* as instrument and OLS). The Hausman test confirms that the results are similar ($chi^2 = 0.02$ and p-value = 1). Therefore OLS is most probably consistent and efficient. We also tested 2SLS models with the lag of pensim as instrument and both pensim and its lag as instruments. It leads to the same conclusions.

Table A13: 2SLS versus OLS

	2SLS Coefficient (Standard error) Instrument for mobile = pensim	**OLS** Coefficient (Standard error)
$mobile_{i,t-1}$	-0.033** (0.014)	-0.031*** (0.005)
$fourg_{i,t-1}$	0.481*** (0.184)	0.472** (0.195)
$service_{i,t-1}$	-0.119*** (0.025)	-0.120*** (0.028)
$facility_{i,t-1}$	0.126*** (0.019)	0.126*** (0.022)
$NE\text{-}other_{i,t-1}$	0.064*** (0.019)	0.064*** (0.022)
$Incumbent\text{-}other_{i,t-1}$	0.021 (0.028)	0.021 (0.032)
$GSP_{i,t-1}$ *(log)*	3.534*** (0.576)	3.528*** (0.654)
$pop\_dens_{i,t-1}$	-0.046 (0.031)	-0.047 (0.033)
$pc\_pen_{i,t-1}$	0.110*** (0.038)	0.112*** (0.039)
$edu_{i,t-1}$	0.015** (0.007)	0.015* (0.008)
$price_{i,t-1}$	-0.012** (0.005)	-0.012** (0.006)
Regression fit (R^2 - within)	0.994	0.994
Number of observations	162	162

Notes: Significance levels are indicated with ***, **, *, respectively 1%, 5% and 10%. We also use country dummies (in addition to year dummies) as we are not able to use a fixed effect model for this test.