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Complementarity In Household Expenditures On Fixed And Mobile Internet In France

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Abstract

This paper revisits the question of whether fixed and mobile Internet expenditures are substitutable or complementary. We estimate a demand system using French household expenditure data to compute price elasticities for different categories of goods. The results indicate that fixed and mobile Internet expenditures are complementary in France. This complementarity effect increases with income level. We then develop a simple theoretical model showing that depending on the characteristics of fixed and mobile data tariffs, fixed and mobile Internet expenditures can exhibit non-substitutability or even complementarity.

Keywords– Internet expenditure; Household behavior; QUAIDS demand system

JEL Classification– C30, D11, D12

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1 Introduction

Internet access for users can be via a fixed connection at home, in the office, in shops or public places, or via a mobile connection.[1] Users can therefore decide to spend money on a single type of connection or both. In many countries, these services are sold through subscriptions, sometimes allowing unlimited data consumption (e.g., for fixed Internet in France), or subscriptions allowing data consumption at no extra cost up to a predefined level. The coexistence of these two services raises the question of whether they are complementary, substitutable or independent. This question has numerous policy implications. It may influence the decision to include the mobile Internet market in the fixed market (Cardona *et al.*, 2009; Grzybowski *et al.*, 2014), has implications for the mergers between fixed and mobile Internet Service Providers (Vélez-Velásquez, 2019), and can influence the policies to overcome the digital divide (Quaglione *et al.*, 2020). In addition, environmental concerns and the fact that the consumption of a gigabyte by a mobile connection is more polluting than by a fixed connection (Lees Perasso *et al.*, 2022) gives another reason to study this issue. This paper revisits this question empirically, focusing on French households, and theoretically, demonstrating the impact of tariff offers tailored specifically to this market.

This question has been studied extensively in the economic literature and the substitutability or complementarity between the two Internet services is still debated. Cardona *et al.* (2009), Srinuan *et al.* (2012), and Grzybowski *et al.* (2014) use discrete choice models and household survey data for Austria in 2006, Sweden in 2009, and Slovakia in 2011. They find a positive cross-price elasticity between fixed and mobile Internet, suggesting that the two types of Internet are substitutable. Madden *et al.* (2015) and Nakamura (2015) confirm this result for Thailand and Japan. They stand out by estimating Internet adoption with a nested logit where consumers can choose a fixed-mobile bundle. Finally, Czajkowski *et al.* (2024) designed a Discrete Choice Experiment in Poland and show substitutability. Further literature on other countries shows that fixed and mobile Internet can be complementary. Lee *et al.* (2011) estimate a logistic model of broadband diffusion with aggregated data for

[1]Fixed Internet includes all FTTx and xDLS technologies, and mobile Internet includes 2G, 3G, 4G, and 5G technologies.

thirty OECD countries between 2003 and 2008. They find that mobile is complementary to fixed Internet services in many countries. Grzybowski & Liang (2015), Liang & Petulowa (2018), Vélez-Velásquez (2019), and Ros (2023) use discrete choice models that let consumers choose a fixed-mobile bundle with households data in a European city in 2013, France in 2012, Colombia between 2013 and 2015, and Mexico in 2015. They show that fixed and mobile Internet services are complementary in these countries and suggest several explanations for this result. First, while mobile Internet can be used outside the home, mobile subscriptions rarely propose unlimited data consumption, contrary to fixed subscriptions. Moreover, Internet subscriptions are often bundled with additional services. This means it is not necessarily the same good behind fixed and mobile internet subscriptions. Finally, Kongaut & Bohlin (2016) and Quaglione *et al.* (2020) highlight that fixed and mobile are complementary for some activities, particularly data-intensive activities such as gaming, video streaming, and cloud services.

The different results in the literature suggest then that consumers' behaviours regarding fixed and mobile Internet strongly depend on the country and, therefore, the telecommunications market. The temporal period studied can also influence the results as the adoption and territory coverage rates of both fixed and mobile Internet have increased considerably in recent years. This paper focuses on the French case and the specific characteristics of its tariff offer. French Internet Service Providers sell fixed and mobile data through subscriptions.[2] Most of these subscriptions are monthly with no commitment period.[3] Generally, fixed Internet subscriptions provide unlimited Internet access, while mobile subscriptions offer a volume of data that can be used without additional charges. The difference in subscription prices between the two types of Internet subscriptions comes from Internet quality (e.g., fiber versus ADSL for fixed Internet, 4G versus 5G for mobile Internet) and the addi-

[2]Today, the French telecommunications market (fixed and mobile) comprises four leading Internet Service Providers: Orange, SFR, Bouygues Telecom, and Free. This has not always been the case. Notably, the French mobile industry was marked by the entry of Free Mobile in 2012. The latter introduced low-cost offers to consumers, such as tariffs with no commitment and no handset subsidy, which forced existing Internet Service Providers to launch their own low-cost brands. The entry of a fourth competitor led to a decrease in prices (Nicolle *et al.*, 2018) and an increase in the variety of mobile subscriptions that have benefited consumers (Bourreau *et al.*, 2021).

[3]Offers with handset subsidies and commitment periods represented almost all the offers in 2010, but only 16,7% of them in 2023 (ARCEP, 2024).

tional services included. In fact, fixed Internet subscriptions are usually bundled with fixed telephony and television services (triple play), and mobile Internet subscriptions with mobile telephony and text messaging services. Quadruple play offers, including fixed and mobile Internet, television, and fixed and mobile telephony, are also widespread. These bundles, offered at a discount, encourage consumers to adopt both fixed and mobile connections with the same Internet Service Provider.

This paper contributes to the existing literature by using a comprehensive database on household expenditures: the *Budget des Familles* survey (Household budget survey) provided by the French Institute of Statistics (Insee) in 2017. This dataset allows us to estimate a demand system using a Quadratic Almost Ideal Demand System (QUAIDS) model (Banks *et al.*, 1997; Shonkwiler & Yen, 1999). The model incorporates three categories of expenditures: fixed internet, mobile internet, and other non-durable goods consumed by households. The estimation allows us to compute own and cross-price elasticities for these categories. Our results show that the uncompensated price elasticities for fixed and mobile Internet are around -0,927 and -0,935, respectively, and the compensated are around -0,909 and -0,923. This indicates that households are price sensitive and, therefore, adjust the composition of their expenditures following a change in fixed and mobile Internet prices. Moreover, French households are heterogeneous in their price sensitivity, with price elasticities for fixed and mobile internet decreasing as household income increases. Finally, the computation of cross-price elasticities allows us to conclude on the substitutability or complementarity between fixed and mobile Internet expenditures in the case of the French market. We find significant negative cross-price elasticities between fixed and mobile Internet, indicating that these two types of expenditures are complementary. Although fixed and mobile Internet use can substitute for one another, in the case of French households, expenditures on these two services do not appear to be substitutable. The complementarity between fixed and mobile Internet expenditures is stronger the higher the household income.

In the second part, the paper proposes a theoretical foundation to explain the complementarity of expenditures on mobile and fixed Internet. This theoretical foundation does not come from consumers' preferences but it comes from the characteristics of tariff offers in this market. To this aim, we consider a consumer who allocates expenditures across mobile data, fixed data, services associated with fixed Internet, and a composite good. A Cobb-Douglas utility function is also assumed. The aim is to show that even with substitutable goods, complementarity between mobile and fixed data expenditures can occur. Several cases representing different tariff offers are considered: unit prices of fixed and mobile data, bundles including unlimited use of fixed data and additional services, and subscriptions allowing consumption of a certain volume of mobile data without additional charges. We show that in the presence of subscriptions for unlimited use of fixed data and subscriptions allowing consumption of a certain volume of mobile data, expenditures on mobile and fixed Internet can be complementary.

The remainder of this paper is structured as follows. Section 2 presents the data, methodology, and results of the household's behaviour estimation. Section 3 presents the theoretical framework. Section 4 concludes.

2 Household's behaviour estimation

2.1 Data

We use the last *Budget des Familles* survey of Insee in 2017, which is the only representative survey about all the expenditures and revenues of French households. It is divided into two parts: an interview and a diary survey. The interview takes two visits and collects information on household characteristics, the rate of equipment in durable goods, and expenditures that can not be obtained with the diaries. The diaries collect all the household expenditures for one week. The survey was conducted over six waves at two-month intervals between September 2016 and September 2017 to account for the seasonality of some expenditures. We only use the latest *Budget des Familles* survey in 2017 because mobile Internet expenditures were weak in the previous one in 2011. The final sample is composed of 11,920 households living in mainland France.[4]

The Insee survey includes a telephone, Internet, and television subscription module. It provides information on the number and type of Internet subscriptions as well as the expenditures and prices paid by each household for each of these subscriptions. Fixed Internet expenditures include high and low-speed fixed Internet subscriptions. Mobile Internet expenditures include all types of mobile subscriptions and prepaid cards. For households without Internet expenditure, we replace the missing price with the average subscription price for all households by survey wave and income decile level. In addition to fixed and mobile Internet, we consider a composite good that includes the remainder of non-durable goods expenditures (food, clothing, water, electricity, fuels, leisure, and restaurants). We describe in Table A.1 in Appendix A the non-durable goods included in the composite good. We only consider non-durable goods in the demand system because the survey only reports expenditures over a short period. Except for Internet subscription prices, prices for each good are not given in the survey. Therefore, we use Insee's monthly consumer price indices. For each household, we match the monthly price index of each subcategory of goods to the corresponding subcategory and survey wave. To obtain the final price index of the composite good, we construct a Stone-Lewbel price index (Lewbel, 1989) for each household defined as:

$$\ln(p_{ih}) = \sum_{l=1}^{N_i} \frac{w_{lh}}{w_{ih}} \ln(p_{lh}), \tag{1}$$

where p_{ih} is the price index of good category i for each household h, p_{lh} is the price index of the subcategory of good l that belongs to good category i, w_{ih} is the share of expenditure of good category i in total expenditure of the household h, and w_{lh} is the share of expenditure of sub-category of good l in total expenditure of good category i. Stone-Lewbel price indices introduce more variability into the prices to produce more robust estimators than a standard aggregate price index (Hoderlein & Mihaleva, 2008).

Table 1 presents descriptive statistics on Internet household expenditures. On average,

[4] We do not consider households living in French Overseas Departments because they are over-represented in the Insee survey. They represent almost 30% of the surveyed households but only 2% of the French population.

households allocate nearly 4% of their non-durable goods budget to access fixed Internet connections and 1.3% for mobile Internet. Nevertheless, some households do not incur any Internet-related expenditure. The average expenditures share related to a fixed Internet connection increases to 5.6% when considering households with a fixed connection and those related to a mobile connection to 3.7% for households with a mobile connection. It represents an average annual expenditure of 505 euros for the fixed connection and 379 euros for the mobile. Moreover, there is a heterogeneity between households concerning their Internet expenditures. Firstly, the average price of an Internet subscription is more expensive for high-income households than for the low-income ones, especially for fixed Internet subscriptions (Figure 1a). As a result, the average Internet expenditure is higher for the last deciles compared to the first deciles (Figure 1b). However, as a proportion of the household budget for non-durable goods, the share of fixed and mobile Internet expenditure is higher for low-income households than the high-income ones (Figure 1c).

Table 1: Descriptive statistics

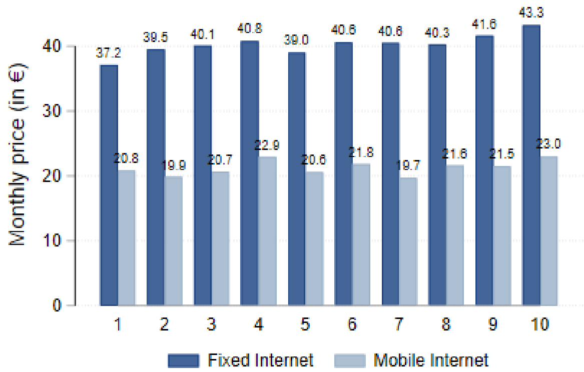
	All sample	**Households with fixed Internet**	**Households with mobile Internet**
Average expenditure share			
Fixed Internet	0.041	0.056	0.038
Mobile Internet	0.013	0.013	0.037
Average annual expenditures (euro)			
Fixed Internet	375.89	505.66	397.31
Mobile Internet	135.09	148.29	379.88
Average monthly price (euro)			
Fixed Internet		40.40	
Mobile Internet			21.28
Number of observations	11,920	8,861	4,239

Notes: 2017 Household budget survey, Insee.

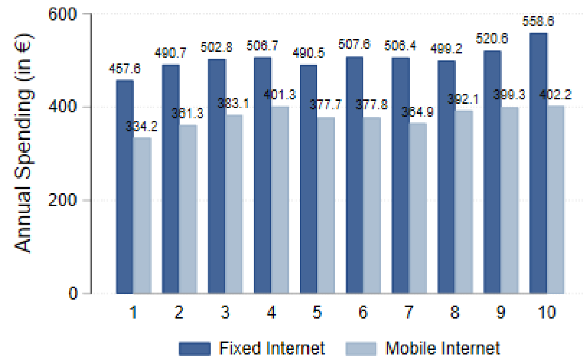
In addition to the household's expenditure level and the price of the goods, we consider the age, household size, disposable income, and digital equipment access (computer and mobile phone), which can influence the probability of accessing the Internet. Computer and mobile phone are dummy variables equal to 1 if the household has the equipment and zero if not.

Figure 1: Descriptive statistics by income decile

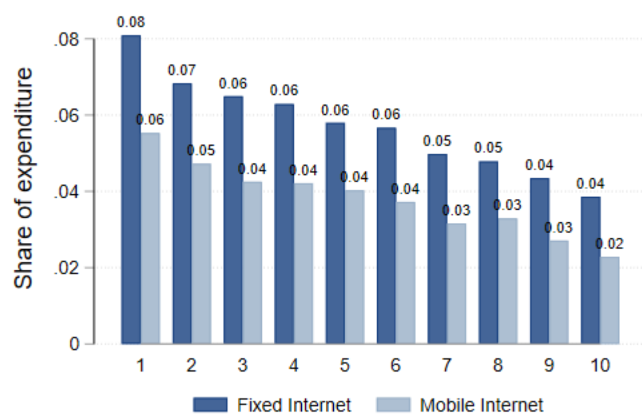
(a) Average price of monthly fixed and mobile Internet subscriptions



(b) Average expenditure on fixed and mobile Internet



(c) Average share of fixed and mobile Internet expenditure in non-durable goods expenditure



Notes: 2017 Household budget survey, Insee.

2.2 Methodology

In this section, we aim to assess households' decisions concerning fixed and mobile expenditures. To this aim, we estimate a *Quadratic Almost Ideal Demand System* (QUAIDS) introduced by Banks *et al.* (1997).[5] It allows us to estimate households' demand for dif-

[5]QUAIDS is often used to estimate income and price elasticities of various goods such as food (Attanasio *et al.*, 2012), food nutrient (Ecker & Qaim, 2011), energy (Douenne, 2020), and housing and utilities (Heinen

ferent goods, taking into account prices and expenditure on other goods, and to compute households' response to a change in price (price elasticities).

The QUAIDS extends the AIDS of Deaton & Muellbauer (1980) by adding a quadratic term, allowing for non-linear Engel curves. It assumes that the indirect utility function takes the following form:

$$\ln V = \left[\left(\frac{\ln m - \ln a(p)}{b(p)} \right)^{-1} + \lambda(p) \right]^{-1}, \tag{2}$$

with m the total expenditure of the household and $a(p)$, $b(p)$, and $\lambda(p)$ three prices indexes given by:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{j=1}^{k} \sum_{i=1}^{k} \gamma_{ij} \ln p_i \ln p_j, \tag{3}$$

$$b(p) = \beta_0 \Pi_{i=1}^{k} p_i^{\beta_i}, \tag{4}$$

$$\lambda(p) = \sum_{i=1}^{k} \lambda_i \ln p_i, \quad \text{with} \quad \sum_{i=1}^{k} \lambda_i = 0, \tag{5}$$

where p_i is the price index of the goods category i and k the number of good category.

The expenditure share w_i of the goods category i can be derived by applying Roy's identity to the indirect utility function given by equation (2). We obtain the budget equation for each good category i to be estimated:

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{i,j} \ln p_j + \beta_i \ln \left(\frac{m}{a(p)} \right) + \frac{\lambda_i}{b(p)} \left[\ln \left(\frac{m}{a(p)} \right) \right]^2. \tag{6}$$

Some conditions must be set on parameters to respect the theory:

$$\sum_{i=1}^{k} \alpha_i = 1, \quad \sum_{i=1}^{k} \beta_i = 0, \quad \sum_{i=1}^{k} \gamma_{ij} = 0, \quad \gamma_{ij} = \gamma_{ji}, \tag{7}$$

where the first three are additivity constraints ensuring that the sum of the expenditure shares ($\sum_{i=1}^{k} w_i$) is equal to 1. The third is a constraint of homogeneity of degree zero on prices and income (a change in income and prices by the same factor does not modify the

et al., 2019).

demand). Finally, the fourth condition is a symmetry (Slutsky) constraint. Control variables z are added in the constant term ($\alpha_i = \alpha_0 + \sum_{j=1}^{k} \eta_{ij} z_j$). In this case, we have to impose a new constraint such as $\sum_{i=1}^{k} \eta_i = 0$ to ensure the additivity constraint. Following Lecocq & Robin (2015), we use households' disposable income as an instrument to control for the endogeneity of total expenditures m. Finally, equation (6) is estimated for the k categories of goods using an iterated linear least-squares (ILLS) estimator (Lecocq & Robin, 2015).

Using the estimation results of the QUAIDS, we compute the uncompensated (Mashallian) price elasticities e^u_{ij} such as:

$$e^u_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}, \tag{8}$$

with

$$\mu_{ij} = \frac{\partial w_i}{\partial \ln p_j} = \gamma_{ij} - \mu_i(\alpha_j + \sum_k \gamma_{jk} \ln p_k) - \frac{\lambda_i \beta_i}{b(p)} \left[\ln \left(\frac{m}{a(p)} \right) \right]^2, \tag{9}$$

and

$$\mu_i = \frac{\partial w_i}{\partial \ln m} = \beta_i + \frac{2\lambda_i}{b(p)} \left[\ln \left(\frac{m}{a(p)} \right) \right], \tag{10}$$

and compensated (Hicksian) price elasticities e^c_{ij} such as:

$$e^c_{ij} = e^u_{ij} + e_i w_j, \tag{11}$$

where δ_{ij} is the Kronecker delta which is equal to one if $i = j$, and zero otherwise. As a reminder, uncompensated (cross) price elasticity measures the percentage change in the expenditure of good i following a price increase of the good i (j), holding other price and budget constant. The compensated (cross) price elasticity ignores the income effect and focuses only on the substitution effect. It measures the percentage change in the expenditure of good i following a price increase of the good i (j) when purchasing power stays constant.

2.3 Empirical results

In this section, we present the own and cross-price elasticities for the three considered goods categories (fixed Internet, mobile Internet, and other non-durable goods), computed using the QUAIDS model estimates. Then, we show the price elasticities by income decile to underline the price sensitivity heterogeneity between households.

Tables 2 and 3 present the uncompensated and compensated own and cross-price elasticities between the goods categories. Own price elasticities of a good category are given in diagonal of the tables, while cross-price elasticities between goods categories are the terms off-diagonal. We find that French households react to a change in fixed and mobile Internet prices by adjusting their expenditures, although the price elasticity is less than 1 in absolute value. The uncompensated and compensated price elasticities of fixed internet are around -0.927 and -0.935, while those of mobile internet are around -0.909 and -0.923. The (un)compensated price elasticities of the other non-durable goods category also show the expected negative sign. We find negative cross-price elasticities between fixed and mobile Internet expenditures, indicating that fixed and mobile Internet expenditures are complementary. This complementary effect can be weak and is non-symmetric. Considering the uncompensated cross-price elasticities given in Table 2, an increase in 10% of the price of fixed Internet would lead to a decrease in mobile Internet expenditure by approximately 5.4%. An equivalent increase in mobile price would result in a lower impact, reducing mobile Internet expenditure by approximately 2.5%. The impact is similar if we consider compensated cross-price elasticities given in Table 3.

Table 2: Uncompensated cross-price elasticities

	Fixed Internet	**Mobile Internet**	**Other non-durable goods**
Fixed Internet	-0.927***	-0.250***	0.954***
	(0.012)	(0.011)	(0.012)
Mobile Internet	-0.546***	-0.935***	1.160***
	(0.021)	(0.020)	(0.018)
Other non-durable goods	0.017***	0.020***	-1.137***
	(0.001)	(0.001)	(0.003)

Notes: This table presents the uncompensated cross-price elasticities calculated at the sample mean and obtained with the results of QUAIDS estimation. The element in row i and column j is the uncompensated price elasticity of good i to the price of good j. Uncompensated (cross) price elasticity measures the percentage change in the expenditure of good i in response to an increase in the price of the good i (j), holding other price and budget constant.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are reported in parentheses.

Table 3: Compensated cross-price elasticities

	Fixed Internet	**Mobile Internet**	**Other non-durable goods**
Fixed Internet	-0.909***	-0.241***	1.150***
	(0.012)	(0.011)	(0.013)
Mobile Internet	-0.520***	-0.923***	1.443***
	(0.021)	(0.019)	(0.022)
Other non-durable goods	0.106***	0.061***	-0.167***
	(0.003)	(0.003)	(0.005)

Notes: This table presents the compensated cross-price elasticities calculated at the sample mean and obtained with the results of QUAIDS estimation. The element in row i and column j is the compensated price elasticity of good i to the price of good j. Compensated (cross) price elasticity measures the percentage change in the expenditure of good i in response to an increase in the of the good i (j), when purchasing power stays constant.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are reported in parentheses.

It is worth noting that we find complementarity between fixed and mobile Internet expenditures and not between consumption which are distinct concepts, especially as the Internet is sold through the form of subscription. Generally, fixed Internet subscriptions include unlimited access to the Internet. The difference in subscription prices comes from Internet quality (e.g., fiber versus ADSL) and the additional services included, such as fixed telephony and television. Therefore, a change in fixed Internet expenditure does not necessarily result in a change in Internet consumption. Mobile subscriptions rarely offer unlimited access to mobile Internet data but a volume of data that can be used without additional charges. Therefore, a change in mobile Internet expenditure can result in a change in mobile data consumption. Nevertheless, the user does not necessarily consume all the mobile data of its subscription. Furthermore, mobile subscriptions also include additional services (e.g., mobile telephony) and are sold with different quality (e.g., 4G versus 5G). The users can, therefore, switch to a cheaper subscription with less data or additional services without reducing their Internet consumption. Our database does not allow us to differentiate between Internet expenditure and consumption, but we make this distinction and discuss it in more detail in the theoretical framework presented in the following section.

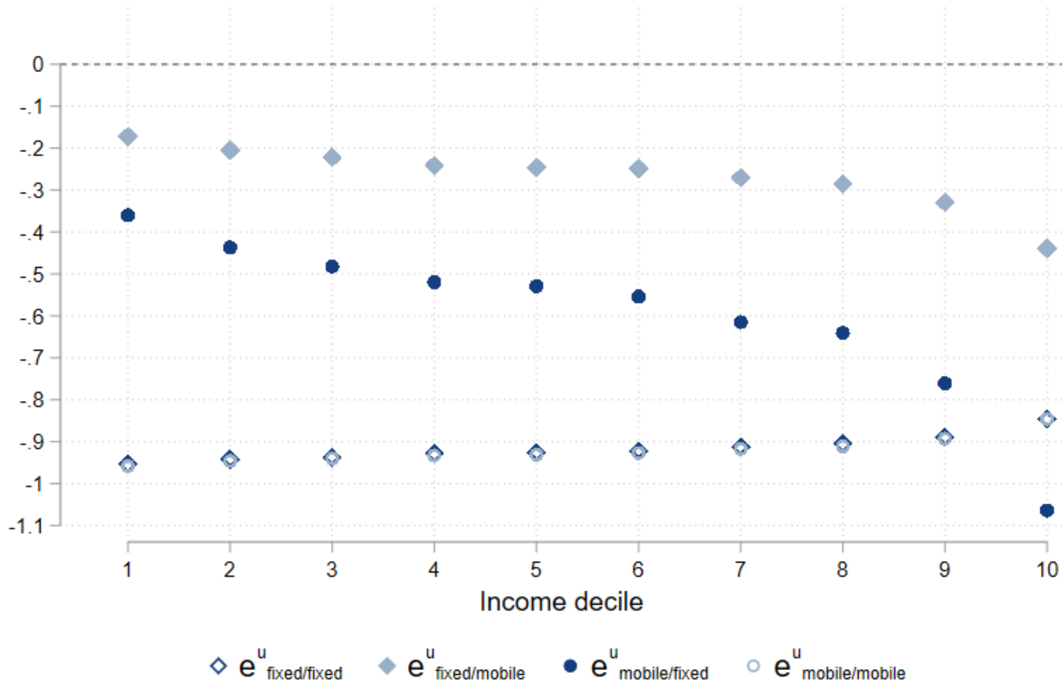
Figure 2 provides the uncompensated price elasticities of fixed and mobile Internet across income deciles.[6] It highlights that French households are heterogeneous in their price sensitivity: the price elasticities in absolute value slightly decrease with the income level. Low-income households are more sensitive to an Internet price change. Since the Internet represents a higher share of expenditures among low-income households as highlighted in Figure 1c, any increase in Internet prices exerts a more important impact on their budget, making them more likely to reduce Internet expenditure in response. Interestingly, this heterogeneity becomes more pronounced when examining cross-price elasticities. The complementarity between fixed and mobile Internet expenditures is stronger among high-income households. For these households, an increase in the price of one type of Internet service (fixed or mobile) is more likely to lead to adjustments in expenditures on both services. On average and intuitively, households are more likely to reduce their fixed Internet expenditures than mobile expenditures when fixed Internet prices increase. Similarly, when mobile internet prices increase, households tend to adjust their expenditures by reducing mobile expenditures more than fixed ones. However, an exception emerges in the last income decile: the average cross-price elasticity of mobile Internet expenditure to the price of fixed Internet is higher in absolute value than the own price elasticity of fixed Internet. It implies that, following a price increase in fixed Internet, the 10% of households with the highest income, will on average decrease their mobile Internet expenditure more than their fixed one.

Several factors can contribute to the complementarity between fixed and mobile Internet expenditures: mobile Internet's limited data allowances compared to fixed subscriptions, the bundling of services with each type of Internet connection, and the different contexts in which these connections are typically used, such at home or outside but also according to the digital equipment used and the type of online activities (e.g., communication, video-games).

In the following section, we introduce a model that shows how the non-substitutability between fixed and mobile Internet expenditures depends on the specific tariff structures offered by Internet Service Providers.

[6] We only display uncompensated price elasticities as they are very similar to compensated price elasticities in the case of fixed and mobile Internet.

Figure 2: Uncompensated own and cross price elasticity by income decile



Notes: This figure presents the uncompensated cross-price elasticities calculated at the sample mean of each income decile and obtained with the results of QUAIDS estimation. e_{ij}^{u} is the uncompensated price elasticity of expenditure on good i to the price of good j.

3 Theoretical analysis of data expenditures

This section aims to develop a simple theoretical model for decision-making regarding fixed and mobile data expenditures, which supports the empirical results obtained in the previous section. It demonstrates that the lack of substitution or the weak complementarity between mobile and fixed data expenditures arises from the type of tariff offers present in the market. To this aim, we explore a range of potential tariff offers, including unit prices for fixed and mobile Internet data, bundles with unlimited fixed data and additional services, and subscriptions allowing consumption of a certain volume of mobile data without additional charges.

Two important assumptions are made. First, we consider a Cobb-Douglas utility function to assume that the goods under consideration are substitutable. In other words, we demonstrate that under some conditions regarding existing tariff offers, mobile and fixed data expenditures can be either non-substitutable or weakly complementary even with goods that are *de facto* substitutable. Second, Internet Service Providers' offers are considered exogenous. This is an important assumption that does not take into account the strategic decisions of Internet providers. However, it allows us to study whether mobile and fixed data expenditures are complementary, substitutable or independent.

3.1 The benchmark model with unit prices

We consider a representative agent who decides on her data purchases. She potentially has access to the following four goods: mobile data, fixed data, additional services associated with fixed data, and another consumption good, say the numeraire.[7] Assume that all the goods are sold at unit prices. We denote by x_0 the quantity of consumption good, by x_m the quantity of mobile data, by x_f the quantity of fixed data, and by s_f the quantity of fixed data-related services.[8] The utility function of a price-taker representative agent, $U(x_0, x_m, x_f, s_f)$, takes the following functional form:

$$U(x_0, x_m, x_f, s_f) = x_0^{\alpha} x_m^{\beta} x_f^{\gamma} s_f^{1-\alpha-\beta-\gamma}. \tag{12}$$

Let us denote by p_0, p_m, p_f, and p_s, respectively, the prices of the consumption good, mobile data, fixed data, and services related to fixed data. Assume for simplicity that $p_0 = 1$. Defining by w the wealth, the budget constraint of the representative household is given by:

$$w \leq p_f x_f + p_m x_m + p_s s_f + x_0. \tag{13}$$

[7]The services associated with fixed data are often included in Internet Service Providers' offers and serve to differentiate the subscription. For the sake of simplicity, we do not consider services associated with mobile data. However, considering them does not qualitatively change our results.

[8]Note that the consumption good allows us to take into account the wealth effects resulting from an increase or decrease in data prices.

The Lagrangian is given by:

$$\mathcal{L} = U(x_0, x_m, x_f, s_f) - \lambda(w - (x_0 + p_f x_f + p_m x_m + p_s s_f)). \tag{14}$$

Differentiating the Lagrangian with respect to the four consumption goods allows us to derive the following demand functions:

$$x_0 = \alpha w, \quad x_m = \frac{\beta}{p_m} w, \quad x_f = \frac{\gamma}{p_f} w, \quad s_f = \frac{1 - \alpha - \beta - \gamma}{p_s} w. \tag{15}$$

The above result is standard: the representative agent allocates a constant portion of her income to each good and goods are substitutes. In what follows, we consider non-unit pricing offers to study how the non-substitution between mobile and fixed data expenditures, empirically highlighted above, stems from the type of tariff offers provided by fixed and mobile Internet Service Providers.

3.2 The model with fixed data subscriptions

Let us now focus on the situation where the representative agent can procure a subscription enabling unlimited consumption of fixed data. Internet Service Providers differentiate their subscription offers. The representative agent can choose between two bundles offering unlimited fixed data and data-related services. Each bundle has a price T_i and a service level s_i, with $T_1 < T_2$ and $s_1 < s_2$.[9] The prices of the other two goods remain unchanged and are still unit prices. The representative agent can either purchase one of the two bundles or neither.

We assume that if the representative agent does not buy any fixed Internet bundle, she can still access fixed data through a free Wi-Fi network, such as in public city networks, educational institutions, airports, but also office buildings, shopping malls, restaurants, and so on. Of course, the quality and extent of such Internet connection varies from city to city

[9] These latter services can also be seen as a proxy for the quality of the service.

and country to country.[10] We thus define $\bar{x}_f$ and $\bar{s}_f$ as the level of mobile data consumption and data-related services, respectively, by the agent in the absence of a subscription.

In this scenario, we distinguish between consumption and purchase. If the representative agent buys a fixed Internet subscription, she can consume as much fixed data as she likes, but obviously, she will, in reality, consume only a limited volume of data. We shall add three reasonable assumptions to account for the distinction between purchasing and consuming fixed data. (i) We assume that the agent anticipates a fixed level of data consumption because purchasing decisions are taken before data consumption. Let the agent's ex-ante anticipation of fixed data consumption be denoted by $\tilde{x}_f$. This anticipation allows us to determine whether the agent purchases a fixed Internet subscription and, if so, which bundle is chosen. (ii) We consider that $\tilde{x}_f^2 > \tilde{x}_f^1$, meaning that the anticipation of fixed data use is greater for the representative agent if she takes the bundle 2, because she anticipates more services and better quality, and therefore anticipates greater data use (if you have access to faster Internet, you anticipate consuming more data). (iii) The purchasing decisions are no longer simultaneous. The rationale behind prioritizing subscription decisions over other purchases is that these decisions have an impact over a longer period and are taken before day-to-day expenditures. We thus consider the following timing: first, the agent can abstain from subscribing or selecting either the bundle 1 or the bundle 2. Second, she determines the numeraire and mobile data consumption levels.

Resolving using backward induction, one can determine x_0 and x_m according to whether the agent has not purchased a subscription or purchased the first or the second. If the representative agent has not subscribed to any bundle, her utility is given by $U(x_0, x_m, \bar{x}_f, \bar{s}_f)$ and her available wealth by w. Given that the consumer maximizes her utility by choosing x_0 and x_m, the demand functions for these two goods are given by:

$$x_0 = \frac{\alpha}{\alpha+\beta}w \quad x_m = \frac{\beta}{\alpha+\beta}\frac{w}{p_m}. \tag{16}$$

[10] Such an assumption could have been considered previously in the case of unit prices, but it would have been innocuous and would not have changed qualitatively the results.

If the representative agent has purchased the bundle i, her utility is $U(x_0, x_m, \tilde{x}_f^i, s_i)$ and her available wealth $w - T_i$. The consumer maximizes her utility by choosing x_0 and x_m, and the demand functions are as follows:

$$x_0 = \frac{\alpha}{\alpha+\beta}(w - T_i) \quad x_m = \frac{\beta}{\alpha+\beta}\frac{(w-T_i)}{p_m}. \tag{17}$$

Using equations (16) and (17), we obtain that the consumer purchases the bundle 1 instead of not purchasing if and only if $T_1 < T_1^*$ with:

$$T_1^* = \left(1 - \left(\frac{\bar{x}_f}{\tilde{x}_f^1}\right)^{\frac{\gamma}{\alpha+\beta}} \left(\frac{\bar{s}_f}{s_1}\right)^{\frac{1-\alpha-\beta-\gamma}{\alpha+\beta}}\right) w, \tag{18}$$

and the bundle 2 instead of the bundle 1 if and only if $T_2 < T_2^*$ with:

$$T_2^* = \left(1 - \left(\frac{\tilde{x}_f^1}{\tilde{x}_f^2}\right)^{\frac{\gamma}{\alpha+\beta}} \left(\frac{s_1}{s_2}\right)^{\frac{1-\alpha-\beta-\gamma}{\alpha+\beta}}\right) w + \left(\frac{\tilde{x}_f^1}{\tilde{x}_f^2}\right)^{\frac{\gamma}{\alpha+\beta}} \left(\frac{s_1}{s_2}\right)^{\frac{1-\alpha-\beta-\gamma}{\alpha+\beta}} T_1. \tag{19}$$

We can provide compelling insights through several observations. First, the threshold T_1^* increases with the consumer's revenue (w), the anticipation of the consumption with bundle 1 ($\tilde{x}_f^1$) and the data-related services provided by bundle 1 (s_1) and decreases with the level of mobile data consumption ($\bar{x}_f$) and data-related services ($\bar{s}_f$) in the absence of a subscription. Of course, a drop in the price of bundle 1 increases the likelihood that the consumer purchases this bundle instead of not purchasing it. Second, the threshold T_2^* increases with the consumer's revenue and the price of bundle 1. Moreover, given that $w > T_1$, it also increases with the anticipation of the consumption with bundle 2 ($\tilde{x}_f^2$) and the data-related services provided by bundle 2 (s_2) while it decreases with the anticipation of the consumption with bundle 1 ($\tilde{x}_f^1$) and the data-related services provided by bundle 1 (s_1). Third, an increase in the price of the more expensive bundle (T_2) can affect mobile data consumption differently. If the price rises but does not lead to a switch by the consumer from the more expensive bundle to the cheaper one (she purchases 1 instead of 2), then mobile data expenditure will fall as the available wealth $(w - T_2)$ decreases. However, if the price of bundle 2 increases and that of the other bundle does not (or not sufficiently), then the consumer buys the cheapest bundle and her mobile data expenditure increases. These results echo the empirical results presented in the previous section: under some conditions, we find that fixed and mobile expenditures are non-substitutable.

3.3 The model with fixed and mobile data subscriptions

We can now introduce a new tariff offer to isolate the effect on mobile subscriptions while maintaining existing assumptions. We focus on studying mobile Internet subscriptions, including a set volume of mobile data at no extra cost. As before, since subscription decisions are taken before consumption, we assume that the agent anticipates a level of mobile data consumption. We assume that this is endogenous to the offers made for mobile data. The idea behind this is that if you buy a subscription with a lot of data, you anticipate consuming more than if you buy a package with little data. Of course, another possibility would be to consider that the consumer has an exogenous anticipation and that if the number of data proposed is lower, he will then anticipate consuming the maximum amount. However, with fairly heterogeneous offers, the result would be the same: the agent would have two different levels of anticipation. Another reason for considering that anticipations are different is that offers with a greater number of mobile data are often accompanied by a greater number of services. The anticipation assumption will be discussed below. Again, the agent can choose between two offers, called A and B, each characterized by a price M_i and a maximum quantity $\overline{q}_i$ of mobile data. We suppose $M_A < M_B$ and $\overline{q}_A < \overline{q}_B$. Moreover, let $\tilde{x}_m^A$ and $\tilde{x}_m^B$, the mobile data consumption anticipated respectively for subscriptions A and B, with $\tilde{x}_m^A < \tilde{x}_m^B$. In this scenario, $x_0 = w - T_i - M_i$, depending on the chosen Internet access option. The agent faces four possibilities: she may opt for no subscription, no mobile data subscription but a fixed data subscription (either subscription 1 or subscription 2), a mobile data subscription (either subscription A or subscription B) but no fixed data subscription, or both fixed and mobile data subscriptions. Furthermore assume for simplicity that $T_2 = T_1 + \rho^T$, with $\rho^T > 0$ and $w > T_2 + M_B$. The first assumption means that the price differential between the two bundles is fixed. Of course, this is a restrictive but simplifying assumption, since it allows us to take into account the simultaneous increase in both prices. The second assumption means that income is sufficient to purchase the most expensive fixed Internet bundle and the most expensive mobile Internet subscription. Finally, let (i, j) be the couple compound of the mobile subscription i and the fixed subscription j.

To study the effect of subscription price increases on mobile and fixed data expenditure, let us first define the utility that the consumer gets following the four alternatives, depending on the purchased fixed and mobile data subscriptions. Since the equilibria are corner solutions, we express the utility according to the couple of the chosen subscriptions. The utilities are given by:

i) $U(1, A) = (w - T_1 - M_A)^{\alpha}(\tilde{x}_m^A)^{\beta}(\tilde{x}_1^f)^{\gamma}(s_1)^{1-\alpha-\beta-\gamma}$,

ii) $U(1, B) = (w - T_1 - M_B)^{\alpha}(\tilde{x}_m^B)^{\beta}(\tilde{x}_1^f)^{\gamma}(s_1)^{1-\alpha-\beta-\gamma}$,

iii) $U(2, A) = (w - T_2 - M_A)^{\alpha}(\tilde{x}_m^A)^{\beta}(\tilde{x}_2^f)^{\gamma}(s_2)^{1-\alpha-\beta-\gamma}$,

iv) $U(2, B) = (w - T_2 - M_B)^{\alpha}(\tilde{x}_m^B)^{\beta}(\tilde{x}_2^f)^{\gamma}(s_2)^{1-\alpha-\beta-\gamma}$.

We can easily compare the different alternatives and observe that $U(1, A) > U(1, B)$ if $\alpha > \bar{\alpha}$ and $U(2, A) > U(2, B)$ if $\alpha > \underline{\alpha}$ with $\bar{\alpha} = \frac{\beta \log\left(\frac{\tilde{x}_m^B}{\tilde{x}_m^A}\right)}{\log\left(\frac{w-T_1-M_A}{w-T_1-M_B}\right)} > \frac{\beta \log\left(\frac{\tilde{x}_m^B}{\tilde{x}_m^A}\right)}{\log\left(\frac{w-T_1-M_A-\rho^T}{w-T_1-M_B-\rho^T}\right)} = \underline{\alpha}$, $\forall\ T_1 \in [0, \bar{T}_1]$ with $\bar{T}_1 = w - M_B - \rho^T$. Since both thresholds $\bar{\alpha}$ and $\underline{\alpha}$ decrease with T_1, given parameter values, three different scenarios can emerge depending on the value of T_1:

- If $\alpha > \bar{\alpha} > \underline{\alpha}$ then the chosen couple will be either $(1, A)$ or $(2, A)$;
- If $\bar{\alpha} > \alpha > \underline{\alpha}$ then the chosen couple will be either $(1, B)$ or $(2, A)$;
- If $\bar{\alpha} > \underline{\alpha} > \alpha$ then the chosen couple will be either $(2, B)$ or $(2, A)$.

The greater the weight given by the consumer to the consumption good, the more likely the consumer is to buy one of the cheapest subscriptions. In all the cases, the choice between the two couples will depend on consumption expectations and prices. Of course, the chosen couple will be the one that generates the most utility. Price changes can alter this choice, but can also alter the comparison between α and the two thresholds $\bar{\alpha}$ and $\underline{\alpha}$. Put another way, a price change in the fixed bundle may alter choice in one interval, but it may also put the consumer in another interval, where her choice will be between other couples of subscriptions. It follows that an increase in the price of fixed data subscriptions may result in one of two outcomes: first, an increase in fixed Internet expenditures; or second, a decrease in the fixed data subscription. The latter scenario could be accompanied by either an increase or a decrease in expenditures on mobile data subscriptions, depending on the extent to which mobile data expenditures are a substitute or a complement for fixed data services expenditures. We provide a numerical example showing the possible emergence of complementarity between mobile and fixed data expenditures in Appendix B.

3.4 Discussion

In a very simple framework, our model shows that under certain conditions based mainly on the specific features of fixed and mobile data tariffs, non-substitutability or even complementarity between fixed and mobile Internet expenditures can occur. These results are in line with the empirical findings presented in this article, which show that fixed and mobile Internet expenditures are complementary (see Tables 2 and 3). We will now discuss the robustness of our results, and propose explanations for our empirical findings, based on our theoretical results and assumptions.

The role of tariff offers specific to the fixed and mobile Internet markets is central to explaining the non-substitutability of fixed and mobile Internet expenditures. We assume a Cobb-Douglas function (in other words, that consumers consider the two goods to be substitutable from the point of view of their preferences) and that, depending on the type of tariff offer used, expenditure is substitutable when prices are unitary, non-substitutable when there is a subscription allowing unlimited consumption of fixed data, and may even be complementary in certain cases when there are subscriptions for mobile data and fixed data.

However, the assumption that the consumer regards the two goods as substitutable is particularly debated in the literature, and rejecting it would naturally lead to additional determinants of the complementarity of fixed and mobile Internet expenditures. Indeed, in our model, it seems reasonable to assert that with a utility function presenting complementary goods, the presence of tariff offers specific to this market would lead to a complementarity of expenditure linked to fixed and mobile internet (the two effects, that come from preferences and from the presence of these specific tariff offers, would go in the same direction). Households may perceive fixed and mobile Internet subscriptions as complementary because the use cases for each differ. Mobile Internet can be used outside the home, but data allocation in typical mobile subscriptions is limited. On the other hand, fixed Internet subscriptions offer unlimited Internet data, but can only be used in proximity to the Internet box, usually at home. As a result, households often engage in data-intensive activities (e.g., gaming, video streaming) using fixed Internet (Quaglione *et al.*, 2020), while activities like social networking and Internet telephony are more commonly performed on mobile Internet (Kongaut & Bohlin, 2016).

Similarly, in the model, we have not taken into account the possible presence of switching costs. The presence of switching costs in our model should, a priori, also lead to a complementarity of fixed and mobile Internet expenditures, at least for sufficiently large switching costs. Switching costs seem present in both the fixed and mobile Internet markets. Indeed, there may be contractual barriers when households sign for a long-term contract. This commitment period is usually present when the subscription is sold with handset subsidies. There also exist financial costs due to, for instance, the installation fees of a new subscription. However, switching costs seem to have diminished in France. First, offers with commitment periods and handset subsidies are decreasing and represented only 16.7% of mobile Internet subscriptions in 2023 (ARCEP, 2024). This is partly due to the arrival of Free mobile on the market in 2012, which introduced low-cost offers. Existing Internet service providers immediately responded by launching their own low-cost brands (Bourreau *et al.*, 2021). The availability of mobile number portability has decreased switching costs associated with mobile Internet subscriptions (Maicas *et al.*, 2009; Sánchez & Asimakopoulos, 2012). However, there are other types of switching costs, such as those incurred in switching from a package with several subscriptions to several subscriptions. Indeed, fixed Internet subscriptions usually include fixed telephony and television. Some Internet Service Providers also include discounts on streaming platforms like Netflix in their premium plans. Mobile Internet subscriptions also feature various services such as unlimited calls, free calls abroad, 5G access, and dual sim cards. Discounts on bundled services may create barriers to switching subscriptions, even after price increases, by raising switching costs. This can also explain why the complementary effect is stronger for high-income households in our empirical results as highlighted in Figure 2. Indeed, high-income households pay on average more expensive fixed Internet subscriptions (Figure 1a).

We can also question one of the model's other important assumptions that Internet Service Providers' offers are exogenous. Internet Service Providers are few in the market, and are therefore strategic. Internet Service Providers maximize then their profits by setting higher prices than in the competitive case. In the case of strategic Internet Service Providers, we can ask whether the results found in the model would be affected. To do this, let us assume that we have a monopoly in each market, fixed Internet data and mobile Internet data. Each monopoly would propose different offers to discriminate between consumers according to their willingness to pay. If a monopoly has two offers on its market, modifying one offer will inevitably mean modifying the second. If one monopoly raises prices in its market, demand in the other market will be less elastic and the other monopoly will be able to raise its prices. In other words, all the prices would be interrelated, and a change in one would lead to a change in all the others. Rising prices for strategic reasons in both markets may be one additional explanation for the observed complementarity.

4 Conclusion

This paper aims to empirically and theoretically assess whether fixed and mobile Internet are substitutable, independent or complementary. In the first part, we estimate a QUAIDS model using data from the latest Household Budget survey conducted by Insee in 2017. It enables us to compute own-price and cross-price elasticities for three categories of goods: fixed

Internet, mobile Internet, and other non-durable goods. The analysis of French household behaviour reveals how households adjust their expenditures in response to price changes for Internet subscriptions. The own-price elasticities for fixed and mobile Internet are approximately -0.927 and -0.909, respectively, indicating significant price sensitivity. This sensitivity decreases with income levels. More notably, we find that fixed and mobile Internet expenditures are complementary, and this complementary effect strengthens as household income rises.

In the second part, we develop a simple theoretical framework to explain the complementarity in French household expenditures between fixed and mobile Internet. We assume a Cobb-Douglas utility function to show that, even with substitutable goods, complementarity in expenditures can emerge. In the model, the complementarity effect is due to the specific tariff offer in the telecommunication market. More precisely, we show that when fixed and mobile Internet are sold through the form of subscriptions including (un)limited data allocation and bundled with additional services, the expenditures on these two types of Internet can exhibit non-substitutability or even complementarity. In contrast, this complementarity does not arise when Internet data is sold at a unit price.

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A Data description

Table A.1: Description of the non-durable goods categories included in the demand system estimation

COICOP	**Good category**
Food products and non-alcoholic beverages	
C0111	Bread and cereals, cereal-based products
C0112	Meat
C0113	Fish and seafood
C0114	Milk, cheese and eggs
C0115	Oils and fats
C0116	Fruits
C0117	Vegetables including potatoes and other tubers
C0118	Sugar, jam, honey, chocolate, ice cream and confectionery
C0119	Other food products
C0121	Coffee, tea, cocoa
C0122	Mineral water, soft drinks, syrups and juices
Clothing and footwear	
C0312	Clothing
C0313	Other articles of clothing, clothing accessories and haberdashery
C0314	Cleaning, repair and rental of clothing
C0321	Shoes and other footwear
C0322	Shoe repair and rental
Water, electricity, gaz, and fuel	
C0443	Water Bills
C0451	Electricity
C0452	Gas and liquefied fuels (town gas, butane...)
C0453	Purchases of liquid fuels: fuel oil, heating oil, petrol
C0454	Purchases of solid fuels: charcoal, coal, coke, wood, other fuel
C0455	Thermal energy
C0722	Fuels and lubricants, antifreeze...
Leisure	
C0941	Sports and recreation services
C0942	Cultural services
C0943	Games of chance
Restaurants and hotels	
C1111	Restaurants and cafes
C1112	Cafeteria
C1120	Hosting Services

Note: COICOP is the Classification of Individual Consumption by Purpose implemented by the United Nations Statistics Division.

B Numerical illustration

In this appendix, we numerically show that an increase in the price of fixed data subscriptions can lead to either an increase in fixed Internet expenditure for the representative agent or a decrease in the fixed data subscription associated with either an increase or a reduction in the expenditures of mobile data subscriptions. In the latter case, fixed and mobile data expenditures are thus complementary. We thus focus on the case $\bar{\alpha} > \alpha > \underline{\alpha}$, and consider a consumer that purchases the most expensive fixed data subscription and the less costly mobile data subscription, (T_2, M_A). An increase in the price of fixed data subscriptions can lead to either an increase in fixed Internet expenditures for the representative agent or a switch from one couple to another one. What is interesting to show is that the change to another couple can be either from (T_2, M_A) to (T_1, M_B) or from (T_2, M_A) to (T_1, M_A).

Assume, for instance, the following parameter values: $w = 15$, $\tilde{x}_m^A = 0.75$, $\tilde{x}_m^B = 1$ $\tilde{x}_1^f = 1.5$, $\tilde{x}_1^f = 2$, $s_1 = 0.5$, $s_2 = 1$, $\alpha = 0.3$, $\beta = 0.1$, $\gamma = 0.15$ and $\rho^T = 2$. Figure C.1 describes the possible scenarios that can emerge depending on the value of T_1. For a low level of T_1, for instance, when $T_1 \to 0$ the level of $\bar{\alpha}$ is at its maximum level, and given parameters' values it is larger than $\alpha = 0.33$. In this case, the consumers choose either $(2, B)$ or $(2, A)$. In the case represented in Figure C.1, they choose $(2, B)$ (orange area). As T_1 increases, the α thresholds decreases until the point where $\alpha = \underline{\alpha}$. In this case, a marginal increase in T_1 implies that $\bar{\alpha} > \alpha > \underline{\alpha}$. It follows that the chosen couple will be either $(1, B)$ (orange area) or, if T_1 increases further the couple $(2, A)$ (green area). A further increase in T_1 would imply that $\bar{\alpha} > \underline{\alpha} > \alpha$. In this case, the preferred couples are $(2, A)$ (green area) or $(1, A)$ (grey area). When T_1 is such that $\alpha \to \bar{\alpha}$ then the preferred couple will be $(2, A)$. However, when T_1 is sufficiently high the consumer will choose the couple $(1, A)$, as shown in Figure C.1. Thus, complementary is a possible outcome that is more likely to emerge when the price of the fixed bundle is sufficiently high.

Figure C.1: Numerical illustration