Market Entry, Fighting Brands and Tacit Collusion:

Evidence from the French Mobile Telecommunications Market*

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Abstract

We study a major new entry in the French mobile telecommunications market, followed by the introduction of fighting brands by the three incumbent firms. Using an empirical oligopoly model with differentiated products, we find that the incumbents' fighting brand strategies cannot be rationalized as unilateral best responses to new entry in a static game. Instead, we show how the incumbents' strategies can be rationalized as a breakdown of tacit collusion: in the absence of entry the incumbents could successfully collude on restricting their product variety to avoid cannibalization; the new entry of the low-end competition made such semi-collusion harder to sustain because of increased business stealing incentives. Consumers gained considerably from the added variety of the new entrant and the fighting brands, and to a lesser extent from the incumbents' price response to the entry.

Keywords: entry, fighting brand, semi-collusion, product variety, mobile telecommunications

JEL codes: L13, L96

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1 Introduction

In many concentrated markets, new entrants challenge incumbent firms by offering a relatively low quality brand at a competitive price. Instead of simply lowering the price of their existing products, the incumbents often respond by introducing *fighting brands*. As shown by Johnson and Myatt (2003), a monopolistic incumbent may have a strategic interest to introduce such a brand as a way to accommodate new entry in the low-end segment, which it would not want to serve otherwise. There are plenty of examples of markets with new entry followed by the introduction of fighting brands. Intel, the dominant microprocessor producer, introduced a low-cost brand (Celeron) to preserve its market leadership, which was challenged by AMD. The largest European airlines, such as Lufthansa and Air France, have also established independent low-cost subsidiaries (Germanwings and HOP!, respectively) in an effort to cope with the competition from an increasing number of low-cost carriers. In the Canadian mobile telecommunications industry, the three largest mobile service providers (Rogers, Bell, and Telus) launched subsidiary brands (Chatr, Koodo, and Solo, respectively) to discourage the growth of new low-cost entrants in 2010 (Marlow, 2010).

While the prior literature has provided theoretical insights on the market primitives that can prompt an incumbent firm to respond to entry through product line expansion, there exists no empirical analysis that rationalizes such a strategy. Furthermore, the existing theoretical literature has mostly limited its attention to the analysis of a monopolist incumbent. Hence, it is unclear whether the fighting brand strategy can emerge as an equilibrium under oligopolistic competition among multiple incumbent firms.

To fill this gap, we examine the French mobile telecommunications market, where incumbent operators introduced new subsidiary brands in response to the arrival of a fourth entrant in 2012. Since 2001, 3G mobile services in France had been supplied by three mobile network operators (MNOs): Orange, SFR, and Bouygues Telecom. To stimulate competition in the mobile sector, the French regulatory authority, ARCEP,[1] granted the fourth 3G radio spectrum license to Free Mobile in 2010 (ARCEP, 2013, p. 81). Within a few months prior to the anticipated entry in early 2012, all three incumbents introduced subsidiary brands to provide low-cost services.[2] The price and quality levels of the subsidiary brands were closely matched to Free Mobile's once the entrant started offering its service to consumers (ARCEP, 2013, p. 83).

The (almost) simultaneous introduction of subsidiary brands by the incumbents, along with its timing, suggests a possibility that their product line expansions were strategically motivated in the face of entry. This is also indicated in the statements from the businesses. For example, Orange's CEO announced at the launch of Sosh, "this is our 'low cost' answer, but not 'low service' or 'low value' vis-à-vis our customers"; and in the context of Free Mobile's entry: "We have been thinking of a whole arsenal of projects to maintain our leadership, to go further in the segmentation of the mobile market. That's why we decided to launch a new brand."[3]

The first objective of this paper is to thoroughly examine the incumbents' underlying incentives to engage in such product strategies through analyzing their counterfactual product line decisions (in the absence of entry). Our second objective is to assess the welfare implications of the fighting brand strategy in the context of entry of a new market player: i.e., to quantify the size of its welfare impact in comparison to the standard

[1] Autorité de régulation des communications électroniques et des postes.

[2] Orange, SFR, and Bouygues Telecom launched the Sosh, RED, and B&You brands, respectively. The launch was on a very limited scale until Free Mobile finally entered.

[3] The quotes are available from Les Echos 28/07/2011 and Le Point 7/09/2011. The low-cost services of the incumbents were referred by business press articles as "Free killer offers" (Nouvel Observateur, 15/12/2011) and "anti-Free weapon" (Les Echos, 28/07/2011).

price and variety effects from entry.

To address these questions, we construct a dataset on the French mobile telecom industry for 2011–2014. In the first step, we estimate a differentiated products demand and consider an oligopoly setting where the network service providers compete in both the wholesale and retail markets. In the second step, we use the empirical model to examine the fighting brand theory. We compute the counterfactual profits under alternative product line and entry decisions to assess whether and to what extent the incumbents had a strategic incentive for launching their subsidiary brands in response to the entry of Free Mobile. In the third step, we compute the impact of entry on consumers and total welfare and decompose it into three different sources: (i) a variety effect that stems from the availability of the entrant's new differentiated service; (ii) a price competition effect due to the incumbents' price responses; and (iii) (potentially) a fighting brand effect from the incumbents' new subsidiary brands.

We find empirical support for the fighting brand theory, but the main intuition requires extending the story of Johnson and Myatt (2003). The crucial difference derives from the strategic interactions among multiple incumbent firms in our analysis. In particular, we find that the incumbents' fighting brand strategies cannot be rationalized as unilateral best responses to new entry in a static game. Instead, we show how the incumbents' strategies can be rationalized as a breakdown of tacit collusion: in the absence of entry the incumbents could successfully collude on restricting their product lines to avoid cannibalization; the new entry of the low-end competition made such semi-collusion harder to sustain because of increased business stealing incentives.

To establish these findings, we first obtain empirical evidence that the three incumbents saw no *joint* profit incentives for collectively releasing fighting brands before the entry of Free Mobile, and that the joint incentives became stronger in the post-entry market. Intuitively, without entry the incumbents' low-cost brands would merely cannibalize each others' profits, while in the presence of entry they would also steal business from the entrant. Nevertheless, the incumbents' joint incentives did not increase sufficiently to rationalize the fighting brands as a collective action after entry. This leads us to alternatively consider a simultaneous one-shot game to examine whether the entry increased the incumbents' *unilateral* incentives to independently release a fighting brand, but we do not find support for this either. This static view would require sufficiently low fixed costs to rationalize the launch of fighting brands as a non-cooperative Nash equilibrium after entry, while sufficiently high fixed costs to account for their absence before entry. However, it turns out that there exists no viable range of fixed costs supporting both restrictions.

We therefore consider a game theoretic framework of repeated interaction to explore the view that the incumbents were colluding on restricting their product lines to avoid cannibalization while competing on prices with differentiated products. We investigate firstly whether such product collusion can emerge as an equilibrium in the pre-entry market, and secondly whether the new entry can lead to a breakdown of the collusive equilibrium. We find that there is a non-empty range of fixed costs under which the product-line collusion can be sustained in the absence of entry, while it becomes harder to be sustained after entry. As such, this finding supports a coordinated strategy interpretation of the fighting brand hypothesis: incumbents may be able to tacitly collude on restricting product variety in the absence of entry, and new market entry can lead to a breakdown of such semi-collusion. We hasten to add that our conclusion does not necessarily imply illegal conduct, as our evidence is only indirect (relating to incentives). Nevertheless, the possible existence of product-line collusion is consistent with earlier conclusions of the French competition authority on anticompetitive agreements in the mobile telecom market. On December 1, 2005, the competition authority decided to impose a fine of €534 million to the three incumbent operators for engaging in two kinds of anticompetitive behavior: (i) sharing strategic information on new subscriptions and cancellations; (ii) an agreement from 2000 to 2002 to stabilize market shares based on jointly-defined targets, through a coordination of their commercial and marketing strategies.[4]

Finally, it seems difficult to reconcile the incumbents' new product releases with an alternative view that they were merely a marketing or product innovation in response to an unrelated event that happened to coincide with the new entry. The differentiating features or their new brands are straightforward, and similar low-cost brands were already offered in other countries. In addition, all three incumbents not only introduced their subsidiaries into the market simultaneously just before the entrant's arrival, but they also rearranged their tariff offerings immediately upon the entry (Berne, Vialle and Whalley, 2019).[5]

After establishing evidence for the fighting brand theory as a strategic response to new entry, we proceed to examine the impact of entry on consumers and total welfare. We find that the entry of Free Mobile considerably increased consumer surplus (by about €4.6 billion or about 7.7% of industry sales during the period 2012–2014). Consumers mainly benefited from the increased variety offered by Free Mobile and from the fighting brands (each responsible for 51% and 31% of the gains, respectively), and to a lesser extent from the existing operators' intensified price competition (accounting for only 18% of the consumer gains approximately). However, the entry of Free Mobile led to large losses in gross producer surplus, so that the total gross welfare benefits were more modest, estimated to be about €2.2 billion (or 3.7% of industry sales). These gross welfare gains can be attributed almost equally to the variety increase by Free Mobile and to the fighting brands (while the intensified price competition made a negligible welfare impact). The net welfare gains would be mitigated if we take into account the fixed costs of the entrant and fighting brands.

Related literature Our paper provides new insights into the question of how market structure may affect tacit collusion. From the repeated games literature, it is well known that increased concentration may facilitate collusive behavior in prices or quantities (e.g. Friedman (1971) and Tirole (1988)). Competition authorities in both the U.S. and Europe have accordingly been concerned with "coordinated effects" from mergers. Miller and Weinberg (2017) provide evidence showing how the MillerCoors joint venture facilitated price coordination with the main rival Anheuser-Busch Inbev. Our paper shows how changes in market structure may also affect semi-collusion, where firms compete in the product market (in prices or quantities), while colluding in other dimensions such as R&D (Fershtman and Gandal, 1994), capacity (Osborne and Pitchik, 1987), or location choices (Friedman and Thisse, 1993).[6]

Our paper also contributes to the literature on adjusting product lines as a fighting brand strategy, which has up to now been largely theoretical. Johnson and Myatt (2003) develop a model of vertical differentiation where fighting brand arises as monopolist's best response to entry in low-quality segment, and does not arise in the absence of such entry. Denicolò et al. (2007) find that the intensity of competition, measured

[4]A press release of the 2005 from the French Competition Authority is available in English at: `http://www.autoritedelaconcurrence.fr/user/standard.php?id_rub=160&id_article=502`.

[5]One event around the time of the entry by Free was the introduction of the EU regulation for price ceilings on wholesale roaming charges (2010 and 2011). But even if such event would induce incumbents to introduce their own low cost brands, it does not explain why such brands were already introduced in other countries.

[6]There is also an empirical literature that considers collusion in the absence of changes in market structure. Most notably, in an interesting recent paper Sullivan (2017) considers the combination of both price and product space collusion. In his setting, the two firms collude on staying in segments differentiated from each other, while in our case they may collude on remaining in the same premium-quality segment (before entry).

by product differentiation or cost efficiency, can determine an incumbent monopolist's optimal response to entry.[7] More recently, Nocke and Schutz (2018) find that the fighting brand equilibrium can be supported in a wider range of oligopoly models with horizontally differentiated products.[8] Our study complements this theoretical literature by empirically analyzing the fighting brand strategy in a non-cooperative setting with *multiple* incumbents and measuring its implications for consumer and total welfare effects of entry.

Previous empirical work has shown how firms adjust their prices in response to entry and even to the threat of entry (Goolsbee and Syverson, 2008), but there exists no evidence on product line adjustment in response to entry.[9] There is however a broader literature on the relationship between concentration and product variety, which also highlights the importance of business stealing and cannibalization forces. In the radio broadcasting industry, Berry and Waldfogel (2001) find that mergers increase aggregate product variety, which is consistent with strategic product positioning to deter entry. In the same industry, Sweeting (2010) shows how merging firms reposition their products to avoid cannibalization, without affecting aggregate product diversity. Davis (2006) finds that new movie theaters mainly steal business from competitors rather than cannibalizing sales from the chain's own existing theaters.

Several studies have considered the impact of entry and concentration in the telecommunications industry. Economides et al. (2008) measure the welfare impact of entry in the U.S. long distance telecommunications industry, but they do not consider the incumbent's strategic reaction to entry. Xiao and Orazem (2011) analyze the broadband network services market to find that the fourth entrant had only marginal impact on the market competition. In a study of the U.S. mobile telecommunications market, Seim and Viard (2011) show how entry reduced prices and induced firms to offer a greater variety of pricing plans. Nicolle et al. (2018) use hedonic regressions to quantify the price impact of Free Mobile's entry in the same French mobile market analyzed in this paper. Finally, Genakos et al. (2018) study the impact of entry and mergers in mobile telecommunications markets for a panel of OECD countries. They find that increased concentration raises not only prices but also investment per operator. The question on how changes in market structure in the mobile telecommunications industry, whether through entry or mergers, affect consumers and welfare continues to be central in the current policy debate.

The rest of the paper is organized as follows. In Section 2, we present the data and in Section 3 the model of demand and oligopoly price-setting. Section 4 reports the empirical results. In Section 5, we analyze the profit incentives to expand product lines both in the absence and the presence of entry. In Section 6, we measure the consumer and total welfare effects of entry and decompose them by various sources. Finally, we conclude in Section 7.

2 Background, data and descriptive analysis

We first discuss some relevant background on the entry of Free Mobile in the French mobile telecom market. Next, we discuss the data set on the demand and tariff characteristics for mobile services and additional data on network coverage for the period 2011-2014. Finally, we provide a preliminary description of the evolution

[7] Earlier theoretical work by e.g. Brander and Eaton (1984) and Judd (1985) studied product line decisions of competing firms, but they did not consider new market entry in their analysis.

[8] They consider a broad class of IIA demand systems, including (nested) CES and logit.

[9] Some empirical work (in particular Eizenberg (2014)) studies how firms configure their product lines in the absence of entry considerations.

of the market during the considered period.

2.1 Background

Before the arrival of new entrant Free Mobile in 2012, there were three large incumbent mobile network operators (MNOs): Orange, SFR, and Bouygues. In addition, there were a multitude of small-scale mobile virtual network operators (MVNOs), which entirely relied on wholesale access from the three incumbent networks. With a large share of the retail and wholesale markets under control, the incumbent MNOs had been able to sustain relatively high prices by limiting the availability of service contracts that are sold without long-term commitment; see the French Competition Authority's Decision of 2005 discussed in the introduction, and ARCEP (2013). Concerned by the weak competition, the government eventually facilitated the entry of the fourth network in January 2012.[10]

The new entrant Free Mobile introduced a new class of products, i.e., contract-free postpaid services. These were distinguished from the standard long-term postpaid contracts by their absence of contractual commitment, SIM-only plans without bundled handset, unlimited consumption allowances, and lower service quality (online-exclusive retail channel and customer service). To promote its new brand, the entrant launched an intensive country-wide marketing campaign, and the three incumbents immediately matched the product strategy by releasing their own branded counterparts, i.e. Sosh, SFR and B&You. Notably, the incumbents' new services were made available only through their new subsidiary brands operating separately from the existing product lines. Nevertheless, the incumbents suffered substantial loss of revenues by about 30% from each subscriber during the first two years since the entry (UFC-Que Choisir, 2014).

2.2 Data

We collect data on the consumption of mobile services in France during 2011–2014 from Kantar, a UK-based market research firm. This dataset contains information on consumers' subscribed network operators, type of service contracts (e.g., prepaid or postpaid), service attributes (e.g., allowances for call and data) including price, along with demographic information (age and income distribution for a sample of approximately 6,000 consumers). The geographical markets cover 22 metropolitan areas classified by the local administration and jurisdiction systems, aggregated to 13 region blocks following the legislation that came to effect in 2016.

The consumer database covers virtually all network operators in France, which include all three incumbent MNOs (Orange, SFR, and Bouygues), the entrant (Free Mobile), the MVNOs, and the lower quality services supplied under the incumbent's respective subsidiary brands (Sosh, Red, and B&You). Since the MVNO market is highly fragmented, we group the MVNOs by their wholesale host networks (i.e., MVNOs for Orange, SFR and Bouygues).[11] This approach reduces the dimension of the choice set, thus helping to avoid the problem of sparse observations for the small scale operators. Considering the MVNO's limited capacity for product differentiation during the sampling period, this simplifying assumption does not appear to be overly

[10] The government opened a process for comparative tender (i.e., beauty contest) to invite a potential licensee of the spectrum for UMTS (3G) standard (Hocepied and Held, 2011). It prescribed various regulations for the incumbents' call termination rates, for example wholesale access to the legacy data network (2G).

[11] While most MVNOs were hosted by a single network, Virgin mobile was the exception as it had been multihoming with all three incumbent MNOs for a limited period of time. Our solution is to randomly assign the subscribers to different MVNO groups in proportion to the share of the MNO cellular antenna stations operating in the region.

restrictive.[12]

The dataset contains information on the monthly subscription of each consumer. In any given time period, a vast number of tariff varieties were available in the market due to the high frequency of new product arrivals (Nicolle et al., 2018). Yet they can be broadly categorized in three unique payment schedules that vary with marginal prices of consumption: prepaid, postpaid, and *forfait bloqué*, with different configurations of fixed, variable and over-usage fee structure.[13] While the tariff categories are reported in the data, no information is available on the consumer's actual usage of voice calls, mobile data, or other services but their consumption allowances only. This poses a challenge in proceeding with a panel data analysis at the individual consumer level since it would require detailed usage information to measure the effective price for each consumers. Without such details, we can only obtain aggregate prices, which may lead to a bias for the micro-data analysis due to the resulting measurement error. Hence, we choose to analyze the consumption at the aggregate level by focusing on the consumer's product subscription choices among a finite set of tariff plans.

Variable	Obs	Mean	Std. Dev.	Min	Max
Subscriber (1,000)	3,328	243	352	2	3,041
Price (€)	3,328	18.69	8.76	3.55	56.26
2G antenna	3,328	902	987	0	3,704
3G antenna	3,328	721	755	0	2,905
4G antenna	3,328	113	266	0	2,055
Prepaid	3,328	0.28	0.45	0	1
Postpaid	3,328	0.46	0.50	0	1
Forfait bloqué	3,328	0.27	0.44	0	1
Call allowance (min)	3,328	658	820	0	3,259
Data allowance (MB)	3,328	622	666	0	2,327

Based on the dataset of 3,328 observations (mobile service products in 13 region blocks from 2011 Q4 to 2014 Q4).

Table 1: Summary statistics of the dataset

Our operating definition of price is based on the total average expenditure expected for the consumption of a given service product in a given time period.[14] To account for possible changes in the composition, we aggregate the tariffs across a predetermined set of price tiers whenever feasible. Our measurement approach is not ideal, but developing a price index is by itself a complex and resource-intensive task in the telecommunications markets (Nicolle et al., 2018). While one may alternatively consider the price basket approach used by organizations such as OECD or ARCEP, it relies on representative usage profiles calibrated from actual consumption patterns, which are endogenous to the price itself. In comparison, our price metric is simple yet effectively captures the overall trend as produced by alternative approaches (for example, see the figure on page 26 of UFC-Que Choisir (2014)).[15] Furthermore, we control for various tariff characteristics

[12] Most MVNOs were simply resellers of the same contracts offered by their hosting network supplier around the time of the new entry.

[13] The original French terms are *prépayé*, *forfait*, and *forfait bloqué*. The prepaid service plans do not charge a fixed access fee but only usage fees for voice, data or text services. In contrast, the postpaid plans are three-part tariffs defined by a fixed access price, consumption allowances, and a usage fee for any consumption in excess of these allowances. Forfait bloqué has the same tariff structure as the postpaid plan, except that it does not practically allow usage beyond the allowances allocated each month.

[14] Given the lack of usage information, the price metric would be constructed in the same way if the individual panel dataset were to be used. The price measure is uniform across the regions, consistent with the fact that there is no geographic price discrimination.

[15] Alternatively, Weiergraeber (2018) proposes to use average revenues per user normalized by minutes of call allowances. While this

that may coincide with price changes over time, in particular the consumption allowances for voice calling and mobile data. Because the dataset records the consumption allowances for voice and data only from the last quarter of 2011, we start our working sample at this quarter and remove the first three quarters from the analysis.

We combine the consumption dataset with a national database on network infrastructure facilities obtained from *L'Agence nationale des fréquences* (ANFR), a public authority that governs the operation of radio communications facilities. The database covers the location, the date of activation, and the technology generation (2G, 3G, and 4G) of base transceiver stations. The base stations, often called cell towers or antennas, provide wireless connections for end user's mobile devices and thus constitute an important capital input for the mobile network to produce increased radio signal strengths and data transmission bandwidths that together determine the connectivity and speed of mobile communications. Hence, we collect the cumulative number of cellular antennas activated by each network operator for a given technology generation and geographic area to measure the quality of the network communications.

Combining the two databases yields a panel of 22 mobile service products in 13 regions over 13 quarters spanning from 2011 Q4 to 2014 Q4, generating total 3,328 observations. Each mobile service product is a tariff type (prepaid, postpaid, or *forfait bloqué*) available under each brand of an MNO or MVNO operator. For each mobile service product (tariff type and operator) in a market (region) and time period (quarter), we observe the number of subscribers, price, tariff characteristics and network quality. To measure the potential market size of each region, we use the regional population from the 2012 census survey conducted by *L'Institut national de la statistique et des études économiques* (INSEE), the national statistics agency in France. Table 1 provides an overview of the main variables and their summary statistics.

2.3 Descriptive analysis

Table 2 provides more detailed information of the mobile market broken down by network operator and brand: the number of antenna stations, price, and the share of subscribers. The table reports only the total number of proprietary antenna stations: the incumbents' subsidiary brands share the network with the existing product lines, and the MVNOs pay a wholesale price to use the incumbent's network. The entrant Free Mobile operates its own antenna network. It also temporarily rented 3G antennas from Orange through a roaming agreement to compensate for its low coverage and quality, but the regulator ARCEP demanded the agreement to be gradually phased out. In our empirical analysis, we will distinguish between the proprietary and roaming antennas to account for the difference in service quality between MNOs and MVNOs. Generally speaking, Table 2 reveals that the incumbent MNOs tend to be more expensive than their subsidiary brands and the new entrant Free Mobile. Since the incumbent services under their operator brands represent high quality products relative to the new subsidiaries, we will use the term *premium* products throughout the paper to distinguish them from the low-cost alternatives.

Figure 1 shows the price changes of the incumbents' classic premium product lines, their subsidiary brands and the entrant Free Mobile. Note that the launch of the incumbent's subsidiary brands (Sosh, Red, and B&You) essentially coincides with the entry of Free Mobile in January of the first quarter of 2012.[16] The

approach may be suitable for studying the consumption of voice calling alone, it would be insufficient to account for the more important consumption of mobile data in our study.

[16]While the subsidiaries had already been introduced one quarter before the entry of Free (B&You in July, and Sosh and RED in

Network operator	Product group	Antenna stations 2G	3G	4G	Price (€)	Market share
Orange	Orange	1,908	1,330	243	31.71	0.289
	Sosh				16.65	0.039
SFR	SFR	1,363	1,205	86	25.99	0.229
	Red				15.53	0.024
Bouygues	Bouygues	1,421	1,119	232	30.74	0.137
	B&You				15.99	0.025
Free	Free	0	380	50	11.53	0.135
Orange	MVNO	0	0	0	17.58	0.043
SFR	MVNO	0	0	0	16.08	0.089
Bouygues	MVNO	0	0	0	17.58	0.014

Based on the dataset of 3,328 observations (mobile service products in 13 region blocks from 2011 Q4 to 2014 Q4).
Market shares are the average share of subscribers across regions.

Table 2: Overview of the mobile services market

new entrant Free charges a much lower price than the incumbents, whereas the subsidiary brands charge prices somewhere in between. Note that the incumbents' prices move in opposite directions: both SFR and Bouygues lower their prices during the period, while Orange maintains or slightly raises its price level. However, the rising price does not necessarily imply the higher unit cost of consumption for consumers since both the consumption speed and allowances have also increased, particularly with the introduction of the 4G technology around 2014 (Nicolle et al., 2018). Figure A.1 in the appendix reveals a similar pattern for the MVNOs: they have lowered their prices over time, which appears to be at least partially attributable to the increased competition among other factors.

Based on Figure 1, one may be tempted to interpret the subsidiary's low prices as the incumbent's predatory actions. However, the scope of predation appears to have been rather limited due to various regulations imposed to prevent the incumbents from raising the entrant's costs, for example, in areas such as call termination rates and access to the incumbent's legacy (2G) network.[17] Considering the strong disincentives for predation, it thus seems difficult to view the incumbent's responses as an anticompetitive behavior.

To obtain a first indication of the disruptive change of market structure, Figure 2 displays the market shares of the MNOs during our sample period. From the first quarter of 2012, the market demand for all of the incumbents' existing services starts shifting towards Free Mobile with the incumbents' losses partly compensated by the gains of the three subsidiary brands. Despite the larger installed bases of the incumbents' antenna network shared by the subsidiary brands, Sosh, Red, and B&You exhibit slow growth relative to Free Mobile, which eventually overtakes the product line of the second largest incumbent operator (SFR). This suggests that the incumbents may have been constrained by the risk of cannibalization through an excessively aggressive fighting brand strategy.

Table 3 provides a more detailed description of how the entry of Free Mobile has affected the market

October), we lacked sufficient sample size for the quarter due to their limited availability and therefore removed them from the analysis.

[17]Price caps were imposed on the call termination rates by ARCEP, and the incumbents were not allowed to charge discriminatory prices (Nicolle et al., 2018).

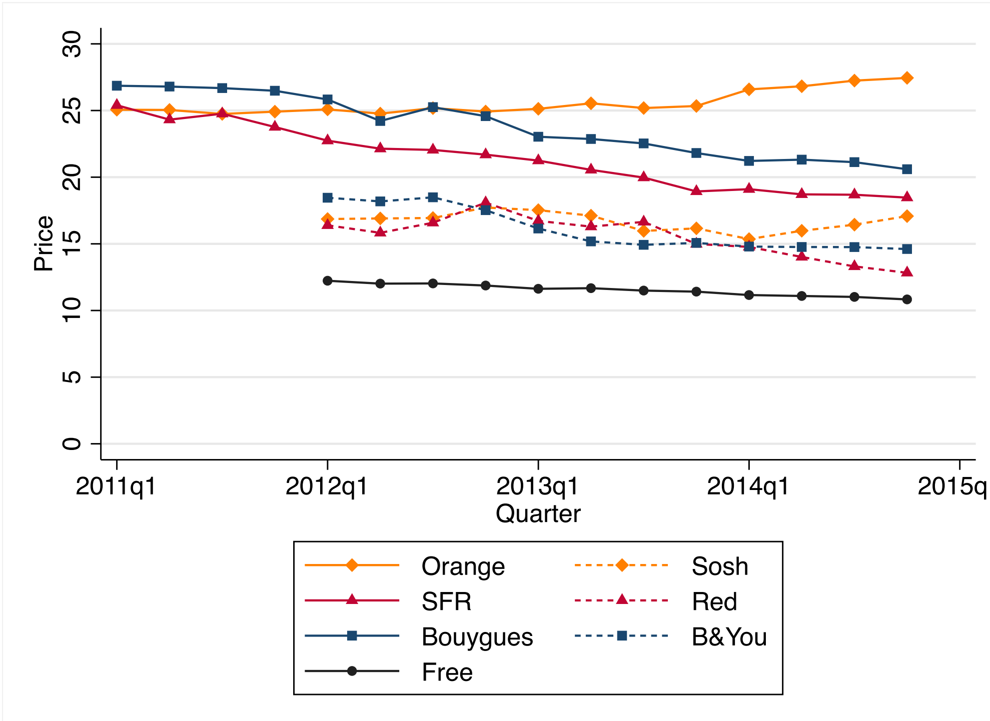

Figure 1: Prices of mobile services by product line brands

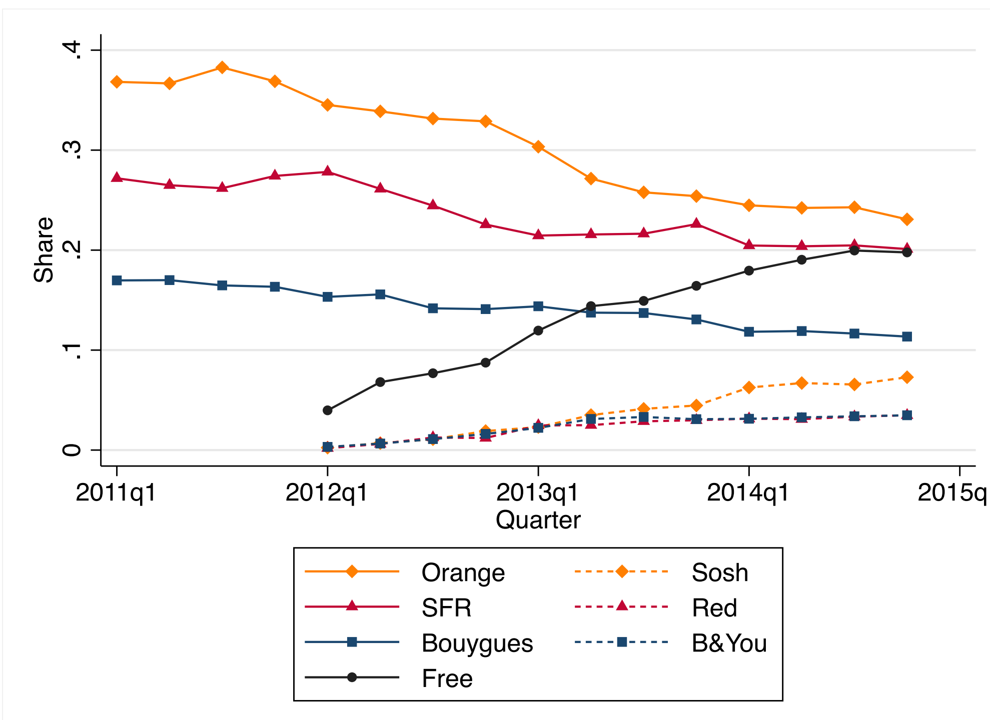

Figure 2: Market shares of mobile services by product line brands

Network operator	Product group	Market share (2011Q4)			Market share (2014Q4)		
		Prepaid	Postpaid	F. bloqué	Prepaid	Postpaid	F. bloqué
Orange	Orange	0.085	0.192	0.098	0.024	0.171	0.041
	Sosh					0.073	
SFR	SFR	0.036	0.185	0.057	0.011	0.170	0.023
	Red					0.035	
Bouygues	Bouygues	0.030	0.114	0.024	0.011	0.094	0.009
	B&You					0.035	
Free	Free					0.198	
Orange	MVNO	0.008	0.008	0.015	0.003	0.022	0.010
SFR	MVNO	0.027	0.064	0.024	0.012	0.064	0.007
Bouygues	MVNO	0.008	0.002	0.015	0.004	0.007	0.001

F. bloqué denotes *forfait bloqué*, a postpaid service with fixed consumption allowances (or infinite variable price implicitly).

Table 3: Change of market shares by the service pricing types

competition asymmetrically. It displays the subscriber shares in the first and last quarters of our working sample divided into the three tariff categories (prepaid, postpaid, and *forfait bloqué*). In the first quarter of our sample (2011 Q4), when Free Mobile had not yet entered, the prepaid and forfait bloqué plans generated large sales for the premium product lines of the incumbent MNOs, collectively accounting for about 47%–95% of the postpaid sales of each operator. By the final quarter of 2014, however, Free Mobile had gained a considerable market share of 19.8%, while the incumbents' subsidiary brands had also become important as a whole with a combined share of 14.3%. While Free Mobile and the subsidiary brands only offered postpaid plans, they did not steal as much market share from the incumbents' postpaid tariff plans as from their prepaid and *forfait bloqué* services. With their aggressive prices, Free Mobile and the fighting brands appear to have appealed to a market segment previously served by the incumbents' prepaid and *forfait bloqué*, differentiating themselves from the premium postpaid services.

3 Model

3.1 Demand

We employ the standard discrete choice framework of Berry, Levinsohn and Pakes (1995) (henceforth BLP) to model the demand for mobile network services in each regional market. Our modeling approach is motivated by the overarching goal of measuring both the incumbents' market power and the competition effects from the new products in a parsimonious framework. We thus abstract from potential demand-side dynamics such as switching costs (see e.g. Weiergraeber (2018)), as it is challenging to identify switching costs separately from persistent preference heterogeneity. It would nevertheless be interesting to explore this in future research.

Each consumer indexed by i receives indirect utility u_{ijt} from consuming mobile service product j among the set of J services available in market t during a given quarter. The market t refers to the geographic area (region) of the consumer; we suppress the index for time periods to simplify the notation. Each mobile service product j is defined by tariff type (prepaid, postpaid or *forfait bloqué*) and product brand (operator or subsidiary) following the structure of Table 3.[18] As Berry et al. (1995), we take the Cobb-Douglas specification for u_{ijt}:

$$u_{ijt} = \alpha \log(y_{it} - p_j) + \beta'_{it} x_{jt} + \xi_{jt} + \epsilon_{ijt}, \tag{1}$$

where y_{it} is the income of consumer i in market t, p_j is the total consumption price of product j, which is uniform across markets (regions) t, though it may vary over time.[19] The vector x_{jt} includes observable controls of product quality: network quality (number of antenna stations for the three different generations in a given region) and tariff characteristics (such as call and data consumption allowances). For a subset of x_{jt}, the vector β_{it} represents the heterogeneous taste of consumer i in market t and is specified as

$$\beta_{it} = \beta + \pi d_t + \nu_{it},$$

where d_t contains the aggregate demographics of market t, and ν_{it} is a vector of tastes that vary across consumers and markets, which may depend on individual demographics as in Nevo (2001). The income and tastes (y_{it}, ν_{it}) are assumed to jointly follow an underlying probability distribution $\mathcal{P}_t$ specific to each market t. The residual component ξ_{jt} captures the mean unobserved quality of mobile service j in market t (the econometric error term), and ϵ_{ijt} is an idiosyncratic unobserved taste shock by consumer i for service j and is assumed to follow an iid extreme value type I distribution.

The outside good is denoted by $j = 0$ and represents a collection of options that range from relying on the Wi-Fi technology to adopting mobile services other than those supplied by the domestic mobile networks; it is assumed to yield indirect utility $u_{i0t} = \alpha \log(y_{it}) + \xi_{0t} + \epsilon_{i0t}$, where ξ_{0t} captures the evolution of the technology of the outside good.

To derive the aggregate market share, we follow the convention of decomposing u_{ijt} as

$$u_{ijt} = \delta_{jt} + \mu_{ijt} + \epsilon_{ijt}, \tag{2}$$

where $\delta_{jt}(\beta, \pi) = (\beta + \pi d_t)' x_{jt} + \xi_{jt}$ is the quality valuation of product j common to all consumers in market t; μ_{ijt} denotes the net heterogeneous component defined as

$$\mu_{ijt}(y_{it}, \nu_{it}; \alpha) = \alpha \log(y_{it} - p_j) + \nu'_{it} x_{jt},$$

and correspondingly $\mu_{i0t} = \alpha \log(y_{it})$. Given the extreme value error assumption, we obtain the probability of product j generating maximal utility for consumer i in market t as the logit choice probability (McFadden, 1973), which yields the aggregate the market share in region t:

$$s_{jt}(\alpha, \beta, \pi) = \int \frac{\exp\left(\delta_{jt}(\beta, \pi) + \mu_{ijt}(y_{it}, \nu_{it}; \alpha)\right)}{\sum_{k=0}^{J} \exp\left(\delta_{kt}(\beta, \pi) + \mu_{ikt}(y_{it}, \nu_{it}; \alpha)\right)} d\mathcal{P}_t(y_{it}, \nu_{it}).$$

[18] Specifically, both operator and subsidiary brands are available from the three incumbent MNOs, while all products are supplied under a single product brand for the new entrant Free Mobile and the MVNO groups.

[19] As discussed in the data section, the consumption price encompasses the monthly subscription and usage fees of all component services such as voice call, mobile data, text messages and various other services, excluding the payment for handset devices.

In the following section, we express the market share $s_{jt}(\boldsymbol{p})$ as a function of the (uniform) retail prices $\boldsymbol{p} = (p_1, ..., p_J)$. We then obtain the total national demand by aggregating the local demands across all 13 regions, i.e.

$$D_j(\boldsymbol{p}) = \sum_t s_{jt}(\boldsymbol{p}) M_t, \tag{3}$$

where M_t is the population size in region t.

3.2 Supply

There are two types of network operators: MNOs and MVNOs. The MNOs possess their own network of antenna stations and may choose to sell access to MVNOs who do not operate their own network infrastructure. In practice, all the incumbent MNOs, Orange, SFR and Bouygues, provide wholesale access to MVNOs, whereas the entrant MNO, Free Mobile, does not do so by setting prohibitively high access prices.

We model the supply side as a two-stage game. In the first stage, the MNOs simultaneously set wholesale prices for access services to the affiliated MVNOs. In the second stage, given the observed wholesale prices, the MNOs and MVNOs simultaneously set retail prices for mobile services to consumers. Both wholesale and retail prices are nondiscriminatory across geographical regions as discussed in Section 2. To be consistent, we make the simplifying assumption that the marginal cost of services is uniform across regions but may differ by product lines. Furthermore, the MVNOs are considered as a single price-setting entity as mentioned earlier.

Let $L_f \subset \mathcal{J} = \{1, ..., J\}$ represent the set of retail product lines served by MNO $f \in \mathcal{F} = \{1, ..., F\}$. The set $\mathcal{J}$ can in principle include up to six alternatives depending on the MNO: the three tariff types at either the MNO's premium product line or at its subsidiary brand. In practice, the number of alternatives is smaller, as evident from Table 3. Furthermore, we denote by f_0 the product line of MVNO hosted by its wholesale firm f. While the MVNO can also carry up to three tariff plans, the description below assumes the MVNO to be a single-product firm for expositional convenience. Lastly, since our focus in this section is on pricing and not product line decisions, we omit the fixed cost of operating a subsidiary brand, a subject that we will introduce later when examining the incentives for the fighting brands in Section 5.

The total profits of host MNO f are the sum of the profits from its own retail product line and the profits from providing access to MVNO f_0:

$$\Pi_f = \sum_{l \in L_f} (p_l - c_l) D_l(\boldsymbol{p}) + (w_{f_0} - c_{f_0}) D_{f_0}(\boldsymbol{p}), \tag{4}$$

where w_{f_0} is the wholesale price for the product of MVNO f_0; c_l and c_{f_0} are the marginal costs of l and f_0, respectively; D_l and D_{f_0} are the national demand for MNO f's product l and MVNO f_0's product hosted on MNO f's network, respectively. The retail profits of MVNO f_0 are

$$\Pi_{f_0} = (p_{f_0} - w_{f_0}) D_{f_0}(\boldsymbol{p}).$$

Note that we normalize f_0's retail marginal cost to zero; it is implicitly included in c_{f_0}.

We first derive the conditions for the optimal retail prices conditional on wholesale prices. Next, we derive the conditions for the optimal wholesale prices chosen in the first stage. Taken together, these conditions enable us to back out the unobserved marginal costs and wholesale prices, as in e.g. Sudhir (2001), Brenkers and Verboven (2006) and Villas-Boas (2007).

Conditional on the wholesale prices $\{w_{f_0}\}$ for $f \in \mathcal{F}$, the second-stage retail prices are characterized by the following first-order necessary conditions:

$$\frac{\partial \Pi_f}{\partial p_j} = D_j + \sum_{l \in L_f} (p_l - c_l) \frac{\partial D_l}{\partial p_j} + (w_{f_0} - c_{f_0}) \frac{\partial D_{f_0}}{\partial p_j} = 0, \qquad j \in L_f, f \in \mathcal{F}, \tag{5}$$

$$\frac{\partial \Pi_{f_0}}{\partial p_{f_0}} = D_{f_0} + (p_{f_0} - w_{f_0}) \frac{\partial D_{f_0}}{\partial p_{f_0}} = 0, \qquad f \in \mathcal{F}. \tag{6}$$

It is implicit in the notation of Equation (5) that $f = f(j)$, where $f(j)$ denotes the host network supplying product j. Likewise, f_0 implicitly denotes $f_0(j)$ in Equation (6), i.e., the MVNO product hosted by network $f(j)$. Equations (5) and (6) implicitly define the equilibrium retail prices as a function of the wholesale price vector, $\boldsymbol{p}(\boldsymbol{w})$.

To characterize the wholesale prices $\boldsymbol{w}$, we first define the derivatives $\partial p_{f_0}/\partial w_{f_0}$ as referring to own pass-through rate, i.e., the rate at which MVNO f_0 passes the change of wholesale price w_{f_0} through to retail price p_{f_0}. The derivative $\partial p_j/\partial w_{f_0}$ for $j \neq f_0$ refers to cross pass-through rate, i.e., the pass-through of the wholesale price for MVNO f_0 into the retail price of other mobile services.

The first-stage wholesale prices can then be determined by the following first-order condition for $f \in \mathcal{F}$:

$$\begin{aligned} \frac{d\Pi_f}{dw_{f_0}} &= \frac{\partial \Pi_f}{\partial w_{f_0}} + \sum_{j \in \mathcal{J}} \frac{\partial \Pi_f}{\partial p_j} \frac{\partial p_j}{\partial w_{f_0}} \\ &= D_{f_0} + \sum_{j \in \mathcal{J} \setminus L_f} \frac{\partial \Pi_f}{\partial p_j} \frac{\partial p_j}{\partial w_{f_0}} \\ &= D_{f_0} + \sum_{j \in \mathcal{J} \setminus L_f} \left(\sum_{l \in L_f} (p_l - c_l) \frac{\partial D_l}{\partial p_j} + (w_{f_0} - c_{f_0}) \frac{\partial D_{f_0}}{\partial p_j} \right) \frac{\partial p_j}{\partial w_{f_0}} = 0. \end{aligned} \tag{7}$$

In the above, the second equality follows from the envelope theorem. The third equality describes the tradeoff for an MNO when deciding on the wholesale price w_{f_0} it charges to its hosted MVNO. This condition is easier to interpret in the special case where there is only a single MNO f (and hence one associated MVNO f_0). In this case, the set of products $\mathcal{J} \setminus L_f = \{f_0\}$, so that the first-order condition becomes:

$$D_{f_0} + \left(\sum_{l \in L_f} (p_l - c_l) \frac{\partial D_l}{\partial p_{f_0}} + (w_{f_0} - c_{f_0}) \frac{\partial D_{f_0}}{\partial p_{f_0}} \right) \frac{\partial p_{f_0}}{\partial w_{f_0}} = 0.$$

Intuitively, the MNO faces the following tradeoff. On the one hand, an increase in the wholesale price w_{f_0} raises wholesale profits proportional to the current demand of the MVNO (first term). On the other hand, an increase in the wholesale price raises the MVNO's retail price ($\partial p_{f_0}/\partial w_{f_0}$): this implies wholesale losses from a demand reduction of the MVNO (through $\partial D_{f_0}/\partial p_{f_0}$), which are partly compensated by a demand increase for MNO f's own retail products (through $\partial D_l/\partial p_{f_0}$). In the more general case with competing

MNOs (Equation (7)), there are further indirect demand effects because the wholesale price increase is also passed through onto the other MNOs' retail prices.

In the appendix, we provide further details on the computation of the pass-throughs $\partial p_j/\partial w_{f_0}$. One can then invert the system given by Equations (5), (6) and (7) to back out the marginal costs and the wholesale prices.

The above exposition assumes that the MNOs and MVNOs set wholesale prices and retail prices independently, so that there are both vertical and horizontal externalities. As an alternative to this independent pricing model, we will also consider a model of vertical integration. In this scenario, each MNO directly sets the retail price of its hosted MVNO to maximize joint profit

$$\Pi_f = \sum_{l \in L_f} (p_l - c_l) D_l(\boldsymbol{p}) + (p_{f_0} - c_{f_0}) D_{f_0}(\boldsymbol{p}), \tag{8}$$

and the wholesale price follows an (unmodeled) sharing rule depending on the parties' bargaining power. The retail prices satisfy the first-order conditions for profit maximization as in a standard multi-product Bertrand Nash equilibrium:

$$\frac{\partial \Pi_f}{\partial p_j} = D_j + \sum_{l \in L_f} (p_l - c_l) \frac{\partial D_l}{\partial p_j} + (p_{f_0} - c_{f_0}) \frac{\partial D_{f_0}}{\partial p_j} = 0, \qquad j \in L_f, f \in \mathcal{F}, \tag{9}$$

$$\frac{\partial \Pi_{f_0}}{\partial p_{f_0}} = D_{f_0} + \sum_{l \in L_f} (p_l - c_l) \frac{\partial D_l}{\partial p_{f_0}} + (p_{f_0} - c_{f_0}) \frac{\partial D_{f_0}}{\partial p_{f_0}} = 0. \tag{10}$$

From these conditions we can again back out the marginal costs of both the MNOs and MVNOs. We will use this vertical integration model as a robustness check to our independent pricing model in the subsequent analysis. It implies that there are no "double marginalization" effects, and it may arise under various circumstances: perfectly competitive MVNOs, some forms of (unobserved) non-linear contracting or some equilibria with interlocking relations (e.g. Rey and Vergé (2010)).

4 Empirical results

4.1 Demand specification and estimation

Our econometric model is based on the utility specification (1) of Section 3. Specifically, the vector x_{jt} contains the network quality variables: the number of proprietary 2G, 3G and 4G antennas for the MNOs and the corresponding roaming antennas for the MVNOs. It also contains tariff characteristics: dummy variables for the postpaid and forfait bloqué plans (with prepaid as the base), and consumption allowances for voice call minutes and data downloads. Finally, we include fixed effects for brands and geographic regions, time trend and time elapsed since first entry of each product. Taken together, these variables also intend to capture unobserved forms of quality differentiation, such as handset subsidies, availability of offline retail channels and add-on services which were typically available only for the contract-based plans (postpaid and forfait bloqué) of the incumbents' premium brands.[20] For all these variables we estimate mean valuations (β). Furthermore, we interact the brand fixed effects with average age (π).

We employ a more parsimonious specification to account for consumer heterogeneity μ_{ijt}. We begin by expanding the log price term in u_{ijt} for $j \in \mathcal{J} = \{1, ..., J\}$ as $\alpha \log(y_{it} - p_j) \approx \alpha \log(y_{it}) - \alpha_{it} p_j$, where $\alpha_{it} = \alpha / y_{it}$. Then, without loss of generality, u_{i0t} can be normalized up to the extreme value error by dropping $\alpha \log(y_{it})$ everywhere. We correspondingly modify the net heterogeneous utility term into

$$\mu_{ijt} = -\alpha_{it} p_j + \nu_{it}' x_{jt} \qquad j \in \mathcal{J}.$$

For the heterogeneous tastes ν_{it}, we include random coefficients for the frontier mobile network technology (the combined number of 4G and its roaming antennas) and for the forfait bloqué service plans. Price, 4G network quality and forfait bloqué jointly reflect the key sources of differentiation between the incumbents' premium and low-cost brands. We allow the preference for the 4G antennas and forfait bloqué plans to vary by income in the same way as the price parameter α_{it}. More precisely, we parameterize (α_{it}, ν_{it}) as $(\alpha, \sigma_\nu)/y_{it}$ for a real-valued vector $\sigma_\nu \in \mathcal{R}^2$ (where σ_ν is not constrained to a positive domain). It is worth noting that each of the parameters (α, σ_ν) regulates both the overall level and dispersion of the distribution of the random coefficients α_{it} and ν_{it}, respectively. Our formulation is intended to capture the idea that a consumer's marginal utility of income may potentially be correlated with the valuation of advanced networks and budget-oriented postpaid plans through the common income term y_{it}. This thus aims to capture the main dimensions of differentiation between the premium and low-cost brands in a flexible yet parsimonious way.[21] The market share function is now given by

$$s_{jt}(\delta_t, \alpha, \sigma_\nu) = \int \frac{\exp\left(\delta_{jt} + \mu_{ijt}(y_{it}; \alpha, \sigma_\nu)\right)}{1 + \sum_{k=1}^{J} \exp\left(\delta_{kt} + \mu_{ikt}(y_{it}; \alpha, \sigma_\nu)\right)} d\mathcal{P}_t(y_{it}), \tag{11}$$

where y_{it} is drawn from a known empirical distribution $\mathcal{P}_t$ in market t.[22]

To estimate the parameters, we use the generalized method of moments (GMM) following the literature (Berry et al., 1995). The main identifying assumption is that the error term ξ_{jt} is mean independent of the observed product characteristics other than price, i.e., $E\left[\xi_{jt} \middle| x_t\right] = 0$. Based on this assumption, Berry et al. (1995) suggest using flexible functions of the exogenous characteristics across products and firms as instruments z_t, i.e., sums of characteristics of other products of the same firm and different firms. In subsequent work, Berry et al. (1999) use Chamberlain's (1987) optimal instruments. The optimal instrument is a specific function of the product characteristics (i.e., the expected derivative of the error term with respect to parameters) and provides an asymptotically efficient estimator. Using a Monte Carlo analysis, Reynaert and Verboven (2014) document how the optimal instruments can deliver considerably more efficient estimates in finite samples, and therefore at the same time improve the stability of the estimation by avoiding convergence to the boundary of the parameter space, as is often experienced with the standard BLP instruments.

[20] Unobserved add-on services include for example preloaded carrier mobile apps, cloud storage, roaming connection, and free access to popular social networking services.

[21] We also considered specifications with additional random coefficients, but these were not significant.

[22] Specifically, $y_i \sim \max\{\underline{y}, N(\bar{y}, \sigma_y^2)\}/100$, where the mean $\bar{y}$ and the standard deviation σ_y are calibrated from the data for each corresponding region, and $\underline{y}$ is set to be €300 based on the minimum observed in the sample.

The vector of optimal instruments takes the form

$$h_{jt}(z_t, \theta) \equiv E\left[\frac{\partial \xi_{jt}(\theta)}{\partial \theta}\middle| z_t\right]$$

for a given parameter vector θ, where $\xi_{jt}(\theta) = \delta_{jt}(s_t, \theta) + \alpha_{it} p_j - \nu'_{it} x_{jt}$, and $\delta_{jt}(s_t, \theta)$ can be obtained by inverting the demand system (11) at a given θ using the BLP contraction mapping. BLP's mean independence assumption then implies a conditional moment restriction $E\big[\xi_{jt}(\theta_0)\big|h(z_t, \theta_0)\big] = 0$ for true parameter θ_0. If the moment restriction is satisfied uniquely at $\theta = \theta_0$, we can obtain a consistent estimate by GMM from the unconditional moment condition $g(\theta_0) \equiv E\big[\xi_{jt}(\theta_0)h(z_t, \theta_0)\big] = 0$. Reynaert and Verboven (2014) use a standard non-optimal BLP instruments in first stage to obtain consistent parameter estimate $\hat{\theta}$. In second stage, they then compute approximately optimal instruments $h(x, \hat{\theta})$ and re-estimate the model by minimizing the GMM objective function:

$$\min_{\theta} \xi(\theta)' h(z, \hat{\theta})' h(z, \hat{\theta}) \xi(\theta)'.$$

Nonetheless, the two-step approach may lose efficiency gains due to the finite-sample bias in the first stage estimation. Furthermore, reliance on a specific choice of non-optimal instruments may be a source of lack of robustness. To address these issues we therefore propose a one-step estimator that continuously updates the optimal instruments $h(z, \theta)$. The one-step estimation is then equivalent to

$$\min_{\theta} \xi(\theta)' h(z, \theta)' h(z, \theta) \xi(\theta)'.$$

Our approach is analogous to the continuous-updating GMM estimator of Hansen et al. (1996) although it has no need to update the GMM weight since in our setting the moments are just identified under optimal instruments.[23] Minimizing the GMM objective function then involves two consecutive fixed point procedures. The first loop inverts the demand system to obtain $\delta(s, \theta)$ through the BLP contraction mapping. The second loop solves for the optimal instruments $h(z, \theta)$ such that it would be consistent with the parameters entering the linear part of the utility function in (1). We discuss the approach more formally in Appendix B.2.[24] To minimize the GMM objective function in the outer loop, we employ the Nelder-Mead simplex method since the continuous updating makes it difficult to obtain analytic derivatives.[25] While the continuous updating procedure significantly increases the overall computational cost, it has the advantage of eliminating the small-sample bias introduced in the first-stage estimates $\hat{\theta}$.

One potential concern for the estimation arises from the possible serial correlation in the unobserved quality ξ_{jt}. For the simple logit specifications, we addressed this problem by aggregating the moments across time periods following Berry et al. (1995). For the random coefficients logit, we adopt the more efficient approach of Newey and West (1987) by formulating a heteroscedasticity and autocorrelation consistent GMM estimator. Note that, although the point estimates are unaffected by the GMM weight under optimal instruments, the standard errors will still be biased unless the weight is robust to the serial correlation.

[23]Nevertheless, the optimal GMM weight is still needed for obtaining efficient standard errors.

[24]Intuitively, the second loop recovers the parameters entering the linear part of the utility following the practice of Nevo (2000) starting from BLP's earlier mentioned sums of other product characteristics to account for price endogeneity, and it then evaluates the optimal instruments conditional on those obtained parameters. This procedure is repeated until convergence is reached for the parameters of the linear utility components.

[25]The global convergence was checked by running the estimation procedure from multiple starting points.

Finally, we approximate the market share function (11) through Monte Carlo integration using 200 quasi-random draws generated by Latin hypercube sampling.[26] This has been found to offer superior sampling efficiency over simple random draws in a recent work of Brunner et al. (2017). We use error tolerances of 10^{-14} and 10^{-8} for the contraction mapping and optimal IV procedures, respectively. While there has been a concern for numerical bias attributed to the nested fixed point algorithm in the literature (Dubé et al., 2012), Lee and Seo (2016) show that the numerical error in the fixed point solutions does not propagate into the parameter estimates. Rather, they prove that the bounds of the parameter bias is within the order of square root of the inner loop tolerance.[27] Hence, we expect the error tolerances to have a limited impact on our GMM estimates.

4.2 Demand parameter estimates

Table 4 presents the main estimation results for the consumer demand model. The full set of results, with the brand fixed effects interacted with consumer demographics, is available in Table A.1 of the appendix. Before we turn to the full random coefficients model, we first briefly comment on the results from simpler logit specifications.

We begin with a simple logit demand in the first column (Logit) without accounting for the price endogeneity. The price is normalized by the average population income of each regional market in the scale of €100s. The price coefficient is negative and significant, but its magnitude is small. Furthermore, the coefficients for most network quality variables are imprecisely estimated. The model also includes fixed effects for tariff types and product brands as well as a constant, which normalizes the utilities with respect to the prepaid plan of the Bouygues MVNOs. The second column (IV logit) estimates the same logit demand but with BLP instruments for price.[28] The price coefficient remains significant, but its magnitude becomes much larger (in absolute value). Furthermore, the coefficients for most network quality variables (except for 2G) are now significant, in particular the 3G antenna variable as one might expect from our considered period of 2011–2014.

The third column (RC logit) displays the estimates of the full model that incorporates consumer heterogeneity in the valuation of price, forfait bloqué service, and 4G network quality.[29] The simulated income draws are divided by €100 for consistency with the scaling in the previous columns.

The estimated random coefficients (α, σ_ν) are presented in the top three rows. The price coefficient (-4.03) remains of the same order of magnitude as the IV logit estimate, generating simulated draws of α/y_{it} ranging between -10.79 and -2.47 for the 10th and 90th percentiles, respectively.[30] We also find significant heterogeneity in the valuation of both the 4G networks and forfait bloqué services. The signs of the heterogeneity parameters indicate that high-income consumers, who have a low price sensitivity (low α/y_{it}), highly appreciate network quality while having little demand for forfait bloqué services relative to other consumers.[31]

[26]Increasing the number of draws implied virtually no change in our estimates.

[27]A series of Monte Carlo evidence is available in a separate work of Lee and Seo (2015).

[28]We use standard BLP instruments: i.e., the sums of other product characteristics of the same firm and sums of product characteristics of other firms. The instruments are constructed based on the log of 2G, 3G and 4G antennas. In addition to the BLP instruments, the antennas of own product enter the set of instrument in linear form, too.

[29]The variable Log 4G/y_{it} combines both Log 4G and its roaming antennas.

[30]This range is obtained after normalizing the draws of y_{it} with respect to national average income $\bar{y}$.

[31]For example, for a consumer with monthly income of €1,000, the coefficient of Log 4G amounts to 0.580 - 3.978/(1,000/10) =

Estimate	Logit	IV logit	RC logit
Price/y_{it} (α)			-4.030***
			(0.485)
Forfait bloqué/y_{it}			39.101***
			(5.681)
Log 4G/y_{it}			-3.978***
			(0.711)
Price/$\bar{y}_t$	-0.241**	-6.051***	
	(0.104)	(0.848)	
Log(2G antenna)	1.097***	0.201	0.532
	(0.144)	(0.361)	(0.362)
Log(2G roaming)	1.063***	-0.130	0.568
	(0.208)	(0.605)	(0.556)
Log(3G antenna)	0.164	0.856***	0.662***
	(0.108)	(0.218)	(0.229)
Log(3G roaming)	0.010	1.101**	0.275
	(0.181)	(0.557)	(0.469)
Log(4G antenna)	0.040	0.217***	0.580***
	(0.033)	(0.067)	(0.134)
Log(4G roaming)	0.044	0.121	0.462***
	(0.038)	(0.076)	(0.168)
Postpaid	-0.941	-2.651	-0.796
	(1.012)	(3.463)	(2.228)
Forfait bloqué	2.536**	2.486	2.016
	(1.032)	(3.408)	(2.554)
Call allow. (1,000 min)	0.078	1.121***	0.585***
	(0.052)	(0.174)	(0.126)
Data allow. (1,000 MB)	0.618***	0.179	0.520***
	(0.059)	(0.156)	(0.123)
1/Time since entry	-2.643***	-2.259***	-2.089***
	(0.107)	(0.276)	(0.265)
Age of population	-6.554***	-7.675***	-4.687***
	(0.530)	(1.503)	(1.647)
Postpaid*age	0.048*	0.170*	0.122**
	(0.026)	(0.088)	(0.058)
Forfait bloqué*age	-0.060**	-0.014	-0.047
	(0.026)	(0.087)	(0.066)
Observations	3,328	3,328	3,328
J statistic		145.70	0.00
D.F.		13	0
Product fixed effects	Yes	Yes	Yes
Market fixed effects	Yes	Yes	Yes

Standard errors in parentheses: * p<0.10, ** p<0.05, *** p<0.01.
y_{it} & $\bar{y}_t$ denote individual & mean incomes scaled by the €100 units.
Time trend, intercept, and other demographics controls are included in all specifications.

Table 4: Estimation of mobile services demand

We now turn to the remaining estimates of the RC logit model. Consumers have a high mean valuation for denser 3G and 4G proprietary networks as well as 4G roaming. Similarly, both types of 2G networks have comparable mean valuations albeit with weaker significance. It may possibly be due to limited intertemporal variation in the already mature 2G networks during the sample period. The mean valuations for both call and data allowances are strongly positive, which contrasts with the Logit and IV logit results where only one of the two was found significant. Moreover, the fixed effects for postpaid and forfait bloqué imply that the average consumer does not prefer such plans over the baseline prepaid tariff. Nevertheless, the postpaid demand is substantially strong among relatively mature consumers, considering its positive interaction with the age of population.

We also include the variable "Time since entry" as an additional control, defined as the inverse of time elapsed since market entry for the new products from Free Mobile, Sosh, Red, and B&You, for example. The coefficient estimate is strongly negative and significant, which may have been driven by the initially high cost of switching from existing services to new operators, as has been documented in other studies on the telecom

0.182, which is lower than 0.580 - 3.978/(2,000/10) = 0.381 for a consumer with y_{it}=€2,000.

industry. Finally, in regions with more aged population, the overall mobile services are less valued in general.

4.3 Substitution patterns and markups

Before evaluating the impact of market entry in the next sections, we first document what the parameter estimates of the full model in Table 4 imply for the substitution patterns and markups.

Substitution patterns We measure substitution patterns through diversion ratios. The diversion ratio $DR_{jk} = (\partial D_k/\partial p_j)/(\partial D_j/\partial p_j)$ is the fraction of lost sales from product j that flows toward product k after a price increase by j. Table 5 shows the diversion ratios for the postpaid tariff plans, while Table A.2 in Appendix shows the full matrix of diversion ratios for all tariff plans (including prepaid and forfait bloqué). Both tables should be read by columns.

Network	Product	Orange		SFR		Bouygues		Free
operator	group	Postpaid	Sosh	Postpaid	Red	Postpaid	B&You	Postpaid
Orange	Prepaid	5.15	5.70	5.58	5.54	4.69	5.62	7.98
	Postpaid	-100.00	11.80	24.58	9.91	26.05	10.90	6.83
	Forfait bloqué	7.02	8.36	7.72	8.40	6.23	8.11	12.78
	Sosh	3.99	-100.00	4.31	3.50	3.65	3.73	4.14
SFR	Prepaid	1.91	2.31	2.19	2.65	1.79	2.32	3.54
	Postpaid	28.32	15.05	-100.00	13.22	24.59	14.14	10.20
	Forfait bloqué	2.51	4.14	2.98	4.71	2.29	4.35	10.88
	Red	2.45	2.77	2.85	-100.00	2.38	2.82	4.03
Bouygues	Prepaid	2.03	2.21	2.19	2.16	1.88	2.31	3.17
	Postpaid	18.39	7.71	15.10	6.63	-100.00	7.58	4.74
	Forfait bloqué	1.28	1.88	1.48	2.11	1.21	2.06	4.30
	B&You	3.13	3.40	3.53	3.23	3.10	-100.00	4.29
Free	Postpaid	12.54	20.78	15.95	23.45	12.41	23.03	-100.00

Percentage of sales diverted toward products (rows) due to price increase (columns). Columns limited to postpaid products; the full matrix is in Table A.2 in Appendix.

Table 5: Diversion ratios (from postpaid products)

According to Table 5, the operator-branded postpaid tariffs mainly divert sales from each other: Orange mainly from SFR (28.3%), and SFR and Bouygues mostly from Orange (24.6% and 26.1%, respectively). In sharp contrast, the fighting brands draw the most consumers from Free Mobile: Sosh, Red and B&You take 20.8%, 23.4% and 23.0% away from Free, respectively. Finally, Free mainly captures sales from both the postpaid and forfait bloqué plans of Orange and SFR.

Table A.2 shows additional intuitive results regarding the diversion from the prepaid and forfait bloqué tariff plans. More specifically, the incumbents' prepaid and forfait bloqué tariffs mainly lose sales to Free Mobile. In sum, the diversion ratios are intuitive and consistent with the earlier documented market share changes after the introduction of Free Mobile and the fighting brands. Free Mobile mainly steals business from the incumbents' premium brands, while the incumbents' fighting brands mainly steal business from Free Mobile (and would mainly cannibalize sales in the absence of Free Mobile). These substitution patterns can have important implications for the profit incentives and welfare effects, which will be evaluated in the next sections.

Markups Table 6 presents a summary of the estimated retail margins (also based on the estimates of the full model in Table 4).[32] We find that the retail markups tend to be lowest for the prepaid and forfait bloqué tariffs (especially those of the MVNOs). The markups are also low for Free Mobile's postpaid and the incumbents' fighting brands (Sosh, Red and B&You). In contrast, the markups of postpaid services are considerably higher for the incumbents' premium products. These differences in markups across brands and tariffs are consistent with expectations, based on the substitution patterns examined above.

Network operator	Product group	Retail price			Retail markup		
		Prepaid	Postpaid	F. bloqué	Prepaid	Postpaid	F. bloqué
Orange	Orange	13.56	39.04	22.56	7.73	13.55	7.39
	Sosh		16.67			9.04	
SFR	SFR	13.33	28.86	18.62	6.83	11.05	5.01
	Red		15.54			7.86	
Bouygues	Bouygues	13.53	35.12	19.89	5.77	10.51	4.36
	B&You		16.07			6.92	
Free	Free		11.54			5.59	
Orange	MVNO	9.27	19.05	18.26	3.55	6.61	3.38
SFR	MVNO	6.36	18.90	17.29	2.99	6.52	3.20
Bouygues	MVNO	4.40	32.93	19.79	2.35	8.42	3.56

Average retail prices and margins of mobile services across times and regions (in euro).
F. bloqué denotes forfait bloqué service. See the note of Table 3 for its definition.

Table 6: Estimated retail markups

These results show that the incumbents earn higher markups in their premium postpaid segment even after the release of fighting brands. Nevertheless, Table 6 highlights that the higher markups for the incumbents' premium products do not entirely explain their higher prices. The remaining part of the price premium is due to the higher marginal costs associated with providing the premium quality postpaid services. For example, the premium postpaid services operated physical retail channels for offline customer support, which was not offered for the low-cost services.[33] The postpaid premium products also used the most recent mobile technologies and made the most intensive use of the network infrastructure. Moreover, the premium products included some costly services that were either unavailable or unnecessary under the low-cost offers (e.g., an optional extra SIM card, real-time billing, and etc).

In sum, our findings imply that the higher prices for the incumbents' premium postpaid products are partly due to higher markups and partly due to higher marginal cost of service. This contrasts with what would be found in a simplified logit demand specification, where a multiproduct firm obtains identical markups for all

[32]Recall that we recover the retail and wholesale margins from the first-order conditions, as given by Equations (5), (6) and (7). More details on the solution procedure are available in the appendix.

[33]It appears reasonable to consider such operational costs as part of variable costs rather than fixed expenditure since it is relatively flexible to adjust the number of physical stores in a local neighborhood on a quarterly basis.

of its products.[34] Hence, in a simplified logit any observed price differences between products of the same firm would have to be attributed entirely to cost differences.

5 Incumbents' incentives for product line expansion

In the last section, we estimated consumer demand and recovered marginal costs from equilibrium retail and wholesale markups. We will now evaluate the impact of market entry by Free Mobile, which coincided with the release of new subsidiary product lines by each of the three incumbent firms. In this section, we explore the evidence for rationalizing such product decisions as a fighting brand strategy in response to the entry of Free Mobile, from the perspective motivated by Johnson and Myatt (2003).[35] Depending on the analysis outcome, we will determine whether to take the fighting brands into account in the welfare analysis of market entry in the next section.

To assess whether we can rationalize the incumbents' product line expansions as a fighting brand strategy, we calculate the equilibrium variable profits for all 16 combinations of product line strategies, which are based on the independent binary decisions of three incumbents on product-line extension along with the entry decision of Free Mobile. These counterfactuals amount to solving the retail and wholesale price equilibrium after eliminating Free and/or each of the incumbents' subsidiary brands. This implies solving Equations (5), (6) and (7), where the pass-through rates in (7) are obtained from Equations (16) and (17) in Appendix A. Table A.4 of the appendix displays the payoffs for each of the three incumbents under all 16 combinations.[36]

To extend Johnson and Myatt (2003)'s monopoly analysis to our setting with multiple incumbents, we proceed as follows. In Subsection 5.1, we first consider the incumbents' *joint* incentives to collectively release low-quality brands in response to the entry of Free Mobile. This exercise is closest to the analytical framework of Johnson and Myatt (2003). We then examine the incumbents' *unilateral* incentives for product line extension by formulating their product line decisions as a static simultaneous-move game. Although we indeed find that the joint incentives for introducing the low-quality brands have been increased by the entry of Free Mobile, the incentives are still not strong enough to justify the coordinated strategy as an equilibrium. Furthermore, we do not find a range of fixed costs that rationalizes the incumbents' fighting brand strategies as unilateral best responses to entry in the static game.

In Subsection 5.2, we therefore explore a dynamic approach to examine the possibility of the incumbents' collusion on their product line strategies within an infinitely repeated game framework. More precisely, we ask whether the incumbents may have been able to tacitly collude on withholding low-cost brands and whether the entry of Free Mobile made this form of collusion more difficult to sustain. Within this modified framework, we aim to identify a non-empty set of fixed costs for the low-cost brand that would generate the same predictions made by Johnson and Myatt (2003).

[34] See for example, (Nevo and Rossi, 2008). Nocke and Schutz (2018) generalize this principle to a wide class of models satisfying the independence of irrelevant alternatives property.

[35] Johnson and Myatt (2003) also consider product line "pruning," where an incumbent withdraws an existing product as a reaction to entry. In this paper, we limit our attention to product line expansion decisions since no product line pruning is observed during our observation period.

[36] We base our analysis on the parameter estimates of the full random coefficients model, i.e., the third column in Table 4. We calculate profits as the net present value from January 1, 2012 (when Free Mobile entered the market) until December 2014 (the last month of our data). This approach has the advantage of simplicity and transparency, and avoids modeling the product line decisions in a dynamic game, e.g., based on the Markov perfect framework of Fershtman and Pakes (2000).

5.1 Joint versus unilateral incentives for product line extension

Joint incentives. Johnson and Myatt (2003) postulated a monopolist threatened by entry in their fighting brand analysis. As a benchmark, it is therefore natural to explore whether their theory extends to our setting by examining whether the incumbents' joint incentives to introduce low-quality brands have increased after the entry of Free Mobile. Based on the payoff matrix of Table A.4, Table 7 quantifies the incremental changes in variable profits when all incumbents jointly switch from withholding the subsidiary brands to releasing them in the absence of entry (first column) and in the presence of entry (second column), respectively.

	Entry of Free Mobile	
Network	No	Yes
Orange	-265	-33
SFR	-345	-129
Bouygues	131	156
Total incumbents	-479	-6
Free	0	-264

The figures represent the profit changes (in million euro) of the incumbents and Free Mobile, when the incumbents jointly introduce their low-cost brands. The calculations are based on the payoffs from Table A.4 of the appendix.

Table 7: Joint profit incentives for the incumbents' fighting brand adoption

According to the first column, in the absence of entry the incumbents would lose considerably from jointly releasing the subsidiary brands. The low-quality brands would lower their joint profits by €479 million, or even larger amount if we were to take into account the fixed costs of launching or operating them. Intuitively, the low-quality brands cannibalize the sales of the high-quality brands, which lowers the incumbents' joint profits. There is therefore no strategic incentives for them to jointly release the subsidiary brands in the absence of entry.

In contrast, according to the second column, if Free Mobile enters the market, the incumbents would lose only a negligible amount from jointly releasing the subsidiary brands (€6 million). Entry thus raises the incumbents' incentives for the fighting brands by €479 million (at the expense of Free Mobile which would lose €264 million because of the fighting brands). Nonetheless, the incumbents' joint incentives for the fighting brands are still not sufficiently strong: business stealing from Free Mobile is too small to compensate for the cannibalization of the premium brands.[37] Note that in the vertically integrated pricing model, the incumbents' incentives for introducing fighting brands do become positive after entry, because of a stronger business stealing from Free Mobile (see Table A.8 in the appendix).

In sum, we are able to find partial support at best for Johnson and Myatt's theory in the cooperative setting. On the one hand, the incumbents' joint incentives for releasing the low-quality brands have increased as a result of Free Mobile's entry. On the other hand, the entry failed to generate strong incentives enough for the incumbents to coordinate on the low-cost product lines, mainly because the business stealing from the

[37] Table 7 also suggests that the incumbents may disagree over their desirable choice of collective actions: Bouygues would prefer all incumbents to launch a subsidiary low-quality brand with or without the entry by Free Mobile.

entrant was not sufficient to overcome the cannibalized sales of the incumbents' premium brands.

Unilateral incentives. We now assess the non-cooperative view of the low-quality product releases as a unilateral best response of the individual incumbents with respect to the entry in a static game framework. Based on the incumbents' observed product line strategies, we posit the following. In the absence of entry, the candidate Nash equilibrium is such that none of the incumbents releases a low-quality brand. Conversely, after the entry of Free Mobile, the candidate equilibrium is such that all incumbents launch a subsidiary brand. More formally, let $\Pi_j^{d,e}$ be incumbent firm j's variable profit when operating a fighting brand or not: $d \in \{FB, noFB\}$. Likewise, the index e indicates the market entry or absence of Free Mobile: $e \in \{E, N\}$. We use f_j to denote j's fixed cost of operating its fighting brand. With these notations, "no fighting brands" is a Nash equilibrium in the case of absent entry if $\Pi_j^{noFB,N} \geq \Pi_j^{FB,N} - f_j$ for each j. Analogously, in the presence of entry, "fighting brands" is a Nash equilibrium if $\Pi_j^{FB,E} - f_j \geq \Pi_j^{noFB,E}$ for each j. The range of fixed costs satisfying both restrictions is then given by

$$\Pi_j^{FB,N} - \Pi_j^{noFB,N} \leq f_j \leq -(\Pi_j^{noFB,E} - \Pi_j^{FB,E}). \tag{12}$$

Table 8 uses the payoff matrix of Table A.4 to calculate the deviation payoffs to the individual incumbents when they unilaterally deviate from the candidate Nash equilibrium product line strategies as expressed in (12).

	Entry of Free Mobile	
	No	Yes
Incumbent network	Equilibrium: no FB $(\Pi_j^{FB,N} - \Pi_j^{noFB,N})$	Equilibrium: FB $(\Pi_j^{noFB,E} - \Pi_j^{FB,E})$
Orange	416	-341
SFR	287	-222
Bouygues	395	-303

The figures represent the incumbents' profit changes (in million euro), resulting from unilateral deviations from the observed candidate Nash equilibrium: no fight brands (no FB) without the entry by Free Mobile, fight brands (FB) in the presence of entry. The calculations are based on the payoffs from Table A.4 of the appendix.

Table 8: Unilateral incentives to deviate from candidate equilibrium product lines

According to the first column of Table 8, each incumbent would experience an *increase* in variable profits if it unilaterally releases a subsidiary brand when there is no entry. Based on the left side of (12), our non-cooperative framework rationalizes the market outcome that no incumbent launches a low-cost brand under absent entry if the fixed costs of operating such a brand exceed the deviation payoff of the first column. For example, since the variable profit gains for Orange amount to €416 million, its fixed cost must be of at least this amount for Orange not to introduce its low-quality brand (Sosh) in the absence of entry.

The second column of Table 8 finds that the incumbents' gross variable profits *decrease* if they unilaterally withhold a subsidiary brand when Free Mobile enters. Based on the right side of (12), we can characterize as an equilibrium the market outcome that all incumbents release a low-cost brand if the fixed costs of subsidiary brands are less than the variable profit losses in absolute terms (since the incumbents would save these fixed costs if they do not launch their new brands). For example, for Orange, the fixed cost of its subsidiary brand Sosh must be smaller than €341 million, since otherwise Orange would not have introduced it upon the entry of Free Mobile.

The first and second columns (in absolute value) thus respectively characterize lower and upper bounds on the incumbents' fixed costs that are necessary to rationalize the fighting brand strategy as a unilateral best-response. From these bounds, it is clear that there are no levels of fixed costs that explain both why the incumbents introduced subsidiary brands upon the entry of Free Mobile, and why they would not have done so already in the absence of entry.[38]

To sum up, we do not find support for the non-cooperative view of the fighting brands as the incumbent's unilateral best response strategy. As a side note, we point out that our finding does not necessarily contradict the analysis of Nocke and Schutz (2018), where product lines can (weakly) expand as competition intensifies. The discrepancy may be arising for two reasons, both based on the unique features of our model. First, our random-coefficients demand specification includes aspects of both horizontal and vertical differentiation. Second, our supply-side model incorporates the fixed operating costs of subsidiary brands to account for the restricted product lines observed before the entry.[39]

But more importantly, our analysis has so far limited attention to simultaneous product line decisions in a static game and, in doing so, ignored the possibility that the incumbents could react to the competitor's unilateral expansion of product portfolio. Hence in the subsequent analysis, we will consider a dynamic approach that allows for the competitors' reactions within an infinitely repeated game framework to examine whether we can find support for the fighting brand theory in the oligopoly setting.

5.2 Collusion in product line strategies

We now examine whether the incumbents can tacitly collude on restricting their product lines and how entry affects the sustainability of such form of collusion. We first develop a simple model of collusion in product line strategies and then calibrate this model based on our estimates.

Model. We consider an industry with three incumbent firms, $j = O, S, B$, and a potential entrant, now denoted as firm F, competing in prices with differentiated products. Each incumbent firm j sells a premium service and has the possibility to expand its brand portfolio by introducing a new low-cost service. To operate the new brand, incumbent firm j has to incur a per-period fixed cost f_j. In contrast to the incumbent firms, the entrant F is a single-product firm, which offers only a low-cost service.

The three incumbent firms play an infinitely repeated game.[40] At each date, they simultaneously decide whether to launch a new low-cost brand (if they have not launched one yet), in addition to their existing

[38]We obtain the same conclusions in the vertically integrated pricing model, as shown in Table A.9 of the appendix: the lower bounds on fixed costs to rationalize no fighting brands in the absence of entry are always higher than the upper bounds to rationalize fighting brands in the presence of entry.

[39]In the absence of fixed costs, as in Nocke and Schutz (2018), our estimates imply that the incumbents would all release low-cost subsidiary brands, regardless of the entry of Free Mobile. Furthermore, they would also potentially proliferate the product portfolio until the marginal revenue from adding a new product is negative. Following Nocke and Schutz (2018), without fixed costs the (equilibrium) number of brands launched by each incumbent may then (weakly) increase with the entry of Free.

[40]In our context, we can think that this infinitely repeated game is played within a specific time period, for example, the month of January, 2012, when entry took place.

premium brand. Once it is launched, an incumbent cannot withdraw its low-cost brand, for example due to high exit costs.[41] We postulate that while firms can potentially collude on their product line strategies, they compete in prices. That is, we consider a context of semi-collusion, where firms collude in one dimension and compete in another.[42]

Each firm $j = O, S, B$ maximizes the present discounted value of its profits, with a discount factor $\delta_j \in (0, 1)$. Firm j's profit at a given date depends on its own product line and that of its competitors, as well as on the equilibrium prices of the one-stage price game given the firms' brand portfolios.

We assume that the one-stage brand expansion game has an equilibrium in which all incumbents decide to launch a new brand. We will infer an upper bound on the fixed costs below which our assumption holds true given our parameter estimates. To define model primitives, we denote by $\Pi_j^{N,e}$ firm j's gross profit in this non-collusive (Nash) outcome, with $e = E$ in case of entry and $e = N$ without entry. The profit is gross of the per-period fixed cost f_j of operating the new brand. All incumbents' launching a new brand constitutes an equilibrium of the one-stage game if and only if $\Pi_j^{N,e} - f_j > \hat{\Pi}_j^e$ for all j, where $\hat{\Pi}_j^e$ denotes firm j's profit if it does not launch a new brand and the two other incumbents would still do so. This condition thus defines an upper bound for the fixed cost, $\bar{f}_j^e \equiv \Pi_j^{N,e} - \hat{\Pi}_j^e$. Intuitively, if firm j's fixed costs are sufficiently low ($f_j < \bar{f}_j^e$), it has no incentive to deviate from the one-stage equilibrium where all incumbents launch a new brand.

On the other hand, we examine whether the incumbent firms can tacitly collude on restricting their product lines. To sustain such collusive outcome, firms adopt the punishment strategy of infinite reversion to the one-stage equilibrium in case any incumbent firm deviates from the collusive equilibrium by unilaterally expanding its brand portfolio. Similarly as above, we denote by $\Pi_j^{C,e}$ firm j's profit in the collusive outcome, and by $\Pi_j^{D,e}$ its gross profit if it deviates from it.

We will say that entry facilitates collusion in product line strategies if it reduces the threshold discount factor above which the collusive outcome can be sustained, and otherwise that it makes collusion more difficult to sustain.

In what follows, we first determine the condition under which collusion on restricting product lines is sustainable. Next, we identify the condition under which collusion becomes more difficult to sustain after entry ($e = E$). Finally, we calibrate this model of semi-collusion using our estimates of operators' profits (for which we continue to rely on Table A.4 of the appendix).

Sustainability of collusion. In both cases, with entry ($e = E$) and without ($e = N$), tacit collusion is sustainable if the sum of discounted profits from collusion is higher than the discounted profits obtained by deviating. If incumbent firm j deviates from the collusive outcome by launching a new brand, it earns the net profit $\Pi_j^{D,e} - f_j$ for one period. In the ensuing punishment phase, the deviating firm makes the profit $\Pi_j^{N,e} - f_j$ in each period. Firm j thus has no incentives to deviate from the collusive outcome if the following condition holds:

$$\frac{\Pi_j^{C,e}}{1 - \delta_j} \geq \Pi_j^{D,e} - f_j + \frac{\delta_j}{1 - \delta_j}(\Pi_j^{N,e} - f_j). \tag{13}$$

[41] Withdrawing the low-cost brand could imply a large reputation cost for the incumbent. See, e.g., Chiou and Scarpa (1992) for a model where withdrawing a new brand has a negative reputational effect on an incumbent's legacy product.

[42] The literature has analyzed semi-collusion in settings where firms compete in the product market (in prices or quantities), while colluding in R&D (Fershtman and Gandal, 1994), capacity (Osborne and Pitchik, 1987), or location choices (Friedman and Thisse, 1993).

Condition (13) holds if and only $\delta_j \geq \underline{\delta}_j^e$, where $\underline{\delta}_j^e$ is the threshold discount factor for firm j, defined by

$$\underline{\delta}_j^e(f_j) \equiv \frac{\Pi_j^{D,e} - \Pi_j^{C,e} - f_j}{\Pi_j^{D,e} - \Pi_j^{N,e}}. \tag{14}$$

There exists a non-empty set of discount factors for the three incumbents such that collusion is sustainable only if $\underline{\delta}_j^e < 1$ for all $j = O, S, B$. Since the threshold discount factor (14) is decreasing in f_j, we have $\underline{\delta}_j^e < 1$ if f_j is sufficiently large. The intuition is that, as the fixed cost of operating a new brand increases, both the deviation and punishment profits decrease, which makes collusion on withholding fighting brands easier to sustain.

Formally, we have $\underline{\delta}_j^e < 1$ if and only if $f_j > \underline{f}_j^e \equiv \Pi_j^{N,e} - \Pi_j^{C,e}$. Obviously, if the gross payoff from collusion is larger than the gross punishment profit (i.e., $\Pi_j^{C,e} \geq \Pi_j^{N,e}$), there always exists a range of discount factors that sustain collusion for all fixed costs $f_j \geq 0$. However, as we will see below with our estimates, the gross profit from collusion can be lower than the gross punishment profit, because under punishment a firm derives additional revenues from its low-cost brand. In this case, a sufficiently high fixed cost of brand operation is necessary to sustain collusion.

To summarize, if for all incumbents $j = O, S, B$ we have $f_j \in (\underline{f}_j^e, \bar{f}_j^e)$, then there is a range of discount factors such that firms can coordinate via repeated interactions on not launching low-cost brands, with or without entry of the competitor. The lower bound on fixed costs guarantees that firms are willing to collude on withholding low-cost brands, whereas the upper bound guarantees that firms are willing to punish by also releasing a low-cost brand when one of the firms deviates.

The impact of entry on collusion incentives. We now discuss the impact of entry by firm F on the possibility of collusion in product line strategies. Entry has countervailing effects on the ability of the incumbent firms to tacitly collude on restricting their product line. On the one hand, entry lowers the collusion profit, which makes collusion harder to sustain. On the other hand, entry also lowers the deviation and punishment profits, which facilitates collusion.

Overall, entry makes collusion more difficult to sustain if and only if $\underline{\delta}_j^E > \underline{\delta}_j^N$. One can verify that

$$\underline{\delta}_j^E(f_j) - \underline{\delta}_j^N(f_j) \equiv \Delta_j(f_j) = \frac{(\Pi_j^{D,E} - \Pi_j^{N,E}) - (\Pi_j^{D,N} - \Pi_j^{N,N})}{(\Pi_j^{D,E} - \Pi_j^{N,E})(\Pi_j^{D,N} - \Pi_j^{N,N})} f_j + \Delta_j(0), \tag{15}$$

with

$$\Delta_j(0) \equiv \frac{\Pi_j^{D,E} - \Pi_j^{C,E}}{\Pi_j^{D,E} - \Pi_j^{N,E}} - \frac{\Pi_j^{D,N} - \Pi_j^{C,N}}{\Pi_j^{D,N} - \Pi_j^{N,N}}.$$

Entry makes collusion in product line strategies more difficult to sustain if, for all $j = O, S, B$, one of the following conditions holds:[43]

1. $\Delta_j(0) > 0$ and $\Pi_j^{D,E} - \Pi_j^{N,E} > \Pi_j^{D,N} - \Pi_j^{N,N}$;

[43]Since the denominator of the coefficient of f_j in (15) is positive, the sign of $\Delta_j(f_j)$ depends on the sign of the numerator of the coefficient of f_j and the sign of $\Delta_j(0)$.

2. $\Delta_j(0) > 0$, $\Pi_j^{D,E} - \Pi_j^{N,E} < \Pi_j^{D,N} - \Pi_j^{N,N}$ and f_j is sufficiently low ($f_j < \bar{\bar{f}}_j$);

3. $\Delta_j(0) < 0$, $\Pi_j^{D,E} - \Pi_j^{N,E} > \Pi_j^{D,N} - \Pi_j^{N,N}$ and f_j is sufficiently high ($f_j > \bar{\bar{f}}_j$).

Otherwise, entry facilitates collusion.[44]

Hence, for entry to make collusion more difficult to sustain, there may be an additional upper bound on the fixed costs (in Case 2) or an additional lower bound (in Case 3). Note that these bounds may be more or less tight than the earlier bounds for sustainability ($\underline{f}_j^e$ and $\bar{f}_j^e$), and we will verify them at our parameter estimates.

Calibration. We can now evaluate whether (i) the three incumbent operators could tacitly collude on restricting their product lines before the entry of Free Mobile, and (ii) whether such collusion became more difficult to sustain after the entry of Free Mobile. Table 9 computes the lower and upper bounds on fixed costs for which collusion is sustainable before entry (i.e., $\underline{f}_j^N$ and $\bar{f}_j^N$) and the bounds for which it becomes more difficult to sustain after entry (i.e., $\bar{\bar{f}}_j$). These are computed from the above definitions, using the incumbents' payoffs under the alternative market configurations shown in Table A.4.

Operator	$\underline{f}_j^N$ (collusion)	$\bar{f}_j^N$ (punishment)	$\bar{\bar{f}}_j$ (breakdown)
(O)range	-265	374	285
(S)FR	-345	259	166
(B)ouygues	131	361	198

Lower and upper bounds on fixed costs for which collusion in restricting product lines is sustainable before entry ($\underline{f}_j^N$ and $\bar{f}_j^N$), and upper bounds for which collusion becomes more difficult to sustain after entry (i.e., $\bar{\bar{f}}_j$), in million euro.

Table 9: Bounds on fixed costs supporting fighting brands in response to entry

The first column of Table 9 computes the lower bounds on fixed costs ($\underline{f}_j^N$) above which firms are willing to collude before the entry of Free Mobile (given their punishment strategies). Formally, these are lower bounds on fixed costs such that $\underline{\delta}_j^N < 1$. Orange and SFR are willing to collude by withholding fighting brand for any level of fixed costs (as the lower bounds are negative). Intuitively, this is because their collusion profits are already higher than their gross profits of punishment (so they would certainly be higher after accounting for the fixed costs under punishment).[45] Bouygues is willing to collude provided its fixed costs are above €131 million. Intuitively, a sufficiently high fixed cost reduces Bouygues' profits from deviating and also makes its punishment more severe.

The second column of Table 9 presents the upper bounds on fixed costs ($\bar{f}_j^N$) below which the incumbents are willing to carry out the punishment outcome as an equilibrium to the one-stage game. The outcome

[44]The upper bound $\bar{\bar{f}}_j$, is defined by:

$$\bar{\bar{f}}_j = \frac{\Pi_j^{C,E}(\Pi_j^{D,N} - \Pi_j^{N,N}) - \Pi_j^{C,N}(\Pi_j^{D,E} - \Pi_j^{N,E}) + \Pi_j^{D,E}\Pi_j^{N,N} - \Pi_j^{D,N}\Pi_j^{N,E}}{(\Pi_j^{D,E} - \Pi_j^{D,N}) - (\Pi_j^{N,E} - \Pi_j^{N,N})}.$$

[45]This can be verified from inspecting the collusion and punishment profits of Orange and SFR in the absence of entry by Free in Table A.4.

in which all three operators punish by releasing a low-cost brand is a one-stage equilibrium provided that the fixed costs are below €374 million for Orange, below €259 million for SFR and below €361 million for Bouygues. It is worth noting that with our estimates, the punishment outcome always corresponds to the harshest (symmetric or asymmetric) punishment for the deviating firm.[46]

Taken together, for each incumbent there is a non-empty range of fixed costs for which both collusion and punishment are sustainable. So we can rationalize the incumbents' decisions to avoid introducing fighting brands in the absence of entry by Free Mobile as a tacitly collusive strategy.

The last column of Table 9 presents the fixed cost bounds for which such collusion becomes more difficult to sustain after the entry by Free Mobile. As shown above, this may either imply further upper or lower bounds on fixed costs. Table A.5 of the appendix shows that for our estimates, we have $\Delta_j(0) > 0$ and $\Pi_j^{D,E} - \Pi_j^{N,E} < \Pi_j^{D,N} - \Pi_j^{N,N}$ for each incumbent $j = O, S, B$. We are therefore in Case 2 defined above. This means that entry makes collusion in product line strategies more difficult to sustain if the fixed costs are sufficiently low, i.e. $f_j < \bar{\bar{f}}_j$: fixed costs should be below €285 for Orange, below €166 for SFR and below €198 for Bouygues.

Note that the upper bounds $\bar{\bar{f}}_j$ are tighter than the earlier upper bounds $\bar{f}_j$ to sustain punishment, but they are still above the lower bounds $\underline{f}_j$ to sustain collusion in the absence of entry. We can conclude that there is a non-empty set of discount factors such that collusion in product line strategies (on not adopting low-cost brands) is sustainable if there is no entry of Free, but it becomes more difficult to sustain if Free enters if the following conditions on fixed costs hold:

$$f_O \in (0, 285), \quad f_S \in (0, 166), \quad f_B \in (131, 198).$$

We obtain the the same conclusions in the model of vertically integrated pricing instead of independent wholesaler-retailer pricing, as shown in Table A.10 of the appendix.

To sum up, we have shown that we can rationalize the introduction of new low-cost brands as "fighting brand" strategies within a dynamic framework of tacit collusion. There indeed exists a set of fixed costs and discount factors such that the incumbents can collude on restricting their product lines in the absence of Free Mobile's entry, whereas such collusion can break down after entry.[47] We are now in a position to evaluate the impact of entry by Free Mobile on consumers and welfare, taking into account the fighting brand responses by the incumbents.

6 Impact of entry on consumers and welfare

In homogeneous products markets, the consumer and total welfare effects from new market entry arise from increased competition and the associated price reduction. In our setting with differentiated products, however, there exist three different channels of such welfare effects. First, entry has a direct variety effect from the arrival of new entrant's product differentiated from existing services. Second, entry, through intensifying price competition, may lead to lower prices for the incumbents' premium brands. Third, as shown in the

[46]Therefore, the trigger strategies with infinite reversion to the one-stage equilibrium of the game (Friedman, 1971) coincide with Abreu's optimal punishment.

[47]As an alternative to our repeated game approach, we could have also considered that incumbent firms take into account their rivals' sequential reactions when they decide unilaterally to deviate from the candidate equilibrium, i.e., no introduction of low-cost brands if there is no entry, and introduction of low-cost brands in case of entry. This approach has a similar intuition and leads to similar findings.

previous section, entry may result in a breakdown of semi-collusion, thus inducing the incumbents to release low-quality fighting brands. This may further improve welfare through increased variety and lower prices.

To assess the relative importance of these three channels, we decompose the consumer and welfare impacts of Free Mobile's entry by considering alternative counterfactual scenarios. First, we consider that Free Mobile enters the market while assuming that the incumbent MNOs do not respond by adjusting prices or by introducing fighting brands. This is the pure variety effect from entry. Second, we assume that the incumbents optimally adjust their prices while their product portfolio is held fixed. This refers to the price effect from entry. Third, we account for the breakdown in the semi-collusion and allow the incumbents to introduce their fighting brands. Technically, we perform these counterfactuals based on the post-entry samples for 2012–2014, since this gives us estimates of the consumer valuations and marginal costs of the new entrant and the fighting brands. Using the post-entry data, our measurement approach thus proceeds as follows. First, we eliminate the fighting brands and compute the new equilibrium wholesale and retail prices. Second, we additionally eliminate Free Mobile, holding the prices of the incumbent MNOs and MVNOs constant. Third, we additionally allow the incumbents and MVNOs to adjust their prices and compute the new Nash equilibrium.

Table 10 summarizes the surpluses measured by this decomposition. The first column reports the impact on consumer surplus over the considered period. The total consumer surplus gains from the changes in market structure amount to about €4.6 billion. To put the figure in perspective, the size of the gains is equivalent to 7.7% of the total €60.1 billion industry retail sales. The consumer surplus gains from the pure variety effect of Free Mobile (holding fixed the price and product line responses) constitute €2.3 billion, or about half of the total consumer gains. The additional consumer gains from the incumbents' and MVNOs' price responses, over and above the variety effect, are rather modest, about €804 million. This implies that the market has indeed become more competitive after entry. The consumer gains from the price responses correspond to price reductions by 1.3% for Orange and 2.4% for SFR, and a 0.7% price increase for Bouygues. Finally, the additional consumer gains from the fighting brands are estimated to be around €1.4 billion, or more than 30% of the total consumer gains. Note that the gains from the fighting brands are mainly obtained from the additional variety offered by themselves, but not from further price responses by Free or other operators (not shown in the table).

Source	Consumer	Producer	Total
Free's entry	3,144	-1,959	1,185
Variety	2,340	-1,200	1,140
Price	804	-759	45
Fight brands	1,417	-378	1,039
Total	4,561	-2,337	2,224

Impact of entry on consumers and welfare, broken down by different sources (in million euro).

Table 10: Sources of consumer and welfare impact from entry

The second column of Table 10 measures the impact of entry on producer surplus. Total producer surplus decreases by €2.3 billion: the incumbents and MVNOs collectively lose €4.4 billion, of which Free Mobile only recapture €2.1 billion. Producer surplus mainly drops due to the direct variety effect (by €1.2 billion): this is due to the reallocation of sales from the high margin incumbent MNOs to the low margin entrant Free Mobile (held fixed in this part of the decomposition). Producer surplus also decreases as a result of the price competition (by €759 million). Finally, producer surplus is further reduced by the incumbents' fighting brands (by €378 million). This is again due to a reallocation effect, from the high margin incumbents to the lower margin fighting brands.

Finally, the total welfare impact of entry is computed in the third column of Table 10. The total gross welfare increase is estimated to reach €2.2 billion. Interestingly, one half of these welfare gains stem from the variety effect by Free and the other half from the fighting brands. Only a negligible part is obtained from the increased price competition (€45 million). Intuitively, this just constitutes a transfer between firms and consumers given that total demand for mobile services is relatively inelastic as the mobile market was already saturated before entry.

As a robustness analysis, we have also evaluated the impact of entry on consumer surplus and welfare under the vertically integrated pricing model instead of the independent retailer-wholesaler pricing model. The results are shown in Table A.11 of the appendix. We find that the impact of Free and the fighting brands is similar. Hence, we conclude that our findings are not sensitive to the pricing assumptions.

Overall, we conclude that the entry of Free Mobile has made a large contribution to consumer surplus, about half of which is due to the increased variety from the new entrant, and 30% is due to additional gains from the fighting brands (with the rest of the gains, albeit of more modest size, from the competitive price responses of the existing firms). At the same time, the entry of Free has led to large losses in gross producer surplus due to inefficient reallocation, implying that the total gross welfare benefits are only half of the consumer benefits.

7 Conclusion

We have analyzed the impact of new entry in the mobile telecommunications market in France. Using detailed information on the demand of network services at the local market level, we estimate a flexible differentiated products demand to capture rich substitution patterns. Taking as input the price elasticity estimates, we use an oligopoly model of wholesale and retail price competition to infer wholesale prices and marginal costs of production. These estimates allow us to evaluate the incumbents' profit incentives to introduce fighting brands and to decompose the welfare impact of entry stemming from different sources.

We find empirical evidence for the fighting brand theory, but our main intuition departs from the existing theory by taking into account strategic interactions among multiple incumbent firms. While entry has raised the incumbents' joint incentives to introduce fighting brands after entry, this increase is not sufficient to rationalize the fighting brands as a collective move. Furthermore, we cannot rationalize the incumbents' fighting brand strategies as unilateral best responses to the new entry in a static game. Instead, we show that the incumbents' launch of the fighting brands can be rationalized as a breakdown of tacit collusion in product lines: before entry the incumbents can collude on suppressing low-cost brands to avoid cannibalization, and after entry this semi-collusion becomes more difficult to sustain because of increased business stealing incentives.

Our findings have implications for the consumer and welfare effects from new entry. We find that the entry of Free Mobile has considerably contributed to consumer welfare, mainly through the increased variety offered by the new entrant and through the incumbents' fighting brands (responsible for, respectively, 51% and 31%, of the consumer consumer gains), and much less by the intensified price competition (responsible for only 18% of the consumer gains). The welfare effects of entry are mitigated by producer surplus losses associated with inefficient reallocation. A general conclusion from our analysis is that concentrated market structures may facilitate tacit collusion on restricting product variety. This adds to traditional concerns that increased concentration may facilitate collusion in prices or quantities, with a potential of generating considerably larger losses to consumers and welfare.

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Appendix A: Estimation of supply model

This section discusses the details on the solution of the wholesale prices and marginal costs. We first differentiate Equation (5) for all $f \in \mathcal{F}$ with respect to the wholesale price w_{g_0} of network $g \in \mathcal{F}$, so that we obtain the following equations: for $j \in L_f$ and $f \in \mathcal{F}$,

$$\sum_{k \in J} \left[\frac{\partial D_j}{\partial p_k} + \sum_{l \in L_f} (p_l - c_l) \frac{\partial^2 D_l}{\partial p_j \partial p_k} + (w_{f_0} - c_{f_0}) \frac{\partial^2 D_{f_0}}{\partial p_j \partial p_k} \right] \frac{\partial p_k}{\partial w_{g_0}} + \sum_{l \in L_f} \frac{\partial p_l}{\partial w_{g_0}} \frac{\partial D_l}{\partial p_j} = b_j^1, \tag{16}$$

where $b_j^1 = -\frac{\partial D_{f_0(j)}}{\partial p_j}$ if $g = f(j)$, and 0 otherwise. Likewise, we differentiate Equation (6) w.r.t. w_{g_0} to obtain

$$\sum_{k \in \mathcal{J}} \left[\frac{\partial D_{f_0}}{\partial p_k} + (p_{f_0} - w_{f_0}) \frac{\partial^2 D_{f_0}}{\partial p_{f_0} \partial p_k} \right] \frac{\partial p_k}{\partial w_{g_0}} + \frac{\partial p_{f_0}}{\partial w_{g_0}} \frac{\partial D_{f_0}}{\partial p_{f_0}} = b_f^2, \tag{17}$$

for all $f \in \mathcal{F}$, where $b_f^2 = \frac{\partial D_{f_0}}{\partial p_{f_0}}$ if $g = f$, and 0 otherwise.

The solution procedure begins by solving the wholesale prices w_{f_0} for $f \in \mathcal{F}$ from Equation (6). Given the wholesale prices, we subsequently solve Equations (5), (7), (16), and (17) to obtain the marginal costs c_j for $j \in L_f$ and c_{f_0} for all $f \in \mathcal{F}$. The solution of the marginal costs in the second step relies on the trust region algorithm.

For each MNO $g \in \mathcal{F}$, we first solve (16)–(17) for the pass-through rates $\partial p_j / \partial w_{g_0}$ for all $j \in \mathcal{J}$, taking the marginal costs as input. To write the equations in matrix form, we let J denote the number of elements in $\mathcal{J}$ and L the number of products contained in $\bigcup_{f \in \mathcal{F}} L_f$, the complete set of the MNO product lines. This convention implies that $L + F = J$. Under these notations, (16) and (17) can be expressed as

$$Ax = b, \qquad A = \begin{bmatrix} A^1 \\ A^2 \end{bmatrix}, \quad b = \begin{bmatrix} b^1 \\ b^2 \end{bmatrix},$$

where $x = [\partial p_1 / \partial w_{g_0}, ..., \partial p_J / \partial w_{g_0}]$, $b^1 = [b_1^1, ..., b_L^1]'$, $b^2 = [b_1^2, ..., b_F^2]'$, and the submatrix A^1 is defined as:

$$A_{ij}^1 = \frac{\partial D_i}{\partial p_j} + \sum_{l \in L_{f(i)}} (p_l - c_l) \frac{\partial^2 D_l}{\partial p_i \partial p_j} + (w_{f_0(i)} - c_{f_0(i)}) \frac{\partial^2 D_{f_0(i)}}{\partial p_i \partial p_j} + 1\{j \in L_{f(i)}\} \frac{\partial D_j}{\partial p_i},$$

for $j = 1, ..., J$ and $i = 1, ..., L$. The submatrix A^2 is defined as

$$A_{fj}^2 = \frac{\partial D_{f_0}}{\partial p_j} + (p_{f_0} - w_{f_0}) \frac{\partial^2 D_{f_0}}{\partial p_{f_0} \partial p_j} + 1\{j = f_0\} \frac{\partial D_{f_0}}{\partial p_{f_0}},$$

for $f \in \mathcal{F}$ and $j \in \mathcal{J}$.

Then, by plugging the derivatives $\partial p / \partial w$ obtained from (16) and (17) into (7), we can fully characterize the marginal costs by jointly solving Equations (5) and (7).

Appendix B: Simulation

Given the estimates for the wholesale prices and marginal costs, we use the same FOCs to solve for the equilibrium retail and wholesale prices. Specifically, the second-stage game is solved by Equations (5) and (6). This solution step is nested in the computation procedure for the first-stage game solved by (7). Given the retail prices and marginal costs, the pass-through rates in Equation (7) can be obtained from Equations (16) and (17). Due to numerical instability caused by extremely low income draws, we adjust the lower bound $\underline{y}$ of the simulated incomes to be €700 on average to ensure the convergence of the solution procedure.

Appendix B2: Continuous updating procedure for optimal instruments

For given nonlinear parameters $\theta_2 = (\alpha, \sigma_\nu)$,

1. BLP contraction loop

   (a) Solve for BLP fixed point $\delta(\theta_2) = (\delta_{jt})_{j,t}$ s.t. $s_{jt}(\delta_t, \theta_2) = s_{jt}$ for all j, t .

2. Optimal instruments loop

   (a) Given δ in step 1 and the optimal instrument z^{k-1} from the previous $(k-1)$-th iteration, obtain linear parameter estimates θ_1^k from the linear IV regression of Nevo (2000).

   (b) Obtain $z^k = E\big[\frac{\partial \hat{\delta}(\theta_1^k, \theta_2)}{\partial \theta}\big|z^{k-1}\big]$ using the implicit function theorem, where $\hat{\delta}$ is the inverse of predicted demand $\hat{s} = E_\xi[s(\xi, \theta_1^k, \theta_2)|z^{k-1}]$.

   (c) Repeat (a) and (b) until $\|\theta_1^k - \theta_1^{k-1}\| < 10^{-8}$.

Appendix C: Additional Tables

Estimate	Logit	IV logit	RC logit
Price/y_{it} (α)			-4.030***
			(0.485)
Forfait bloqué/y_{it}			39.101***
			(5.681)
Log 4G/y_{it}			-3.978***
			(0.711)
Price/$\bar{y}_t$	-0.241**	-6.051***	
	(0.104)	(0.848)	
Log(2G antenna)	1.097***	0.201	0.532
	(0.144)	(0.361)	(0.362)
Log(2G roaming)	1.063***	-0.130	0.568
	(0.208)	(0.605)	(0.556)
Log(3G antenna)	0.164	0.856***	0.662***
	(0.108)	(0.218)	(0.229)
Log(3G roaming)	0.010	1.101**	0.275
	(0.181)	(0.557)	(0.469)
Log(4G antenna)	0.040	0.217***	0.580***
	(0.033)	(0.067)	(0.134)

(Table continues in the next page.)

Table A.1: Full results for Table 4

Estimate	Logit	IV logit	RC logit
Log(4G roaming)	0.044	0.121	0.462***
	(0.038)	(0.076)	(0.168)
Postpaid	-0.941	-2.651	-0.796
	(1.012)	(3.463)	(2.228)
Forfait bloqué	2.536**	2.486	2.016
	(1.032)	(3.408)	(2.554)
Call allowance (1,000 min)	0.078	1.121***	0.585***
	(0.052)	(0.174)	(0.126)
Data allowance (1,000 MB)	0.618***	0.179	0.520***
	(0.059)	(0.156)	(0.123)
Orange	-0.718	0.700	-0.971
	(1.151)	(4.336)	(2.280)
SFR	-0.905	-1.358	-0.685
	(1.155)	(2.755)	(2.812)
Bouygues	-1.004	0.155	-1.230
	(1.181)	(5.582)	(2.619)
Free	0.687	-1.413	-0.185
	(1.989)	(4.587)	(3.157)
Sosh	1.911	1.839	1.265
	(1.933)	(4.532)	(4.229)
B&You	1.759	0.070	-1.776
	(1.996)	(4.468)	(3.085)
Red	-0.904	-2.751	-4.292
	(1.972)	(4.298)	(3.379)
MVNO:Orange	0.366***	0.136	1.242***
	(0.066)	(0.227)	(0.250)
MVNO:SFR	1.189***	0.446**	1.223***
	(0.057)	(0.190)	(0.187)
Time trend	0.063***	-0.086***	0.024
	(0.007)	(0.018)	(0.036)
1/Time since entry	-2.643***	-2.259***	-2.089***
	(0.107)	(0.276)	(0.265)
Orange*age	0.650**	0.743	1.202**
	(0.295)	(1.102)	(0.561)
SFR*age	0.663**	0.945	0.886
	(0.297)	(0.703)	(0.710)
Bouygues*age	0.550*	0.557	1.005
	(0.301)	(1.425)	(0.663)
Free*age	0.285	-0.207	-0.052
	(0.508)	(1.169)	(0.793)
Sosh*age	-0.495	-1.053	-0.662
	(0.496)	(1.153)	(1.040)
B&You*age	-0.483	-0.895	-0.061
	(0.510)	(1.133)	(0.770)
Red*age	0.310	0.071	0.796
	(0.506)	(1.091)	(0.846)
Age of population	-6.554***	-7.675***	-4.687***
	(0.530)	(1.503)	(1.647)
Postpaid*age	0.048*	0.170*	0.122**
	(0.026)	(0.088)	(0.058)
Forfait bloqué*age	-0.060**	-0.014	-0.047
	(0.026)	(0.087)	(0.066)
Constant	21.721***	29.698***	24.645***
	(1.946)	(5.630)	(6.039)
Observations	3,328	3,328	3,328
J statistic		145.70	0.00
D.F.		13	0

(Table continues in the next page.)

Table A.1: Full results for Table 4

Estimate	Logit	IV logit	RC logit
Simulation draws			200
Market fixed effects	Yes	Yes	Yes

Standard errors in parentheses: p<0.10, ** p<0.05, *** p<0.01.
y_{it} & $\bar{y}_t$ denote individual & mean incomes scaled by €100.

Table A.1: Full results for Table 4

Network operator	Product group	Orange Prepaid	Orange Postpaid	Orange F. bloqué	Orange Sosh	SFR Prepaid	SFR Postpaid	SFR F. bloqué	SFR Red	Bouygues Prepaid	Bouygues Postpaid	Bouygues F. bloqué	Bouygues B&You	Free Postpaid
Orange	Prepaid	-100.00	5.15	8.00	5.70	7.02	5.58	7.51	5.54	7.09	4.69	7.11	5.62	7.98
	Postpaid	8.79	-100.00	8.32	11.80	7.57	24.58	3.75	9.91	8.44	26.05	4.85	10.90	6.83
	Forfait bloque	11.02	7.02	-100.00	8.36	9.90	7.72	11.21	8.40	10.01	6.23	10.45	8.11	12.78
	Sosh	3.26	3.99	3.28	-100.00	3.16	4.31	1.89	3.50	3.18	3.65	2.21	3.73	4.14
SFR	Prepaid	2.92	1.91	2.97	2.31	-100.00	2.19	3.04	2.65	2.76	1.79	2.78	2.32	3.54
	Postpaid	11.19	28.32	10.73	15.05	10.15	-100.00	5.16	13.22	10.61	24.59	6.48	14.14	10.20
	Forfait bloque	7.03	2.51	7.62	4.14	6.87	2.98	-100.00	4.71	6.52	2.29	9.39	4.35	10.88
	Red	2.54	2.45	2.62	2.77	2.69	2.85	2.14	-100.00	2.50	2.38	2.17	2.82	4.03
Bouygues	Prepaid	2.79	2.03	2.83	2.21	2.63	2.19	2.72	2.16	-100.00	1.88	2.75	2.31	3.17
	Postpaid	5.72	18.39	5.23	7.71	5.07	15.10	2.43	6.63	5.51	-100.00	3.24	7.58	4.74
	Forfait bloque	2.91	1.28	3.08	1.88	2.77	1.48	4.32	2.11	2.90	1.21	-100.00	2.06	4.30
	B&You	2.98	3.13	2.94	3.40	2.95	3.53	2.00	3.23	2.91	3.10	2.25	-100.00	4.29
Free	Postpaid	23.87	12.54	25.95	20.78	25.62	15.95	34.71	23.45	23.98	12.41	30.07	23.03	-100.00

Percentage of sales diverted toward products (rows) due to price increase (columns)

Table A.2: Diversion ratios

Upstream network	Downstream network	Wholesale price			Wholesale markup		
		Prepaid	Postpaid	F. bloqué	Prepaid	Postpaid	F. bloqué
Orange	MVNO	5.72	12.43	14.88	4.81	9.38	4.64
SFR	MVNO	3.37	12.37	14.09	4.08	8.63	4.37
Bouygues	MVNO	2.05	24.51	12.48	2.44	9.91	3.31

Average prices and margins in the wholesale market across times and regions.

Table A.3: Estimated wholesale prices and markups

		SFR			
		Fight		Not	
		Orange		Orange	
Bouygues	Payoffs	Fight	Not	Fight	Not
Entry of Free mobile					
Fight	Orange	9,534	9,193	9,668	9,318
	SFR	7,135	7,291	6,913	7,061
	Bouygues	3,774	3,873	3,838	3,940
Not	Orange	9,784	9,432	9,928	9,567
	SFR	7,334	7,500	7,106	7,264
	Bouygues	3,471	3,559	3,528	3,618
No entry of Free mobile					
Fight	Orange	11,084	10,709	11,292	10,901
	SFR	8,446	8,680	8,187	8,409
	Bouygues	4,482	4,635	4,590	4,746
Not	Orange	11,541	11,147	11,765	11,349
	SFR	8,824	9,078	8,555	8,791
	Bouygues	4,121	4,258	4,215	4,351

Equilibrium profits for 2011Q4–2014Q4 in million euros

Table A.4: Equilibrium profits under all entry and product line strategies

Operator	$\Delta_j(0)$	$\Pi_j^{D,E} - \Pi_j^{N,E}$	$\Pi_j^{D,N} - \Pi_j^{N,N}$	$\bar{\bar{f}}_j$
(O)range	0.31	394	681	285
(S)FR	0.19	365	632	166
(B)ouygues	0.44	166	264	198

First column is a ratio, other columns are in million euros.

Table A.5: Impact of entry on collusion: background conditions

Operator	Product	Retail price	Change(%)	Change
Orange	Prepaid	13.82	1.70	0.23
Orange	Postpaid	39.52	0.97	0.39
Orange	F. bloqué	22.83	1.13	0.26
Sosh	Postpaid	16.87	1.15	0.20
SFR	Prepaid	13.50	1.68	0.23
SFR	Postpaid	28.71	1.21	0.34
SFR	F. bloqué	19.05	4.16	0.74
Red	Postpaid	15.73	1.28	0.19
Bouygues	Prepaid	13.12	-2.69	-0.35
Bouygues	Postpaid	34.84	0.17	0.06
Bouygues	F. bloqué	19.70	0.31	0.05
B&You	Postpaid	15.65	-2.87	-0.43

Percentage change in prices due to the incumbent's response to entry. The change is measured by the subtracting the observed prices under entry from the counterfactual prices under no entry in equilibrium and divided by the observed price. The unit is in euros.

Table A.6: Price effects of entry

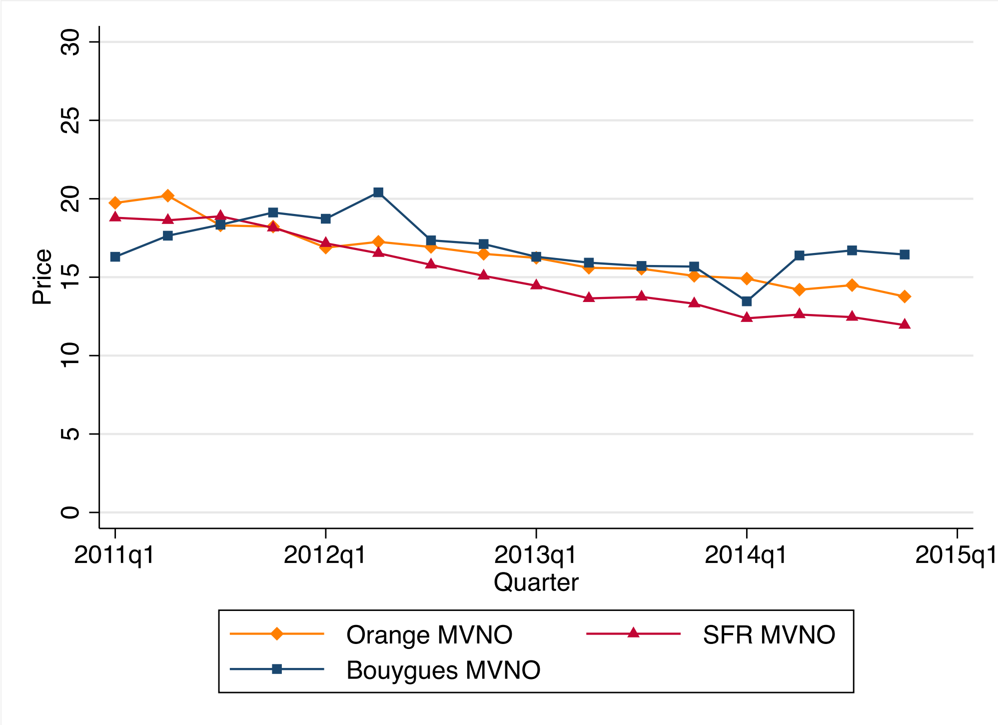

Figure A.1: Prices of the MVNO services

Appendix D: Profit incentives and welfare effects under vertically integrated pricing

		SFR			
		Fight		Not	
		Orange		Orange	
Bouygues	Payoffs	Fight	Not	Fight	Not
Entry of Free mobile					
Fight	Orange	9,652	9,084	9,867	9,279
	SFR	7,196	7,481	6,847	7,112
	Bouygues	3,797	3,924	3,875	4,012
Not	Orange	9,950	9,354	10,184	9,567
	SFR	7,428	7,740	7,062	7,353
	Bouygues	3,393	3,497	3,457	3,569
No entry of Free mobile					
Fight	Orange	11,299	10,614	11,659	10,939
	SFR	8,626	9,098	8,173	8,613
	Bouygues	4,287	4,487	4,421	4,645
Not	Orange	11,823	11,087	12,244	11,467
	SFR	9,078	9,633	8,589	9,111
	Bouygues	3,790	3,946	3,892	4,065

Equilibrium profits for 2011Q4–2014Q4 in million euros

Table A.7: Equilibrium profits under all entry and product line strategies

	Entry of Free Mobile	
Network	No	Yes
Orange	-168	-85
SFR	-485	157
Bouygues	222	-228
Total incumbents	-431	-156
Free	0	-375

The figures represent the profit changes (in million euro) of the incumbents and Free Mobile, when the incumbents jointly introduce their low-cost brands. The calculations are based on the payoffs from Table A.7 of the appendix.

Table A.8: Joint profit incentives for fighting brand adoption: vertically integrated pricing

	Entry of Free Mobile	
	No	Yes
Network	Equilibrium: no fighting brands	Equilibrium: fighting brands
Orange	777	-568
SFR	522	-349
Bouygues	580	-404

The figures represent the incumbents' profit changes (in million euro), resulting from unilateral deviations from the observed candidate Nash equilibrium: "no fighting brands" without the entry by Free Mobile, "introduce fighting brands" in the presence of entry. The calculations are based on the payoffs from Table A.7 of the appendix.

Table A.9: Unilateral incentives to deviate from candidate equilibrium profit lines: vertically integrated pricing

Operator	$\underline{f}_j^N$ (lower)	$\bar{f}_j^N$ (upper)	$\bar{\bar{f}}_j$ (collusion)
(O)range	-168	685	411
(S)FR	-485	453	228
(B)ouygues	222	497	237

Lower and upper bounds on fixed costs for which collusion in restricting product lines is sustainable before entry ($\underline{f}_j^N$ and $\bar{f}_j^N$), and upper bounds for which collusion becomes more difficult to sustain after entry (i.e., $\bar{\bar{f}}_j$), in million euro.

Table A.10: Bounds on fixed costs supporting fighting brands in response to entry: vertically integrated pricing

Source	Consumer	Producer	Total
Free's entry	2,467	-1,688	779
Variety	2,339	-874	1,465
Price	128	-814	-686
Fight brands	1,368	-218	1,150
Total	3,835	-1,906	1,929

Impact of entry on consumers and welfare, broken down by different sources (in million euro).

Table A.11: Sources of consumer and welfare impact from entry: vertically integrated pricing