Research Article

Game Theoretic Modeling of NGANs: Impact of Retail and Wholesale Services Price Variation

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The increasing demand for broadband access leads operators to upgrade the existing access infrastructures (or building new access network). Broadband access networks require higher investments (especially passive infrastructures such as trenches/ducts and base station towers/masts), and before making any decision it is important to analyze all solutions. The selection of the best solution requires understanding the technical possibilities and limitations of the different access technologies, as well as understanding the costs of building and operating the networks. This study analyzes the effect of asymmetric retail and wholesale prices on operators' NPV, profit, consumer surplus, welfare, retail market, wholesale market, and so on. For that, we propose a technoeconomic model complemented by a theoretic-game model. This tool identifies all the essential costs of building (and operating) access networks and performs a detailed analysis and comparison of the different solutions in various scenarios. Communities, operators/service providers, and regulators can use this tool to compare different technological solutions, forecast deployment costs, compare different scenarios, and so on, and help them in making deployment (or regulatory) decisions. The game-theory analyses give a better understanding of the competition and its effect on the business case scenarios' economic results.

1. Introduction

Service providers, network operators, and Internet access providers are faced with the challenge of providing higher-capacity access to the end user and offering wider services [1]. Consequently, new Internet infrastructure and technologies that are capable of providing high-speed and high-quality services are needed to accommodate multimedia applications with diverse quality of service (QoS) requirements. Until a few years ago, Internet access for residential users was almost exclusively provided via public switched telephone networks (PSTN) over the twisted copper pair [2]. The new quadruple play services (i.e., voice, video, data, and mobility), which require high-speed broadband access, created new challenges for the modern broadband wireless/wired access networks [3]. The new services led to both the development of several different last-mile solutions to make the access network capable of supporting the requirements and a stronger integration of optical and wireless access networks.

The move toward next-generation networks (NGNs) has significant implications for the technical architecture and design of access network infrastructure, as well as the value chains and business models of electronic communications' service provision [4]. This migration has begun to transform the telecommunication sector from distinct single-service markets into converging markets [5]. NGNs allow consumers to choose between different access network technologies to access their service environment. In our work, the NGN architecture will be limited to the developments of network architectures in the access network (local loop), referred to as the next-generation access network (NGAN).

Although the cost of bandwidth in the active layer has reduced significantly (and continually) in recent years, the cost of civil works (such as digging and trenching) represents a major barrier for operators to deploy NGA infrastructure. Studies and deployments [7] show that civil infrastructure is the largest proportion of the costs of fixed access deployment (up to 80%). Duct is a critical part of the next-generation access networks, and its sharing would

FIGURE 1: Network layers [6].

reduce or eliminate this capital cost and barrier to entry. However, duct access may need to be complemented by extra civil work to increase infrastructure capacity, the use of dark fiber (where available), or the use of conduits of alternative infrastructure providers. This also highlights that different and/or complementary regulatory tools may be required in different parts of the network [8].

2. Effects of NGNs on Market Definition

The entry of new competitors can be based on the resale of services from the incumbent, on building up their own infrastructures, on renting unbundled infrastructure from incumbents, or on the combination of the above elements. The availability of these options to competitors and price definition are generally determined by regulatory policies [9]. So, the introduction of NGNs by telecommunication network operators obligates the national regulators to adapt their access regulation regimes to the new technological conditions. Regulation and/or promotion of competition by regulatory measures need to be analyzed and compared.

The access network is usually the most expensive component in terms of capital investment (specifically passive infrastructure) and OA&M costs. Of the several costs, civil engineering costs are greatest when it is necessary to run a new fiber or copper connection to the cabinet, building, or home. Moreover, access to existing infrastructure, such as the ducts of the incumbent or other market players or sewage pipes, is critically important to avoid digging.

For [6], a local loop network can be divided into three main layers or segments: a service layer and two infrastructure layers (see Figure 1). Layer 1 includes passive infrastructures, such ducts and cables, and requires the greatest investment. Layer 2 consists of active infrastructures, such as the technical installations at the end of the fibers that send, receive, and manage the optical signals. Layer 3 includes several services that consumers buy from telecommunication operators.

3. Business Case Definition

The definition of a business case implies a great number of assumptions, such as the penetration rate, components prices, and the market share rate. However, it is difficult to get an exact forecast of its performance. The utility of a business case is to offer a more approximated estimation that allows the construction of scenarios for the future. A business case should be as realistic as possible in order to be useful and

TABLE 1: Average lengths assumptions.

Segment	Region 1 (urban)	Region 2 (rural)
Feeder	750 m	1500 m
Distribution	300 m	750 m
Drop	15 m	25 m

TABLE 2: Service profile characteristics: retail prices.

Service profiles	One-time activation fees (Connection)	Expected tariff evolution (%)	Monthly subscription fees	Expected tariff evolution (%)
Serv. 1	100€	−10%	20€/month	−5%
Serv. 2	100€	−10%	50€/month	−8%

reflect all the variables of interest of the market, as well as their evolution and expected behavior [10].

3.1. Territory and Demography. The geographical areas considered are an area with high population density and an area with low population density and high coverage. For the rural area, the roll-out strategy does not cover the whole area (1173 km²)—the target area is limited to 34.04 km² with 23,000 inhabitants (see Table 1). In our model, we consider the last 10 years to estimate the average rate of increase: 0.62% for the urban area and value of 0.01% for rural target area. The population density in the urban area is 3,748 inhabitants per square kilometer and 675 in the rural area.

Parameters presented in Table 1 are important to calculate the cost of trenches/ducts, which are the most significant proportion of the costs of fixed-access deployment.

Several studies and models [11–13] assume that, in urban areas, the duct availability rate is about 60% for feeder segments and 40% for the distribution segment. In rural areas, the duct availability rate is 25% for feeder and 0% for the distribution network. The report from [14] assumes that a substantial proportion (80% near to the CO and 30% nearer to the premises) of existing ducts can be reused for fiber deployment [15].

3.2. Service Profile Assumptions. In this business case, we define two different services: slow Internet browsing service with downstream throughput of 2 Mbps and triple play service with 20 Mbps of downstream rate. The expected tariff evolution (the factor by which the tariff is expected to increase or decrease annually) is defined for both tariffs: connection and monthly fee (see Table 2).

The assumptions presented are based on the data from the review of the literature. We observe that several studies and deployments [11, 16–20] use the yearly price erosion of between 5% and 15%. The service price assumptions (prices and annual variation) are presented in Table 2.

3.3. Broadband Market Forecasts. Figure 2 shows the penetration forecast for DSL, HFC, fiber, and WiMAX for urban areas. In 2020, for the urban area, the expected penetration rates for the fixed technologies are 1.5% for WiMAX, 14.25%

TABLE 3: Willingness assumptions.

Parameters	Region 1 (urban area)		Region 2 (rural area)	
	Serv. 1	Serv. 2	Serv. 1	Serv. 2
Monthly subscription fee (Year 1)	20€	50€	20€	50€
Willingness value	26€	65€	22€	55€
Willingness multiplier	1.3	1.3	1.1	1.1

FIGURE 2: Fixed broadband penetration forecasts (2010–2020).

for HFC, 22.71% for fiber, and 30.97% for DSL. In the rural area, the expected penetration rate in 2020 is 10.95% for HFC, 23.7% for DSL, 16.41% for fiber, and 7.5% for FWA. We also assume that in rural areas the FWA operator has higher market share than in urban areas.

3.4. Competitive Situation and Operators' Market Share. In this section, the market share (relative size) of all the firms (operators) is projected. As competition between operators is different in each area, we estimate the market share for each operator depending on the area, technology, service, and the market (see Figure 3).

4. Game Theory for Competing Modeling

With game theory, we want to understand the effects of the interaction between the different players defined in our business case. In the proposed games, the profit (outcome) of each operator (player) will be dependent not only on their actions, but also on the actions of the other operators in the market.

This section analyzes the impact of the price (retail and wholesale) variations on several output results: players' profit, consumer surplus, welfare, costs, service adoption, and so on. For that, two price-setting games are played (Figure 4). Players' profits and NPV are used as the payoff for the players in the games analyzed.

FIGURE 3: Market share per operator and region (FTTH market).

From the several markets presented previously, in this section we present the results for FTTH (PON) market. We assume that two competing FTTH (PON) networks (incumbent operator and new entrant) are deployed in both areas. For the game-theoretic model, it is necessary to change the adoption model used in the technoeconomic model in a way that reflects the competition between players (see Figure 5). We assume that the variation of the services prices of one player has an influence on the market share of all players (detailed in the next section).

In our model we also use the Nash equilibrium to find equilibrium. Proposed tools include a module to search the Nash equilibrium in the game. One strategy is a Nash equilibrium when both competitors play their best strategy related to the other strategies selected (players know each other's strategy in advance).

4.1. Strategies. To analyze the impact of retail and wholesale services price variations, we propose two games (see Figure 4): (1) analysis of the impact of retail price variation on NPV (wholesale prices are defined by regulator) and (2) analysis of the impact of retail and wholesale price variations on profit, consumer surplus, welfare, and retail/wholesale market (different wholesale prices in each region). For the game-theoretic evaluation, the model calculates the NPV and operator's profit for both operators' pricing strategies. Operators' NPVs are used as payoffs for the players in the first and second games, and operators' profits for the third game.

From the several assumptions, we posit (a) the price that players charge for their services (retail and wholesale) will be varied; (b) the retail price setting will influence the market share of both players (resulting in a higher or lower market share); (c) consumers only buy a retail service if the price is less than their willingness to pay.

As stated above, we assume that when one player increases/decreases the retail price, the market share of all players will be affected. For example, if one player offers cheaper services, it will be able to capture a higher market share. If a price decreases to nearly zero, everyone will use the service, and the market share of this operator will be close to 100% (total market). On the other hand, if an operator charges a higher price for a service, no one will subscribe to

TABLE 4: Wholesale infrastructure assumptions.

Parameters	Region 1 (urban)		Region 2 (rural)	
	Feeder segment	Distribution segment	Feeder segment	Distribution segment
Provider 1				
Duct availability	100%	100%	90%	90%
Wholesale price charged to access ducts (€/Km)	€110	€110	€90	€90
Proportion of ducts leased	0%	0%	10%	10%
From operator	—	—	2	2
Provider 2				
Duct availability	0%	0%	10%	10%
Wholesale price charged to access ducts (€/Km)	€110	€110	€90	€90
Proportion of ducts leased	75%	75%	100%	100%
From operator	1	1	1	1

FIGURE 4: Games proposed.

FIGURE 5: Models to estimate the impact of the price on the service adoption ($a = 0.4$, $b = 3$, $dx = 0.3$).

the service from this player and its market share will decrease to 0%.

4.2. Adoption Model. The impact of varying retail prices on market shares is estimated using the Boltzmann equation.

4.3. Main Assumptions. We assume that the willingness to pay for each retail service is different in both regions. In the urban area (region 1), the maximum amount subscribers would be willing to pay for service 1 is 26 Euros and 65 Euros for service 2. In the rural area we assume a willingness value of 22 Euros for service 1 and 55 Euros for service 2 (see Table 3).

For the wholesale infrastructure, we assume a duct availability of player 1 100% in the urban area and 90% in the rural area. We also assume that operator 2 (new entrant) leases 100% of the ducts available in the urban area and 100% of the ducts available (operator 1 has only 90% and the remaining 10% are deployed by operator 2) in the rural area from operator 1 (incumbent operator). In the other hand, player 1 leases the 10% remaining (in region 2) from operator 2. The wholesale prices assumptions are 9.1€ (month/km/cm²) for urban area and 7.5€ (month/km/cm²) for the rural area. The wholesale infrastructure assumptions are described in Table 4.

The next sections present the three game results and analyses. In the first game, retail prices vary between tariff multiplier by 0.7 and 1.3 (in increments of 0.1). For the second game, retail prices vary between 0.8 and 1.2, and wholesale prices between 0.5 and 1.5.

FIGURE 6: NPV variation: Operator 1 and 2/retail service 2.

FIGURE 7: Profit variation: retail service 2.

TABLE 5: Retail prices variation values.

Tariff multiplier factor	0.7	0.8	0.9	1	1.1	1.2	1.3
Service 1 price	14	16	18	20	22	24	26
Service 2 price	35	40	45	50	55	60	65

Game 1: Impact of Retail Prices Variation on NPV. In this game we assume that wholesale prices are fixed and that operators choose retail prices to maximize their profit. The impact of varying retail prices on market shares is estimated using the Boltzmann equation (described above). The main goal of this analysis is to determine the optimal retail price strategy for both players. The retail prices vary between -30% and 30% , with increasing steps of 10% (Table 5).

The combination of the two retail prices and seven multiplier factors leads to 49 possible strategies for each player (49×49 matrix) in each region (2,401 total strategies).

FIGURE 8: Profit variation: wholesale service.

Table 6 presents the structure of the combinations and calculated NPV.

The results (payoff matrix) of this game are presented in Figure 11 which shows the sum of the payoffs of each player in both regions. This table presents the NPV for both players for each possible combination of strategies (one strategy for each player); Nash equilibrium strategies are also identified.

The first two rows represents the prices multiplier factor of Player 2 (for services 1 and 2) and the first two columns show the variation (multiplier factors) of Player 1. Each cell contains two values: The left value corresponds to the NPV of Player 1, and the value on right side corresponds to the NPV of Player 2. For example, the first value calculated (15831024€) corresponds to the NPV of Player 1 when the strategy of Player 1 is to decrease the price of Service 1 and service 2 by about 30% (multiplier factor 0.7) and the strategy of Player 2 is also to decrease the price of service 1 and service 2 by about 30% .

From these results presented in Figure 11, we find three pure NE strategies (black cells) that are described in Table 7. Table 7 shows the NE strategies that maximize the profit of

TABLE 6: Structure of combinations and results for Game 1.

Strategies	Player 1		Player 2		NPV				Tot. P1	Tot. P2
	Retail Price		Retail Price		Player 1		Player 2			
	R1 and R2		R1 and R2							
	S1	S2	S1	S2	R1	R2	R1	R2		
1	0.7	0.7	0.7	0.7	...	...	...	...	...	...
2	0.7	0.7	0.7	0.8	...	...	...	...	...	...
<i>n</i>	...	...	...	...	...	...	...	...	...	...

TABLE 7: Pure NE strategies for both regions.

Strategy	Player 1 (incumbent)		Player 2 (new entrant)		NPV K€ Player 1	NPV K€ Player 2
	Retail serv. 1	Retail serv. 2	Retail serv. 1	Retail serv. 2		
1	1.1 (22€)	1.1 (55€)	0.7 (14€)	0.8 (40€)	9.565	555
2	1.2 (24€)	1.2 (60€)	1.3 (26€)	1.1 (55€)	1.435	23.715
3	1.3 (26€)	1 (50€)	1.2 (24€)	0.7 (35€)	5.015	3.295

TABLE 8: Retail and wholesale prices variation values for Game 2.

Service	Tariff multiplier factor				
	0.8	0.9	1	1.1	1.2
Retail price	0.8	0.9	1	1.1	1.2
Wholesale price	0.5	0.75	1	1.25	1.5

FIGURE 9: Consumer surplus variation.

both players. To maximize profit, in the first equilibrium strategy, Operator 1 increases retail prices by 10%. Operator 2, in face of the imposed wholesale prices, decreases the price of service 1 and service 2 by 30% and 20%, respectively. A new entrant has to pay the wholesale to the incumbent, but if increase the retail prices, their market share will decrease (see model above).

Figure 6 shows the impact of service 2 variation on NPV of both operators. From the analysis of Figure 6, we can conclude that the variation of retail prices of Service 2 has a greater influence in the NPV than the variation of Service 1 price. Service 2 price variation can drop the NPV of Operator 1 to negative. On the other hand, Operator 2 can turn the NPV positive when the tariff of service 2 increases.

Game 2: Impact of Retail and Wholesale Prices Variation on NPV. In this game we assume that wholesale prices are

FIGURE 10: Retail market variation.

not preimposed, and we investigate what is the reaction of operators when they can also choose different wholesale prices in different regions (see Table 8). In game 2 we assume that has the same variation for both regions. Retail prices vary between 0.8 (−20%) and 1.2 (20%) (in increments of 0.1). For wholesale price we assume a variation between 0.5 and 1.5 (in increments of 0.25).

In this context, the combination of the three prices and variation multipliers (described in Table 8) leads to 625 (5^4) possible strategies for each player (625×625 matrix) in each region (390625 strategies in both regions) Table 9 shows the structure used.

As the matrix is too bigger, for this game we decide to present the NE strategies (players profit is used as payoff) and the graphs that show the impact of variation in several results (presented in Figure 12).

The analysis of the results finds five NEs strategies. As Player 2 does not operate in the wholesale market of region 1, the variation of this price is not significant (see Table 10). We

TABLE 9: Structure of combinations and results for Game 2.

Strategies	Player 1				Pl 2	Results-NPV					
	Retail price		Wholesale price		...	Player 1		Player 2		Tot. P1	Tot. P2
	R1 and R2		R1	R2	...	R1	R2	R1	R2	R1 + R2	R1 + R2
	S1	S2	Duct Access		...						
1	0.8	0.8	0.8	0.8	...						
2	0.8	0.8	0.8	0.8	...						
<i>n</i>	...	...	...	...	...						

TABLE 10: Pure NE strategies in both regions (Game 2).

Player 1 (incumbent operator)				Player 2 (new entrant)				Profit (K€) Player 1	Profit (K€) Player 2
Retail		Wholesale		Retail		Wholesale			
S1	S2	R1	R2	S1	S2	R1	R2		
0.8	0.8	1.25	1.25	0.8	0.8	0.50	1.25	22402	101
						0.75			
						1			
						1.25			
						1.5			
0.8	0.9	1.25	1	0.8	0.8	0.50	1.25	19543	6.198
						0.75			
						1			
						1.25			
						1.5			

Price S1	Player 2 (new entrant) strategies															
	0.7				1.2				1.3				1.1			
	Price S2	0.7	0.8	1.3	0.7	1.2	1.3	0.7	1.2	1.3	0.7	1.2	1.3	1.1	1.2	1.3
	0.7	15831024	-18582287	18183087	-19363781	28936533	-30770826	17496173	-19795217	30601681	-31983756	18113915	-20768607	26428738	-25938555	
	0.8	14472132	-14083788	19556293	-16693988	34299456	-30618352	16137281	-15296719	35964604	-31831283	16755023	-16270109	29303695	-23304216	
	0.9	12185918	-9824136	17582209	-11580297	39612688	-30427158	13851067	-11037066	41277837	-31640088	14468808	-12010456	31362952	-20234582	
	1	9338223	-5994009	14713466	-6738115	44866176	-30195243	11003372	-7206939	46531325	-31408173	11621113	-8180329	32577289	-16820707	
	1.1	6280874	-2707019	11341982	-2384199	50053039	-29925006	7946023	-3919949	51718187	-31137937	8563765	-4893339	33014991	-13215411	
	1.2	-7258790	6298197	-6933535	11368737	-4619767	-29519466	-5593641	5085267	-2954619	-30732396	-4975899	4111877	-3280895	23715662	
	1.3	-7216198	6452291	-6935595	11588571	-4402383	-29202072	-5551049	5239361	-2737234	-30415002	-4933308	4265971	-3375080	24186698	
Player 1 (incumbent operator) strategies	0.7	14054700	-15642494	16406763	-16423988	27160208	-27831033	19064485	-17729134	32169993	-29917673	21886956	-20768607	30201779	-25938555	
	0.8	12695808	-11143995	17779969	-13754195	32523131	-27678559	17705593	-13230635	37532916	-29765199	20528064	-16270109	33076737	-23304216	
	0.9	10409594	-6884343	15805885	-8640503	37836364	-27487364	15419379	-8970983	42846148	-29574004	18241850	-12010456	35135994	-20234582	
	1	7561899	-3054215	12937141	-3798322	43089852	-27255449	12571684	-5140855	48099637	-29342089	15394155	-8180329	36350330	-16820707	
	1.1	4504550	232775	9565657	555595	48276714	-26985213	9514335	-1853865	53286499	-29071853	12336806	-4893339	36788033	-13215411	
	1.2	-9035114	9237991	-8709859	14308530	-6396091	-26579672	-4025329	7151351	-1386307	-28666312	-1202858	4111877	492146	23715662	
	1.3	-8992522	9392085	-8711919	14528364	-6178707	-26262279	-3982737	7305445	-1168922	-28348918	-1160266	4265971	397962	24186698	
	0.7	13511514	-15140682	15863576	-15922176	26617022	-27329221	19138606	-17069339	32244114	-29257878	22830217	-20768607	31145040	-25938555	
	0.8	12152622	-10642183	17236783	-13252383	31979945	-27176747	17779714	-12570840	37607037	-29105404	21471325	-16270109	34019997	-23304216	
	0.9	9866407	-6382531	15262698	-8138692	37293177	-26985553	15493499	-8311188	42920269	-28914210	19185110	-12010456	36079254	-20234582	
1.2	1	7018712	-2552404	12393955	-3296511	42546666	-26753638	12645805	-4481060	48173758	-28682294	16337416	-8180329	37293591	-16820707	
	1.1	3961364	734586	9022471	1057406	47733528	-26483401	9588456	-1194070	53360620	-28412058	13280067	-4893339	37731293	-13215411	
	1.2	-9578300	9739802	-9253046	14810342	-6939278	-26077861	-3951208	7811146	-1312186	-28006517	-259597	4111877	1435407	23715662	
	1.3	-9535709	9893896	-9255106	15030176	-6721894	-25760467	-3908617	7965240	-1094801	-27689124	-217006	4265971	1341222	24186698	
	0.7	11507889	-13885393	13859952	-14666887	24613397	-26073932	11507889	-9292724	24613397	-21481263	11492251	-20732168	19807074	-25902116	
	0.8	10148997	-9386894	15233158	-11997094	29976320	-25921458	10148997	-4794225	29976320	-21328789	10133359	-16233669	22682032	-23267776	
	0.9	7862782	-5127242	13259073	-6883402	35289552	-25730264	7862782	-534573	35289552	-21137595	7847145	-11974017	24741289	-20198142	
	1	5015088	-1297114	10390330	-2041221	40543041	-25498349	5015088	-3295555	40543041	-20905679	4999450	-8143889	25955625	-16784268	
	1.1	1957739	1989876	7018846	2312695	45729903	-25228112	1957739	6582545	45729903	-20635443	1942101	-4856899	26393328	-13178971	
	1.2	-11581925	10995092	-11256671	16065631	-8942903	-24822571	-11581925	15587761	-8942903	-20229902	11597563	4148317	-9902559	23752102	
	1.3	-11539334	11149186	-11258730	16285465	-8725518	-24505178	-11539334	15741855	-8725518	-19912509	11554971	4302411	-9996743	24223138	

FIGURE 11: Game 1 results—summary.

conclude that, in the business case defined, when operators can charge different retail and wholesale prices, they choose to increase wholesale prices. To maximize profits, operators increase wholesale prices and decrease retail prices. However, the increase in wholesale prices precludes entry of new operators into the market.

The main results of this game are summarized in the next figures. In the graphs we can see the impact of retail prices (Figure 7) and wholesale prices (Figure 8) on players

profit. We can verify that both prices can turn profit positive/negative.

As expected, consumer surplus decreases with the increase of prices (Figure 9). As also predictable and modeled above the impact of retail prices, variation has higher influence in the market share of competitors (see Figure 10).

The comparison of the two games above shows that when the regulator defines wholesale prices, operators increase retail prices to maximize profit. However, when wholesale

R Price S1		Player 2 strategies									
		0.80									
		0.80									
		0.50									
Player 1 strategies	0.8	0.8	W Price R1	0.50							
				0.80							
				0.50							
				0.75							
0.5	0.5	0.5	W Price R2	0.50							
				0.75							
				1.00							
				1.25							
0.75	0.75	0.75	W Price R2	0.50							
				0.75							
				1.00							
				1.25							
1	1	1	W Price R2	0.50							
				0.75							
				1.00							
				1.25							
1.25	1.25	1.25	W Price R2	0.50							
				0.75							
				1.00							
				1.25							
1.5	1.5	1.5	W Price R2	0.50							
				0.75							
				1.00							
				1.25							

FIGURE 12: Game 2 results—summary.

prices are not regulated, operators maximize profit by decreasing retail prices and increasing wholesale prices. However, without regulation, the higher wholesale prices will limit the entrance of new competitors.

5. Conclusions

The European Commission argues that infrastructure-based competition is the best and fastest way for broadband development. The arguments are that infrastructure-based competition provides efficiency incentives to operators, reduces prices, increases penetration, stimulates innovation, and so on. On the other hand, service-based competition implies that the new entrants (alternative operators) are dependent on the incumbent. However, because of the high costs of deploying infrastructures (especially trenching and ducting), service competition has been used as a substitute or complement to infrastructure competition. In regions with lower numbers of existing access infrastructures, new entrants are obligated to build their own infrastructure. In this way, infrastructure sharing can stimulate the construction of new access infrastructures that can be leased to other operators.

The results of this investigation show that the sharing of passive infrastructures (e.g., ducts, trenching, base station sites, and antenna masts) is a viable strategy, particularly in the context of new building (in scenarios with developed access infrastructure). When an operator deploys an access network, the access to existing civil engineering significantly reduces the investment. There are strong arguments to be made for allowing infrastructure sharing.

In this context, regulators must guarantee new entrant operators access to civil engineering; this will stimulate investment in new networks. The reduction of the barriers to new infrastructure investment by opening passive existing infrastructure would be key in the future. This study has shown that in rural areas, characterized by a small number of developed access infrastructure, the access to civil

engineering does not make the scenario economically viable for the operator.

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