EXPLAINING THE DEFINITION OF WHOLESALE ACCESS PRICES IN THE PORTUGUESE TELECOMMUNICATIONS INDUSTRY

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Abstract. The 2016–2018 triennium was a period marked by a fierce dispute between the European Commission and Autoridade Nacional de Comunicações, Portugal, on the need to regulate wholesale access prices. While the European Commission defended the imposition of Fiber-To-The-x regulation in non-competitive areas, the Portuguese sectoral regulator argued in favor of the persistence of Fiber-To-The-x deregulation. Following a Game Theory approach, the present study demonstrates that the transition from Fiber-To-The-x deregulation to Fiber-To-The-x regulation should only occur when a given territorial unit becomes a competitive area since the subgame perfect Nash equilibrium captures a regulatory framework optimally characterized by the imposition of active access price deregulation (regulation) in non-competitive (competitive) areas, that is, local administrative units characterized by a weak (strong) degree of vertical spillover, respectively. Meanwhile, ducts access regulation must be permanently imposed throughout the national territory, despite it can be relaxed in competitive areas if the regulator imposes intra-flexibility to establish a monopolistic bottleneck to ensure social welfare maximization. Previous conclusions require to introduce both facility-based and service-based competition at the entry stage as well as active and passive obligations at the regulation stage in a multi-stage game with complete information. The present analysis legitimizes the emergence of a new optimization theory in the telecommunications literature, whose modus operandi is contrary to (coincident with) the ladder of investment theory in non-competitive (competitive)

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areas, respectively. Differently from the view sustained by the ladder of investment theory, which defends that a short-term regulatory touch combined with long-term market deregulation is a socially optimal strategy, the new theory confirms that a regulatory intervention is socially desirable only in the long run. The conceptual refinement is meticulously explained and labeled as the theory of creative creation because, differently from the Schumpeterian gale of creative destruction, whose processes of industrial mutation are permanently market-driven by assumption, a period of regulatory holidays followed by successive regulatory interventions dependent on the degree of vertical spillover observed in the telecommunications industry can effectively promote investment realization that continuously revolutionizes the market structure from within, incessantly destroying the old technology. The theory of creative creation reflects the regulatory framework currently in force in the Portuguese Telecommunications Industry.

1. Introduction. A broad consensus among stakeholders (e.g., national governments, regulatory agencies, market operators) recognizes that the deployment of Next Generation Access (NGA) networks is a fundamental step to satisfy broadband needs and improve the productivity of national economies. Although the set of strategies for NGA networks rollout varies considerably among European Union (EU) Member States, common targets are defined in the recent EU 2025 Connectivity for a European Gigabit Strategy (CEGS). From a historical perspective, regulatory interventions in Europe have been centered on controlling downstream (i.e. retail) market prices. Currently, regulatory surveillance is primarily focused on changing upstream (i.e. wholesale) market conditions.

The wholesale market of a telecommunications industry is composed by two layers. The active layer corresponds to the set of vital inputs that ensure the flow of information in processes carried out through pulses of light from the core of the network to a final destination (e.g., home), while the passive layer corresponds to the physical infrastructure (i.e. ducts and poles) necessary to create indispensable space for the installation of vital inputs (i.e. network infrastructure). Therefore, the wholesale market of a telecommunications industry is characterized by the presence of two distinct types of access prices (i.e. active access price and ducts access fee), which may or may not be subject to regulatory intervention.

From a historical perspective, more attention has been given to the active layer of wholesale markets. First, due to the wave of privatizations that affected incumbents (i.e. historical operators) in the late 1990s and early 2000s. Second, because a considerable amount of physical infrastructure already existed in the pre-liberalization period. These reasons spurred incumbents to increase the active access price in a clear attempt to secure higher wholesale revenue and block retail competition.

Currently, the regulatory focus is centered on the passive layer of wholesale markets. On the one hand, because the physical infrastructure has a limited lifetime, which means that it requires renewal after a certain number of years. On the other hand, due to the fact that significant benefits can emerge if operational processes concerning the access to physical equipment are properly implemented. Measures to ensure the equivalence and equality of access between the incumbent and alternative facility-based competitors acquired a real expression in Europe after the publication of Directive 2014/61/EU [26], whose economic substance was reinforced by the 2016 European Commission (EC) proposal for a European Electronic Communications Code (EECC) [27].

As part of the jargon commonly used by telecommunications experts, a service-based competitor means that a new operator enters the market by requiring access
to the incumbent’s network infrastructure, thereby implying that a *buy strategy* is adopted. Service-based competition is represented by the ladder of investment theory proposed in [21], also known as the stepping stone hypothesis, due to the gradual climb approach followed by new entrant firms to reach the phase of building own network infrastructure. In opposition, a facility-based competitor means that a new operator enters the market by directly building own network infrastructure, thereby implying that a *make strategy* is followed because new entrant firms leapfrog in the sense of [31] the phase of requiring access to the incumbent’s vital input.

Regardless whether the active layer of wholesale markets is subject to regulatory intervention, social welfare is influenced by the active access price because alternative service-based competitors may not have the incentive to enter the market through a buy strategy if the active access price is excessively high. Intuitively, this reflects that negative effects from the absence of active access price regulation can be transmitted to the downstream market. However, similar argument is not necessarily applied to the ducts access fee. In the absence of regulation applied to the passive layer of wholesale markets, the duct owner has the incentive to increase the ducts access fee up to the level where alternative facility-based competitors no longer have the incentive to enter the market through a make strategy. Although this action certainly influences allocative efficiency, it may not affect static efficiency. On the one hand, because such a predatory pricing strategy would be automatically dissuaded by the regulator through the surveillance of the ducts access fee being, thus, out of the equilibrium path. On the other hand, because the ducts access fee is neutral from a social welfare point of view since it corresponds to a transfer that flows from the alternative facility-based competitor to the duct owner. Even if subject to regulatory oversight, the ducts access fee is not expected to be imposed at an excessively high level to guarantee the persistence of a fair level playing field, particularly in the early rollout of a disruptive innovation like NGA technology. This suggests that the main concern of a sectoral regulator at the wholesale passive infrastructure level is to ensure that the respective cost is not transmitted to the downstream market. Because of this reason, sectoral regulators like Autoridade Nacional de Comunicações (ANACOM) and supranational institutions such as the Body of European Regulators for Electronic Communications (BEREC) recognize that a regulated ducts access fee should be oriented to marginal cost in the initial rollout of NGA networks.

1.1. **Motivation.** Considering that the entry mode of new market operators is not exhausted to the stepping stone hypothesis and after introducing the imposition of active and passive obligations in the regulation stage, the analysis wants to show that market entry through the ladder of investment approach implies a reduction of innovation incentives and creates a deadweight loss in non-competitive (NC) areas compared to the new regulatory proposal presented in this study. Therefore, the analysis wants to confirm that the absence of active access price regulation when effective facility-based competition is not ensured or, similarly, when it is not considered sustainable in NC areas due to the sufficiently weak willingness to pay for improved services does not necessarily imply re-monopolization. Instead, alternative market structures can be established (e.g., triopoly) based on the combination of ducts access regulation with active access price deregulation. Under this circumstance, the level of investment and the amount of social welfare from applying the stepping stone hypothesis in NC areas are both lower than the level of investment and the amount of social welfare from applying our proposal.
From a practical point of view, this research is motivated by the legal dispute that occurred between the EC and ANACOM in the period 2016 – 2018. The Portuguese Telecommunications Industry (PTI) is composed by a vertically integrated incumbent (i.e. Altice) and two alternative licensed operators (i.e. facility-based competitor NOS and service-based competitor Vodafone). On 23 March 2017, ANACOM approved a final decision related to the market analysis carried out for the wholesale local access provided at a fixed location (i.e. market 3a) and wholesale central access at a fixed location for mass-market products (i.e. market 3b). As frequently observed in this type of analyses, the final decision results from a three-stage procedure composed by: (I) definition of product and geographic markets, including the separation between competitive (C) and NC areas; (II) assessment of significant market power (SMP); (III) release of a decision regarding the imposition, maintenance, amendment or withdrawal of regulatory obligations.

In relation to the first step, ANACOM identified as relevant markets for the purpose of applying ex-ante regulation the wholesale local access provided at a fixed location throughout the national territory (i.e. entire market 3a) and the wholesale central access at a fixed location for mass-market products in NC areas (i.e. NC areas of market 3b). Regarding the second step, considering the national and EU regulatory framework governing the analysis and evaluation of SMP for electronic communications networks, ANACOM concluded that Altice has SMP in both relevant markets and, consequently, an ex-ante obligation may be imposed on the access to the incumbent’s network infrastructure and the use of specific network resources, non-discrimination, transparency, accounting separation and price control, and cost accounting and financial reporting. On the third step, considering that both relevant markets are theoretically divided in two separate geographic markets (i.e. C and NC areas) and using factual data on network coverage and market shares either provided by market operators or directly collected from Instituto Nacional de Estatística (INE), ANACOM determined: (I) absence of regulated access to Altice’s fiber network infrastructure in NC areas of the market 3b; (II) maintenance of regulated access to Altice’s NGA network infrastructure in market 3a; (III) maintenance and intention to strengthen the imposition of remedies applied to the passive layer of the wholesale market throughout the national territory.

Therefore, main conclusions resulting from the final deliberation expressed in [1] related to the Portuguese NGA networks market that readers should retain in mind for a full comprehension of the present research are summarized as follows:

- Portuguese NC areas are subject to active access price deregulation.
- Portuguese C areas are subject to active access price regulation.
- Ducts access fee regulation is applied to the entire national territory.

Before ANACOM’s final decision, the EC issued a recommendation requesting ANACOM to grant regulated access to Altice’s fiber network infrastructure and bitstream offers in NC areas based on the argument that these territorial units have little prospect of being subject to additional competitiveness and lack of commercial access or co-investment opportunities that ensure a sustainable competition. According to [24], active access price regulation is mandatory in NC areas, so that a degree of pricing flexibility for the access to Altice’s fiber network infrastructure should be imposed by ANACOM following the guidelines exposed in [25] and using Altice’s own commercial offers as a basis for the definition of the regulated active access price. Based on [24], the EC concluded that the proposal of ANACOM is not compliant with EU Competition Law and that a sufficiently strong argumentation
was not provided to justify why Fiber-To-The-x (FTTx) deregulation in NC areas would foster a sustainable competition at the retail market level and why FTTx deregulation in NC areas would represent an acceptable balance between efficient investment and consumer protection.

Summarizing, while the EC considers that FTTx regulation is a mandatory step to ensure that alternative operators gradually invest in NC areas, ANACOM claims that FTTx deregulation is the optimal action to ensure the highest level of investment incentives and social welfare in NC areas. This means that EC defends the stepping stone hypothesis proposed in [21], while ANACOM supports a different regulatory paradigm inspired from the leapfrogging concept proposed in [31] and designated by theory of creative creation.

1.2. Research questions. The primary goal of this study is to provide a tutorial on how the regulated wholesale access pricing scheme of the PTI is defined in order to understand which entity is correct about the aforementioned dispute given that both sides have a diametrically opposed view on the need to regulate the active layer of the upstream market in NC areas. To satisfy this research objective, we construct a theoretical model that captures the evolution, characteristics and reasons behind the success of the PTI to the present date. Since we want to describe the market environment observed in Portugal, we assume that ducts are owned by the incumbent, which is also considered the SMP operator. Thenceforth, we provide answers to the following research questions:

1. Should FTTx deregulation be applied to NC areas?
2. Within a given local administrative unit, when should the transition from FTTx deregulation to FTTx regulation occur?
3. When a given territorial unit is subject to FTTx regulation, which additional instruments can be provided to the sectoral regulator to ensure a permanent maximization of social welfare?
4. Are current measures envisaged by the EC sufficient or, differently, are new measures needed to ensure a permanent maximization of social welfare?
5. Although Portugal is considered a success case in terms of FTTx implementation, NGA networks investment incentives and social welfare maximization, how can the regulatory policy of this national jurisdiction be improved?

Among several findings, we show that deregulation (regulation) is both privately and socially desirable in NC (C) Portuguese municipal areas or, equivalently, in the short (long) run equilibrium, respectively. This result reflects a regulatory environment diametrically opposed to that observed in other European countries, whose regulatory option consists of following the ladder of investment theory. Our contribution is important to reveal that such a regulatory option may have fostered a reduction in the number of facility-based competitors and promoted considerable investment and social welfare losses in NC areas of countries that present similar characteristics to those observed in the PTI.

The study is organized as follows. The methodology is initially clarified. Thereafter, equilibrium outcomes and robustness checks are reported. Finally, policy recommendations and conclusions are provided. For the sake of brevity, details and mathematical proofs are relegated to the Appendix.
2. Method.

2.1. Economic basis. Satisfying the goal of this study requires a prior understanding of distinctive features of the PTI in relation to European peers through the conception of a theory that differs from the one considered dominant in the telecommunications literature. Three main characteristics support the theory of creative creation:

- **Presence of competition in the entry stage.**
- **Persistence of ducts access regulation throughout the national territory, while having the possibility to impose either FTTx regulation or FTTx deregulation depending on the competitive nature of a territorial unit in the regulation stage.**
- **Application of ex-ante regulation with respect to investment realization.**

Combining the previous elements ensures a high number of alternative operators in the initial deployment phase of the NGA networks market, so that the expected impact of this new approach is to improve investment incentives and social welfare in NC areas compared to the stepping stone hypothesis.

2.2. Model. Assume that the following model represents a certain hierarchical spatial unit level (e.g., parish, municipality, national) that can be either C or NC area. The market consists of three licensed operators: the incumbent is a vertically integrated firm that owns a NGA network infrastructure, while two entrant firms have to choose their competitive type. If the decision is to become a service-based competitor, the entrant firm requires access to the incumbent’s vital input. If the decision is to become a facility-based competitor, the entrant firm builds own NGA network infrastructure inside the incumbent’s ducts. We exogenously assume the presence of a NGA networks market because Digital Subscriber Line (xDSL), FTTx and Data Over Cable Service Interface Specification (DOCSIS) 3.x are considered NGA technologies as long as these are capable of transmitting data at a very high speed, namely at least 30 Megabytes per second (Mbps) on downloads [30].

2.2.1. Demand side. The inverse demand function of incumbent $I$ for the market of the final homogeneous output is represented by

$$p_I = v_I - Q, \quad v_I := a + \beta x_I, \quad Q := \sum_j q_j, \quad j \in \{I, N, E\},$$

where $v_I$ represents consumers’ willingness to pay for services provided by the incumbent, $a > 0$ is a proxy of the market size, $\beta \geq 0$ is the degree of vertical spillover, $x_I > 0$ is the investment level or amount of vital input owned by the incumbent operator, $Q$ is the total industry output and $q_j \geq 0$ is the quantity supplied by firm $j$. Note that $I$ represents the incumbent operator, while $N$ and $E$ represent the alternative market operators.

From a demand side perspective, parameter $\beta$ represents the willingness to pay for improved retail services. If the parameter takes a null value, the retail market is not served by NGA technology. Under this circumstance, consumers exhibit a preference for non-improved retail services, which does not constitute the scope of this study. If the parameter takes a positive value, the retail market is served by NGA technology, which means that consumers exhibit preference for improved services. In light of the present analysis, the transition from copper to fiber is an outdated concern, despite the model can capture this feature because the migration from copper to NGA technology occurs when $\beta$ moves from zero to a positive value. Alternatively, from a supply side perspective, parameter $\beta$ represents the magnitude
of the retail market expansion for each additional monetary unit of investment carried out in the wholesale market.

In turn, the inverse demand function of entrant firm \( i \), with \( i = \{ E, N \} \), for the market of the final homogeneous output is represented by

\[
p_i = v_i - Q, v_i := \begin{cases} a + \beta x_I, & \text{if entrant } i \text{ adopts service-based competition;} \\ a + \beta x_i, & \text{if entrant } i \text{ adopts facility-based competition}, \end{cases}
\]

where \( v_i \) represents consumers’ willingness to pay for services provided by firm \( i \). The surplus obtained by consumers subscribing firm \( j \)’s service is given by

\[
CS_j = \frac{(v_j - p_j)}{2} q_j,
\]

such that total consumer surplus yields

\[
CS = \frac{Q^2}{2} = \sum_j CS_j.
\]

2.2.2. Supply side. The investment cost function of facility-based firm \( j \) is given by

\[
C(x_j) = \frac{x_j^2}{2}.
\]

This specification reflects that the building cost increases quadratically in the amount of vital inputs to justify the gradual rollout of network infrastructures in the PTI. For the sake of simplicity, we normalize marginal costs to zero. The profit of incumbent \( I \) is given by

\[
\pi_I = \begin{cases} p_I q_I + w \sum_i q_i - C(x_I), & \text{if both entrants adopt service-based competition;} \\ p_I q_I + wq_k - C(x_I) + F, & \text{if entrants adopt asymmetric entry strategies;} \\ p_I q_I - C(x_I) + 2F, & \text{if both entrants adopt facility-based competition}, \end{cases}
\]

where the subscript \( k \) denotes a service-based entrant in the asymmetric entry regime, \( w \geq 0 \) represents the active access price paid by access seekers to use the incumbent’s vital input for the provision of retail services and \( F \geq 0 \) represents the ducts access fee (i.e. the transfer that flows from facility-based entrants to the incumbent for the installation of vital input inside the incumbent’s ducts). The profit of entrant firm \( i \), with \( i = \{ E, N \} \), is given by

\[
\pi_i = \begin{cases} (p_i - w)q_i, & \text{if entrant firm } i \text{ adopts service-based competition;} \\ p_i q_i - C(x_i) - F, & \text{if entrant firm } i \text{ adopts facility-based competition}. \end{cases}
\]

Social welfare corresponds to the sum of consumer surplus and profits

\[
W = CS + \sum_j \pi_j.
\]

The following assumption ensures that we restrict the focus on the interior solution of the profit maximizing investment problem.

**Assumption 1.** \( \beta \in \left[ 0, \sqrt{\frac{2}{3}} \right] \).
2.3. **Timing structure of the game.** Considering the presence of a historical operator in the market, the timing structure is described as follows:

- **First stage:** Two alternative market operators simultaneously and noncooperatively choose their entry (make or buy) strategy to maximize profit.

- **Second stage:** The regulator chooses to regulate or not the ducts access fee and the active access price. In affirmative case, the regulated price level for each layer of the wholesale market is determined by targeting social welfare (i.e. sum of consumer surplus and firms’ profit) maximization. Otherwise, deregulation means that the wholesale market is free of regulatory touch, which implies that both wholesale access prices are defined to maximize profit.

- **Third stage:** Facility-based operators simultaneously and noncooperatively choose their investment level to maximize profit.

- **Fourth stage:** Firms engage in Cournot competition to maximize profit.

2.4. **Contextualization in the telecommunications literature.** In the *first stage*, each entrant firm decides whether to become service-based or facility-based competitor. Given the presence of a vertically integrated incumbent that may or may not be subject to regulatory intervention, different market structures can prevail in the PTI: vertical monopoly, monopolistic bottleneck, duopolistic bottleneck with asymmetric downstream access, duopoly or triopoly. The ladder of investment theory, according to which a new firm only conceives to enter the market as a service-based competitor, was canonically proposed in [21]. Thereafter, [22] reinforces that regulators should induce a gradual migration from copper to fiber, albeit several dilemmas are expected to hold [34, 13]. The theory of creative creation, according to which a new firm may enter the market either as service-based competitor or as facility-based competitor, is inspired by the leapfrogging concept proposed in [31]. From a theoretical point of view, leapfrogging has a twofold conceptualization.

On the one hand, this concept means that incremental innovations lead the dominant firm to stay ahead of rivals, however, radical or drastic innovations may allow entrant firms to leapfrog the dominant firm. The analysis in [42] underlines that leapfrogging may arise because an incumbent has a lower incentive to innovate due to the revenue it receives from the persistence of the old technology. In this sense, leapfrogging is based on the Schumpeterian notion of creative destruction [40], thereby reflecting that a drastic innovation may reverse market dominance and business leadership (i.e. *impatient form of leapfrogging*).

On the other hand, this concept means that an entrant firm, more than being focused on the future strategic interaction with the incumbent, is predominantly concerned with the strategic interaction with the rival entrant since the initial goal of an entrant firm is to learn the corporate strategy that better fits to the consolidation of its entry position. If an entrant firm becomes a service-based competitor but ends up paying an excessive active access price, the rival entrant firm can perfectly internalize such a disadvantage and, thus, may instead adopt a make strategy by requiring access to the incumbent’s ducts. This is because following a buy or make strategy in a context where ducts already exist corresponds to a trade-off between paying an active access price or a ducts access fee since the cost of building ducts and poles is already sunk. This means that such cost should not be taken into account at the moment of entrant firms’ decision on which corporate strategy to adopt in the NGA networks market. Moreover, it also means that such cost is supported by a sufficiently high regulated ducts access fee in a long run perspective, thereby acting
as a compensation mechanism in favor of the incumbent to ensure the renewal of passive network infrastructure when the willingness to pay for improved service is sufficiently high, namely in C areas (i.e. patient form of leapfrogging).

Past contributions analyze entry strategies by merely relying on the monopolistic bottleneck, thus, neglecting that entry through the stepping stone hypothesis does not fully characterize all possible modes of market entry in telecommunications industries. For instance, [3] use data covering 15 EU Member States for 17 semesters to test the ladder of investment approach and conclude the absence of empirical support to this hypothesis. Nevertheless, some past studies consider the analysis of alternative market structures beyond the monopolistic bottleneck. A dual channel market structure is analyzed in [33] and [14]. Unfortunately, these studies either take symmetric downstream access as a given or consider that downstream operators use all the available vital inputs to provide retail services. However, interconnection or interchangeability is not a dominant characteristic in markets 3a and 3b of the PTI and, thus, goals of this study are only satisfied if the analysis is focused on asymmetric downstream access without the option of interchangeability.

With that being said, this research is particularly relevant for telecommunications industries of countries where asymmetric regulation is applied to the active layer of the wholesale market, namely Portugal and South Korea. Nevertheless, passive access price regulation is currently the EC’s main focus given that a regulatory framework applied to this layer of the wholesale market is being refined [9], which suggests that all the lessons learned by Portugal in the past 15 years of passive access price regulation may be useful to improve the quality of passive access price regulation in other European nations.

In the second stage, the regulator decides whether to regulate or not each wholesale access price. Relevant EU regulatory frameworks for the NGA networks market are clarified in [28], [25], [26] and [27]. Considerable attention on the NGA networks market is justified by the fact that the social benefit of investing in the new technology by far outweighs the private incentive [20, 43, 18]. It seems fair to recognize that the telecommunications literature is predominantly concerned with the migration from copper to fiber since the impact of the wholesale access price of copper on the decision to invest in fiber has been frequently analyzed [10, 19, 12, 11, 17, 15]. However, our analysis reflects on the patient form of leapfrogging by disregarding the migration from copper to fiber and focusing instead on churn (i.e. consumer migration between different NGA providers). By taking the NGA networks market as a given, this research is relevant for telecommunications industries with a high penetration of NGA technology and, consequently, whose main concern relies on evaluating whether FTTx and ducts should be subject to regulatory intervention.

Considering that the regulator decided in favor of acting on the market by imposing regulatory guidelines, the optimal access charge applied to each layer of the wholesale market needs to be determined. It is mandatory to understand that this stage captures four theoretical scenarios: active access price regulation with passive access regulation, active access price deregulation with passive access regulation, active access price regulation with passive access deregulation, and active access price deregulation with passive access deregulation. By considering the regulatory framework defined by the 2013 EC Recommendation, retail-minus regulation (RMR) is the wholesale access price control method used to determine the regulated active access price [25, 8]. The adoption of RMR is justified by past studies showing that the active access price may be price-oriented [36, 37, 5, 6, 4, 44, 39]. This option is not
restrictive because the regulator targets social welfare maximization, which means that cost-based regulation (CBR) necessarily implies similar equilibrium outcomes.

In the third stage, upstream investment is realized by facility-based firms. This means that the multi-stage game assumes ex-ante regulation with respect to the investment carried out by facility-based competitors, but ex-post regulation with respect to the long run corporate strategy adopted by each entrant firm. Hence, this study is framed and contributes for the strand of literature that analyzes the interplay between access price regulation, investment incentives and social welfare maximization in the context of NGA networks. Moreover, the present research complements past studies by analyzing whether entry strategies are shaped by or shape the regulatory intervention on both layers of the wholesale market.

In the fourth stage, firms engage in Cournot competition. The game is solved by the method of backward induction, which allows to capture the set of market structures sustained in equilibrium as a function of the degree of vertical spillover. This parameter represents the willingness to pay for improved services supported by the NGA networks market.

Summarizing, past contributions recognize that the main concern of sectoral regulation is restricted to the active layer of the wholesale market based on the following dilemma. On the one hand, high active access price fosters investment in new infrastructure, but also encourages infrastructure duplication. On the other hand, low active access price limits infrastructure duplication, but also discourages access seekers from rolling out new infrastructure [38]. Although previous research and respective results are both important to improve the quality of policy making decisions, they fail to capture the reality observed in the NGA networks market of national jurisdictions like Portugal due to the lack of formal models that contemplate the inclusion of ducts access regulation and multiple forms of market entry. As such, the main contribution of this study is to fill this gap by determining the subgame perfect Nash equilibrium (SPNE) in a multi-stage game with complete information, which is characterized by the possibility to regulate or not a pair of endogenous wholesale access prices and by the introduction of competition at the entry stage maintaining, at the same time, the satisfaction of the principle of ex-ante regulation enshrined in European supranational law behind any doubt.

2.5. Analysis and definitions. Four subgames should be solved to find the SPNE:

- The one representative of active access price deregulation combined with ducts access fee regulation (i.e. DR regime).
- The one representative of active access price regulation combined with ducts access fee regulation (i.e. RR regime).
- The one representative of active access price deregulation combined with ducts access fee deregulation (i.e. DD regime).
- The one representative of active access price regulation combined with ducts access fee deregulation (i.e. RD regime).

For the sake of brevity, simplicity and elegant presentation of the equilibrium results, the complete analysis and expressions of $F_{u}(\beta)$, $F_{rc}(\beta)$ and $F_{rd}(\beta)$ can be consulted in the S1 File. Between the presentation of Proposition 1 and its connection with the Portuguese case that motivates the present analysis, intermediate steps with a direct interpretation of the model’s results are relegated to the Appendix. Finally, two definitions are introduced to facilitate the comprehension of the study’s key findings.
Definition 1 (Transitivity). Within the NGA networks market, the transition of a territorial unit from a non-competitive to a competitive status depends on the degree of vertical spillover.

Definition 2 (Intra-flexibility). Whatever the wholesale price control method in force and when a territorial unit is considered competitive, intra-flexibility corresponds to the ability that the sectoral regulator should have to change the value of the regulated active access price to ensure that social welfare is permanently maximized.

Definition 1 emphasizes that a territorial unit is NC (C) if and only if the positive degree of vertical spillover is below (above) some critical threshold that must be endogenously determined rather being exogenously imposed, respectively. This means that the relevant task that should be executed by the sectoral regulator is to ensure that the degree of vertical spillover is subject to permanent monitoring. Definition 2 highlights that a sectoral regulator may have the incentive to promote some adjustment in the regulated active access price applied to C areas to ensure that the maximization of social welfare is not compromised.

3. Results.

3.1. Optimal wholesale access price scheme. The main result of this study is summarized as follows.

Proposition 1. Let \( a > 0 \). The wholesale access pricing scheme of the PTI is described by the following SPNE.

(I) \( \forall \beta \in [0, 0.4476) \), triopoly is the equilibrium market structure. Active access price deregulation combined with ducts access fee regulation (DR) constitutes the optimal regime. The regulatory policy is characterized by

\[
(w^*, F^*) = \left( 0, \frac{a^2F_d(\beta)}{2(8 - 3\beta^2)^2(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)^2} \right).
\]

(II) \( \forall \beta \in [0.4476, 0.7435) \), a duopolistic bottleneck with asymmetric downstream access is the equilibrium market structure. Regulation of both wholesale access prices (RR) constitutes the optimal regime. The regulatory policy is characterized by

\[
(w^*, F^*) = \left( \frac{2a(-8 + 62\beta^2 - 122\beta^4 + 69\beta^6)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, \frac{a^2F_{rc}(\beta)}{2(16 + 44\beta^2 - 35\beta^4)(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2} \right).
\]

(III) \( \forall \beta \in [0.7435, 0.7923) \), monopolistic bottleneck is the equilibrium market structure. Regulation of both wholesale access prices (RR) or active access price regulation combined with ducts access fee deregulation (RD) constitute the optimal
Regimes. The regulatory policy is characterized by

\[(w^*, F^*) = \begin{cases} 
\left( \frac{8a(5\beta^2 - 1)}{35\beta^4 - 44\beta^2 - 16}, \frac{a^2F_{rd}(\beta)}{2(16 + 44\beta^2 - 35\beta^4)^2(16 + 212\beta^3 - 788\beta^6 + 789\beta^6 - 216\beta^8)^2}, \right) \beta \in [0.7435, 0.7866); \\
\left( \frac{8a(5\beta^2 - 1)}{35\beta^4 - 44\beta^2 - 16}, \frac{a^2F_{rd}(\beta)}{2(8 - 13\beta^2 + 3\beta^4)^2(16 + 44\beta^2 - 35\beta^4)^2}, \right) \beta \in [0.7866, 0.7923]. 
\end{cases} \]

(IV) \forall \beta \in [0.7923, \sqrt[3]{\frac{2}{3}}], a duopolistic bottleneck with asymmetric downstream access is the equilibrium market structure. Regulation of both wholesale access prices (RR) constitutes the optimal regime. The regulatory policy is characterized by

\[(w^*, F^*) = \left( 0, \frac{a^2F_{rd}(\beta)}{2(8 - 13\beta^2 + 3\beta^4)^2(16 + 44\beta^2 - 35\beta^4)^2} \right). \]

Proof. The complete proof is presented in the S1 File. Nevertheless, Appendix A at the end of the present research clarifies Lemmas 1 – 4, which give support to the mathematical validation of Proposition 1. In particular: Lemma 1 confirms outcomes under the DR regime, Lemma 2 confirms outcomes under the RR regime, Lemma 3 confirms outcomes under the DD regime and Lemma 4 confirms outcomes under the RD regime. Their comparison, which is detailed in Appendix B, allows to find the SPNE.

Four key messages should be highlighted. First, based on Definition 1, a given territorial unit is NC (C) if and only if \(0 \leq \beta < 0.4476, (0.4476 \leq \beta < \sqrt[3]{\frac{2}{3}})\), respectively. As a result, FTTx deregulation (regulation) is applied to NC (C) areas since this regulatory option guarantees the maximization of social welfare and investment incentives, respectively.

In case of mistakenly adopting FTTx regulation in NC areas, the regulator is unable to impose the socially desirable market structure and the RR regime would prevail. This scenario implies the sustainability of a monopolistic bottleneck instead of a triopoly, particularly given the absence of any explicit modelling assumption to introduce subsidies for ducts building. Also note that, when the degree of vertical spillover is within the interval \(0 \leq \beta < 0.4476\), the equilibrium market structure is a triopoly, which means that pure facility-based competition holds in equilibrium. Consequently, the deregulated active access price corresponds to an empty set since it becomes irrelevant the level at which the incumbent sets its active access price because both alternative operators build own network infrastructure for the provision of retail offers to end users. This implies that only the regulated ducts access fee is paid by both alternative operators to ensure the right of passage inside the incumbent’s ducts.

In terms of actual regulatory practice, the first point of Proposition 1 implies that the decision of ANACOM to keep FTTx deregulation in NC areas is appropriate, while the view defended by the EC is inadequate. The imposition of FTTx
regulation in NC areas would constitute a preventive form of regulation given that the regulator would fall in the trap of over-regulation, over-enforcement or type-I regulatory error. This action would not only be considered excessive, but would also reduce innovation incentives and social welfare in addition to promote negative effects on multiple economic (e.g., practice of third-degree price discrimination by the incumbent at the retail market level, incapacity to safeguard competition in downstream and upstream markets) and legal (e.g., violation of the principle of proportionality) spheres. Therefore, the theory of creative creation brings the novelty of recognizing that the optimal regulatory strategy consists of imposing FTTx deregulation in NC areas to ensure the proliferation of make strategies and boost facility-based competition.

The higher number of active facility-based operators in NC areas does not necessarily imply a higher aggregate investment level compared to that observed in C areas because, depending on the degree of vertical spillover, NGA networks investment can be greater in territorial units holding a sufficiently high willingness to pay for improved service. However, it constitutes the premise through which inter-technological diversity at the wholesale market level is ensured and unequivocal gains in static efficiency are conquered relative to the out-of-equilibrium scenario of FTTx regulation. A NC area becomes competitive when it reaches the critical threshold $\beta = 0.4476$, so that FTTx regulation turns out to be socially desirable. Only at that moment, it becomes irrelevant whether the regulatory policy is inspired by the theory of creative creation or by the stepping stone hypothesis since both approaches collapse in their conclusions as demonstrated by the second, third and fourth points of Proposition 1.

In case of assertively adopting FTTx regulation in C areas, the regulator always imposes the socially desirable market structure, which implies that this regulatory option guarantees the highest level of social welfare only in territorial units characterized by a sufficiently high willingness to pay for improved service. Meanwhile, ducts access regulation must be permanently imposed throughout the entire national territory, despite it can be relaxed in C areas when the regulator imposes intra-flexibility to ensure the maximization of social welfare, that is, when the degree of vertical spillover is within the interval $0.7435 \leq \beta < 0.7923$.

Second, triopoly is the equilibrium market structure in NC areas due to the adoption of FTTx deregulation. In turn, either monopolistic bottleneck or duopolistic bottleneck with asymmetric downstream access are sustained in C areas based on the adoption of FTTx regulation. Therefore, one concludes that (FBC, FBC), (SBC, SBC) and (SBC, FBC) or (FBC, SBC) correspond to equilibrium strategy profiles. By no means, the greater number of facility-based operators in NC areas constitutes a paradox, but it rather reflects that only a sophisticated and distinct regulatory intervention has the ability to create creatively through the combination of FTTx deregulation (regulation) with ducts access regulation in NC (C) areas, respectively.

Third, the adoption of FTTx deregulation provides an extremely important source of advantage for the sectoral regulator on the debate related to whether regulation shapes the market or vice-versa. If the option of FTTx deregulation is disregarded, the market shapes regulation in NC areas where the degree of vertical spillover is too weak. The regulator is unable to impose the socially optimal market structure since this action would require a negative ducts access fee, which is impossible by assumption. However, this study demonstrates that FTTx deregulation
should be applied to NC areas and this action ensures that the regulator shapes the market since it holds the ability to impose the socially optimal market structure. Differently, regulation permanently shapes the market in C areas where the degree of vertical spillover is too strong given that the socially optimal market structure is unambiguously imposed.

Lastly, one should emphasize that ducts access deregulation can be a Pareto dominated strategy. This option belongs to the SPNE only for intermediate degree of vertical spillover, $0.7435 < \beta < 0.7923$. This subdomain is characterized by the presence of FTTx regulation and the equilibrium market structure is the monopolistic bottleneck, which means that the regulatory surveillance on the passive layer of the wholesale market may be softened or even disregarded since it constitutes a non-credible threat in the sense of [35] if the incumbent decides to increase the unregulated ducts access fee. This action does not improve the incumbent's profit because both entrant firms are service-based competitors for this domain of vertical spillover. This conclusion explains why [1] assertively claims that ducts access regulation constitutes a pillar of the NGA networks market in the PTI. Knowing that the theory of creative creation is described by the SPNE, a full characterization of the optimal regulatory policy can be summarized as follows:

- **In the non-NGA networks market (i.e. for $\beta = 0$):** Imposition of active access price deregulation combined with ducts access fee regulation.

- **In the NGA networks market (i.e. for $\beta > 0$):** Imposition of active access price deregulation (regulation) when a given territorial unit is NC (C) or, similarly, if $0 \leq \beta < 0.4476$ ($0.4476 \leq \beta < \sqrt{2/3}$), respectively; permanent imposition of ducts access fee regulation, eventually smoothed when the regulator imposes intra-flexibility for the first time (i.e. to promote the establishment of the monopolistic bottleneck); imposition of intra-flexibility occurs at $\beta = 0.7435$ and $\beta = 0.7923$ to ensure social welfare maximization; the largest number of facility-based operators is sustained in NC areas; when a given NC area becomes competitive, several facility-based operators may still be active, except when the regulator imposes intra-flexibility for the first time.

### 3.2. Remaining equilibrium outcomes.

Let us interpret and provide the economic intuition behind other important results.

#### 3.2.1. Number of facility-based competitors.

Fig 1 shows the number of facility-based competitors in equilibrium and the number that would be sustained in case of applying FTTx regulation to NC areas.

Focusing on the subdomain $0 \leq \beta < 0.7923$, the number of facility-based operators is strictly decreasing when a telecommunications industry follows the creative creation approach. We then conclude that this theory consists of a top-down approach relatively to the number of active facility-based operators in the market. If strictly considering the application of FTTx regulation, the number of facility-based operators would be increasing (decreasing) for $0 \leq \beta < 0.7435$ ($0.7435 \leq \beta < 0.7923$), respectively. Since this alternative scenario is representative of the stepping stone hypothesis, we conclude that the ladder of investment theory consists of a non-monotonic approach relatively to the number of active facility-based operators in the market, which is an equilibrium outcome perfectly aligned with the snake environment described in [22].
3.2.2. Wholesale access prices. Fig 2 provides the graphical representation of the optimal pair \((w^*, F^*)\) in the domain of the vertical spillover. Let us initially focus on the equilibrium ducts access fee. Although the degree of vertical spillover is weak in NC areas, FTTx deregulation boosts the presence of a triopoly since alternative market operators do not have the incentive to seek access to the incumbent’s vital input. Moreover, this action is incentivized by a regulated ducts access fee that decreases in the degree of vertical spillover, \(\partial F^*/\partial \beta < 0\), which means that the regulator finds optimal to promote access to the passive layer of the wholesale market as the willingness to pay for improved service increases, respectively. Formally, this requires to impose the regulated ducts access fee at the critical point of indifference between the triopoly and duopolistic bottleneck with asymmetric downstream access in NC areas. In opposition, the regulated ducts access fee is increasing in the degree of vertical spillover when FTTx regulation is adopted, \(\partial F^*/\partial \beta > 0\). This is because the persistence of facility-based competition is more likely in C areas given that the willingness to pay for improved service is sufficiently high. This implies less available space inside the incumbent’s ducts to install new vital input, which means that the supply curve of the available space inside the incumbent’s ducts moves upward. As such, by the law of demand and supply, the amount of additional vital input that can be installed inside the incumbent’s ducts decreases, while the regulated ducts access fee increases. Intuitively, from a formal point of view, this means that the regulated ducts access fee is imposed at the point of indifference between the monopolistic bottleneck and duopolistic bottleneck with asymmetric downstream access in C areas.
Let us now focus on the equilibrium active access price. The market is absent of FTTx regulation for weak degree of vertical spillover, $0 \leq \beta < 0.4476$. The deregulated active access price is characterized by an empty set because it is irrelevant the level of active access price imposed by the incumbent since alternative operators are facility-based competitors in the provision of retail offers to end users. However, FTTx regulation is deemed necessary for $0.4476 < \beta \leq \sqrt{2}/3$. The regulated active access price is increasing in the degree of vertical spillover for $0.4476 \leq \beta < 0.7923$ to ensure that social welfare is permanently maximized. Moreover, based on Definition 2, intra-flexibility should be applied twice.

The first discontinuity in the active access price, which is characterized by an upward jump at $\beta = 0.7435$, is justified by the need to compensate the incumbent for the additional investment that is necessary to accommodate a second access seeker given that the socially optimal market structure changes from the duopolistic bottleneck with asymmetric downstream access to the monopolistic bottleneck. Consequently, the first need of intra-flexibility at $\beta = 0.7435$ reflects that the ownership concentration of vital inputs is socially desirable for $0.7435 \leq \beta < 0.7923$, which means that social welfare maximization requires to stimulate the incumbent’s innovation incentives. An increasing regulated active access price makes the incumbent more likely to innovate and more prone to accommodate free riding behavior.

The second discontinuity in the active access price, which is characterized by a downward jump at $\beta = 0.7923$, is justified by the transmission of the excessive dynamic efficiency into the downstream market via excessive retail price charged by the incumbent. In the absence of adequate regulatory intervention, the loss in static efficiency would become the dominant effect, hence, undermining social welfare. Active access price regulation ensures that the incumbent is less likely to innovate or, similarly, that its investment level decreases for any $\beta \geq 0.7923$. This allows to correct the identified market failure and ensure the persistence of social welfare maximization. Consequently, the second need of intra-flexibility at $\beta = 0.7923$ reflects that the ownership dispersion of vital inputs is socially desirable for $0.7923 \leq \beta < \sqrt{2}/3$, which means that social welfare maximization requires to decrease the incumbent’s innovation incentives. This is achieved by imposing the regulated active access price at the marginal cost level. For this subdomain of the vertical spillover, the willingness to pay for improved service is extremely high, so one or both entrant firms have the incentive to develop alternative network infrastructure. The imposition of regulated active access price at the marginal cost level avoids that the excessive dynamic efficiency generates a loss in static efficiency of greater proportion.

According to [2], innovation incentives reach the highest (lowest) level under perfect competition (monopoly), respectively. In this sense, the Arrow’s replacement effect may be interpreted as the gradual move towards monopoly, thus, reflecting a decrease in innovation incentives. According to [40], innovation incentives reach the highest level under monopoly. In this sense, Arrow’s replacement effect may be interpreted as the reduced incentive of the incumbent to innovate in order to avoid free riding behavior of alternative operators. It follows that, in the context of PTI oligopolistic market, the jump observed in the regulated active access price at $\beta = 0.7435$ leading to a positive impact on incumbent’s investment level corresponds to the reversal of Arrow’s replacement effect, while the jump observed in the regulated active access price at $\beta = 0.7923$ leading to a negative impact
Figure 2. Equilibrium wholesale access prices. Red (Blue) [Black] lines represent the parameter space where the triopoly (monopolistic bottleneck) [duopolistic bottleneck with asymmetric downstream access] is sustained in equilibrium, respectively. Continuous (Dashed) lines represent the regulated active access price (ducts access fee), respectively. The plot assumes \( a = 1 \).

on incumbent’s investment level corresponds to the canonical Arrow’s replacement effect.

3.2.3. Investment. The equilibrium investment level of facility-based operators is given by

\[
(x^*_I, x^*_N, x^*_E) = \begin{cases} 
  \left( \frac{3a\beta}{8 - 3\beta^2}, \frac{3a\beta}{8 - 3\beta^2}, \frac{3a\beta}{8 - 3\beta^2} \right), & \beta \in [0, 0.4476); \\
  \left( \frac{2a\beta(-4 + 71\beta^2 - 171\beta^4 + 108\beta^6)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, \frac{3a\beta^3(44 - 115\beta^2 + 72\beta^4)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, 0 \right), & \beta \in [0.4476, 0.7435); \\
  \left( \frac{a\beta(4 - 35\beta^2)}{35\beta^4 - 44\beta^2 - 16}, 0, 0 \right), & \beta \in [0.7435, 0.7923); \\
  \left( \frac{a\beta(2 - 3\beta^2)}{8 - 13\beta^2 + 3\beta^4}, \frac{3a\beta(1 - \beta^2)}{8 - 13\beta^2 + 3\beta^4}, 0 \right), & \beta \in [0.7923, \sqrt{2}/3), 
\end{cases}
\]

as clarified in Fig 3. Focusing on the subdomain \( 0 \leq \beta < 0.4476 \), investment level is similar across market operators. FTTx deregulation increases the investment level of all market operators relative to FTTx regulation, which implies unequivocal gain in dynamic efficiency materialized by the higher aggregate investment level. The conclusion that FTTx regulation would have a negative impact on the aggregate
investment level is recognized in previous empirical and theoretical contributions [32], [41], [16]. Therefore, the reinforcement of measures focused on ducts access regulation in NC areas constitutes a sufficient action to achieve regulatory targets and constitutes a less onerous action compared to FTTx regulation.

At $\beta = 0.4476$, the optimal market structure is subject to a change since the triopoly becomes a duopolistic bottleneck with asymmetric downstream access. The incumbent makes a downward adjustment in the investment level due to the transition to FTTx regulation, but systematically increases the investment level for $0.4476 \leq \beta < 0.7923$ due to the increase of the regulated active access price. The regulatory policy is influenced by the entry strategy of new market operators, but also influences the investment level of alternative facility-based competitors in C areas, $0.4476 \leq \beta < \sqrt{2}/3$. Contrary to the incumbent, the investment level of the alternative facility-based firm raises at $\beta = 0.4476$ due to its expectation of churn. This operator unambiguously invests more than the incumbent and its investment level is increasing in the degree of vertical spillover when the duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium, which reflects the engagement in investment war to conquer additional market share.

At $\beta = 0.7435$, the optimal market structure is subject to a change since the duopolistic bottleneck with asymmetric downstream access becomes a monopolistic bottleneck. This implies an upward jump in the investment level of the incumbent, which is supported by a higher regulated active access price. The incumbent’s investment level increases in the degree of vertical spillover until threshold $\beta = 0.7923$ is reached. Above this critical value, the risk of abuse of a dominant position is not only manifested at the wholesale market level, but would also be transmitted into the downstream market through the practice of excessive retail price. It is worth mentioning that the transition from the duopolistic bottleneck with asymmetric downstream access to the monopolistic bottleneck unambiguously reduces the aggregate investment level.

The strong downward adjustment in the regulated active access price observed at $\beta = 0.7923$ implies a reduction of the incumbent’s investment and the persistence of an inverse relation between the incumbent’s investment and willingness to pay for improved service in the subdomain $0.7923 \leq \beta < \sqrt{2}/3$. In opposition, the investment carried out by the alternative facility-based operator increases in the degree of vertical spillover due to the expectation of churn. It is worth mentioning that the transition from the monopolistic bottleneck to the duopolistic bottleneck with asymmetric downstream access strictly increases the aggregate investment level, which reaches the maximum value at $\beta = \sqrt{2}/3$.

Finally, let us coordinate previous results with theoretical ideas disseminated in the reference literature. The relationship between regulation, competition and innovation in the telecommunications industry assumes utmost importance because the NGA networks investment is a key driver to boost dynamic efficiency gains throughout the national economy. Past contributions focused on innovation recognize some tension between regulation, competition and innovation, but also seem to support a non-monotonic relation between competition and innovation [45]. Accordingly, low (excessive) degree of competition is beneficial (harmful) for innovation and investment level, respectively. Note that, despite excessive competition can harm innovation above some critical threshold, the descending phase of the $\cap-$shape curve is not the focus of this study because this phase can only be achieved in the long run. Instead, we focus on short run policy measures conceived for the NGA
networks market aimed at ensuring the satisfaction of targets clarified in the 2020 Digital Agenda and EU CEGS Strategy.

Based on the premise that more regulation reduces competition, the current state-of-the-art in this domain of knowledge demonstrates that more regulation implies less innovation in the ascending phase of the innovation curve. Consequently, regulation and innovation are characterized by strategic substitutability not only because regulation may restrain investment (e.g., not allowing the appropriation of a high rate of return from the improved service), but also due to direct negative effects of regulation on innovation incentives [32, 16]. Indeed, [45] considers that the potential conflict between regulation and innovation is caused by two main reasons: consumer protection and political economy. The first one means that innovation incentives may require larger profit opportunities due to the need of consumer protection, while the second one means that the entrenched regulation of a legacy industry conflicts with creating a new industry that may or may not be regulated, thereby imposing a bias against innovation. Intuitively, [45] considers that the prospect of converting a regulated environment into a deregulated market after the occurrence of innovation can unambiguously increase investment incentives, which reflects Cave’s argumentation.

However, Fig 3 confirms that the main idea disseminated by both experts does not have adherence to the Portuguese reality due to two main reasons.

First, when there is a change from FTTx deregulation to FTTx regulation, despite the number of facility-based competitors decreases, by no means there is a reduction of investment incentives. The bottom sub-plot in Fig 3 clearly shows that part of the first black line and the whole second black line lie above the red line. Consequently, more regulation effectively reduces the number of facility-based competitors, but may or may not increase the aggregate level of investment. This means that, despite a higher number of facility-based operators can be observed in NC areas, the aggregate level of investment may be higher in C areas, particularly when the degree of vertical spillover is sufficiently strong. This conclusion should be emphasized because it seems advisable to understand that investment plans and installation of own network infrastructure correspond to distinct business activities. An investment plan is motivated by opportunities that result from demand side forces (e.g., sufficiently high willingness to pay for improved service) and consists in upgrading the quality of existing network infrastructures being, therefore, predominantly verified in C areas. The installation of own network infrastructures is motivated by opportunities that result predominantly from the supply side of the market (e.g., space for installation of vital input inside the ducts, existence of poles to extend the network infrastructure, subsidies for installation of vital input in less favorable regions) being, thus, mostly observed in NC areas. In the Portuguese case, even the ascending phase of the innovation curve can be non-monotonic rather than being strictly increasing. Knowing that the observed reality is too complex to be explained on the basis of a quadratic function representative of a theoretical relation between innovation and competition, the main lesson to be inferred from the present analysis is that mathematical models should be taken with caution. Consequently, the higher is the heterogeneity of theoretical models accommodated by the specialized literature, better and more easily can be explained the observed reality of different telecommunications industries worldwide.

Second, previous contributions disseminate the idea that the long-term trajectory of telecommunications industries is to converge towards the wholesale market
Figure 3. Equilibrium investment level of the facility-based operators. Red (Blue) [Black] lines represent the parameter space where the triopoly (monopolistic bottleneck) (duopolistic bottleneck with asymmetric downstream access) is sustained in equilibrium, respectively. Continuous (Dashed) [Dotted] lines represent investment level of the incumbent (first alternative facility-based) [second alternative facility-based] operator, respectively. The right middle panel compares the profit level of the facility-based competitors I and N. Gray lines represent the investment level that would be achieved if FTTx regulation were adopted in the subdomain $0 \leq \beta < 0.4476$. The last subplot captures the total amount of investment in the telecommunications industry. The plot assumes $a = 1$.

deregulation [39, 45]. The antagonism of this study in relation to past contributions is now clear given that we demonstrate that social welfare maximization requires
the establishment of FTTx deregulation (regulation) in the embryonic (growth, maturity and decline) phase (phases) of the industry’s lifecycle, respectively.

Consequently, regulatory guidelines seem to be mandatory only in the long run, regardless whether being applied to the passive or active layer of the wholesale market and independently of being symmetric or asymmetric in their nature.

3.2.4. Retail quantities and prices. Equilibrium outcomes are given by

\[
q_i^* = \begin{cases} 
\frac{2a}{8 - 3\beta^2}, & \beta \in [0, 0.4476); \\
\frac{a\beta^2(80 - 220\beta^2 + 147\beta^4)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, & \beta \in [0.4476, 0.7435); \\
\frac{16 + 44\beta^2 - 35\beta^4}{30a\beta^2}, & \beta \in [0.7435, 0.7923); \\
\frac{a(2 - 3\beta^2)}{8 - 13\beta^2 + 3\beta^4}, & \beta \in [0.7923, \sqrt{2/3}]. 
\end{cases}
\]

\[
q_N^* = \begin{cases} 
\frac{2a}{8 - 3\beta^2}, & \beta \in [0, 0.4476); \\
\frac{2a\beta^2(44 - 115\beta^2 + 72\beta^4)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, & \beta \in [0.4476, 0.7435); \\
\frac{16 + 44\beta^2 - 35\beta^4}{2a(5\beta^2 - 4)), & \beta \in [0.7435, 0.7923); \\
\frac{35\beta^4 - 44\beta^2 - 16}{2a(1 - \beta^2)}, & \beta \in [0.7923, \sqrt{2/3}]. 
\end{cases}
\]

\[
q_E^* = \begin{cases} 
\frac{2a}{8 - 3\beta^2}, & \beta \in [0, 0.4476); \\
\frac{a(2 - 3\beta^2)^2(4 + \beta^2)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, & \beta \in [0.4476, 0.7435); \\
\frac{35\beta^4 - 44\beta^2 - 16}{2a(5\beta^2 - 4)), & \beta \in [0.7435, 0.7923); \\
\frac{a(2 - 3\beta^2)}{8 - 13\beta^2 + 3\beta^4}, & \beta \in [0.7923, \sqrt{2/3}]. 
\end{cases}
\]

\[
p_I^* = p_E^* = \begin{cases} 
\frac{2a}{8 - 3\beta^2}, & \beta \in [0, 0.4476); \\
\frac{a\beta^2(80 - 220\beta^2 + 147\beta^4)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, & \beta \in [0.4476, 0.7435); \\
\frac{16 + 44\beta^2 - 35\beta^4}{30a\beta^2}, & \beta \in [0.7435, 0.7923); \\
\frac{8 - 13\beta^2 + 3\beta^4}{2a(1 - \beta^2)}, & \beta \in [0.7923, \sqrt{2/3}]. 
\end{cases}
\]

\[
p_N^* = \begin{cases} 
\frac{2a}{8 - 3\beta^2}, & \beta \in [0, 0.4476); \\
\frac{2a\beta^2(44 - 115\beta^2 + 72\beta^4)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, & \beta \in [0.4476, 0.7435); \\
\frac{16 + 44\beta^2 - 35\beta^4}{30a\beta^2}, & \beta \in [0.7435, 0.7923); \\
\frac{8 - 13\beta^2 + 3\beta^4}{2a(1 - \beta^2)}, & \beta \in [0.7923, \sqrt{2/3}]. 
\end{cases}
\]

as clarified in Fig 4.
Under FTTx deregulation, results indicate that the retail market is totally symmetric since all market operators sell the same quantity and charge similar price. In fact, [24] presents the argument that Altice holds a very high market share in NC areas, namely 84%. In turn, [1] reveals that no failure has been acknowledged in the retail market to require the imposition of FTTx regulation. In particular, the lack of saturation of the downstream market and consumer switching are dominant characteristics of the Portuguese retail market. Based on the positive analysis carried out in this study, one concludes that the argumentation provided by the EC may be exaggerated given that equilibrium results indicate that an egalitarian market share holds in NC areas. Moreover, [1] clarifies that the SMP position of the historical operator results from its market share in the non-NGA networks market, which is subject to regulatory obligations.

However, Proposition 1 reveals that the imposition of FTTx deregulation in the non-NGA networks market constitutes an equilibrium result and, consequently, this theoretical finding differs from the determination exposed in [1]. This suggests that a potential inconsistency may exist between the optimal wholesale regulatory policy from a theoretical point of view and the one followed in actual regulatory practice by ANACOM, which legitimizes a concern related to the fact that the 2016 market review only clarifies the relevant product market and the delineation of the geographic market for the purpose of benchmarking on the basis of [29] and [28]. In other words, it urges the need of adequate supranational guidelines for a better delineation of which vital inputs should be considered NGA technology to avoid the temporal proliferation of regulatory errors.

Fig 4 also shows that, when FTTx regulation is imposed and duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium, the alternative facility-based operator holds the largest market share and charges the highest retail price. Moreover, both outcomes are increasing in the degree of vertical spillover. This means that churn in favor of the alternative facility-based operator is verified.

**Figure 4. Equilibrium prices and quantities in the retail market.** Red (Blue) [Black] lines represent the parameter space where the triopoly (monopolistic bottleneck) [duopolistic bottleneck with asymmetric downstream access] holds in equilibrium, respectively. Continuous (Dashed) [Dotted] lines represent retail prices and market share of the incumbent (alternative facility-based) [alternative service-based] operator, respectively. The plot assumes $a = 1$. 
and it suggests the presence of strategic complementarity between wholesale investment and retail quantity given that more investment is accompanied by additional quantity sold in the retail market.

In turn, the disadvantage of free riding behavior is manifested under this market circumstance because the alternative service-based operator holds the smallest market share, which is decreasing in the degree of vertical spillover. This means that churn in favor of the alternative service-based operator is not verified and it suggests the presence of strategic complementarity between wholesale investment and retail quantity given that the lack of investment realization is accompanied by the reduction of the quantity sold in the downstream market. Meanwhile, the alternative service-based operator charges similar retail price to the incumbent, which is below the price charged by the alternative facility-based operator.

Nevertheless, when FTTx regulation prevails and the regulator imposes intra-flexibility at $\beta = 0.7435$, the superiority of the alternative facility-based operator is drastically reversed. The incumbent secures the highest market share, which is increasing in the degree of vertical spillover. Both entrant firms hold similar market share, which is lower than that held by the incumbent in addition to be decreasing in the degree of vertical spillover. As such, the regulatory action benefits the incumbent at the expense of harming both alternative operators. When the regulator imposes intra-flexibility at $\beta = 0.7923$, results applied to the duopolistic bottleneck with asymmetric downstream access are restored, thereby suggesting that the alternative facility-based firm would secure a higher profit in the absence of a ducts access fee charge.

3.2.5. Profits. The equilibrium profit of each market operator is given by

$$
\pi^*_i = \begin{cases} 
\frac{a^2 Z_d(\beta)}{2(8 - 3\beta^2)^2(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)^2}, & \beta \in [0, 0.4476); \\
\frac{a^2 Z_r(\beta)}{2(16 + 44\beta^2 - 35\beta^4)^2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}, & \beta \in [0.4476, 0.7435); \\
\frac{a^2(-256 + 1584\beta^2 + 480\beta^4 - 1225\beta^6)}{2(16 + 44\beta^2 - 35\beta^4)^2}, & \beta \in [0.7435, 0.7923); \\
\frac{a^2(-4096 + 56064\beta^2 - 154368\beta^4 + 102736\beta^6)}{2(8 - 13\beta^2 + 3\beta^4)^2(16 + 44\beta^2 - 35\beta^4)^2} + \frac{a^2(133680\beta^8 - 233613\beta^{10} + 122240\beta^{12} - 22050\beta^{14})}{2(8 - 13\beta^2 + 3\beta^4)^2(16 + 44\beta^2 - 35\beta^4)^2}, & \beta \in [0.7923, \sqrt{2/3}) 
\end{cases}
$$
operators), respectively. Two conclusions related to the incumbent’s profit can be after the imposition of intra-flexibility benefits (harms) the incumbent (alternative vtical spillover, thus, reflecting that the consolidation of the monopolistic bottleneck the incumbent (alternative operators) is increasing (decreasing) in the degree of ver-
matic downstream access is already in a mature phase (not consolidated yet), incumbent

When FTTx deregulation is imposed, the incumbent holds the highest profit, which is decreasing in the degree of vertical spillover. The level and evolution of profits

\[ \pi_E^* = \begin{cases} \frac{a^2(16 - 32\beta^2 - 18\beta^4 + 45\beta^6)}{(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)^2}, & \beta \in [0, 0.4476); \\ \frac{a^2(2 - 3\beta^2)^4(4 + \beta^2)^2}{(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}, & \beta \in [0.4476, 0.7435); \\ \frac{4a^2(4 - 5\beta^2)^2}{(16 + 44\beta^2 - 35\beta^4)^2}, & \beta \in [0.7435, 0.7923); \\ \frac{a^2(2 - 3\beta^2)^2}{(8 - 13\beta^2 + 3\beta^4)^2}, & \beta \in [0.7923, \sqrt{2/3}). \end{cases} \]

\[ \pi_N^* = \begin{cases} \frac{a^2(16 - 32\beta^2 - 18\beta^4 + 45\beta^6)}{(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)^2}, & \beta \in [0, 0.4476); \\ \frac{4a^2(4 - 5\beta^2)^2}{(16 + 44\beta^2 - 35\beta^4)^2}, & \beta \in [0.4476, \sqrt{2/3}). \end{cases} \]

\[
Z_d(\beta) := 2908160 - 23579648\beta^2 + 81250520\beta^4 - 155073024\beta^6 + 179293632\beta^8 \\
- 129746304\beta^{10} + 59199336\beta^{12} - 16876755\beta^{14} + 2818800\beta^{16} - 218700\beta^{18},
\]

\[
Z_r(\beta) := -163840 - 147456\beta^2 + 9490432\beta^4 + 24297472\beta^6 \\
- 341056128\beta^8 + 88089860\beta^{10} - 607337440\beta^{12} - 1013739204\beta^{14} \\
+ 2341508704\beta^{16} + 1927740837\beta^{18} + 748418310\beta^{20} - 114307200\beta^{22},
\]
as clarified in Fig 5.

When FTTx deregulation is imposed, the incumbent holds the highest profit, which is decreasing in the degree of vertical spillover. Both alternative operators enjoy similar profit, which is lower than that held by the incumbent. Nevertheless, it is increasing in the degree of vertical spillover. The level and evolution of profits secured by all market operators are justified by the impact of the regulated ducts access fee. When FTTx regulation is imposed and duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium, profit of the incumbent (alternative operators) is increasing (decreasing) in the degree of vertical spillover. In terms of profit level, one observes that \( \pi_N^* > \pi_N^* > \pi_N^* \) for \( \beta \in [0.4476, 0.4500) \), \( \pi_N^* > \pi_N^* \) for any \( \beta \in [0.4500, 0.4525) \), \( \pi_N^* \). \( \pi_N^* > \pi_N^* \) for any \( \beta \in [0.4525, 0.6308) \), \( \pi_I^* > \pi_I^* \geq \pi_N^* \) for any \( \beta \in [0.6308, 0.7435) \cup [0.7923, 0.8086] \) and \( \pi_I^* > \pi_N^* \geq \pi_N^* \) for any \( \beta \in \left[ 0.8086, \sqrt{2/3} \right) \).

These results suggest that, when the duopolistic bottleneck with asymmetric downstream access is already in a mature phase (not consolidated yet), incumbent (alternative facility-based) operator is the firm that benefits more from regulation applied to both layers of the wholesale market, respectively.

When FTTx regulation is imposed and monopolistic bottleneck is sustained in equilibrium, the incumbent holds higher profit than entrant firms since the wholesale investment is compensated by the retail demand expansion. Moreover, profit of the incumbent (alternative operators) is increasing (decreasing) in the degree of vertical spillover, thus, reflecting that the consolidation of the monopolistic bottleneck after the imposition of intra-flexibility benefits (harms) the incumbent (alternative operators), respectively. Two conclusions related to the incumbent’s profit can be
Figure 5. Equilibrium profits. Red (Blue) [Black] lines represent the parameter space where the triopoly (monopolistic bottleneck) [duopolistic bottleneck with asymmetric downstream access] is sustained in equilibrium, respectively. Continuous (Dashed) [Dotted] lines represent profit of the incumbent (alternative facility-based) [alternative service-based] operator, respectively. The left bottom panel compares the profit level of the facility-based competitors I and N. Gray lines represent the profit level that would be obtained if FTTx regulation were adopted in the subdomain $0 \leq \beta < 0.4476$. The plot assumes $a = 1$.

Inferred when equilibrium results are framed within the 2016–2018 dispute between the EC and ANACOM.

First, [24] considers that FTTx deregulation combined with ducts access regulation benefits the incumbent in NC areas. Although this claim requires a static assessment of investment conditions where, on the basis of current NGA networks investment, key indicators must be identified to determine the optimal regulatory policy, Fig 5 validates the standpoint defended by the EC since it shows that the profit enjoyed by the incumbent with the application of FTTx deregulation is greater than that enjoyed with the application of FTTx regulation.

Second, when ducts access regulation is in force, market operators should be on a level playing field. Although the incumbent benefits from FTTx deregulation in NC areas, it may obtain a higher profit in C areas despite the persistence of a RR regime. As clarified in Fig 5, the profit enjoyed by the incumbent in C areas can be higher than that previously enjoyed when the area was NC, particularly for a sufficiently strong degree of vertical spillover. This suggests that ducts access regulation acts as a compensation mechanism in favor of the incumbent after the transfer of passage rights to other licensed operators. Consequently, the argument used by the EC to justify the positive impact of FTTx deregulation on the incumbent’s profit in
NC areas should instead be considered for cases of abnormal profits enjoyed by the incumbent in C areas due to the positive impact of FTTx regulation combined with ducts access regulation on the profit sustained by the incumbent. This issue was not reflected in [1] because the willingness to pay for improved service is still too restrictive in Portuguese C areas [23]. However, this suggests that the regulated ducts access fee applied to C areas can become the main focus of regulatory concern in future market reviews.

3.2.6. Consumer surplus, producer surplus and social welfare. Equilibrium outcomes are given

\[
CS^* = \begin{cases}
\frac{18a^2}{(8 - 3\beta^2)^2}, & \beta \in [0, 0.4476); \\
\frac{2a^2(8 + 62\beta^2 - 213\beta^4 + 150\beta^6)^2}{(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}, & \beta \in [0.4476, 0.7435); \\
\frac{2a^2(8 + 5\beta^2)^2}{(16 + 44\beta^2 - 35\beta^4)^2}, & \beta \in [0.7435, 0.7923); \\
\frac{2a^2(3 - 4\beta^2)^2}{(8 - 13\beta^2 + 3\beta^4)^2}, & \beta \in \left[0.7923, \sqrt{2/3}\right).
\end{cases}
\]

\[
PS^* = \begin{cases}
\frac{3a^2(8 - 9\beta^2)}{2(8 - 3\beta^2)^2}, & \beta \in [0, 0.4476); \\
\frac{a^2\beta^2(2496 + 16480\beta^2 - 166516\beta^4 + 469936\beta^6)}{2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}, & \beta \in [0.4476, 0.7435); \\
\frac{a^2\beta^2(-613101\beta^8 + 384120\beta^{10} - 93312\beta^{12})}{2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}, & \beta \in [0.7435, 0.7923); \\
\frac{a^2(944 + 880\beta^2 - 1225\beta^4)}{2(16 + 44\beta^2 - 35\beta^4)^2}, & \beta \in [0.7435, 0.7923); \\
\frac{a^2(24 - 77\beta^2 + 74\beta^4 - 18\beta^6)}{2(8 - 13\beta^2 + 3\beta^4)^2}, & \beta \in \left[0.7923, \sqrt{2/3}\right),
\end{cases}
\]

as clarified in Fig 6.

When either triopoly or duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium, producer surplus is lower than consumer surplus. The opposite is applied to the case in which the monopolistic bottleneck is sustained in equilibrium, which reflects that a measure of intra-flexibility to impose the monopolistic bottleneck (duopolistic bottleneck with asymmetric downstream access) constitutes a regulatory action that benefits the incumbent (consumers), while it harms consumers (the incumbent), respectively.

When FTTx deregulation is imposed, producer (consumer) surplus is decreasing (increasing) in the degree of vertical spillover, respectively. However, if erroneously applying FTTx regulation, then producer (consumer) surplus would be higher (lower), respectively. FTTx deregulation improves consumer surplus, while it harms producer surplus due to the promotion of inter-technological diversity in the upstream market and provision of burden choice to the final consumer in the downstream market. In terms of regulatory practice, social welfare and aggregate investment reach the maximum value in NC areas if and only if FTTx deregulation combined with ducts access regulation is applied.
When FTTx regulation is imposed and duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium, producer surplus is non-monotonic for $0.4476 \leq \beta < 0.7435$, while it is strictly increasing for $0.7923 \leq \beta < \sqrt{2/3}$. Differently, consumer surplus is strictly increasing in the degree of vertical spillover.

When FTTx regulation is imposed and monopolistic bottleneck is sustained in equilibrium, both surpluses increase in the degree of vertical spillover. Knowing that social welfare level is strictly increasing in the degree of vertical spillover, we conclude that:

- The transition from FTTx regulation to FTTx deregulation within a given NC area improves social welfare and, combining this result with the one yielding for investment, static and dynamic efficiency are both improved.
- The adjustment in the equilibrium market structure promoted at $\beta = 0.4476$ (i.e. the case where a territorial unit becomes competitive such that the transition from FTTx deregulation to FTTx regulation occurs) is justified by the fact that the gain in consumer surplus overrides the loss in producer surplus.
- The adjustment in the equilibrium market structure promoted at $\beta = 0.7435$, which corresponds to the transition from the duopolistic bottleneck with asymmetric downstream access to the monopolistic bottleneck within a given C area subject to FTTx regulation, is justified by the fact that the gain in producer surplus overrides the loss in consumer surplus.

**Figure 6. Equilibrium consumer surplus, producer surplus and social welfare.** Gray lines represent the level of social welfare that would be achieved if FTTx regulation were adopted in the subdomain $0 \leq \beta < 0.4476$. The deadweight loss in NC areas corresponds to the space between the red and gray line in the subdomain $0 \leq \beta < 0.4476$ that can be observed in the right bottom panel. The plot assumes $a = 1$. 
The adjustment in the equilibrium market structure promoted at $\beta = 0.7923$ (i.e. the case corresponding to the transition from the monopolistic bottleneck to the duopolistic bottleneck with asymmetric downstream access within a given C area subject to FTTx regulation) is justified by the fact that the gain in consumer surplus overrides the loss in producer surplus.

3.3. **Robustness checks.** *S1 File* contains several extensions characterized by the inclusion of market asymmetries in NC and C areas to demonstrate that benchmark results may or may not remain qualitatively valid depending on the specific value taken by parameters, which suggests the need of caution on the formulation of the optimal wholesale pricing scheme when both layers of the wholesale market are subject to regulatory oversight.

4. **Policy recommendations.**

4.1. **For the domestic regulator.** Market reviews carried out by ANACOM are based on data either received from market operators or collected from incomplete databases. To discourage the proliferation of type-II regulatory errors (i.e. under-provision of valid information), the persistence of perfect and transparent information with respect to demand side data is mandatory to satisfy the recommendation expressed in [7]. Consequently, the Information System of Fit Infrastructure (ISFI) should include demand side data directly coming from final consumers in addition to the existing data related to the supply side of the market.

4.2. **For the supranational authority.** Some EU Member States are lagging behind the investment targets defined in the 2020 Digital Agenda and EU CEGS Strategy, which means that regulatory goals may be biased towards dynamic efficiency. However, sectoral regulators should also ensure that static efficiency is not compromised. Hitherto, the EC has not developed any concrete action to provide intra-flexibility in the definition of the active access price of NGA technology. However, this study confirms that sectoral regulators should have the ability to freely change the active access price when deemed necessary. This measure is a key step to ensure the fulfillment of NGA targets and the permanent maximization of social welfare. Moreover, access price obligations are typically limited to proportionate access to the incumbent’s vital input. Although the EC opens in-depth investigations in case of FTTx deregulation in regions with little prospect of alternative infrastructure deployment, the supranational entity should also understand that FTTx deregulation can improve both investment incentives and social welfare in NC areas of national jurisdictions whose characteristics resemble to the ones circumscribed by the theory of creative creation. Policy recommendations are summarized as follows:

1. Independently of the wholesale price control method adopted, active access price should always reflect the degree of vertical spillover.
2. Practicality and implementation of wholesale price control methods depend on data availability concerning willingness to pay for improved services.
3. Sectoral regulators should be provided with the possibility to apply intra-flexibility when the degree vertical spillover is sufficiently strong.
4. Market asymmetries (e.g., different vertical spillover or marginal cost between facility-based operators) may distort benchmark results of the creative creation theory, which reinforces the need of caution on final regulatory decisions and additional attention on demand side characteristics.
5. Conclusions. The availability of ultra-fast broadband connectivity is important for the growth of a country’s economy. The digital ecosystem is a new economic reality given that the Cloud Virtual Space already belongs to the daily routine of most citizens. Although access price regulation was important for the liberalization of telecommunications industries during the 1990s and early 2000s, its extension to the fiber era may be ill-advised if set uniformly, that is, if not taking into account the dynamics of each EU Member State. Bearing this hypothesis in mind, a comprehensive analysis of access price regulation in the context of the NGA networks market is provided in this study, which is focused on specific characteristics of one of the most advanced telecommunications industries in Europe: the PTI.

First, in the context of the strong dispute that occurred between the EU and ANACOM in the period 2016 – 2018, we show that the decision of ANACOM applied to NC areas is the correct one. We demonstrate that FTTx deregulation combined with ducts access regulation should be imposed when the degree of vertical spillover is weak, while FTTx regulation combined with ducts access regulation should be imposed when the degree of vertical spillover is strong. The critical threshold where there is a change in the regulatory paradigm is endogenously determined and allows to infer whether a given territorial unit is competitive or not. The parameter space corresponding to a sufficiently weak degree of vertical spillover is representative of a NC area, whereas the parameter space corresponding to a sufficiently strong degree of vertical spillover is representative of a C area. Overall, the analysis clarifies that a given NC (C) area should be subject to FTTx deregulation (regulation), respectively. This implies that a triopoly is established in NC areas, while either duopolistic bottleneck with asymmetric downstream access or monopolistic bottleneck constitute equilibrium market structures in C areas. By no means the previous result applied to NC areas constitutes a paradox because, in the context of the NGA networks market, entrant firms have to trade-off between paying an active access price or a ducts access fee. Since costs associated with the physical infrastructure are sunk and, hence, disregarded at the moment of deciding on whether to invest on accessing to the incumbent’s vital input or acquiring passage rights to build own network infrastructure inside the incumbent’s ducts, it follows that a new firm unambiguously prefers a make strategy in case of FTTx deregulation. This conclusion is justified by the presence of a third operator in addition to the alternative facility-based operator and incumbent. On the one hand, the third operator adopts a make strategy if the area is NC due to the greater availability of profitable opportunities to install a new vital input, but it becomes access seeker if the area is C since it secures a higher profit by engaging in free riding. This conclusion implies that the incumbent’s optimal behavior consists of exploiting rent seeking opportunities only in C areas. On the other hand, the optimal strategy of the third operator is justified by the evolution of the regulated ducts access fee in the degree of vertical spillover. The regulated ducts access fee applied to NC areas is low and decreasing in the degree of vertical spillover. However, the regulated ducts access fee applied to C areas is unambiguously increasing in the degree of vertical spillover and, in some cases, it may exceed twice the value of the regulated ducts access fee applied to NC areas, which discourages the persistence of a triopoly in C areas. It is then clear that, in light of the theory of creative creation, the evolution of a telecommunications industry in NC areas is at odds with the idea of a gradual climb in the ladder of investment as implicit in [21]. Once confronting both theories, one concludes that FTTx deregulation applied to NC areas ensures
considerable static and dynamic efficiency gains relative to the application of FTTx regulation (i.e. a situation where the monopolistic bottleneck is the equilibrium market structure since the regulator follows the ladder of investment approach). This result also implies the confirmation that applying FTTx deregulation in NC areas overcomes the trade-off between dynamic and static efficiency since the highest level of social welfare and the maximum incentive to innovate (i.e. investment level) are both ensured under the theory of creative creation.

Second, we conclude that both theories collapse in their conclusions applied to C areas. Knowing that the regulatory policy is asymmetric because it is only incident on the SMP operator, it follows that the duopolistic bottleneck with asymmetric downstream access (monopolistic bottleneck) corresponds to the equilibrium market structure in a territorial unit where the willingness to pay for improved service is already sufficiently high if and only if the degree of vertical spillover is either weak or strong (intermediate), respectively. This suggests that a measure of intra-flexibility may be needed to ensure the permanent maximization of social welfare. As clarified in Definition 2, intra-flexibility corresponds to the ability that the regulator should have to change the value of the regulated active access price in C areas when deemed necessary. For intermediate degree of vertical spillover, the regulator finds optimal to impose intra-flexibility to promote the sustainability of the monopolistic bottleneck. In actual regulatory practice, this means that the alternative facility-based operator is induced to sell, at least partially, its vital input to the incumbent operator, so that it becomes access seeker. This conclusion does not constitute a paradox because the optimal regulatory policy simultaneously articulates active and passive obligations, which is a realistic characteristic of telecommunications industries that has been neglected so far by previous contributions. From an economic point of view, an increasing regulated ducts access fee in the degree of vertical spillover applied to C areas is justified by the reduction of the available space for the installation of new vital input inside the incumbent’s ducts. As such, the first need of intra-flexibility results from the fact that the regulated ducts access fee takes an excessively high value, namely much greater than the value charged in NC areas, which discourages the installation of new vital input by the alternative facility-based operator. The goal of intra-flexibility for intermediate degree of vertical spillover is then to promote the ownership concentration of vital inputs on the incumbent’s side in order to ensure maximum static efficiency gains. However, for a sufficiently strong degree of vertical spillover, the regulator finds optimal to impose intra-flexibility to recover the duopolistic bottleneck with asymmetric downstream access as equilibrium market structure. The second need of intra-flexibility is justified by fact that the first application of intra-flexibility exacerbates the incumbent’s dominant position in the entire value chain of the telecommunications industry. Although social welfare maximization initially imposes the monopolistic bottleneck as the optimal equilibrium market structure, this is no longer true above some critical threshold of the degree of vertical spillover because this circumstance provides to the incumbent the incentive to charge an excessive price at the retail market level. As such, the pass-through of the incumbent’s dominant position into the downstream market justifies the imposition of a regulated active access price at marginal cost level when the willingness to pay for improved service is too high. It should be noted that the third operator has always remained active in the market by requiring access to the network infrastructure owned by the incumbent. The goal
of intra-flexibility for strong degree of vertical spillover is then to promote the ownership dispersion of vital inputs among various facility-based operators in order to ensure maximum static efficiency gains. This simultaneously allows to boost inter-technological competition (e.g., competition between FTTx and DOCSIS 3.x) at the wholesale market level and intra-technological competition at the retail market level (e.g., competition in the provision of FTTx services).

Furthermore, in the context of C areas, several particularities with respect to the remaining equilibrium variables are highlighted throughout this study. First, the theory of creative creation is clearly aligned with the notion that regulation, rather than deregulation, is mandatory in a long run perspective. Second, although ducts access regulation can be relaxed when intra-flexibility is applied to promote the establishment of the monopolistic bottleneck, it should have a permanent character and should be systematically improved and reinforced to guarantee a fair level playing field. Third, contrary to what is defended in some past studies (e.g., [39]), regulation applied to both layers of the wholesale market not only guarantees social welfare maximization, but also ensures the highest level of aggregate investment. Fourth, the market operator that invests more when the duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium is not the incumbent, but rather the alternative facility-based operator. This is materialized at the retail market level because, for the parameter space where the duopolistic bottleneck with asymmetric downstream access is sustained in equilibrium, the alternative facility-based operator holds the largest market share. However, more investment is not translated into a higher profit since the regulated ducts access fee acts as a compensation mechanism in favor of the incumbent. Fifth, regulated active access price should always reflect the willingness to pay for improved service, which means that a regulatory policy should be driven from demand characteristics of the NGA networks market whatever the type of wholesale price control method adopted to regulate the active layer of the upstream market.

Lastly, several extensions are developed to check the robustness of benchmark results. Market asymmetries reinforce the need of caution in the formulation of the optimal regulatory policy, particularly if these are excessively flagrant (e.g., strong hiatus between the vertical spillover enjoyed or marginal cost supported by facility-based competitors). Knowing that the incumbent would have the incentive to practice third-degree price discrimination at the retail market level in case of FTTx regulation applied to NC areas, we analyze the impact resulting from the combination of a misguided regulatory policy with the expected behavior of the SMP operator. We show that all market operators in the NC area would practice the same retail price. However, it would have a higher level, which would imply a reduction of consumer surplus. For a reasonable parameter space, social welfare would be reduced given that the loss in consumer surplus plus the incumbent’s profit reduction would supplant the increase in profit held by alternative operators.

Two final comments seem to be mandatory. First, the present research should not be understood as a critique to the dominant theory of the telecommunications literature. Instead, the theory of creative creation should be interpreted as complementary to the stepping stone hypothesis provided in [21]. Second, the present research strengthens the idea that the optimal solution for Europe will never be the disintegration of regulation and EU Competition Law. In fact, this study disseminates the vision that the appropriate response to achieve a coherent consolidation of public policies applied to a heterogeneous group of telecommunications industries...
from Europe is to set progressively more flexible and richer recommendations where
the sense of belonging of each EU Member State is reinforced. In this regard, be-
sides strengthening the protection of rights and interests of end users to mitigate the
economic and social impact of COVID-19, ANACOM’s performance during the bi-
ennium 2020-2021 has been marked by the transposition of the EECC. On December
18, 2020, the EC approved EU Recommendation 2020/2245 on relevant markets for
products and services in the electronic communications sector susceptible to ex-ante
regulation in accordance with EU Directive 2018/1972 of the European Parliament
and of the Council, which establishes the EECC. In this new Recommendation,
the EC identifies two wholesale markets as susceptible to ex-ante regulation at EU
level: market 1 refers to the wholesale local access provided at a fixed location
(i.e. the wholesale market 3a), while market 2 refers to specific wholesale capac-
ity. The fact that this supranational regulatory guideline focuses on the wholesale
market 3a reinforces the political and economic importance of the present research.
ANACOM followed this project closely since its inception, having participated in
meetings aimed at discussing the application of criteria for each EU Member State.
Market operators were also able to participate in this process by contributing with
elements that were sent to the EC, while being permanently informed about new
developments to ensure the persistence of best regulatory practices through the
institutionalization of a market environment characterized by perfect information.

Supporting information

S1 File. A supplementary file compiles mathematical proofs and extensions that
support the findings of this study. It can be accessed by clicking on the following
hyperlink: S1 File.

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Appendix. The introduction of a stage where the regulator decides whether to
regulate or not the ducts access fee is the key refinement that allows to endogenize
and find the competitive nature of a given territorial unit. This formal step does
not exist in past studies focused on the telecommunications field because previous
theoretical models did not contemplate the simultaneous presence of ducts access
fee and active access price, but are rather restricted to the analysis of a wholesale
market that is only explained by the active access price. As a consequence of this
technical improvement, an equilibrium result is obtained according to which if the
degree of vertical spillover is below (above) some critical threshold, then the area
under analysis will be NC (C), so that FTTx deregulation (regulation) will be
applied to the active layer of the wholesale market, respectively. For the sake of
brevity, the complete analysis and interpretation of results for each possible subgame
is exposed in the Online Appendix, which is available at S1 File. Mathematica files
that confirm the veracity of our results can be provided upon request to the first
author. In what follows, the Appendix is organized in two distinct parts to facilitate
the comprehension of mathematical details and respective economic intuition.

Appendix A. Clarification of each possible subgame. Since the game follows
the method of backward induction such that each possible subgame is solved by
starting at the fifth stage, Appendix A provides outcomes sustained at the third
stage. Independently of the subgame in hands, we emphasize that the process to
compute the endogenous ducts access fee requires to execute three steps: determine
the privately desirable market structure with exogenous ducts access fee, determine
the socially desirable market structure with exogenous ducts access fee and, from
the combination of both steps, the endogenous ducts access fee is found.

A.1. DR regime: Active access price deregulation combined with ducts access fee
regulation.

Lemma 1. Let $a > 0$. Under the DR regime:
(i) $\forall \beta \in [0, 0.4961)$, triopoly is the prevailing market structure. Wholesale access
prices are given by

$$\left(w^{DR}, F^{DR}\right) = \left(0, \frac{a^2 F_d(\beta)}{2(8 - 3\beta^2)^2 (352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)}\right),$$

such that social welfare is given by

$$W^{DR} = \frac{3a^2(20 - 9\beta^2)}{2(8 - 3\beta^2)^2}.$$

(ii) $\forall \beta \in [0.4961, 0.7611)$, duopolistic bottleneck with asymmetric downstream access
is the prevailing market structure. Wholesale access prices are given by

$$\left(w^{DR}, F^{DR}\right) = \left(\frac{6a(16 - 52\beta^2 + 52\beta^4 - 15\beta^6)}{352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8}, \frac{a^2(8 - 9\beta^2)(56 - 168\beta^2 + 145\beta^4 - 30\beta^6)^2}{2(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)}\right),$$

such that social welfare is given by

$$W^{DR} = \frac{a^2 B(\beta)}{2 (352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)^2}.$$

(iii) $\forall \beta \in [0.7611, 0.7611)$, vertical monopoly is the prevailing market structure.
Wholesale access prices are given by

$$\left(w^{DR}, F^{DR}\right) = \begin{cases} \left(\frac{a}{2 - \beta^2}, \frac{a^2 (8 - 9\beta^2)(56 - 168\beta^2 + 145\beta^4 - 30\beta^6)^2}{2(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)}\right), & \beta \in \left[0.7611, \sqrt{\frac{2}{15}}(-1 + \sqrt{3}\overline{1})\right]; \\
\left(\frac{a}{2 - \beta^2}, \frac{a^2 (8 - 9\beta^2)}{18(2 - \beta^2)^2}\right), & \beta \in \left[\sqrt{\frac{2}{15}}(-1 + \sqrt{3}\overline{1}), \sqrt{\frac{2}{3}}\right), \end{cases}$$

1With

$$F_d(\beta) := 958464 - 780800\beta^2 + 27033088\beta^4 - 51781120\beta^6 + 59953856\beta^8 - 43276992\beta^{10} + 19610208\beta^{12} - 5551065\beta^{14} + 927450\beta^{16} - 72900\beta^{18};$$

$$B(\beta) := 111360 - 718400\beta^2 + 1859456\beta^4 - 24898094\beta^6 + 1798284\beta^8 - 734805\beta^{10} + 170100\beta^{12} - 16200\beta^{14}.$$
such that social welfare is given by
\[ W^{DR} = \frac{a^2(3 - \beta^2)}{2(2 - \beta^2)^2}. \]

Proof. Consult the Online Appendix B.

Economic intuition. The subgame that simultaneously incorporates FTTx deregulation and ducts access regulation leads to the formation of three different market structures.

When the degree of vertical spillover is weak, the prevailing market structure is a triopoly and, thus, pure facility-based competition holds in the production and commercialization of improved services. The deregulated active access price is characterized by an empty set given that the active access price imposed by the incumbent is irrelevant because, by definition of triopoly, none of the two alternative operators will require access to the vital input owned by the incumbent for the provision of retail offers to end users.

However, similar argument does not hold when the degree of vertical spillover is strong. For intermediate degree of vertical spillover, the prevailing market structure is a duopolistic bottleneck with asymmetric downstream access given that alternative operators have the incentive to adopt asymmetric entry strategies reflecting, on the one hand, inter-technological diversity in the upstream market due to the presence of two distinct vital inputs and, on the other hand, hybrid competition in the downstream market due to the simultaneous presence of service-based and facility-based retail providers. When the degree of vertical spillover is too strong, the prevailing market structure is a vertical monopoly, thus, reflecting the complete absence of competition in the production and commercialization of improved services.

Summarizing, the regulator ensures infrastructure-based competition if allowing FTTx deregulation in the early rollout of a disruptive technology. As the maturity of the vital input increases, the regulator promotes the persistence of a single vertically integrated firm. Consequently, the economic rationale of a telecommunications industry that follows the RD regime is opposite to the one that resorts to the ladder of investment approach.

A.2. RR regime: Active access price regulation combined with ducts access fee regulation.

Lemma 2. Let \( a > 0 \). Under the RR regime:
(i) \( \forall \beta \in [0, 0.4476), \) monopolistic bottleneck is the prevailing market structure. Regulatory policy is characterized by

\[ F_{\alpha}(\beta) := 4352 - 36224\beta^2 + 60368\beta^4 + 202592\beta^6 - 898316\beta^8 + 1331240\beta^{10} - 890067\beta^{12} + 2258463\beta^{14}; \]
\[ F_{\beta}(\beta) := 65536 + 1970176\beta^2 - 112640\beta^4 + 130075136\beta^6 - 676566656\beta^8 + 1468882160\beta^{10} - 601811648\beta^{12} - 259714560\beta^{14} - 11025\beta^{16}. \]

2With
\[ F_{\alpha}(\beta) := 4352 - 36224\beta^2 + 60368\beta^4 + 202592\beta^6 - 898316\beta^8 + 1331240\beta^{10} - 890067\beta^{12} + 2258463\beta^{14}; \]
\[ F_{\beta}(\beta) := 65536 + 1970176\beta^2 - 112640\beta^4 + 130075136\beta^6 - 676566656\beta^8 + 1468882160\beta^{10} - 601811648\beta^{12} - 259714560\beta^{14} - 11025\beta^{16}. \]
such that social welfare is given by

\[
W_{RR} = \begin{cases}
\frac{a^2(60 - \beta^2)}{2(8 - \beta^2)^2}, & \beta \in [0, 1/\sqrt{5}); \\
\frac{a^2(16 + 35\beta^2)}{2(16 + 44\beta^2 - 35\beta^4)}, & \beta \in [1/\sqrt{5}, 0.4476].
\end{cases}
\]

(ii) \( \forall \beta \in [0.4476, 0.7435], \) duopolistic bottleneck with asymmetric downstream access is the prevailing market structure. Regulatory policy is characterized by

\[
(w_{RR}, F_{RR}) = \begin{cases}
\left(0, \frac{3a^2\beta^2(8 - 17\beta^2 + 8\beta^4)}{2(8 - \beta^2)(8 - 13\beta^2 + 3\beta^4)}\right), & \beta \in [0, 0.4435]; \\
\left(0, \frac{\beta^3 a^2 F_{rr}(\beta)}{2(8 - \beta^2)(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}\right), & \beta \in [0.4435, 1/\sqrt{5}); \\
\left(\frac{8a(5\beta^2 - 1)}{35\beta^4 - 44\beta^2 - 16}, \frac{\beta^3 a^2 F_{rr}(\beta)}{2(16 + 44\beta^2 - 35\beta^4)^2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}\right), & \beta \in [1/\sqrt{5}, 0.4476],
\end{cases}
\]

such that social welfare is given by

\[
W_{RR} = \begin{cases}
\frac{2a(-8 + 62\beta^2 - 122\beta^4 + 69\beta^6)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, & \beta \in [0, 1/\sqrt{5}); \\
\frac{a^2(16 + 192\beta^2 - 617\beta^4 + 432\beta^6)}{2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}, & \beta \in [1/\sqrt{5}, 0.4476].
\end{cases}
\]

(iii) \( \forall \beta \in [0.7435, 0.7923], \) monopolistic bottleneck is the prevailing market structure. The regulatory policy is characterized by

\[
(w_{RR}, F_{RR}) = \begin{cases}
\left(0, \frac{8a(5\beta^2 - 1)}{35\beta^4 - 44\beta^2 - 16}, \frac{\beta^3 a^2 F_{rr}(\beta)}{2(16 + 44\beta^2 - 35\beta^4)^2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2}\right), & \beta \in [0.7435, 0.7866]; \\
\left(\frac{8a(5\beta^2 - 1)}{35\beta^4 - 44\beta^2 - 16}, \frac{\beta^3 a^2 F_{rr}(\beta)}{2(8 - 13\beta^2 + 3\beta^4)^2(16 + 44\beta^2 - 35\beta^4)^2}\right), & \beta \in [0.7866, 0.7923],
\end{cases}
\]

such that social welfare is given by

\[
W_{RR} = \frac{a^2(16 + 35\beta^2)}{2(16 + 44\beta^2 - 35\beta^4)}. \]
(iv) $\forall \beta \in \left[0, 0.7923, \sqrt{\frac{2}{3}}\right]$, duopolistic bottleneck with asymmetric downstream access is the prevailing market structure. Regulatory policy is characterized by

$$ (w^{RR}, F^{RR}) = \left(0, \frac{a^2 F_{rd}(\beta)}{2(8 - 13\beta^2 + 3\beta^4)(16 + 44\beta^2 - 35\beta^4)^2}\right), $$

such that social welfare is given by

$$ W^{RR} = \frac{a^2(120 - 346\beta^2 + 276\beta^4 - 36\beta^6)}{(16 - 26\beta^2 + 6\beta^4)^2}. $$

**Proof.** Consult the Online Appendix C.

**Economic intuition.** The subgame that incorporates FTTx regulation and ducts access regulation implies the formation of three different market structures.

When the degree of vertical spillover is weak, the prevailing market structure is the monopolistic bottleneck, thereby reflecting pure service-based competition in the commercialization of improved services.

For intermediate degree of vertical spillover, wholesale access price regulation plays a fundamental role on the established market structure. Bearing in mind the regulatory goal of satisfying social welfare maximization, a duopolistic bottleneck with asymmetric downstream access (monopolistic bottleneck) is sustained for low (high) willingness to pay for improved services, respectively.

When the degree of vertical spillover is strong, the prevailing market structure is a duopolistic bottleneck with asymmetric downstream access reflecting, on the one hand, inter-technological diversity in the upstream market due to the presence of two vital inputs and, on the other hand, hybrid competition in the downstream market due to the simultaneous presence of service-based and facility-based retail providers.

**Difference between DR and RR regimes.** The main difference between resorting to the absence or presence of FTTx deregulation under the presence of ducts access regulation is now clear. While active access price deregulation boosts the proliferation of a make strategy when the willingness to pay for improved service is low, active access price regulation is only capable of doing it for a sufficiently high willingness to pay for improved service. This corresponds to the key aspect that allows to distinguish the creative creation theory from the stepping stone hypothesis when the degree of vertical spillover is sufficiently weak. The former option internalizes that entrant firms trade-off between paying a regulated ducts access fee or an unregulated active access price, while the later option only conceives that entrant firms are restricted to follow a buy strategy that is necessarily subject to the imposition of regulation on the active layer of the wholesale market. The misleading and inflexible vision that characterizes the later option is not only in sharp contrast to the Portuguese reality, but also implies a reduction of investment incentives and creates a deadweight loss in NC areas because, as further confirmed in Proposition 1, FTTx regulation is out of the equilibrium path for a weak degree of vertical spillover. On the contrary, FTTx deregulation combined with ducts access regulation provides maximum incentives for a new market operator to follow a make strategy in NC areas.

**A.3. DD regime: Active access price deregulation with ducts access fee deregulation.**
This subgame resembles to the DR regime, but deregulation of the ducts access fee is now introduced to complement the deregulated active access price.

**Lemma 3.** Let $a > 0$. Under the DD regime:

(i) $\forall \beta \in [0, 0.4961)$, vertical monopoly is the prevailing market structure. Wholesale access prices are given by

$$
(w_{DD}^*, F_{DD}^*) = \left(0, \frac{a^2(8 - 9\beta^2)(56 - 168\beta^2 + 145\beta^4 - 30\beta^6)^2}{2(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)^2}\right),
$$

such that social welfare is given by

$$
W_{DD}^* = \frac{3a^2(20 - 9\beta^2)}{2(8 - 3\beta^2)^2}.
$$

(ii) $\forall \beta \in \left[0.4961, \sqrt{\frac{2}{3}}\right)$, prevailing market structures and wholesale access prices resemble to the DR regime.

**Proof.** Consult the Online Appendix D.

**Economic intuition.** When the ducts access fee is set by the incumbent to maximize profit, the NGA networks market may be characterized by the absence of alternative facility-based operator because the incumbent has the incentive to charge an exclusionary ducts access fee to avoid infrastructure-based competition. Consequently, the triopoly obtained in Lemma 1 becomes a vertical monopoly in Lemma 3 when the degree of vertical spillover is weak.

However, this private action is irrelevant or, similarly, it constitutes a non-credible threat in the spirit of Kreps and Wilson (1982) for intermediate degree of vertical spillover given that the alternative facility-based operator secures a null profit even under ducts access regulation. This is because the downstream revenue acquired by the alternative facility-based operator is unable to compensate the upstream cost (i.e. investment in vital input plus regulated ducts access fee). This outcome does not constitute a problematic issue because it only suggests that any regime accommodating FTTx deregulation for intermediate degree of vertical spillover is out of the equilibrium path.

Finally, similar is applied to strong degree of vertical spillover given that a vertical monopoly was already the prevailing market structure with ducts access regulation.

**A.4. RD regime: Active access price regulation with ducts access fee deregulation.**

This subgame resembles to the RR regime, but deregulation of the ducts access fee is introduced to complement the regulated active access price.

**Lemma 4.** Let $a > 0$. Under the RD regime:

(i) $\forall \beta \in [0, 0.4476) \cup [0.7435, 0.7923)$, prevalent market structure and wholesale access prices resemble to the RR regime.

(ii) $\forall \beta \in [0.4476, 0.7435) \cup \left[0.7923, \sqrt{\frac{2}{3}}\right)$, monopolistic bottleneck with a single access seeker is the prevailing market structure. Wholesale access prices are given by
\[(w^{RD}, F^{RD}) = \left( \frac{2a(-8 + 62\beta^2 - 122\beta^4 + 69\beta^6)}{16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8}, \frac{a^2\beta^4(8 - 9\beta^2)(8 - 13\beta^2 + 3\beta^4)^2}{2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)^2} \right), \]

such that social welfare is given by

\[W^{RD} = a^2(120 - 346\beta^2 + 276\beta^4 - 36\beta^6) \left( \frac{16 - 26\beta^2 + 6\beta^4}{(16 - 26\beta^2 + 6\beta^4)^2} \right), \text{ for } \beta \in \left[0.7923, \sqrt{\frac{2}{3}}\right].\]

**Proof.** Consult the Online Appendix E1.

**Economic intuition.** Similarly to Lemma 3, when both entrant firms require access to the vital input owned by the incumbent, raising the ducts access fee due to market deregulation constitutes a non-credible threat in the spirit of Kreps and Wilson (1982). Consequently, for the parameter space where a monopolistic bottleneck is the prevailing market structure in the RR regime, ducts access deregulation does not change the qualitative nature of results.

However, for the parameter space where new market operators adopt asymmetric entry strategies, ducts access deregulation allows the incumbent to take possession of the surplus that would be retained by the alternative facility-based competitor in case of ducts access regulation being in force. Therefore, the market structure ceases to be a duopolistic bottleneck with asymmetric downstream access to become a monopolistic bottleneck. The application of FTTx regulation for a strong degree of vertical spillover suggests that the regulator should not only have a concern with dynamic and static efficiency, but also with allocative efficiency between facility-based competitors. In this sense, ducts access regulation constitutes a precondition to ensure inter-technological diversity at the wholesale market level and choice burden to consumers at the retail market level.

**Appendix B. Subgame perfect Nash equilibrium.** Knowing that the game is solved by the method of backward induction, the regulator decides whether to regulate or not each wholesale access price at the second stage. To understand how to solve it, the following economic intuition should be internalized. On the one hand, regardless of whether ducts access fee is subject to regulatory oversight, the regulator is in favor of FTTx regulation if and only if

\[W^{Rs} > W^{Ds},\]

which means that the regulatory goal applied to the active layer of the wholesale market is social welfare maximization, with \(s = \{R \cup D\}\) representing the passive layer of the wholesale market. On the other hand, regardless of whether active access
price is subject to regulatory oversight, ducts access deregulation ensures the same level of social welfare to that yielding with ducts access regulation. This implies that the regulatory target applied to the passive layer of the wholesale market is not social welfare maximization per se, but rather the minimization of allocative inefficiency subject to the persistence of a socially desirable market structure for every degree of vertical spillover. This is equivalent to say that, if ducts access deregulation prevails but this action allows the incumbent’s appropriation of surplus that would be otherwise retained by the alternative facility-based operator, then ducts access regulation will be the optimal choice taken by the regulator.

Summarizing, FTTx regulation occurs if and only if this action increases the level of social welfare relative to FTTx deregulation, while ducts access regulation occurs if and only if this action decreases the allocative inefficiency relative to ducts access deregulation. Thenceforth, it is straightforward to extrapolate the optimal entry decision of each new market operator at the first stage.

**B.1. Second stage analysis and support to Proposition 1.**

**Goal on the active layer of the wholesale market: Maximization of social welfare.**

Assume that the ducts access fee is regulated. Then, let us focus on the RR and DR regimes. The level of social welfare level emerges directly from Lemma 1 and Lemma 2. Under the DR regime:

\[
W^{DR} = \begin{cases} 
\frac{3a^2(20 - 9\beta^2)}{2(8 - 3\beta^2)^2}, & \beta \in [0, 0.4961) \\
\frac{a^2 B(\beta)}{2(352 - 1216\beta^2 + 1360\beta^4 - 555\beta^6 + 90\beta^8)}, & \beta \in [0.4961, 0.7611) \\
\frac{a^2 (3 - \beta^2)}{2 (2 - \beta^2)^2}, & \beta \in [0.7611, \sqrt{2/3}) 
\end{cases}
\]

Under the RR regime:

\[
W^{RR} = \begin{cases} 
\frac{a^2(60 - \beta^2)}{2(8 - \beta^2)^2}, & \beta \in [0, 1/\sqrt{5}) \\
\frac{a^2(16 + 35\beta^2)}{2(16 + 44\beta^2 - 35\beta^4)}, & \beta \in [1/\sqrt{5}, 0.4476) \\
\frac{a^2(16 + 192\beta^2 - 617\beta^4 + 432\beta^6)}{2(16 + 212\beta^2 - 788\beta^4 + 789\beta^6 - 216\beta^8)}, & \beta \in [0.4476, 0.7435) \\
\frac{a^2(16 + 35\beta^2)}{2(16 + 44\beta^2 - 35\beta^4)}, & \beta \in [0.7435, 0.7923) \\
\frac{a^2(120 - 346\beta^2 + 276\beta^4 - 36\beta^6)}{(16 - 26\beta^2 + 6\beta^4)^2}, & \beta \in [0.7923, \sqrt{2/3}) 
\end{cases}
\]

Then, it becomes clear that

\[
W^{RR} < W^{DR}, \forall \beta \in [0, 0.4476)
\]

while

\[
W^{RR} > W^{DR}, \forall \beta \in \left[0.4476, \sqrt{2/3}\right)
\]
which means that the DR (RR) regime is (is not) optimal and, therefore, FTTx deregulation (regulation) is the optimal regulatory decision when the degree of vertical spillover is weak (strong), respectively.

Goal on the passive layer of the wholesale market: Minimization of allocative inefficiency.

Focus on $\beta \in [0, 0.4476)$. Since the RR regime is not adopted, similar is applied to the RD regime because this regime does not improve social welfare relative to the RR regime according to Lemma 4. Moreover, for this parameter space, it is clear that the DD regime will not be adopted because, according to Lemma 3, ducts access fee deregulation leads to the formation of a vertical monopoly such that the industry would sustain a level of social welfare necessarily below the level of social welfare achieved under the DR regime

$$W^{DD} < W^{DR} \iff \frac{a^2(3 - \beta)}{2(2 - \beta^2)^2} < \frac{3a^2(20 - 9\beta^2)}{2(8 - 3\beta^2)^2}$$

since the previous inequality is strictly satisfied, $\forall a > 0, \beta \in [0, 0.4476)$. Focus on $\beta \in \left(0.4476, \sqrt{2/3}\right)$. Since the DR regime is not adopted, similar is applied to the DD regime because this regime does not improve social welfare relative to the RR regime according to Lemma 3. Consequently, the DD regime constitutes a strictly Pareto dominated strategy. Moreover, for this parameter space, it is clear that the RD regime:

- Is adopted when the equilibrium market structure is the monopolistic bottleneck under the RR regime because even if the incumbent raises the ducts access fee under deregulation, it will not induce allocative inefficiency in the industry. From point (i) of Lemma 4, this is only verified for $\beta \in [0.7435, 0.7923)$. For this parameter space, the RD regime belongs to the SPNE not because the level of social welfare under this regime is equal to that under the RR regime (in fact, this is always true in the entire domain of the vertical spillover), but rather due to the fact that allocative efficiency is not compromised under the presence of ducts access fee deregulation.

- Is not adopted when the equilibrium market structure is the duopolistic bottleneck with asymmetric downstream access under the RR regime because, from point (ii) of Lemma 4, ducts access fee deregulation leads to the formation of a monopolistic bottleneck with a single access seeker. Although the level of social welfare is unchanged, allocative inefficiency necessarily prevails in the industry. Since the regulator ensures that allocative efficiency is not compromised, then the RD regime is out of the equilibrium path for $0.4476 \leq \beta < 0.7435 \cup 0.7923 \leq \beta < \sqrt{2/3}$.

- Therefore, the RD regime is only considered a Pareto dominated strategy (but not strictly dominated because it has the ability to be equivalent to the RR regime in terms of allocative efficiency) for $0.7435 \leq \beta < 0.7923$. From here, Proposition 1 flows straightforwardly. □

REFERENCES

[1] ANACOM, Final decision on the consideration of Commission Recommendation of 29.11.2016 on cases PT/2016/1888 and PT/2016/1889: Wholesale local access provided at a fixed location and wholesale central access provided at a fixed location for mass-market products -
Reasoned justification for deciding not to amend or withdraw the draft measure, 2017. Available from: https://www.anacom.pt/streaming/FinalDecision23March2017considerationECRecommendation.pdf?contentId=1414023&field=ATTACHED_FILE.

[2] K. J. Arrow, Economic welfare and the allocation of resources for invention, in The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton University Press, 1962, 609–626.

[3] M. Bacache, M. Bourreau and G. Gaudin, Dynamic Entry and Investment in New Infrastructures: Empirical Evidence from the Fixed Broadband Industry, Rev. Ind. Organ., 44 (2014), 179–209.

[4] W. J. Baumol, J. A. Ordover and R. D. Willig, Parity pricing and its critics: A necessary condition for efficiency in the provision of bottleneck services to competitiors, Yale J. Regul., 14 (1997), 145–164.

[5] W. J. Baumol and J. G. Sidak, The pricing of inputs sold to competitors, Yale J. Regul., 11 (1994), 171–202.

[6] W. J. Baumol and J. G. Sidak, Toward Competition in Local Telephony, MIT University Press, Cambridge, 1994.

[7] BEREC, Report on challenges and drivers of NGA roll out and infrastructure competition, 2016. Available from: https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/6488-berec-report-challenges-and-drivers-of-nga-rollout-and-infrastructure-competition.

[8] BEREC, Regulatory Accounting in Practice 2014, 2014. Available from: https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/4595-berec-report-regulatory-accounting-in-practice-2014.

[9] BEREC, Report on access to physical infrastructure in the context of market analyses, 2019. Available from: https://berec.europa.eu/eng/document_register/subject_matter/berec/reports/8597-berec-report-on-access-to-physical-infrastructure-in-the-context-of-market-analysis.

[10] M. Bourreau, C. Cambini and P. Do˘gan, Access pricing, competition, and incentives to migrate from “old” to “new” technology, Int. J. Ind. Organ., 30 (2012), 713–723.

[11] M. Bourreau, C. Cambini and P. Do˘gan, Access regulation and the transition from copper to fiber networks in telecoms, J. Regul. Econ., 45 (2014), 233–258.

[12] M. Bourreau, C. Cambini and S. Hoernig, Ex-ante regulation and co-investment in the transition to next generation access, Telecom. Pol., 36 (2012), 399–406.

[13] M. Bourreau, P. Do˘gan and M. Manant, A critical review of the “ladder of investment” approach, Telecom. Pol., 34 (2010), 683–696.

[14] M. Bourreau, J. Hombert, J. Pouyet and N. Schutz, Upstream competition between vertically integrated firms, J. Ind. Econ., 59 (2011), 677–713.

[15] M. Bourreau, P. Lupi and F. M. Manenti, Old technology upgrades, innovation, and competition in vertically differentiated markets, Inf. Econ. Pol., 29 (2014), 10–31.

[16] W. Briglauer, How EU sector-specific regulations and competition affect migration from old to new communications infrastructure: Recent evidence from EU-27 member states, J. Regul. Econ., 48 (2015), 194–217.

[17] W. Briglauer, C. Cambini and M. Grajek, Why is Europe lagging on next generation access networks?, Brueg. Pol. Contrib., 14 (2015), 1–13.

[18] W. Briglauer and K. Gugler, The deployment and penetration of high-speed fiber networks and services: Why are EU member states lagging behind?, Telecom. Pol., 37 (2013), 819–835.

[19] D. Brito, P. Pereira and J. Vareda, Incentives to invest and to give access to non-regulated new technologies, Inf. Econ. Pol., 24 (2012), 197–211.

[20] C. Cambini and Y. Jiang, Broadband investment and regulation: A literature review, Telecom. Pol., 33 (2009), 559–574.

[21] M. Cave, Encouraging infrastructure competition via the ladder of investment, Telecom. Pol., 30 (2006), 223–237.

[22] M. Cave, Snakes and ladders: Unbundling in a next generation world, Telecom. Pol., 34 (2010), 80–85.

[23] J. Confraria, T. Ribeiro and H. Vasconcelos, Analysis of consumer preferences for mobile telecom plans using a discrete choice experiment, Telecom. Pol., 41 (2017), 157–169.

[24] European Commission, Commission decision concerning case PT/2016/1888 and case PT/2016/1889, 2016. Available from: https://www.anacom.pt/streaming/ResponseEC29July2016.pdf?contentId=1403390&field=ATTACHED_FILE.
European Commission, Commission recommendation of 11 September 2013 on consistent non-discrimination obligations and costing methodologies to promote competition and enhance the broadband investment environment, *Official J. European Union*, (2013). Available from: [http://data.europa.eu/eli/reco/2013/466/oj](http://data.europa.eu/eli/reco/2013/466/oj).

European Commission, Directive 2014/61/EU of the European Parliament and of the Council of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communications network, *Official J. European Union*, (2014). Available from: [https://eur-lex.europa.eu/eli/dir/2014/61/oj](https://eur-lex.europa.eu/eli/dir/2014/61/oj).

European Commission, Directive of the European Parliament and of the council establishing the European Electronic Communications Code, *Official J. European Union*, (2016). Available from: [http://data.europa.eu/eli/dir/2018/1972/oj](http://data.europa.eu/eli/dir/2018/1972/oj).

European Commission, European Commission recommendation on regulated access to Next Generation Access Networks (NGA), 2010. Available from: [https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010H0572&from=EN](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010H0572&from=EN).

European Commission, Guidelines on market analysis and the assessment of significant market power under the Community regulatory framework for electronic communications networks and services, 2002. Available from: [https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52002XC0711(02)&from=EN](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52002XC0711(02)&from=EN).

European Commission, Trends in European broadband markets, 2014. Available from: [https://digital-strategy.ec.europa.eu/en/library/scoreboard-2014-trends-european-broadband-markets-2014](https://digital-strategy.ec.europa.eu/en/library/scoreboard-2014-trends-european-broadband-markets-2014).

D. Fudenberg, R. Gilbert, J. Stiglitz and J. Tirole, Preemption, leapfrogging and competition in patent races, *Eur. Econ. Rev.*, **22** (1983), 3–31.

M. Grajek and L.-H. Röller, Regulation and investment in network industries: Evidence from European telecoms, *J. Law Econ.*, **55** (2012), 189–216.

F. Höfler and K. M. Schmidt, Two tales on resale, *Int. J. Ind. Organ.*, **26** (2008), 1448–1460.

J. Huige and M. Cave, Regulation and the promotion of investment in next generation networks – A European dilemma, *Telecom. Pol.*, **32** (2008), 713–721.

D. M. Kreps and R. Wilson, Sequential equilibria, *Econometrica*, **50** (1982), 863–894.

J.-J. Laffont and J. Tirole, Access pricing and competition, *Eur. Econ. Rev.*, **38** (1994), 1673–1710.

J.-J. Laffont and J. Tirole, *Competition in Telecommunications*, MIT University Press, Cambridge, 2000.

R. Lestage and D. Flacher, Infrastructure investment and optimal access regulation in the different stages of telecommunications market liberalization, *Telecom. Pol.*, **38** (2014), 569–579.

P. Sarmento and A. Brandão, Access pricing: A comparison between full deregulation and two alternative instruments of access price regulation, cost-based and retail-minus, *Telecom. Pol.*, **31** (2007), 236–250.

J. Schumpeter, *Capitalism, Socialism and Democracy*, Harper Press, New York, 1942.

T. Shortall and M. Cave, Is symmetric access regulation a policy choice? Evidence from the deployment of NGA in Europe, *Com. Strat.*, **98** (2015), 17–41.

J. Tirole, *The Theory of Industrial Organization*, MIT University Press, Cambridge, 1988.

I. Vogelsang, The endgame of telecommunications policy? A survey, *Rev. Econ.*, **64** (2013), 195–270.

I. Vogelsang, Price regulation of access to telecommunications networks, *J. Econ. Lit.*, **41** (2003), 830–862.

I. Vogelsang, The role of competition and regulation in stimulating innovation–Telecommunications, *Telecom. Pol.*, **41** (2017), 802–812.

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