CEPREMAP
CENTRE POUR LA RECHERCHE ECONOMIQUE ET SES APPLICATIONS

Wholesale Markets in Telecommunications

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Résumé :

Dans l'industrie des télécommunications, les opérateurs "facility-based" ont déployé leurs propres réseaux tandis que les opérateurs "service-based" n'ont pas d'infrastructure. Ces derniers doivent acheter un service de gros aux opérateurs facility-based pour être actifs sur les marchés finaux. Nous montrons que, même lorsque les opérateurs facility-based offrent un service de gros parfaitement homogène et se font concurrence en prix, le marché de gros peut ne pas être concurrentiel. Partant de notre analyse théorique, nous proposons certaines pistes de réflexion pour les industries du haut débit et de la téléphonie mobile.

Mots-clés : marchés amont et aval, intégration verticale, télécommunications

Classification JEL : L13, L51

Summary :

In telecommunications some operators have deployed their own networks whereas others have not. The latter firms must purchase wholesale products from the former to be able to compete on the final market. We show that, even when network operators compete in prices and offer homogenous products on the wholesale market, that market may not be perfectly competitive. Based on our theoretical analysis, we derive some policy implications for the broadband and the mobile telephony markets.

Keywords : upstream and downstream markets, vertical integration, telecommunications

JEL classification : L13, L51

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Résumé technique :

Les marchés de gros peuvent demeurer non concurrentiels, même s'ils présentent des caractéristiques a priori pro-concurrentielles. Afin d'établir le bon diagnostic de régulation, ces marchés ne doivent en aucun cas être étudiés isolément des marchés aval. Explications.

Dans certains marchés des télécommunications, le développement d'une concurrence par les infrastructures entre opérateurs de réseaux a conduit à l'émergence d'un marché de gros. Par exemple, sur le marché de la téléphonie mobile, les opérateurs mobiles virtuels (MVNO) peuvent mettre en concurrence plusieurs opérateurs de réseaux mobiles pour la fourniture d'un service de téléphonie mobile en gros. Sur le marché français du haut débit, plusieurs opérateurs de réseaux (Orange, Neuf-Cegetel, Completel…) proposent un service haut débit en gros de type « *bitstream access* » à des fournisseurs de services.

La concurrence sur les marchés de gros dynamise la concurrence sur les marchés de détail

La concurrence entre opérateurs de réseaux sur les marchés de gros peut être vue comme un moyen de dynamiser la concurrence sur les marchés de détail. Une question importante pour la politique publique est donc de déterminer si, dans un contexte de concurrence par les infrastructures, un marché de gros concurrentiel peut s'établir.

Pour répondre à cette question, nous avons construit un modèle d'économie industrielle avec les caractéristiques suivantes. Nous considérons des opérateurs de réseaux, verticalement intégrés, avec une unité réseaux et une unité services, ainsi qu'un fournisseur de services, qui ne dispose pas d'unité réseaux. Pour pouvoir être actif sur le marché de détail, le fournisseur de services doit avoir accès au réseau d'un des opérateurs intégrés.

La concurrence s'exerce à deux niveaux : sur le marché de gros et sur le marché de détail. Tout d'abord, chaque opérateur intégré propose un prix pour le service de gros au fournisseur de services. Nous dotons volontairement le marché de gros de tous les ingrédients propices à une concurrente forte : les services de gros des opérateurs intégrés sont identiques (parfaitement substituables), ils se font concurrence par les prix, et leurs coûts marginaux sont constants et identiques. Ensuite, une fois que les opérateurs intégrés ont proposé leurs offres de gros, ces opérateurs et le fournisseur de services se font concurrence sur le marché de détail, en proposant des services différenciés. Dans toute notre analyse, nous excluons que les firmes puissent s'entendre sur les prix.

L'effet adoucissant de la concurrence

Dans un cadre très général, nous montrons que plusieurs « issues raisonnables » (équilibres de Nash parfaits) sont possibles dans ce modèle : une concurrence forte sur le marché de gros mais aussi une situation de concurrence très atténuée, équivalente à une situation de monopole sur le marché de gros. La logique de la concurrence dite à la Bertrand explique l'issue de forte concurrence : des

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entreprises qui se font concurrence par les prix sont incitées à proposer un prix légèrement inférieur aux prix de leurs rivales pour attirer toute la demande ; cette dynamique conduit à un équilibre concurrentiel. Qu'est-ce qui explique l'équilibre de monopole ? Ce résultat est dû à ce que nous appelons l'effet d'adoucissement de la concurrence.

L'idée est que l'opérateur intégré qui fournit le marché de gros est moins agressif sur le marché de détail qu'il ne le serait s'il ne servait pas ce marché de gros. Pour lui, en effet, une perte de part de marché sur le marché de détail n'est pas une perte sèche, car il récupérera une partie de ces clients par le biais du marché de gros. Il est donc moins incité à lutter avec ses concurrents sur le marché de détail pour conserver ses clients. Ce comportement peu agressif de l'opérateur intégré qui sert le marché de gros bénéficie à l'opérateur de réseau qui n'est pas actif sur le marché de gros. Ainsi, la décision de s'engager dans une guerre en prix sur le marché de gros est soumise à la tension suivante : d'un côté, un opérateur intégré qui réduirait son prix de gros pour capter la demande sur le marché de gros augmenterait son profit de gros ; d'un autre côté, il rendrait par là-même son rival intégré plus agressif sur le marché de détail en supprimant l'effet d'adoucissement, ce qui pénaliserait son profit de détail. Lorsque ce deuxième effet est plus fort que le premier, un opérateur intégré n'a pas d'incitation à être agressif sur le marché de gros, et l'équilibre de monopole émerge.

Un élément important qui influence l'intensité de la concurrence sur le marché de gros est le degré de différenciation sur le marché de détail. Lorsque la différenciation est forte sur le marché de détail, on peut s'attendre à un marché de gros plutôt concurrentiel. A l'inverse, pour un marché de détail commoditisé, on doit plutôt s'attendre à un marché de gros peu concurrentiel. Ceci est dû à l'effet d'adoucissement de la concurrence : celui-ci sera d'autant plus fort que les services sont peu différenciés.

Quelques pistes pour la régulation

Dans l'éventualité où la concurrence sur le marché de gros serait jugée trop faible, plusieurs solutions peuvent être envisagées. Nous montrons qu'un prix plafond pour les offres de gros peut être un remède adéquat, en poussant les opérateurs intégrés à entrer dans une logique de concurrence sur le marché de gros. Une autre forme d'intervention possible est l'introduction d'un pur opérateur de réseaux, c'est-à-dire un opérateur présent uniquement sur le marché de gros. Il pourrait s'agir de l'unité réseaux d'un opérateur intégré séparé fonctionnellement ou structurellement ou d'un réseau construit par une municipalité et ouvert aux fournisseurs de services. Nous montrons qu'en cassant les liens entre le marché de détail et le marché de gros, on supprime l'effet d'adoucissement qui conduit à des équilibres peu concurrentiels sur le marché de gros ; la concurrence peut alors s'établir sur le marché de gros.

1 Introduction

In telecommunications, most markets have a two-tier structure and are populated with two types of firms. Facility-based firms roll out proprietary networks and rely mainly on their own infrastructures to provide services to end-customers. Service-based firms do not invest in facilities and lease access to the networks of facility-based firms in order to offer services on retail markets.[1] Consequently wholesale markets have emerged, where facility-based firms compete to provide wholesale services to service-based firms.

For example, in the mobile market, 'mobile virtual network operators' (MVNOs) do not have a spectrum license nor a mobile network and therefore have to purchase a wholesale mobile service from mobile network operators.[2] In the broadband market, DSL operators and cable networks own a broadband infrastructure and compete at the retail level.[3] They can also compete to provide wholesale broadband services to pure downstream firms.

Potential competition on the markets for access is viewed as a way to boost competition at the retail level. If service-based operators could get cheap access to end-users, so the argument goes, the competitive pressure on final markets should increase, with a direct benefit passed through to end-users in the form of price cuts.

Therefore, among practitioners, one question arises recurrently: when facility-based competition is in place, will the wholesale market deliver its promises? There is so far no clear consensus on the answer. Some telecoms regulators question the idea that a wholesale market can be competitive and therefore regulate the wholesale market on such grounds. Others consider that in an unregulated environment facility-based firms would lease the access to their infrastructures at a competitive price, allowing service-based operators to compete on a level playing field with facility-based firms.[4]

The main objective of this paper is to provide an economic analysis of the functioning of such wholesale markets in telecommunications. Using a stylized model, we show that these wholesale markets may be non-competitive even when all the usual ingredients of Bertrand competition are in place, and that they cannot be studied in isolation of the related retail markets.

In our model, two vertically integrated and a pure downstream firms compete in prices with differentiated products. The goods sold to end-users are derived from an intermediate input that the integrated firms can produce in-house, while the pure downstream firm must

[1] Note, however, that facility-based firms might lease some network elements to other integrated firms, and that service-based firms might have to install some telecommunications equipments. In a nutshell, a facility-based firm builds more than it leases, and a service-based firm leases more than it builds.

[2] In 2005 there were around 20 MVNOs in the US (see Hazlett (2005)). In the European Union there were 214 MVNOs in 14 Member States out of 25 (see European Commission (2006)).

[3] The cable modem and the digital subscriber line (DSL) technologies are the two main technologies used to deliver broadband.

[4] E.g., the UK telecoms regulatory authority, Ofcom, in its review of the wholesale broadband market (Ofcom (2004)) argues that: "Under competitive market conditions, both cable and BT would have an incentive to offer a wholesale product. [...] In a competitive market, cable's and BT's upstream (network) and downstream (retail) divisions would each earn a normal return".

buy it from either of the integrated firms. Integrated firms compete, first on the upstream market, to provide the input to the pure downstream firm, and second on the downstream market, with the pure downstream firm. The upstream market exhibits the usual ingredients of tough competition: integrated firms compete in prices, produce a perfectly homogeneous upstream good and incur the same constant marginal cost. Throughout most of the paper, we do not specify the downstream demand and cost functions and make no particular assumptions on the nature of the strategic interaction on the downstream market.

A first question is whether the perfect competition outcome is an equilibrium. Under reasonable conditions, we show that there exists an equilibrium in which both integrated firms sell the upstream good at the corresponding marginal cost. Intuitively, a downward deviation would generate upstream losses, while an upward deviation would not affect the outcome.

The second issue is whether the perfect competition outcome is the only equilibrium. If one considers the upstream market in isolation of the downstream one, one could be tempted to believe that integrated firms would always have incentives to cut prices to gain wholesale revenues until the marginal cost is attained, as the usual logic underlying Bertrand competition would predict. While attractive, we shall show that this reasoning misses an important point.

The reason lies in the softening effect: the integrated firm which supplies the upstream market at a strictly positive price-cost margin adopts a soft behavior on the downstream market. Realizing that final customers lost on the downstream market may be recovered indirectly via the upstream market, the upstream supplier is willing to preserve its upstream profit through its downstream pricing. Because this soft behavior favors its integrated rival on the downstream market, the upstream supplier earns less profit on the downstream market than the integrated firm which does not supply the upstream market. A crucial consequence is that, even once the upstream profits are accounted for, the upstream supplier might earn less total profit than its integrated rival. Differently stated, when an integrated firm undercuts its rival on the upstream market, it earns additional upstream profits at the cost of making its integrated rival more aggressive on the downstream market. When the softening effect is strong enough, the incentives to undercut the upstream market vanish and the Bertrand logic collapses.

In particular, consider as a benchmark the situation in which one integrated firm is exogenously given a monopoly position on the upstream market and assume that the pure downstream firm is not completely foreclosed.[5] Provided that the softening effect is strong enough, competition on the upstream market does not destabilize this outcome. Put differently, the monopoly outcome may persist even under the threat of competition on the upstream market.

In order to delineate more precisely the conditions under which non-competitive equilibria exist, we propose an illustration, which highlights the role of product differentiation at

[5]Throughout most of the paper, the issue of complete versus partial foreclosure is left aside as it is orthogonal to our focus.

the downstream level in the competitiveness of the upstream market. When final products are strongly differentiated, downstream demands are almost independent and the softening effect is consequently weak. As a result, undercutting on the upstream market is always profitable and this market ends up being competitive. Conversely, when downstream products are strong substitutes, the softening effect is strong and the monopoly outcome is an equilibrium. This comparative static result exhibits a tension between downstream and upstream competitiveness.

Then, assuming that downstream prices are strategic complements, we show that the presence of an additional pure upstream firm generates a competitive upstream market. The intuition may be explained as follows. An integrated firm always has the incentives to undercut a pure upstream competitor: this generates upstream gains, the other integrated firm does not become more aggressive on the downstream market, and the soft behavior of the integrated firm which supplies the upstream market triggers an increase in all downstream prices under strategic complementarity. A similar logic applies when one of the integrated firm is vertically separated, giving birth to a pure upstream firm (and another pure downstream firm).

Analyzing the mobile telephony and broadband markets, we give some empirical support to these conclusions and deduce several policy implications from our theoretical results. Overall, the results point towards the following warning: any competition policy or regulatory recommendations regarding wholesale markets in telecommunications should be based on the specifics of both the upstream and the downstream markets. Analyzing the upstream market on a stand-alone basis is likely to yield wrong conclusions.

Our paper is related to different strands of the literature.

The literature on network competition in telecommunications consider competition on a downstream market only between facility-based firms, and focus on the impact of two-way interconnection charges on downstream prices; see Dessein (2003), Laffont, Rey, and Tirole (1998a), Laffont, Rey, and Tirole (1998b), and Valletti and Cambini (2005) among others. We abstract away from such a perspective, and focus instead on wholesale market competition, i.e., competition between network operators to attract service-based firms.

The literature on one-way access pricing deals with situations in which a service-based firm must gain access to the network of a facility-based firm; see, among others, Laffont and Tirole (2001), Armstrong (2002), De Bijl and Peitz (2002), Foros (2004). These papers are, by definition, silent on the issue of the competitiveness of wholesale markets, which is central to our analysis.

Ordover and Shaffer (2006) and Brito and Pereira (2006) have independently studied related questions, in more specific environments. Both papers consider various scenarii for the entrant's positioning on the downstream market[6] and are mainly interested in whether

[6]Ordover and Shaffer (2006) consider different cases according to the impact of entry on the downstream demand faced by integrated firms. Brito and Pereira (2006) consider asymmetrically localized firms in the Hotelling-Salop circle model of spatial competition, and assumes that the entrant locates at the midpoint of the largest available gap. By contrast, we consider a symmetric environment.

the entrant will be completely foreclosed or not at equilibrium. When the entrant is not completely foreclosed, both papers argue that the competitive outcome emerges on the upstream market. Our paper challenges that view and shows that this result has limitations. Whether the wholesale market exhibits competitive or non-competitive features is rooted in the softening effect and cannot be taken for granted. To make our contribution even more transparent, we abstract away from the issue of complete foreclosure throughout most of our analysis. Höffler and Schmidt (2007) take a complementary perspective and study the impact on welfare of having pure downstream firms but assume an exogenous structure on the upstream market (i.e., which integrated firms are upstream suppliers or not). Our results tend to indicate that allowing competition on the upstream market might still leave integrated firms with as much market power as when the market structure is exogenously fixed.

Our paper is closely related to the literature on vertical foreclosure. The so-called traditional foreclosure theory argues that integrated firms have incentives to raise their non-integrated rivals' costs through their pricing of the intermediate input. After having been challenged by the Chicago School, this theory has been given firmer theoretical grounds by several authors; see, among others, Avenel and Bartlett (2000), Chen (2001), Choi and Yi (2000), Hart and Tirole (1990), Ordover, Saloner, and Salop (1990). One important difference is that these papers do not consider the competition on the upstream market between integrated firms to supply a downstream competitor. Our analysis unveils that integrated firms do not always have incentives to corner the upstream market and that there is a grain of truth both in the traditional foreclosure theory and in the Chicago school criticism.

The paper is organized as follows. Section 2 describes the model. Section 3 presents our main results, namely the possibility of non-competitive equilibria on the upstream market, and illustrates them. Section 4 discusses several extensions and robustness checks of our basic framework, including the possibility of complete foreclosure. Section 5 builds on the theoretical analysis to derive some policy implications, in terms of regulation and competition policy, for the telecommunications industry. Finally, section 6 concludes and presents a few avenues for future research.

2 Model

Firms. There are two vertically integrated firms, denoted by 1 and 2, and one pure downstream firm, denoted by d. Integrated firms are composed of an upstream and a downstream unit, which produce the intermediate input and the final good, respectively. The pure downstream competitor is composed of a downstream unit only. In order to be active on the final market, it must purchase the intermediate input from one of the integrated firms on the upstream market.

Both integrated firms produce the upstream good under constant returns to scale at unit cost c_u. The downstream product is derived from the intermediate input on a one-to-one basis at cost $c_k(.)$ for firm $k \in \{1, 2, d\}$. We assume that integrated firms have the same

downstream cost function: $c_1(.) = c_2(.)$.

Markets. All firms compete in prices on the downstream market and provide imperfect substitutes to final customers. Let p_k be the downstream price set by firm $k \in \{1, 2, d\}$ and $p \equiv (p_1, p_2, p_d)$ the vector of final prices. Firm k's demand is denoted by $D_k(p)$; it depends negatively on its price and positively on its competitors' prices: $\partial D_k/\partial p_k < 0$ and $\partial D_k/\partial p_{k'} > 0$ for $k \neq k' \in \{1, 2, d\}$. Symmetry of the integrated firms is assumed again: $D_1(p_1, p_2, p_d) = D_2(p_2, p_1, p_d)$ and $D_d(p_1, p_2, p_d) = D_d(p_2, p_1, p_d)$ for all p.

On the upstream market, integrated firms compete in prices and offer perfectly homogeneous products. We denote by a_i the upstream price set by integrated firm $i \in \{1, 2\}$.[7] The structure of the model is summarized in Figure 1.

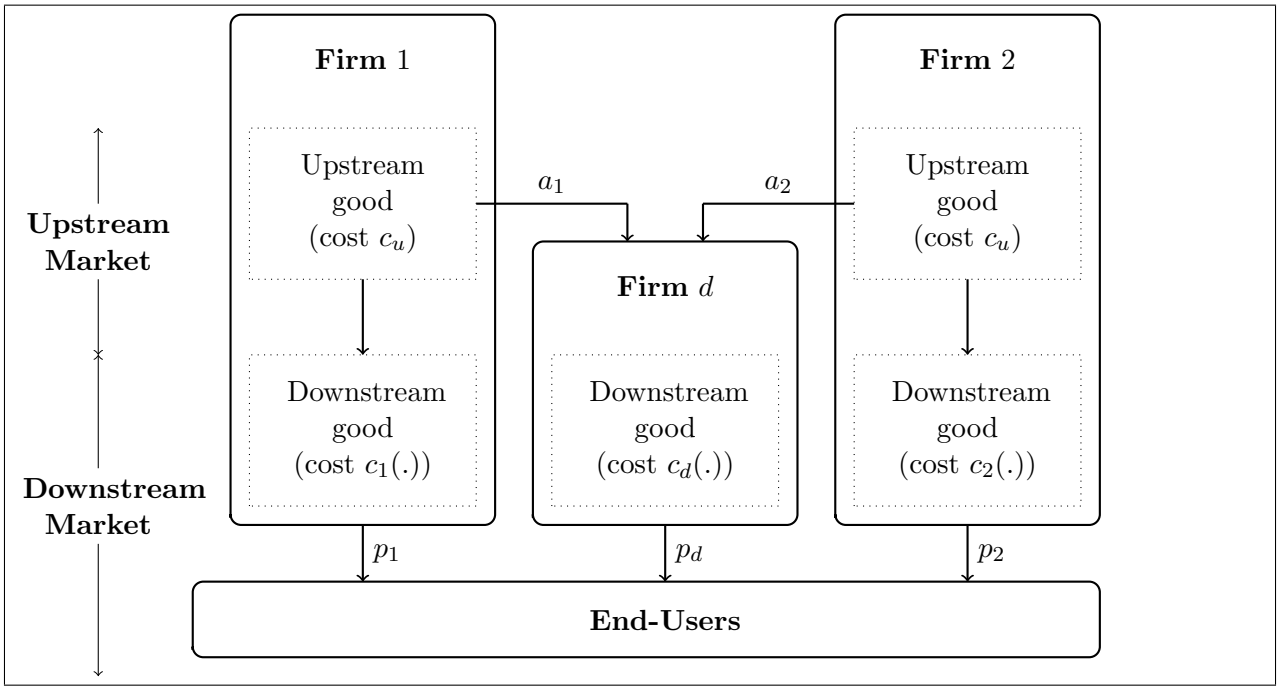

Figure 1: Structure of the model.

Timing. The sequence of decision-making is as follows:

Stage 1 – Upstream competition: The vertically integrated firms simultaneously and non-cooperatively set their prices on the upstream market. Then, the terms of the offers become known to all parties and the pure downstream firm elects at most one upstream provider.

Stage 2 – Downstream competition: All firms simultaneously and non-cooperatively choose their prices on the downstream market.

We focus on pure strategies subgame-perfect equilibria and reason by backward induction.

[7] Throughout the paper, subscripts i and j refer to integrated firms only, whereas subscript k refers either to an integrated firm or to the pure downstream firm.

Profits. The profit of integrated firm $i \in \{1,2\}$ which supplies the upstream market at price a_i is:[8]

$$\tilde{\pi}_i^{(i)}(p, a_i) = (p_i - c_u)D_i(p) - c_i(D_i(p)) + (a_i - c_u)D_d(p).$$

The profit of integrated firm $j \neq i \in \{1,2\}$ which does not supply the upstream market is given by:

$$\tilde{\pi}_j^{(i)}(p, a_i) = (p_j - c_u)D_j(p) - c_j(D_j(p)).$$

The profit of pure downstream firm d is given:

$$\tilde{\pi}_d^{(i)}(p, a_i) = (p_d - a_i)D_d(p) - c_d(D_d(p)).$$

Note that when the upstream price is equal to the upstream unit cost, i.e., $a_i = c_u$, there is no upstream profit and all firms compete on a level playing field. This would be the outcome if the upstream market were perfectly competitive.

3 Main Results

In this section, we develop our main argument: competition on the upstream market (stage 1) does not always yield the perfect competition outcome, even though integrated firms offer homogenous products and compete in prices on that market.

3.1 Preliminaries

Downstream market competition. Consider first the situation in which upstream offers (a_i, a_j) are such that pure downstream firm d is completely foreclosed from the downstream market. We denote by π_{duopoly} the profit earned by each integrated firm in this case.

Conversely, consider situations in which at least one of the upstream offers is acceptable, i.e., allows firm d to be active on the downstream market. Denote by $i \in \{1,2\}$ the upstream supplier and let $j \neq i$. The best-response in downstream price of firm $k \in \{1,2,d\}$ is defined by $BR_k^{(i)}(p_{-k}, a_i) = \arg\max_{p_k} \tilde{\pi}_k^{(i)}(p, a_i)$.[9] To streamline the analysis, we make the following standard assumptions: $BR_k^{(i)}(.,.)$ is unique, bounded, characterized by the corresponding first-order condition, and such that $|\partial BR_k^{(i)}/\partial p_{k'}| < 1$, for all $k' \neq k \in \{1,2,d\}$.[10] We denote by $p_k^{(i)}(a_i)$ the equilibrium price of firm $k \in \{1,2,d\}$ and by $p^{(i)}(a_i)$ the vector of these downstream prices. At the equilibrium of this subgame, firms' profits are given by functions $\pi_k^{(i)}(a_i) \equiv \tilde{\pi}_k^{(i)}(p^{(i)}(a_i), a_i)$, which are defined over the set of acceptable offers. Note that $p_i^{(i)}(c_u) = p_j^{(i)}(c_u)$ and $\pi_i^{(i)}(c_u) = \pi_j^{(i)}(c_u)$.

[8] Throughout the paper, the superscript in parenthesis indicates the identity of the upstream supplier.

[9] As usual, p_{-k} is the vector obtained by removing p_k from vector p.

[10] This corresponds to the usual stability condition for a duopoly but it is less stringent than the stability requirement in an oligopoly with $n > 2$ firms, which can be stated as $\sum_{k' \neq k} \left|\partial BR_k^{(i)}/\partial p_{k'}\right| < 1$. See Vives (1999).

Choice of upstream supplier. If only one integrated firm has made an acceptable offer, then it is obviously chosen by the pure downstream firm.

Consider now that both offers are acceptable. If $\pi_d^{(i)}(a_i) > \pi_d^{(j)}(a_j)$, then firm d chooses firm i as its upstream supplier. If both offers lead to the same profit, then firm d chooses any of them. We now make the following economically meaningful assumption:

Assumption 1. *The profit of the pure downstream firm is strictly decreasing in the upstream price.*[11]

If firm d preferred to choose the most expensive upstream provider, we would have another, somewhat trivial (and pathological), reason for the existence of non-competitive equilibria on the upstream market. Assumption 1 rules out these cases.

Upstream monopoly benchmark. Consider the hypothetical scenario in which the upstream market is monopolized by integrated firm i. Its upstream pricing decision involves a trade-off between partial and complete foreclosure. The elimination of one downstream rival may create discontinuous changes on the demand faced by the remaining competitors. These discontinuities may in turn cause the non-existence of a solution to the firm i's optimization problem on the upstream market. To avoid such issues, and to focus on situations in which complete foreclosure does not arise in equilibrium, we make the following assumptions:

Assumption 2. $\pi_i^{(i)}(.)$ *is quasiconcave and admits a unique maximum* $a_m > c_u$.

Assumption 3. $\pi_i^{(i)}(a_m) > \pi_{duopoly}$.

To summarize, if the upstream market were exogenously monopolized, the pure downstream firm would not be completely foreclosed; as an aside, this means equivalently that complete foreclosure never arises when integrated firms compete on the upstream market. We discuss this assumption in section 4. Besides, monopoly market power on the upstream market leads to a strictly positive mark-up on the price of the upstream good, hence to partial foreclosure under an exogenously monopolized upstream market. a_m is referred to as the monopoly upstream price.

3.2 Persistence of the monopoly outcome

We now study the first stage of our game in which integrated firms compete on the upstream market, and establish the main result of the paper. We show that the usual mechanism of Bertrand competition may be flawed and that non-competitive equilibria may exist.

[11] An increase in firm d's cost has typically two impacts on its profit. First, the price-cost margin is directly reduced, leading unambiguously to a lower profit. Second, the best-response (in downstream price) of firm d shifts upward, which affects the equilibrium of the final market. These first two effects are standard in any IO models with price competition and product differentiation. In our context, there is also a third effect since the best-response of the upstream supplier also shifts upward (the softening effect that we explain later on). The overall impact on firm d's profit is a priori ambiguous and depends typically on the strategic interaction on the downstream market. In line with most IO models, Assumption 1 implies that the direct effect outweighs the strategic ones.

Assume that integrated firm i has made an acceptable upstream offer to firm d, $a_i > c_u$, and let us see whether integrated firm j is willing to corner the upstream market, as it is the case with standard (single-market) Bertrand competition.

The integrated firms' best-responses on the downstream market are characterized by the following first-order conditions:

$$\frac{\partial \tilde{\pi}_i^{(i)}}{\partial p_i}(p, a_i) = D_i + (p_i - c_i'(D_i) - c_u)\frac{\partial D_i}{\partial p_i} + (a_i - c_u)\frac{\partial D_d}{\partial p_i} = 0, \quad (1)$$

$$\frac{\partial \tilde{\pi}_j^{(i)}}{\partial p_j}(p, a_i) = D_j + (p_j - c_j'(D_j) - c_u)\frac{\partial D_j}{\partial p_j} = 0. \quad (2)$$

The comparison between (1) and (2) shows that the upstream supplier has more incentives to raise its downstream price than its integrated rival. It internalizes the fact that, when it increases its downstream price, some of the customers it loses will purchase from the pure downstream firm, thereby increasing its upstream revenues. As formally shown in Appendix, this mechanism, together with our stability assumption, implies that the upstream supplier charges a higher downstream price than its integrated rival.[12]

Lemma 1. *Let $a_i > c_u$ be an acceptable offer. Then the upstream supplier charges a strictly higher downstream price than its integrated rival:*

$$p_i^{(i)}(a_i) > p_j^{(i)}(a_i).$$

Proof. See Appendix A.1. □

The literature on vertical foreclosure has long emphasized that an integrated firm may have incentives to preserve its downstream profit through its upstream offer. Lemma 1 points out that the reverse mechanism also exists: the integrated firm which supplies the upstream market has incentives to preserve its upstream profit through its downstream pricing. Realizing that final customers lost on the downstream market may be recovered via the upstream market, the upstream supplier is less aggressive on the downstream market in order not to jeopardize its upstream profit. We shall refer to that mechanism as the 'softening effect'.[13]

This effect implies that the upstream supplier is a soft competitor on the downstream market. This favors the other integrated firm which, by a revealed preference argument, earns more downstream profit than the upstream supplier.

Lemma 2. *Let $a_i > c_u$ be an acceptable offer. Then, the upstream supplier earns strictly smaller downstream profits than its integrated rival:*

$$\left[p_i^{(i)}(a_i) - c_u\right] D_i(p^{(i)}(a_i)) - c_i\left(D_i(p^{(i)}(a_i))\right) < \left[p_j^{(i)}(a_i) - c_u\right] D_j(p^{(i)}(a_i)) - c_j\left(D_j(p^{(i)}(a_i))\right).$$

[12] This holds whatever the nature of the strategic interaction between downstream prices.

[13] This result bears similarities with that of Chen (2001), who shows that an integrated firm sets a higher downstream price when it supplies the upstream market than when a pure upstream competitor does.

Proof. See Appendix A.2. □

A key consequence of that result is that we cannot tell unambiguously which of the integrated firms earns more total profits. On the one hand, the upstream supplier extracts revenues from the upstream market. On the other hand, its integrated rival benefits from larger downstream profits, owing to the softening effect. It may well be the case that the integrated firm which does not supply the upstream market earns larger total profits, if the additional downstream profits outweigh the foregone upstream revenues. Hence, the usual logic of Bertrand competition may not work anymore. An integrated firm may not always want to undercut its integrated rival on the upstream market, even though the upstream price is above the marginal cost. This potentially opens the door to non-competitive equilibria on the upstream market, in which the intermediate input would be priced above its marginal cost. In particular, the monopoly outcome can be an equilibrium, as illustrated by the following proposition.

Proposition 1. *Under Assumptions 1 and 3, there exists a monopoly-like equilibrium, i.e., a subgame-perfect equilibrium in which the upstream market is supplied by an integrated firm at price a_m if and only if $\pi_j^{(i)}(a_m) \geq \pi_i^{(i)}(a_m)$.*[14]

Proof. Suppose firm i offers $a_i = a_m$ and firm j sets $a_j = \emptyset$. Then, firm j has no incentives to undercut firm i and, by Assumption 3, firm i has no incentives to deviate. Conversely, if $\pi_j^{(i)}(a_m) < \pi_i^{(i)}(a_m)$, and if firm i supplies the upstream market at price a_m, then it is strictly profitable for firm j to offer $a_m - \epsilon$. □

Because losers on the upstream market become winners on the downstream market, the usual competitive forces may collapse. This does not hinge on any commitment device for the integrated firms to exit the upstream market;[15] nor does this rely on any kind of overt or tacit collusion.

As Proposition 1 highlights, the existence of monopoly-like equilibria depends on a comparison between profit levels. In Subsection 3.4, we provide one illustration which allows us to understand that condition more fully.

At this stage, our result deserves a slight digression on a related literature, namely the vertical foreclosure theory. That theory points out that competition on the upstream market may be flawed since buyers and sellers interact on the downstream market, so that integrated firms have incentives to raise the pure downstream firms' costs. The Chicago School has forcefully criticized the validity of this argument on the following grounds: even if integrated firms have incentives to raise their rivals' costs, these incentives are not strong enough to offset the competitive forces on the upstream market. In other words, as long as the upstream price remains above the marginal cost, an integrated firm could always undercut its integrated rival

[14]Notice that different strategies can be used to support a monopoly-like equilibrium: $a_i = a_m$ and $a_j = \emptyset$, or $a_i = a_m$ and a_j acceptable such that $\pi_j^{(i)}(a_j) \leq \pi_i^{(i)}(a_m)$.

[15]In our model, firms cannot commit not to enter the upstream market; however, endogenously, the incentives to corner the upstream market may disappear.

by a small amount, thereby stealing the upstream profit without altering the downstream outcome. Our results highlight the fact that an important point is missing in the Chicago School critique: the softening effect implies that undercutting on the upstream market does have an important adverse impact on the downstream outcome. This may lead to partial foreclosure.

3.3 Other equilibria

Given the effects demonstrated above, one could legitimately ask whether other equilibria may exist.

We then obtain the following proposition.

Proposition 2. *Under Assumptions 1-2, there exists a matching-like equilibrium at price a_*, i.e., a subgame-perfect equilibrium in which the outcome on the upstream market is such that both integrated firms offer the same upstream price a_*, if and only if $\pi_i^{(i)}(a_*) = \pi_j^{(i)}(a_*)$ and $a_* \leq a_m$.*

Proof. See Appendix A.3. □

A particular matching-like equilibrium corresponds to the case $a_* = c_u$, in which both integrated firms offer an upstream price equal to their upstream marginal cost. As the intuition suggests, the competitive outcome on the upstream market is an equilibrium.

Corollary 1. *Under Assumptions 1-2, there exists an equilibrium with a competitive upstream market: $a_1 = a_2 = c_u$.*

Proof. Immediate. □

However, nothing precludes a priori the existence of other matching-like equilibria featuring either a supra-competitive upstream market (i.e., $a_* > c_u$) or a super-competitive upstream market (i.e., $a_* < c_u$). The existence of these equilibria also hinges on the softening effect. For $a_* > c_u$, the integrated firm which does not supply the upstream market benefits from the softening effect and may not want to undercut. For $a_* < c_u$, the softening effect is reversed. The upstream supplier offers an aggressive downstream price to reduce the upstream demand, which hurts its integrated rival. Even though the upstream supplier makes losses on the upstream market, it does not want to exit that market since it would then suffer from an adverse softening effect.

We conclude that paragraph with the following result:

Proposition 3. *Under Assumptions 3-2:*

- *Only monopoly-like and matching-like outcomes can arise in equilibrium.*
- *From the viewpoint of the integrated firms, any monopoly-like equilibrium Pareto-dominates any matching-like equilibrium.*

Proof. See Appendix A.4. □

Propositions 1, 2 and 3 provide a characterization of all the possible equilibria of our game. Moreover, the monopoly-like equilibria, when they exist, Pareto-dominate all other equilibria from the integrated firms' standpoint. Therefore there is a strong presumption that, if they exist, the monopoly-like outcomes emerge in equilibrium.

3.4 The dilemma between upstream and downstream competitiveness

A key ingredient of the persistence of the monopoly outcome is the degree of differentiation of the pure downstream firm. Suppose that the entrant is on a niche market, in the sense that its demand does not depend on the prices set by the rival downstream firms and vice-versa.[16] In that situation, the wholesale profit of the upstream supplier is fully disconnected from its retail behavior: the upstream market can no longer be used to soften competition. Hence, with a pure downstream firm on a niche market, the upstream market is always competitive at equilibrium.

In order to refine this intuition, consider the following illustration. The demand that addresses to firm $k \in \{1, 2, d\}$ is given by $D_k(p) = 1 - p_k - \gamma(p_k - \bar{p})$, where $\bar{p}$ is the average of downstream prices and $\gamma \geq 0$ traduces the intensity of downstream competition or the degree of differentiation between downstream products.[17] All costs are set to zero: $c_u = 0$ and $c_k(.) = 0$.[18] With that specification, profit functions satisfy all the assumptions we made so far. Figure 2 offers a graphical representation of the profit functions $\pi_i^{(i)}(.)$, $\pi_j^{(i)}(.)$ and $\pi_d^{(i)}(.)$; it shows in particular that, conditionally on firm j not serving the upstream market, firm i does not want to foreclose the pure downstream firm.

We then obtain the following proposition.

Proposition 4. *Consider the linear demands and zero costs case. There exists $\bar{\gamma} > 0$ such that:*
If $\gamma \geq \bar{\gamma}$, then there exist four subgame-perfect equilibria:[19]

- *the* perfect competition *outcome;*
- *a supra-competitive* matching-like *outcome;*
- *two* monopoly-like *outcomes.*

Otherwise, i.e., when $\gamma < \bar{\gamma}$, the perfect competition outcome is the only subgame-perfect equilibrium.

[16] Formally, this requires that: $\partial D_d/\partial p_i = \partial D_i/\partial p_d = 0$ for $i \in \{1, 2\}$.

[17] The normalization of the intercepts of demands is without loss of generality (through a change of unit for instance).

[18] With linear demands, provided that there are constant returns to scale, the normalization of the costs is without loss of generality.

[19] The perfect competition and monopoly-like equilibrium are stable; the matching-like is unstable.

Proof. See Appendix A.5. □

As illustrated in Figure 2 and discussed in Subsection 3.2, when $a_i > c_u$, two opposite effects are at work. On the one hand, the upstream supplier derives profit from the upstream market; on the other hand, its integrated rival benefits from the softening effect on the downstream market. When the upstream price is not too high, the upstream profit effect dominates and $\pi_i^{(i)}(a_i) > \pi_j^{(i)}(a_i)$. When the upstream price is high enough, upstream revenues shrink, the softening effect is strengthened and $\pi_i^{(i)}(a_i) < \pi_j^{(i)}(a_i)$.

Suppose that the upstream supplier sets the monopoly upstream price. When the substitutability between final products is strong, the integrated firm which supplies the upstream market is reluctant to set too low a downstream price since this would strongly contract its upstream profit. An implication is that the integrated firm which does not supply the upstream market benefits from a substantial softening effect and, as a result, has no incentives to become the upstream supplier. There exists a monopoly-like equilibrium when downstream products are sufficient substitutes (i.e., $\gamma \geq \bar{\gamma}$ or $a_* \leq a_m$). By the reverse token, only the perfect competition outcome emerges when the competition on the downstream market is sufficiently weak (i.e., $\gamma < \bar{\gamma}$ or $a_* > a_m$).[20] In other words, tension exists between competitiveness on the downstream market and competitiveness on the upstream market. Intuitively, the same downstream interactions which strengthen the competitive pressure on

[20]Note that if demand functions are derived from the Hotelling-Salop circle model of product differentiation with linear transportation costs, firms are symmetrically localized, and the market is covered, then monopoly-like equilibria always exist.

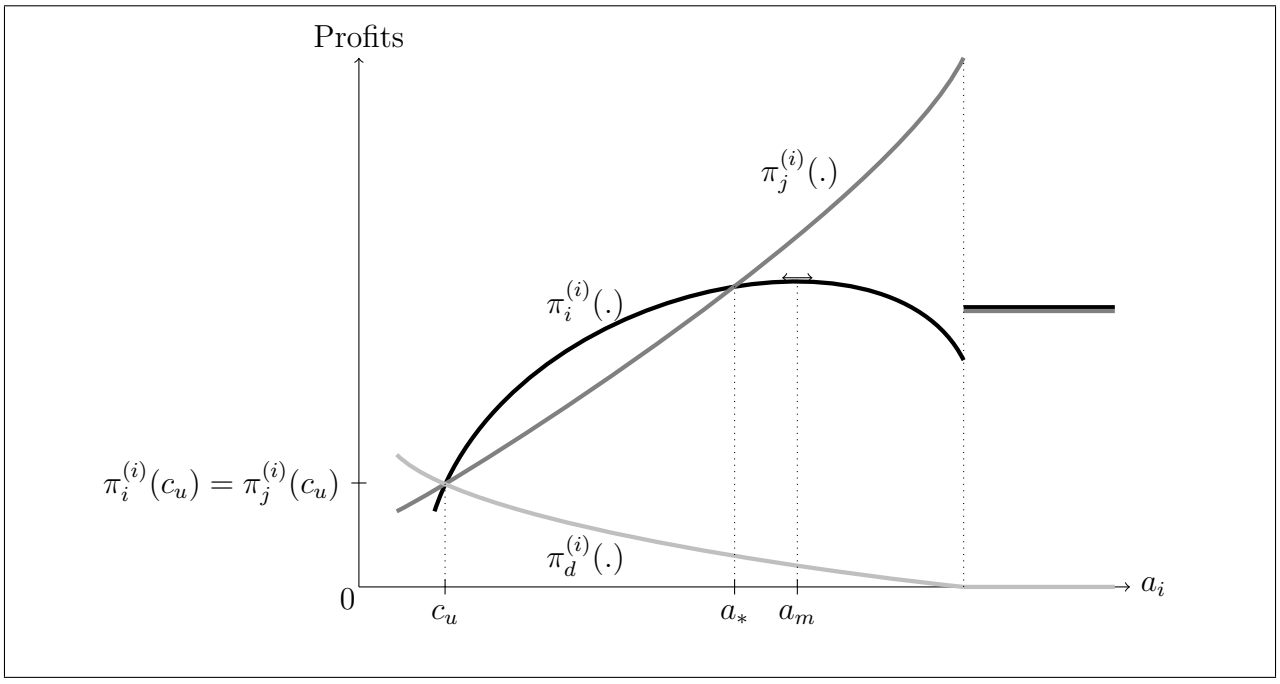

Figure 2: Stage 1 profits in the linear case with zero costs (under the assumption $\gamma \geq \bar{\gamma}$).

the downstream market, are those which soften the competitive pressure on the upstream market.

This tension is revealed in downstream prices, which turn out to be non-monotonic in the substitutability parameter (provided that the monopoly-like equilibrium is selected when it exists). The level of downstream prices results indeed from two combined forces: the level of upstream prices on the one hand, and the intensity of downstream competition / substitutability on the other hand.

3.5 Pure upstream competitor

Throughout the paper, we have assumed that the upstream market could only be supplied by integrated firms. In this extension, we assume that a pure upstream competitor, firm u, is able to produce the intermediate input at constant marginal cost c_u. Denote by $\pi_d^{(u)}(a_u)$ the profit earned by firm d when the upstream market is supplied by firm u at price a_u. We suppose that $\pi_d^{(u)}(.)$ is strictly decreasing. Together with Assumption 1, this implies that, whatever the upstream supplier, the profit of the pure downstream firm decreases in the upstream price.

It is natural to wonder whether the mere presence of firm u is sufficient to break the interactions between the upstream and the downstream markets, and to ensure that the perfect competition outcome emerges. The following proposition states that this is indeed the case provided that downstream prices are strategic complements.

Proposition 5. *Under Assumptions 3-2, if $\pi_d^{(u)}(.)$ is strictly decreasing and downstream prices are strategic complements, there is no subgame-perfect equilibrium in which the upstream market is supplied at a price strictly above the marginal cost.*

Proof. See Appendix A.6. □

Let us briefly state the intuition underlying that proposition. Assume that firm u supplies the upstream market at price $a_u > c_u$. We claim that both firm i and firm d become strictly better off if firm i matches firm u's price, and firm d elects firm i as its upstream supplier. If firm d agrees to purchase the input from firm i at price a_u, this creates a softening effect: firm i raises its downstream price and, by strategic complementarity, firms j and d react by increasing their prices as well. By a revealed preference argument, these price increases benefit firms i and d. Moreover, when firm i matches firm u, it also earns upstream profits, which provides additional incentives to match.

Conversely, if the upstream market is supplied by integrated firm i at a price $a_i > c_u$, then firm u always wants to undercut, for its sole source of profit comes from the upstream market. Moreover, firm u is always able to attract firm d, provided that it offers a sufficiently low upstream price.[21]

[21] $\pi_d^{(u)}(.)$ and $\pi_d^{(i)}(.)$ are decreasing and $\pi_d^{(u)}(c_u) = \pi_d^{(i)}(c_u)$.

Having said that, it becomes clear that the upstream market cannot be supplied at a supra-competitive price in equilibrium. One may then wonder which outcome will arise on the upstream market. As noted above, in our basic setting, Proposition 2 implies that the competitive outcome is always a subgame-perfect equilibrium. Obviously, adding a pure upstream competitor does not affect this result. However, nothing precludes a priori the existence of super-competitive equilibria.

A similar logic applies if the pure upstream competitor comes from the vertical separation of one of the integrated firm.[22]

4 Extensions and Discussions

We now discuss some extensions of our basic setting. This allows us both to check for the robustness of our results and to support several policy implications developed in the next section.

Complete foreclosure. Let us first relax Assumption 3: assume that $a_m = \emptyset$, i.e., a hypothetical upstream monopolist would prefer foreclosing completely the entrant to allowing it to be active in the downstream market. Then, for trivial reasons there exists an equilibrium in which the pure downstream firm is completely foreclosed.

Whether or not such an equilibrium exists, i.e., whether or not Assumption 3 is satisfied, is orthogonal to our analysis. To see why, it is worth rephrasing our main result. When an integrated firm undercuts its integrated rival which supplies the upstream market, it steals the upstream profits at the cost of losing the softening effect. By contrast, when it starts supplying a pure downstream firm which was previously completely foreclosed, an integrated firm does not lose the softening effect. On the other hand, it modifies profoundly the pattern of downstream demands. Analyzing how downstream demands are affected is obviously beyond the scope of this paper; readers interested in this issue should refer to Brito and Pereira (2006) and Ordover and Shaffer (2006).

The role of upstream pricing. The mere presence of the variable part in the upstream tariff is sufficient to generate the softening effect. In particular, the possibility for non-competitive equilibria carries over to the case of two-part tariffs $\{(a_i, T_i), (a_j, T_j)\}$ on the upstream market. The equilibrium upstream variable part maximizes the joint profit of the upstream supplier and the pure downstream firm, i.e., $a_{tp} = \arg\max_{a_i} \pi_i^{(i)}(a_i) + \pi_d^{(i)}(a_i)$.[23] The fixed fee T_i must be such that, first, firm j does not want to undercut, and, second, firm d is willing to accept that tariff, or: $T_i \leq \min\{\pi_j^{(i)}(a_{tp}) - \pi_i^{(i)}(a_{tp}); \pi_d^{(i)}(a_{tp})\}$.[24]

[22] The difference with the previous case is that there are two pure downstream firms now; see Hombert, Pouyet, and Schutz (2007) for the complete analysis.

[23] See Bonanno and Vickers (1988).

[24] Note that the equilibrium fixed part T_i may be negative.

Having said that, the characterization of the subgame-perfect equilibria of the game with two-part tariffs becomes straightforward.

If $\pi_i^{(i)}(a_{tp}) + \pi_d^{(i)}(a_{tp}) \leq \pi_j^{(i)}(a_{tp})$,[25] then the only two equilibria are such that one of the integrated firm charges the variable part a_{tp} and a fixed fee equal to $\pi_d^{(i)}(a_{tp})$, which extracts all the rent from the downstream firm, while the other integrated firm makes no upstream offer. Under two-part tariff competition, this is a monopoly-like equilibrium.

If $\pi_i^{(i)}(a_{tp}) + \pi_d^{(i)}(a_{tp}) \geq \pi_j^{(i)}(a_{tp})$, then the only equilibrium features both integrated firms charging the variable part a_{tp} and a fixed fee equal to $\pi_j^{(i)}(a_{tp}) - \pi_i^{(i)}(a_{tp})$, which makes them indifferent between supplying the upstream demand or not. This is a matching-like equilibrium.

Proposition 6. *Under two-part tariff competition on the upstream market, the equilibrium is either monopoly-like or matching-like.*

Proof. Immediate. □

Once again, upstream competition does not modify the outcome with respect to the monopoly benchmark. If the upstream equilibrium is monopoly-like, both the fixed and the variable part of the tariffs remain the same; obviously, downstream prices are not affected either. If the equilibrium is matching-like, competition modifies the fixed part only, without affecting any downstream price. In other words, the only impact of competition is to redistribute some profits from the integrated firms to the pure downstream firm. Besides, provided that $a_{tp} > c_u$, it is straightforward to show that the upstream profit is strictly positive.[26] In this sense, we claim that the upstream market remains non-competitive under two-part tariff competition.

Quantity competition. The softening effect exists if the upstream supplier can enhance its upstream profits by behaving softly on the downstream market. As discussed previously, this requires that it actually interacts with the pure downstream firm. One may wonder whether the softening effect hinges on the assumption of price competition on the downstream market, for if the downstream strategic variables are quantities and all firms play simultaneously, then the upstream supplier can no longer impact its upstream profit through its downstream behavior. However, if for instance integrated firms are Stackelberg leaders on the downstream market, then the upstream supplier's quantity choice modifies its upstream profit, and the softening effect is still at work. To summarize, the question is not whether firms compete

[25] This inequality holds, for instance, with Hotelling-Salop demand specifications and constant marginal costs.

[26] If the equilibrium is monopoly-like, this is obvious. If it is matching-like, then the upstream profit is equal to $[a_{tp} - c_u] D_d(p^{(i)}(a_{tp})) + \pi_j^{(i)}(a_{tp}) - \pi_i^{(i)}(a_{tp}) = \left[p_j^{(i)}(a_{tp}) - cu\right] D_j(p^{(i)}(a_{tp})) - c_j \left(D_j(p^{(i)}(a_{tp}))\right) - \left[p_i^{(i)}(a_{tp}) - cu\right] D_i(p^{(i)}(a_{tp})) + c_i \left(D_i(p^{(i)}(a_{tp}))\right)$, which is strictly positive by Lemma 2.

in prices or in quantities, but whether the strategic choice of a firm can affect its rivals' quantities.[27]

Single upstream supplier assumption. Throughout the paper, we have assumed that the pure downstream firm is constrained to choose one upstream supplier only. Consider now that, when upstream offers are identical, the pure downstream firm splits its demand equally between integrated firms. We can still think about the upstream market in terms of softening effect and upstream profit effect. To see this, suppose that integrated firms i and j share the upstream market. Firm i obviously earns upstream profits. It also benefits from a softening effect: firm j has incentives to be less aggressive on the downstream market since it also supplies the upstream market.

It becomes clear that non-competitive equilibria can still exist. Assume that firm i supplies the upstream market at some price a_i. If firm j chooses to make an unacceptable offer, by setting a price higher than a_i, it benefits fully from the softening effect at the cost of giving up upstream profits. If it undercuts its rival, it gets all the upstream profits, but loses the softening effect. If it matches its rival, i.e., if it also sets a_i, it benefits partly from both effects. As before, there is no reason why firm j would always want to undercut, since there is no reason why the upstream profit effect would always dominate the softening effect.[28]

A similar reasoning applies to the case of multiple pure downstream firms. The total upstream demand may then be shared among integrated firms, which would enjoy both the softening effects and positive upstream profits. The incentives to undercut would depend in turn on the relative strength of these two effects.

Downstream strategic interaction. In Bourreau, Hombert, Pouyet, and Schutz (2007), we provide another illustration, in which downstream prices can be either strategic substitutes or strategic complements. We obtain two results of interest. First, as downstream prices become more strategic complements, the softening effect weakens and the incentives to undercut on the upstream market are reinforced; therefore, the nature of the strategic interaction on the downstream sector may give some hints on the potential competitiveness of the upstream market. Second, with high strategic substitutability and assuming that there exists a pure upstream supplier, there exists an equilibrium in which both integrated firms are inactive on the upstream market and the pure upstream firm sets its monopoly price on that market; in that case, vertical separation is not the ideal remedy to a poorly competitive upstream market.

[27] With a linear demand function and quantity competition, if integrated firms are Stackelberg leaders on the downstream market, then a monopoly-like equilibrium always exists (proof available upon request).

[28] For instance, solving the model with Hotelling-Salop demand specifications and constant marginal costs and assuming that the pure downstream firm splits equally its demand when upstream prices are identical, we get the following subgame-perfect equilibria: the two monopoly-like outcomes, the competitive outcome, and a continuum of non-competitive equilibria in which both integrated firms set the same price and share the upstream demand (proof available upon request).

5 Policy Implications

The competitiveness of wholesale markets Facility-based competition has clear benefits; as facility-based firms do not rely on historical incumbents (or to a limited degree only) to provide services to end consumers, the regulatory burden can be lifted to some extent. However, as our analysis indicates, it seems unlikely that facility-based competition will also always lead to a competitive wholesale market and thus stimulate the development of service-based competition.

One good example is the broadband market. Facility-based competition has grown, with the development of cable modem networks and local loop unbundling (LLU) operators. Therefore, potential competition in the wholesale broadband market exists, and a wholesale market has even emerged in some countries. However, there is little evidence that these markets are strongly competitive. This is consistent with our analysis, which has highlighted that competitive outcomes are unlikely.

Downstream differentiation in the mobile industry We have also suggested that the nature of competition in the retail market, and in particular, the degree of differentiation between firms in that market, might affect the outcome in the wholesale market. More precisely, we showed that if differentiation in the retail market was sufficiently high, the wholesale market was competitive, and that otherwise, non-competitive outcomes were also possible.

Possibilities of bypass Our model suggests that strongly differentiated MVNOs are more likely to enter the final markets, as they are more likely to benefit from attractive wholesale offers by MNOs. Hence, in the mobile industry we might expect a high degree of product diversity and moderate price competition on the downstream market.

Finally, consider the following extension of our model: at cost $I > 0$, the pure downstream firm may decide to bypass the upstream market and build its own infrastructure if the upstream offers are prohibitively costly; in that case, it competes on a level-playing field with the integrated firms on the downstream markets. Then, integrated firms prefer supplying the pure downstream firm than not supplying it because it relaxes competition on the downstream market. In Bourreau, Hombert, Pouyet, and Schutz (2007) we show that this possibility of bypass limits the capability of the upstream supplier to charge too high a price on the upstream market. In particular, if the cost of bypass I is such that the upstream supplier cannot set an upstream price above a_*, then only the perfect competition equilibrium emerges.

This result has interesting policy implications. For the broadband market, it implies that favorable conditions for local loop unbundling (e.g., a low rate for the unbundled lines) might stimulate the development of the wholesale broadband market. In the mobile industry, it means that favorable terms for spectrum licences (e.g., terms for ungranted mobile licences, or for Wimax licences) might increase MNOs' incentives to set low wholesale prices for MVNOs.

Asymmetric regulation The regulator could decide to regulate the wholesale offer of one vertically integrated firm (e.g., the incumbent firm) while leaving the offer of the other vertically integrated firm (if any) unregulated. In our application, sufficiently low a price cap is an appropriate remedy to enhance the competitiveness of the wholesale market. The broadband market provides an example of this form of asymmetric regulation on the wholesale market. In some European countries, the broadband wholesale offers of Incumbent Local Exchange Carriers (ILECs) are regulated, while those of Competitive Local Exchange Carriers (CLECs) are left unregulated.

Vertical separation It is sometimes advocated that vertical separation of the incumbent operator, into two independent upstream and downstream divisions, can also promote competition in the telecommunication industry. In that scenario, the upstream division of the ILEC sets the price of its wholesale offer, without taking into account the impact on the downstream division, and reciprocally.

In particular, vertical separation has been considered to stimulate competition in the broadband market. Two types of separation could be implemented.[29] First, the local access unit of the ILEC could be separated from its downstream unit. Second, the Internet service provider unit of the ILEC could be separated from the upstream unit.[30]

In Section 4, we have analyzed how the competitiveness of the wholesale market is affected when a pure upstream competitor is introduced. We have shown that if downstream prices are strategic complements, the introduction of a pure upstream firm leads to a competitive wholesale market.

Pure upstream competitors There are two other types of situations in which a pure upstream unit can operate. First, municipalities can decide to invest in broadband networks and to offer wholesale broadband services to stimulate competition in the wholesale market. This is likely to stimulate competition on wholesale markets. However, the burden of the financing of these investments is likely to be born by the taxpayers as tough competition on the upstream market will erode the upstream profits.

Second, some private companies can decide to enter as pure upstream providers. For instance, in the broadband market, firms like Covad or Northpoint in the US, or Mangoosta in France, adopted this strategy. In the mobile market, so-called mobile virtual enablers (MVNEs) are also pure upstream firms. Our model suggests that this type of strategy is

[29]Different technologies can deliver broadband, but two of them dominate local broadband markets worldwide: the cable modem platform (which is the most widely used in the US) and the copper-based digital subscriber line (DSL) platform (which is the dominant technology in the EU). With the DSL technology, the broadband market has a three-tiered structure, with three types of product: local access (which is an input for the wholesale broadband service), the wholesale broadband service (also known as 'bitstream access') and, finally, the retail broadband Internet access service. Therefore, two markets can be interpreted as the upstream market in our model: the market for local access, and the wholesale broadband market.

[30]This type of situation has been observed in some countries. For instance, in France, some years ago, the ILEC's Internet service provider, Wanadoo, was a subsidiary of its parent company, France Télécom.

likely not to be viable.

6 Conclusion

Our analysis has focused on the links between vertically-related markets, when the upstream good is an essential input to the downstream product, and when the competitors on the upstream market are also rivals on the downstream one. Such a theoretical framework clearly depicts wholesale markets in telecommunications.

One of the main insights conveyed in the paper is that these upstream markets might not be competitive. Put differently, the monopoly outcome, which is obtained when the upstream market is exogenously monopolized, might persist even when competition in that market is possible. The main reason lies in the softening effect, according to which an integrated firm supplying the upstream market tends to be a soft competitor on the downstream market. This implies in turn that the rival integrated firm might not be willing to compete at all on the upstream market. An example has been proposed to illustrate this mechanism and one of its determinants: product differentiation at the downstream level. Roughly speaking, product differentiation affects the strength of the softening effect and therefore the potential competitiveness of the upstream market.

The theoretical analysis has been the basis of several policy implications and robustness checks. Let us reemphasize that, from a competition policy perspective, our analysis suggests that analyzing upstream markets in isolation of the related downstream markets is bad economics. Taken on a stand-alone basis, our upstream market has all the features of a perfectly competitive market. Once the downstream market is added to the analysis, the picture is much more mixed. Overall, the potential competitiveness of upstream markets hinges as much on the economic fundamentals pertaining to that market as on the fundamentals of the related downstream markets.

Various extensions would certainly be worth studying.

From a more industry-specific perspective, and as regards the broadband market, it would be worth investigating the role of the local loop in our setting. Most facility-based firms rely to some extent on the local loop owned by the incumbent to offer broadband services to final customers. It would be interesting to understand how the competition on the wholesale market is affected by the regulation of access to the local loop. Likewise, as regards the mobile telephony market, interconnection flows between MNOs, and their regulation, may impact on competition between MNOs to attract MVNOs.

From a more theoretical viewpoint, the role of the market structures remains to be studied. A first set of questions relates to the impact of the number of vertically integrated firms and of pure downstream firms on the competitiveness of the wholesale market. A second set of questions relates to the entry process in this industry: are vertically integrated firms more likely to enter than pure downstream ones?

Finally, our upstream price competition game can be viewed as an auction run by the

pure downstream firm in which integrated firms bid to supply the upstream market. Given that the outcome of this auction determines the efficiency of the pure downstream firms, this auction is characterized by externalities which depend on the price paid by the pure downstream firm, as studied by Ettinger (2002). As our analysis indicates, these externalities are non-monotonic with respect to the price, which explains the multiplicity of equilibria. Under asymmetric information, it would be worth studying how different auction formats impact the outcome of our game, as in Jehiel and Moldovanu (2000). In the same vein, if upstream suppliers offer differentiated inputs which affect differently the outcome on the downstream market, then identity-dependent externalities emerge; this may be another force which affects the integrated firms' incentives to participate to the upstream market, as in Jehiel and Moldovanu (1996).

All these questions are left for future research.

A Appendix

A.1 Proof of Lemma 1

To begin with, we prove the following fixed point lemma:

Lemma 0. *Let $f : [0,\infty) \to [0,\infty)$ be a $\mathcal{C}^1$ function. Assume that f is bounded and $|f'(.)| < 1$.*
Then, f admits a unique fixed point x^*. Besides, $f(x) > x$ if, and only if, $x < x^*$; and $f(x) < x$ if, and only if, $x > x^*$.

Proof. Define $g(x) \equiv f(x) - x$. Computing its first derivative, we see that $g(.)$ is strictly decreasing, since $f'(.) < 1$. $g(0) = f(0) \geq 0$, and $\lim_{x\to\infty} g(x) = -\infty$, since $f(.)$ is bounded. By continuity, there exists a unique $x^* \geq 0$ such that $g(x) = 0$. Since $g(.)$ is strictly decreasing, $g(x) > 0$ if, and only if, $x < x^*$. And $g(x) < 0$ if, and only if, $x > x^*$. This concludes the proof. □

Assume that integrated firm $i \in \{1,2\}$ is the upstream supplier at price $a_i > c_u$, and let us show that $p_i^{(i)}(a_i) > p_j^{(i)}(a_i)$. By definition of the unique downstream equilibrium,

$$p_i^{(i)}(a_i) \;=\; BR_i^{(i)}\left(BR_j^{(i)}\left(p_i^{(i)}(a_i), p_d^{(i)}(a_i), a_i\right), p_d^{(i)}(a_i), a_i\right).$$

We see from the first-order condition (2) that firm j's best-response function does not depend on a_j: $BR_j^{(i)}(.,.,a_i) = BR_j^{(i)}(.,.,c_u)$. By contrast, (1) implies that firm i's best-response is increasing in the upstream price: $BR_i^{(i)}(.,.,a_i) > BR_i^{(i)}(.,.,c_u)$. Hence:

$$p_i^{(i)}(a_i) > BR_i^{(i)}\left(BR_j^{(i)}\left(p_i^{(i)}(a_i), p_d^{(i)}(a_i), c_u\right), p_d^{(i)}(a_i), c_u\right). \tag{3}$$

By assumption, $|\partial BR_i^{(i)}/\partial p_j| < 1$ and $BR_i^{(i)}$ is bounded. We can apply Lemma 0 to function $BR_i^{(i)}(., p_d^{(i)}(a_i), c_u)$: There exists a unique p^* such that $BR_i^{(i)}(p^*, p_d^{(i)}(a_i), c_u) = p^*$. Besides, since $BR_i^{(i)}(., ., c_u) = BR_j^{(i)}(., ., c_u)$, we also have that $BR_j^{(i)}(p^*, p_d^{(i)}(a_i), c_u) = p^*$. p^* is the downstream price set by integrated firms in the hypothetical situation in which firm i would supply the upstream market at c_u and firm d's price would be exogenously fixed at $p_d^{(i)}(a_i)$.

Define the following function:

$$f : x \mapsto BR_i^{(i)}\left(BR_j^{(i)}\left(x, p_d^{(i)}(a_i), c_u\right), p_d^{(i)}(a_i), c_u\right).$$

Note that $f(p^*) = p^*$, by definition of p^*. Obviously, f is bounded and $|f'(.)| < 1$. Thus, it admits a unique fixed point: p^*. Besides, $f(x) < x \Leftrightarrow x > p^*$. We deduce from (3) that $p_i^{(i)}(a_i) > p^*$.

We can now apply the mean value inequality to function $BR_j^{(i)}(., p_d^{(i)}(a_i), c_u)$ between p^* and $p_i^{(i)}(a_i)$:

$$\left|BR_j^{(i)}\left(p_i^{(i)}(a_i), p_d^{(i)}(a_i), c_u\right) - BR_j^{(i)}\left(p^*, p_d^{(i)}(a_i), c_u\right)\right| \leq \sup_{p_i \in \left[p^*, p_i^{(i)}(a_i)\right]} \left|\frac{\partial BR_j^{(i)}}{\partial p_i}\left(p_i, p_d^{(i)}(a_i), c_u\right)\right| \left|p_i^{(i)}(a_i) - p^*\right|.$$

Since the upper bound is taken over a compact set, it is strictly lower than 1. Besides, since firm j's best-response does not depend on the upstream price, and by definition of $p_j^{(i)}$, $BR_j^{(i)}(p_i^{(i)}(a_i), p_d^{(i)}(a_i), c_u) = p_j^{(i)}(a_i)$. By definition of p^*, $BR_j^{(i)}(p^*, p_d^{(i)}(a_i), c_u) = p^*$. Using the fact that $p^* < p_i^{(i)}(a_i)$, the mean value inequality can then be rewritten as:

$$\left|p_j^{(i)}(a_i) - p^*\right| < p_i^{(i)}(a_i) - p^*.$$

In particular, $p_j^{(i)}(a_i) - p^* < p_i^{(i)}(a_i) - p^*$, hence, $p_j^{(i)}(a_i) < p_i^{(i)}(a_i)$.

A.2 Proof of Lemma 2

Let integrated firm $i \in \{1, 2\}$ be the upstream supplier at price $a_i > c_u$. Its downstream profit is given by:

$$(p_i^{(i)}(a_i) - c_u) D_i(p_i^{(i)}(a_i), p_j^{(i)}(a_i), p_d^{(i)}(a_i)) - c_i\left(D_i(p_i^{(i)}(a_i), p_j^{(i)}(a_i), p_d^{(i)}(a_i))\right), \tag{4}$$

with $p_i^{(i)}(a_i) > p_j^{(i)}(a_i)$ by Lemma 1. Define $\hat{p} > p_i^{(i)}(a_i)$ such that:

$$D_i(\hat{p}, p_i^{(i)}(a_i), p_d^{(i)}(a_i)) = D_i(p_i^{(i)}(a_i), p_j^{(i)}(a_i), p_d^{(i)}(a_i)).$$

Downstream profit (4) is smaller than:

$$(\hat{p} - c_u)D_i(\hat{p}, p_i^{(i)}(a_i), p_d^{(i)}(a_i)) - c_i \left(D_i(\hat{p}, p_i^{(i)}(a_i), p_d^{(i)}(a_i)) \right).$$

By symmetry between integrated firms, this can be rewritten as:

$$(\hat{p} - c_u)D_j(p_i^{(i)}(a_i), \hat{p}, p_d^{(i)}(a_i)) - c_j \left(D_j(p_i^{(i)}(a_i), \hat{p}, p_d^{(i)}(a_i)) \right).$$

By revealed preferences, this profit is smaller than the downstream profit of firm j:

$$(p_j^{(i)}(a_i) - c_u)D_j(p_i^{(i)}(a_i), p_j^{(i)}(a_i), p_d^{(i)}(a_i)) - c_j \left(D_j(p_i^{(i)}(a_i), p_j^{(i)}(a_i), p_d^{(i)}(a_i)) \right),$$

which concludes the proof.

A.3 Proof of Proposition 2

Suppose first that both integrated firms offer the same upstream price $a_* \leq a_m$, such that $\pi_i^{(i)}(a_*) = \pi_j^{(i)}(a_*)$. The pure downstream firm chooses indifferently one of them as its upstream supplier, and both integrated firms earn the same profit.

Consider an upward deviation of integrated firm 1, be it the upstream supplier or not. Now, by Assumption 1, firm d strictly prefers buying the upstream good from firm 2 at price a_*, and firm 1's profit is unchanged. Consider now a downward deviation: $a_i < a_*$. Firm d strictly prefers to buy from firm 1, which then earns $\pi_i^{(i)}(a_i)$. By Assumption 2, since $a_* \leq a_m$, this profit is smaller than $\pi_i^{(i)}(a_*) = \pi_j^{(i)}(a_*)$. That situation is therefore an equilibrium.

Conversely, consider that both integrated firms offer the same upstream price a_*, and assume that one of the assumptions of Proposition 2 is not satisfied. Suppose first that $a_* > a_m$. The upstream supplier then has a strictly profitable deviation: propose a_m.

If $\pi_i^{(i)}(a_*) < \pi_j^{(i)}(a_*)$, then the upstream supplier would rather set an upstream price above a_* to earn $\pi_j^{(i)}(a_*)$.

If $\pi_i^{(i)}(a_*) > \pi_j^{(i)}(a_*)$, then the integrated firm which does not supply the upstream market would rather set an upstream price slightly smaller than a_* to earn a profit almost equal to $\pi_i^{(i)}(a_*)$.

A.4 Proof of Proposition 3

Consider by contradiction an equilibrium configuration in which $a_i < a_j$ and $a_i \neq a_m$. By Assumption 1, the upstream supplier is firm i.

If $a_j > a_m$, it is a strictly profitable deviation for firm i to offer a_m. If $a_j \leq a_m$, firm 1 would rather charge any upstream price in (a_i, a_j), since $\pi_i^{(i)}(.)$ is increasing in this interval by Assumption 2.

Let us now show that a monopoly-like equilibrium Pareto-dominates any matching equilibrium with upstream price a_*, from the viewpoint of integrated firms. We have $\pi_j^{(i)}(a_m) \geq$

$\pi_i^{(i)}(a_m)$ by Proposition 1. Consider a matching-like equilibrium at upstream price a_*. By definition of a_m, $\pi_i^{(i)}(a_m) \geq \pi_i^{(i)}(a_*) = \pi_j^{(i)}(a_*)$. This concludes the proof.

A.5 Proof of Proposition 4

The proof proceeds in several steps. We first compute the downstream equilibrium, and check that all the assumptions we need are satisfied. We can then compute the monopoly benchmark and make some comparisons between integrated firms' profits. This allows us to apply Propositions 1, 2 and 3, and obtain all existing subgame-perfect equilibria.

Downstream equilibrium. Assume that integrated firm i supplies the upstream market at price a_i, and denote its integrated rival by j. For all downstream and upstream prices, we have:

$$\frac{\partial^2 \tilde{\pi}_k^{(i)}}{\partial p_k^2} = -2(1 + \frac{2}{3}\gamma) < 0, \quad \forall k \in \{1, 2, d\}.$$

This ensures that the best-response functions are uniquely defined. They are equal to:[31]

$$\begin{aligned} BR_i^{(i)}(p_j, p_d, a_i) &= \frac{3 + a_i\gamma + \gamma(p_j + p_d)}{6 + 4\gamma}, \\ BR_j^{(i)}(p_i, p_d, a_i) &= \frac{3 + \gamma(p_i + p_d)}{6 + 4\gamma}, \\ BR_d^{(i)}(p_i, p_j, a_i) &= \frac{3 + 3a_i + 2a_i\gamma + \gamma(p_i + p_j)}{6 + 4\gamma}. \end{aligned}$$

The stability condition is satisfied, since, for all $k \neq k'$, we have:

$$\left| \frac{\partial BR_k^{(i)}}{\partial p_{k'}} \right| = \frac{\gamma}{6 + 4\gamma} < 1.$$

There is a unique downstream equilibrium, which can be calculated by solving the set of first-order conditions. We get:

$$\begin{aligned} p_i^{(i)}(a_i) &= \frac{18 + 15\gamma + 9a_i\gamma + 5a_i\gamma^2}{36 + 42\gamma + 10\gamma^2}, \\ p_j^{(i)}(a_i) &= \frac{18 + 15\gamma + 3a_i\gamma + 3a_i\gamma^2}{36 + 42\gamma + 10\gamma^2}, \\ p_d^{(i)}(a_i) &= \frac{18 + 18a_i + 15\gamma + 21a_i\gamma + 7a_i\gamma^2}{36 + 42\gamma + 10\gamma^2}. \end{aligned}$$

[31] At first sight, these best-response functions seem to be unbounded, which would violate one of our assumptions. If downstream demands are defined more carefully, as $D_k = \max\{1 - p_k - \gamma(p_k - \bar{p}), 0\}$, then it can be shown that downstream prices have to lie below a certain threshold for the three firms to be active. We abstract from these considerations in the following, since we are only interested in configurations in which all firms supply a positive quantity.

They are well-defined if the equilibrium quantity served by downstream firm d is positive, which is equivalent to:

$$a_i \leq a_{\max}(\gamma) \quad \equiv \quad \frac{6+5\gamma}{6+7\gamma+\gamma^2} > 0.$$

Assumption 1 is satisfied, since:

$$\pi_d^{(i)}(a_i) = \frac{3(1+\gamma)^2(6+\gamma)^2(3+2\gamma)}{4(3+\gamma)^2(6+5\gamma)^2}[a_i - a_{\max}(\gamma)]^2,$$

thus $\pi_d^{(i)}(.)$ is decreasing for $a_i \leq a_{\max}(\gamma)$.

Monopoly benchmark. Assumption 2 is ensured by:

$$\frac{d^2\pi_i^{(i)}}{da_i^2} = -\frac{648+1944\gamma+2205\gamma^2+1158\gamma^3+269\gamma^4+20\gamma^5}{2(18+21\gamma+5\gamma^2)^2} < 0,$$

implying that $\pi_i^{(i)}(.)$ is concave, hence quasiconcave. Firm i's maximum is reached for:

$$a_i = a_m(\gamma) \quad \equiv \quad \frac{324+594\gamma+360\gamma^2+75\gamma^3}{648+1296\gamma+909\gamma^2+249\gamma^3+20\gamma^4}.$$

Since $a_m \in (0, a_{\max}(\gamma))$, Assumption 3 is satisfied.

Comparison of integrated firms' profits. $\pi_i^{(i)}(.)$ and $\pi_j^{(i)}(.)$ are parabolas, they cross each other twice, in $a_i = c_u$ and in:

$$a_i = a_*(\gamma) \quad \equiv \quad \frac{9(12+16\gamma+5\gamma^2)}{108+180\gamma+93\gamma^2+13\gamma^3}.$$

$\pi_i^{(i)}(.)$ is concave and $\pi_j^{(i)}(.)$ is convex since:

$$\frac{d^2\pi_j^{(i)}}{da_i^2} = \frac{3(3+2\gamma)\gamma^2(1+\gamma)^2}{2(3+\gamma)^2(6+5\gamma)^2} > 0.$$

Hence, we have:

$$\pi_i^{(i)}(a_i) \geq \pi_j^{(i)}(a_i) \quad \Leftrightarrow \quad a_i \in [0, a_*(\gamma)]. \tag{5}$$

Let us now check whether or not $a_m(\gamma) \in [0, a_*(\gamma)]$:

$$a_m(\gamma) - a_*(\gamma) = \frac{3(3+\gamma)(6+5\gamma)(-648-1296\gamma-864\gamma^2-183\gamma^3+5\gamma^4)}{(108+180\gamma+93\gamma^2+13\gamma^3)(648+1296\gamma+909\gamma^2+249\gamma^3+20\gamma^4)}.$$

Analyzing the above function, we establish that there exists $\overline{\gamma} > 0$, such that:

$$a_m(\gamma) \geq a_*(\gamma) \quad \Leftrightarrow \quad \gamma \geq \overline{\gamma}.$$

Upstream equilibrium. Since $\pi_i^{(i)}(0) = \pi_j^{(i)}(0)$ and $0 \leq a_m(\gamma)$, Proposition 2 implies that the Bertrand outcome is always an equilibrium.

If $\gamma < \overline{\gamma}$, then $0 < a_m(\gamma) < a_*(\gamma)$. By Proposition 1, (5) implies that there is no monopoly-like equilibrium. Moreover $a_*(\gamma) > a_m(\gamma)$ implies by Proposition 2 that there is no other matching-like equilibrium than the Bertrand equilibrium.

Similarly, if $\gamma \geq \overline{\gamma}$, then $a_m(\gamma) \geq a_*(\gamma)$ and there exist monopoly-like equilibria. This is also a necessary and sufficient condition for the matching-like equilibrium with upstream price a_*.

A.6 Proof of Proposition 5

The proof is made easier by noting that our game exhibits some supermodular features. More precisely, assume that firms 1 and u propose the same upstream price $a_1 = a_u = a$, while firm 2 makes no upstream offer. The game $(\mathbb{R}; (p_k, p_{-k}, i) \mapsto \tilde{\pi}_k^{(i)}(p_k, p_{-k}, a), i = u, 1; k = 1, 2, d)$ is strictly supermodular (with the order relation $u < 1$).[32] For all k, $\tilde{\pi}_k^{(i)}(p_k, p_{-k}, a)$ has increasing differences in (p_k, i), and $\tilde{\pi}_1^{(i)}(p_1, p_{-1}, a)$ has strictly increasing differences in (p_k, i). Besides, the downstream equilibrium is, by assumption, unique. Supermodularity theory (see Vives (1999), p. 35) tells us that the equilibrium of that game is strictly increasing in i, i.e., $p_k^{(u)}(a) < p_k^{(1)}(a)$ for $k = 1, 2, d$.

Let us now show by contradiction that the upstream market cannot be supplied at an upstream price strictly larger than c_u.

Suppose that integrated firm 1 supplies the upstream market at $a_1 > c_u$. Pure upstream firm u earns zero profit. However, it is able to corner the upstream market and earn a positive profit by offering $a_u > c_u$. Since $\pi_d^{(u)}(c_u) = \pi_d^{(1)}(c_u) > \pi_d^{(1)}(a_1)$, the pure upstream firm can undercut with an upstream price close enough to c_u.[33]

Suppose now that the upstream market is supplied by pure upstream firm u at $a_u = a > c_u$. Let us show that, if it offers $a_1 = a_u = a$, integrated firm 1 corners the upstream market and enhances its profit. First, firm d strictly prefers to purchase from firm 1. When it purchases from firm u, it earns:

$$\pi_d^{(u)}(a) = (p_d^{(u)}(a) - a) D_d(p_1^{(u)}(a), p_2^{(u)}(a), p_d^{(u)}(a)) - c_d \left(D_d(p_1^{(u)}(a), p_2^{(u)}(a), p_d^{(u)}(a)) \right).$$

[32] The new notations are similar to the previous ones: $\tilde{\pi}_k^{(u)}(.,.,a)$ denotes the out-of-equilibrium profit of firm k when the upstream market is supplied by firm u at price a, while $\pi_k^{(u)}(a)$ (resp. $p_k^{(u)}(a)$) denotes its profits (resp. downstream price) at downstream equilibrium.

[33] It cannot undercut with $a_1 - \varepsilon$ since, as we shall see below, firm d would still prefer to buy from firm 1 in that case.

Since $p_k^{(u)}(a) < p_k^{(1)}(a)$ for $k = 1, 2$, there exists $\hat{p} > p_d^{(u)}(a)$ such that:

$$D_d(p_1^{(1)}(a), p_2^{(1)}(a), \hat{p}) = D_d(p_1^{(u)}(a), p_2^{(u)}(a), p_d^{(u)}(a)).$$

Then,

$$\pi_d^{(u)}(a) < (\hat{p} - a) D_d(p_1^{(1)}(a), p_2^{(1)}(a), \hat{p}) - c_d \left(D_d(p_1^{(1)}(a), p_2^{(1)}(a), \hat{p}) \right),$$

and, by revealed preference,

$$\pi_d^{(u)}(a) < (p_d^{(1)}(a) - a) D_d(p_1^{(1)}(a), p_2^{(1)}(a), p_d^{(1)}(a)) - c_d \left(D_d(p_1^{(1)}(a), p_2^{(1)}(a), p_d^{(1)}(a)) \right),$$

which is equal to $\pi_d^{(1)}(a)$. Therefore, firm d prefers to purchase from firm 1. It remains to be shown that firm 1's profit is larger when it supplies the upstream market. When u supplies the upstream market firm 1 earns:

$$\pi_1^{(u)}(a) = D_1(p_1^{(u)}(a), p_2^{(u)}(a), p_d^{(u)}(a)) - c_1 \left(D_1(p_1^{(u)}(a), p_2^{(u)}(a), p_d^{(u)}(a)) \right).$$

Using that $p_k^{(u)}(a) < p_k^{(1)}(a)$ for $k = 2, d$, there exists $\tilde{p} > p_1^{(u)}(a)$ such that:

$$D_1(\tilde{p}, p_2^{(1)}(a), p_d^{(1)}(a)) = D_1(p_1^{(u)}(a), p_2^{(u)}(a), p_d^{(u)}(a)).$$

Then,

$$\pi_1^{(u)}(a) < (\tilde{p} - c_u) D_1(\tilde{p}, p_2^{(1)}(a), p_d^{(1)}(a)) - c_1 \left(D_1(\tilde{p}, p_2^{(1)}(a), p_d^{(1)}(a)) \right),$$

which is smaller than:

$$(\tilde{p} - c_u) D_1(\tilde{p}, p_2^{(1)}(a), p_d^{(1)}(a)) - c_1 \left(D_1(\tilde{p}, p_2^{(1)}(a), p_d^{(1)}(a)) \right) + (a - c_u) D_d(\tilde{p}, p_2^{(1)}(a), p_d^{(1)}(a))$$

since $a > c_u$. Finally we find by revealed preference that:

$$\pi_1^{(u)}(a) < (p_1^{(1)}(a) - c_u) D_1(p_1^{(1)}(a), p_2^{(1)}(a), p_d^{(1)}(a)) - c_1 \left(D_1(p_1^{(1)}(a), p_2^{(1)}(a), p_d^{(1)}(a)) \right) + (a - c_u) D_d(p_1^{(1)}(a), p_2^{(1)}(a), p_d^{(1)}(a)),$$

which is equal to $\pi_1^{(1)}(a)$. This concludes the proof.

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