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Abstract

We show how a monopolist in a primary market uses mixed bundling to extract surplus from quality-enhancing investment by a single-product rival in a complementary market, or even force the rival to provide low quality. In our model, bundling does not hinge on commitment ability. Although we assume that bundling creates efficiency gains, we find that bundling reduces consumer surplus and may reduce social welfare, even if the rival is not foreclosed, and investment is not blockaded. Nonetheless, bundling improves welfare when prevents inefficient investment. We propose to check bundled offers via a price test that controls the monopoly component stand-alone price to preserve efficiencies from both bundling and investment. When the rival invests, the test improves consumer surplus and welfare compared with the 'do-nothing' scenario, or a ban on bundling. The test is not consistent with the predatory pricing framework. Qualitative results hold when we endogenize the bundling strategy.

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1 Introduction

Product bundling is a widely employed strategy in many industries. Public policy and academic research have recognized that bundling by a dominant firm can be an issue when used as a method of predation or a tying arrangement leading to foreclosure of an efficient single-product competitor. This issue is particularly relevant in high-technology industries, where a key feature of competition is continuing innovation. Indeed, in the last years there has been close antitrust scrutiny on bundling practices in high-tech sectors both in the US and Europe.[1] Furthermore, technological convergence has recently raised new interest in bundling strategies in regulated industries such as electronic communications markets.

In this paper, we show that the dominant firm in a primary market finds it profitable to use bundling so as to extract surplus from the rival firm's investment in quality in a complementary market. Provided that there is a sunk cost of investment, bundling may deny the rival firm the necessary scale to invest and thus force the rival to provide low quality. We explicitly assume that bundling creates efficiency gains.[2] Nonetheless, we find that bundling may be socially harmful even if there is competition in the complementary market, and if the rival's investment is not blockaded.

Although this finding builds a relatively strong case against bundling, a *per se* rule prohibiting bundling would not be appropriate since we also find that bundling is socially beneficial when it precludes some inefficient investment that would occur under stand-alone selling. Thus, we propose to check the viability of a bundled offer using a price test that aims at preserving efficiencies from both bundling and quality investment. We show that, when the rival firm invests under the proposed test, consumer surplus and social welfare rise compared with the do-nothing scenario (that is, the

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[1] Major examples are recurring cases against Microsoft in the software industry and the General Electric/Honeywell merger in aircraft engines and avionics equipment industries.

[2] Bundling may be achieved through product design, which realizes technical improvements in the quality of products (technological bundle), or through contracting, which realizes consumers' savings on research and transaction costs (commercial bundle). In both cases, product bundling raises consumers' valuation. Although it is widely held that there may be efficiencies from bundling (see e.g. EC, 2008), the academic literature seems to have overlooked this point.

case when the dominant firm freely sets prices), or with a ban on bundling.[3] Our test does not comply with the logic of predatory pricing, which is usually embraced by antitrust agencies. We show that, when the rival invests, our test improves welfare compared with a predatory pricing test.

We assume that consumers have heterogeneous willingness to pay (henceforth, wtp) for systems of complementary products. We assume partial market participation, so as consumers with the lowest wtp are not active. We also assume that the dominant firm's bundle raises consumers' wtp[4] and, to a greater extent, so does the rival firm's quality investment.

In our basic model, we consider an instance of partial mixed bundling, where the monopoly component is sold both in bundle and as a stand-alone product, while the competitive component is sold only in bundle.[5] We find that bundling is a profitable strategy independent of the rival firm's product choice. Thus, bundling is credible and does not rely on a commitment assumption. When the rival provides a perfect substitute in the complementary market, bundling introduces vertical differentiation between systems and raises both firms' profits. When the rival provides a superior complementary component, bundling makes the dominant firm's system more competitive relative to stand-alone selling. In addition, the dominant firm can use the stand-alone price of the monopoly component as a price discrimination device to extract surplus from consumers with a strong preference for quality, which buy the system including the rival's complementary component.

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[3] When the rival firm does not invest, consumer surplus and welfare are not affected.

[4] It follows that there is not any outcome with bundling that the firm can exactly replicate with separate component pricing. For simplicity, we assume that the dominant firm can bundle products at a negligible sunk cost, which is normalized to zero. Qualitative results are not affected when the fixed cost of bundling is sufficiently low.

[5] There are several real-world examples. Sky provides its exclusive content in bundle with the satellite TV decoder and on a stand-alone basis, but not the decoder stand-alone. Many retailers offer the video game console Nintendo Wii in bundle with Wii accessories, or the accessories by themselves, but not the console stand-alone. Software firms, having developed a full-featured version, may also provide a second version that removes some functions (think of read-only versions of Adobe Acrobat, or play-only versions of Real Player). A number of telecommunications incumbents in the EU provide triple-play offers with voice calls, broadband access and IP TV. While consumers can choose not to buy IP TV, thus opting for one or both of the other services, they cannot choose to buy IP TV alone. Similar options are offered by cable TV firms. Focusing on partial mixed bundling is thus empirically grounded. In section 6, we show that it is also theoretically grounded, since the main qualitative results are not altered when we endogenize the bundling strategy.

We find that bundling induces less market participation and has a negative effect on consumer surplus. We also find that, when the rival firm's investment is feasible under product bundling, the dominant firm's bundle reduces social welfare. However, bundling may raise welfare by preventing the rival's investment when the sunk cost is (socially) too high relative to quality improvement.

Consistent with the results obtained, antitrust authorities usually abstain from imposing such restrictions on the dominant firm as pure stand-alone selling. In practice, they rather investigate anticompetitive effects of bundling according to a rule of reason standard. This, in turn, often employs a price-cost test which obeys to predatory pricing principles.

We argue that a predatory pricing test is not well grounded in a setting where products are vertically differentiated. Indeed, we find that using such test may be socially detrimental. Therefore, we introduce an alternative welfare-enhancing price test that simply imposes the dominant firm not to artificially raise the stand-alone price of the monopoly component over the monopoly level as a consequence of the bundled offer.[6] In essence, the proposed test controls price discrimination between consumers who buy the entire system from the dominant firm, and consumers who buy the alternative system including the rival's component.

When the incremental wtp for the bundle is low, the proposed test tolerates a margin between the bundle price and the stand-alone price of the monopoly component that is *below* the dominant firm's average incremental cost of producing the complementary component. On the other hand, as the incremental wtp for the bundle rises, the test entails a *strictly above* cost margin. In both cases, the outcome of the test is different from a predatory pricing test, which in our setting would induce the dominant firm to set a margin that *exactly* reflects the relevant cost.

Finally, we extend our basic model to allow the dominant firm to practice pure bundling (so as the firm provides only the bundle) and complete mixed bundling (so as the firm provides the bundle

[6] This simple rule is mainly intended to safeguard the practical implementation of the price test (we outline a refined version of the test in section 5.3). Greenlee *et al.* (2008) develop the same idea to manage bundled rebates in a model with exogenous quality of firms' products (we further discuss their work in section 2).

and all products on a stand-alone basis). For simplicity, while extending the model we deal only with the case of technological bundling. We find that, in the do-nothing scenario, mixed bundling is more profitable than pure bundling, and welfare implications are qualitatively the same as in the basic model. Conversely, under the price test regime, the dominant firm may opt for pure bundling. If the bundle is technological, then the rival is foreclosed. Since welfare is negatively affected, then an authority should require the dominant firm to provide the monopoly component on a stand-alone basis. In such a case, we can prove that qualitative results are not altered relative to the basic model.

This paper is organized as follows. Section 2 analyzes the relevant literature. Section 3 presents the basic model. Section 4 derives welfare effects of bundling. Section 5 introduces the price test and discusses policy implications. Section 6 develops model extensions. Section 7 concludes.

2 Relevant literature

The literature strand that is most relevant to our paper is the one which has devoted attention to studying the foreclosure effects of product bundling. Carlton and Waldman (2002) as well as Choi and Stefanadis (2001) analyze the case of pure bundling of complementary products.[7] They set up dynamic models to show how a dominant firm can use tying both to preserve and create a monopoly position. This is to the detriment of alternative producers of single components that may serve as superior substitutes for a system composed of a primary and a complementary good.

In the cited papers, bundling produces benefits to the dominant firm only when it deters entry, while it should be avoided when entry is inevitable. Thus, entry deterrence relies critically on the firm's ability to commit to bundling. Conversely, in our model bundling raises the dominant firm's profit even when the rival firm is active, and independent of the rival's product choice.

Nalebuff (2004) and, more recently, Peitz (2008) provide two models where bundling is a credible strategy. Both models consider pure bundling of independent products. The former defines a setting where the entrant's and one of the incumbent's products are perfect substitutes, while the

[7] In his pioneering work, Whinston (1990) analyzes pure bundling both of independent and complementary products.

latter assumes that firms produce horizontally differentiated varieties.[8]

When firms simultaneously set prices, these authors obtain partially diverging welfare results. In both models, welfare is higher under competition than monopoly, so that bundling reduces welfare when it achieves foreclosure. However, when the rival firm is active, welfare is higher under product bundling in Nalebuff's model, but under stand-alone selling in Peitz's model. Therefore, when entry costs are such that competition is likely under stand-alone selling, there are opposite policy implications. While Nalebuff's results justify a 'do-nothing' scenario, Peitz's results, conversely, entail a ban on bundling. It is worth noting that things are not so clear-cut in our model of vertical differentiation, where bundling reduces welfare *given* the type of competition (e.g. when the rival firm is high-quality), and either reduces or raises welfare when it *affects* the type of competition (so as the rival firm gives up investing and provides low quality).

Choi (2004) elaborates on the idea that tying by a dominant firm can stifle investment in cost-reducing R&D by a competitor in the tied good market. He finds that tying can be profitable even if the rival firm is active, which is a similar point to ours. However, contrary to our paper, in the absence of investment tying intensifies price competition and reduces the tying firm's profit.[9]

It follows from the review that the literature on bundling and market structure focuses on pure bundling. Since pure bundling is not profitable in our model, then we focus on mixed bundling.[10] Moreover, the literature analyzes the two polar cases where bundling is allowed or prohibited, but does not consider the case where the viability of a bundled offer is subject to a suitable price test.

A notable exception is Greenlee *et al*. (2008). They show that the incumbent's bundled rebates

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[8] In Nalebuff's basic model, firms sequentially set prices and bundling deters entry. In an alternative version, firms simultaneously set prices, as in Peitz's model. Then, bundling facilitates entry, while it deters entry in Peitz's model.

[9] Chen (1997) also provides a model where bundling does not require the rival firm's exit to be profitable. Indeed, bundling is used to segment the market and soften competition. However, he does not consider the case of investment.

[10] Choi (2008) analyzes the case of a merger where the merged firm becomes able to engage in mixed bundling, and finds that welfare is negatively affected if the merger leads to foreclosure of outsiders. He initially assumes that firms and market demands are symmetric. Thus, in his model outside firms have incentives to counter-merge, which would lead to bundle-to-bundle competition. It is also possible that this prevents the initial merger from taking place at all.

can fail existing (predation–style) price tests[11] when welfare rises, and pass these tests when welfare declines. Thus, they define an alternative test based on comparing the monopoly component price before and after the institution of bundled rebates. They show that their test has the clear implication of improving consumer surplus when firms produce a homogeneous competitive component. However, this is not necessarily the case when competitive components are horizontally differentiated, where bundled rebates may deter entry or induce exit.

In this paper, we consider vertically differentiated products. An important point is that, with respect to Greenlee *et al*. (2008), we extend the model to endogenize both the dominant firm's choice of bundling strategy (partial mixed, complete mixed, or pure bundling) and the rival firm's product selection (high or low quality). We find that, in this more complex setting, using the proposed price test is socially beneficial compared with the do-nothing scenario, while a predatory pricing test is still not consistent with consumer surplus or welfare maximization.

3 The model

In this section, we present a simple model to analyze how the dominant firm's bundle affects competition and the incentives to invest of a single-product rival firm.

3.1 Basic assumptions

We consider two firms, a dominant firm (firm 1) and a rival firm (firm 2), and two products, A and B. The market for product A is monopolized by firm 1, while the market for product B is served by both firms. Marginal costs are normalized to zero for both products. Products A and B are perfect complements. Thus, consumers receive no benefit from purchasing a unit of either product by itself and are interested in using a system consisting of exactly one unit of product A and one unit of

[11] A prominent example is the so-called *Ortho* test. For a bundled discount on two products that are provided one in monopoly and one in a competitive market, the test allocates the bundle rebate to the competitive product and compares the discount-adjusted price of this product to the incumbent's incremental cost of providing the product. If the discount-adjusted price exceeds cost, the bundled rebate is deemed not to be anticompetitive (see Carlton *et al.*, 2008).

product B.[12] Consumers may choose between buying both products from the dominant firm (system 1) or buying product A from the dominant firm and product B from the rival firm (system 2).

The dominant firm can decide to sell products A and B in bundle or on a stand-alone basis. We assume that, when the dominant firm bundles, it also sells product A stand-alone. Thus, we consider an instance of partial mixed bundling.[13] We assume that, when purchasing products in bundle, consumers perceive an increase in gross utility. There are two alternative motivations, depending on the type of bundle. Technological bundling realizes some technical enhancement due to integrating products (e.g. an improved system functionality), while commercial bundling enables consumers to save on research and transaction costs (e.g. due to *one-stop shopping*). Under technological bundling, consumers cannot undo the bundle. This means that they cannot add a unit of firm 2's product to system 1, because the former is incompatible with the latter. This is not the case for a commercial bundle, so that consumers are able to undo the bundle. In what follows, we focus on technological bundling, but the main qualitative results are preserved with commercial bundling.

The rival firm has two alternative strategies available in market B. First, it can invest in product quality so as to sell a superior component that raises consumers' wtp for system 2. If the rival firm invests then it incurs a sunk cost F, but system 2 is able to capture the highest-wtp consumers (thus, we will refer to the rival firm as the *high*-quality firm)[14]. Second, the rival firm can produce a perfect substitute of the dominant firm's component at no cost. In such a case, provided that firm 1 bundles products, system 2 is of lower quality than system 1 (so that we will refer to firm 2 as the *low*-quality firm) and only low-wtp consumers may decide to purchase system 2.

When purchasing system 1 or system 2 respectively, consumer x gets the following utilities:

$$U_{S1} = \begin{cases} V + x - p_A - p_{B1} & \text{under stand - alone selling} \\ V + \beta x - p_{AB} & \text{under product bundling} \end{cases}$$

[12] The main results of this paper are diluted, but not reversed, in the case of imperfect complements.

[13] In section 6, we extend the basic model so as to allow firm 1 to also engage in pure and complete mixed bundling.

[14] A similar idea is developed in Avenali *et al.* (2010).

$$U_{S2} = \begin{cases} V + x - p_A - p_{B2} & \text{if firm 2 is low} - \text{quality} \\ V + \gamma x - p_A - p_{B2} & \text{if firm 2 is high} - \text{quality} \end{cases}$$

Parameter V in the utility function denotes the gross benefit that each consumer receives from using a system. Parameter *x*, which is uniformly distributed over the unit interval [0,1], identifies the consumer's type and measures the additional wtp of consumer *x* for the system. We consider a population of mass 1 of heterogeneous consumers. Parameter β ($\beta > 1$) measures the incremental wtp for the bundle, while parameter γ ($\gamma > 1$) measures the incremental wtp related to firm 2's quality investment.[15] Henceforth, we assume $\gamma > \beta$. Finally, p_A denotes the price of the monopoly component A, p_{Bi} the price of component B set by firm *i* (*i*=1, 2), and p_{AB} the price of the bundle.

We focus on market sharing equilibria with partial market participation, where low-wtp consumers may not be active. Under technological bundling, this means that $V \in (0,1)$ and $\gamma \leq \bar{\gamma}$, where the expression of $\bar{\gamma}$ is obtained in the proof of Proposition 4 (see Appendix 1, which reports the proofs of all propositions).[16] We also assume $F \in \left(0, F^{ah}\right]$, where $F^{ah} = (\gamma - 1)/4$ is the critical value of the sunk cost that reduces firm 2's profit to zero when it invests under stand-alone selling. This means that investing is always feasible in the most favourable scenario to firm 2.

We define a game of complete information in the following three stages.

Stage 1. Firm 1 chooses whether or not to bundle products (we use superscript *b* to denote firm 1's partial mixed bundling strategy, and *a* to denote stand-alone selling).

Stage 2. Firm 2 chooses whether or not to invest in product quality (we use superscript *h* to denote firm 2's high-quality production, and *l* to denote low-quality production).

[15] The multiplicative model specification entails that high-wtp users value quality or time more than low-wtp users.

[16] For $V \leq 0$, firm 1 would monopolize market B both under stand-alone selling with a high-quality rival firm and under product bundling with a low-quality rival. For $V \geq 1$, there would be full market participation under stand-alone selling. For $\gamma > \bar{\gamma}$, firm 1 would prefer to exit market B under stand-alone selling with a high-quality rival.

Stage 3. Firms simultaneously set prices.[17]

In this section, we consider the case where firm 1 can freely bundle products (we refer to this case as the *do-nothing* scenario). In section 5, we will consider the case where firm 1's bundled offer is subject to a price test. We solve the game backwards.

3.2 Price competition

At stage 3, firms compete in prices given firm 1's choice whether or not to bundle (stage 1) and firm 2's choice whether or not to invest (stage 2). We thus have to analyze four different subgames.

3.2.1 Stand-alone selling and low-quality production

Assume that the two products are sold separately by firm 1, and that firm 2 is low-quality. Thus, firm 1's profit is $\pi_1 = p_{B1}q_{S1} + p_A(q_{S1} + q_{S2})$ and firm 2's profit is $\pi_2 = p_{B2}q_{S2}$, where q_{Si} denotes the quantity sold of system *i* (*i*=1, 2).

Since firms provide perfect substitutes in market B, then product B is priced at marginal cost (i.e. $p_{B1}^{al} = p_{B2}^{al} = 0$), while firm 1 sets the monopoly price for product A, that is, $p_A^{al} = (V+1)/2$.[18] Thus, the total quantity sold is $q_{S1}^{al} + q_{S2}^{al} = (V+1)/2$. Hence, at equilibrium firm 1 achieves the monopoly profit, namely, $\pi_1^{al} = (V+1)^2/4$, while firm 2 gains $\pi_2^{al} = 0$.

3.2.2 Stand-alone selling and high-quality production

Assume that firm 1 offers the two products separately and firm 2 invests in quality. Thus, firm 1's profit is $\pi_1 = p_{B1}q_{S1} + p_A(q_{S1} + q_{S2})$, while firm 2's profit is $\pi_2 = p_{B2}q_{S2} - F$. High-wtp consumers buy system 2, while the marginal consumer (i.e. the lowest-wtp consumer to be active) is the one

[17] The timing of the game is tailored to the case of technological bundling. Under commercial bundling, it is reasonable to assume that the rival firm may decide to invest at the first stage, and the dominant firm may decide to bundle at the second stage. Our main results are robust to this change in timing.

[18] Since products are complements, then we should more properly state that the monopoly price for product A is the price that firm 1 sets for product A under stand-alone selling when the price of product B is set at cost.

who derives zero utility from buying system 1. Thus, the demand curves for system 2 and system 1 respectively are $q_{S2}^{ah}=1-\left(p_{B2}^{ah}-p_{B1}^{ah}\right)/(\gamma-1)$ and $q_{S1}^{ah}=\left(p_{B2}^{ah}-p_{B1}^{ah}\right)/(\gamma-1)-\left(p_{B1}^{ah}+p_{A}^{ah}-V\right)$.

Firms' profit maximization leads us to obtain the following equilibrium prices and profits:

$$p_{A}^{ah}=(V+1)/2 \qquad p_{B1}^{ah}=0 \qquad p_{B2}^{ah}=(\gamma-1)/2;$$

$$\pi_{1}^{ah}=(V+1)^{2}/4 \qquad \pi_{2}^{ah}=(\gamma-1)/4-F,$$

where the value of p_{B1}^{ah} is a corner solution given by the binding non-negativity constraint on that price,[19] while the corresponding quantities are $q_{S1}^{ah}=V/2$ and $q_{S2}^{ah}=1/2$.

As expected, firm 2's price for product B (and firm 2's profit) rises with *γ*. Although firm 1's prices (and profit) are the same as when firm 2 is low-quality, the rationale for setting these prices is quite different. If firm 2 is low-quality then firm 1 is not able to gain from products A and B being perfect complements, since there is Bertrand competition with homogeneous products in market B. Conversely, if firm 2 is high-quality then firm 1 can take advantage of product complementarity to the extent that product B is not priced below cost.

3.2.3 Product bundling and low-quality production

If firm 1 bundles and firm 2 is low-quality, then high-wtp consumers buy system 1. Firm 1's profit is $\pi_1=p_{AB}q_{S1}+p_{A}q_{S2}$ and firm 2's profit is $\pi_2=p_{B2}q_{S2}$. Demand curves for system 1 and system 2 respectively are $q_{S1}^{bl}=1-\left(p_{AB}^{bl}-p_{B2}^{bl}-p_{A}^{bl}\right)/(\beta-1)$ and $q_{S2}^{bl}=\left(p_{AB}^{bl}-p_{B2}^{bl}-p_{A}^{bl}\right)/(\beta-1)-\left(p_{B2}^{bl}+p_{A}^{bl}-V\right)$.

[19] Since marginal costs are normalized to zero, then a zero price is a cost-oriented price. If we relax non-negativity constraints on prices, then we find that the dominant firm would set a below-cost price in market B and subsidize the competitive component with profit from the monopoly component. Thus, firm 1 would achieve a virtual tie on complementary products. However, in so doing the dominant firm would restrict competition and the rival firm's ability to invest in quality. Hence, firm 1's strategy would be subject to antitrust scrutiny. We can prove that, in our model, this strategy would be detrimental for consumer surplus and social welfare. Consequently, it is reasonable to assume that, in our full information setting, to prevent antitrust sanctions firm 1 does not set a below-cost price in market B under stand-alone selling. Removing this assumption would not significantly restrict the scope of the results (see footnote 20).

First-order conditions of profit maximization give the following equilibrium prices and profits:

$$p_{AB}^{bl} = (V+\beta)/2 \qquad p_A^{bl} = \left(V(1+2\beta)+3\beta\right)/6\beta \qquad p_{B2}^{bl} = V(\beta-1)/3\beta\,;$$

$$\pi_1^{bl} = \left(18V\beta+9\beta^2+V^2(5+4\beta)\right)/36\beta \qquad \pi_2^{bl} = V^2(\beta-1)/9\beta\,,$$

while the corresponding quantities are $q_{S1}^{bl} = (V+3\beta)/6\beta$ and $q_{S2}^{bl} = V/3$.

At equilibrium, the price of the bundle, the price of system 2 (i.e. $p_{S2}^{bl} = p_A^{bl} + p_{B2}^{bl}$) and the price of firm 2's component B rise with *β*, while the price of the monopoly component decreases with *β*. Both firms' profits rise with *β*. It is worth noting that the implicit price of product B in the bundle is always above cost, that is, the margin $\Delta^{bl} = p_{AB}^{bl} - p_A^{bl}$ is always positive.

3.2.4 Product bundling and high-quality production

If firm 1 bundles and firm 2 is high-quality then, since $\gamma > \beta$, high-wtp consumers buy system 2. Firm 1's profit is $\pi_1 = p_{AB}q_{S1} + p_A q_{S2}$ and firm 2's profit is $\pi_2 = p_{B2}q_{S2} - F$. Demand curves for systems 2 and 1 respectively are $q_{S2}^{bh} = 1-\left(p_{B2}^{bh}+p_A^{bh}-p_{AB}^{bh}\right)/(\gamma-\beta)$ and $q_{S1}^{bh} = \left(p_{B2}^{bh}+p_A^{bh}-p_{AB}^{bh}\right)/(\gamma-\beta)-\left(p_{AB}^{bh}-V\right)/\beta$.

First-order conditions of profit maximization give the following equilibrium prices and profits:

$$p_{AB}^{bh} = (V+\beta)/2 \qquad p_A^{bh} = (3V+\beta+2\gamma)/6 \qquad p_{B2}^{bh} = (\gamma-\beta)/3\,;$$

$$\pi_1^{bh} = \left(18V\beta+9V^2+5\beta^2+4\beta\gamma\right)/36\beta \qquad \pi_2^{bh} = (\gamma-\beta)/9-F\,,$$

while the corresponding quantities are $q_{S1}^{bh} = (3V+\beta)/6\beta$ and $q_{S2}^{bh} = 1/3$.

At equilibrium, the bundle price and the stand-alone monopoly component price rise with *β*. Contrary to the preceding case, firm 2's component price and the price of system 2 decrease with *β*. In addition, the stand-alone monopoly component price and firm 2's component price rise with *γ*.

Since bundling raises consumers' wtp for system 1, then we have that firm 1 sets a higher price for the system than the sum of component prices under stand-alone selling, regardless of firm 2's product choice. This finding is different from the conventional case with no efficiency gains from bundling, where the dominant firm sets a bundled rebate to induce consumers to buy the bundle.

Given that $\gamma > \beta$, we find that $p_{AB}^{bh} < p_{A}^{bh}$, so as $\Delta^{bh} = p_{AB}^{bh} - p_{A}^{bh} < 0$. Thus, technological bundling enables firm 1 to evade the non-negativity constraint on the price of product B that it has to fulfil under stand-alone selling.[20] If the bundle is technological and firm 2 invests, then the implicit price of product B within the bundle is below cost. Hence, to persuade some consumers to buy a lower quality system than the one including the rival's component, firm 1 subsidizes the competitive component with the monopoly one. It is worth noting that subsidization occurs at no loss to firm 1.

As expected, firm 2's profit increases with γ and decreases with β. Less intuitively, firm 1's profit may increase or decrease with β. Indeed, the demand for the bundle shrinks when β rises ($\partial q_{S1}^{bh} / \partial \beta = -V / 2\beta^2 < 0$). Thus, the negative effect of β on demand (the higher the value of V, the stronger the negative effect) may offset the positive effect of β on prices. Note that firm 1's profit rises with γ, even though a higher γ provides a competitive advantage to system 2. The motivation is that consumers always have to buy the monopoly component A jointly with firm 2's product.

3.3 Firms' choices about bundling and investment

In this section, first we analyze firm 2's choice about quality investment (stage two), and then firm 1's choice about product bundling (stage one).

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[20] This finding is tailored to the case of technological bundling. If the bundle is commercial, then firm 1 cannot set a higher price for the monopoly component than for the bundle. In fact, high-wtp consumers who intend to use firm 2's component would buy the entire system from firm 1 and then disentangle it to use only the monopoly component. It follows that, at equilibrium, the constraint $p_{AB}^{bh} \geq p_{A}^{bh}$ is binding on firm 1. We thus find $p_{AB}^{bh} = p_{A}^{bh} = (V + \beta)/2$ and $p_{B2}^{bh} = (\gamma - \beta)/2$, while the corresponding quantities are $q_{S1}^{bh} = V/2\beta$ and $q_{S2}^{bh} = 1/2$. Compared with technological bundling, the bundle price is the same while the price of system 2 decreases (where the stand-alone monopoly component price decreases and firm 2's component price rises). Moreover, the quantity sold by firm 2 rises while the quantity sold by firm 1 decreases. This entails that firm 2's profit rises while firm 1's profit decreases.

3.3.1 The rival firm's choice

At the second stage, firm 2 decides whether to provide low or high quality, depending on whether or not firm 1 bundles products at the first stage. If firm 1 opts for stand-alone selling, then firm 2 always invests when it is feasible. Indeed, we find:

$$\pi_2^{ah} \geq \pi_2^{al} \quad \text{for } F \leq F^{ah} \text{ and } \gamma > 1 .$$

If firm 1 bundles then firm 2 chooses to invest provided that the sunk cost of investment is sufficiently low, and consumers' incremental wtp for quality is high enough. In fact, we have:

$$\pi_2^{bh} \geq \pi_2^{bl} \quad \text{for } F \leq F' \text{ and } \gamma > \gamma' ,$$

where $F' = \left(\beta(\gamma-\beta) - V^2(\beta-1)\right)/9\beta$ and $\gamma' = \left(V^2(\beta-1)+\beta^2\right)/\beta > 1$.

We find that $F' < F^{bh}$, where $F^{bh} = (\gamma-\beta)/9$ is the critical value of the sunk cost that reduces firm 2's profit to zero when it invests as a response to firm 1's bundle. Differently from the case of stand-alone selling, if firm 1 bundles then firm 2 may choose to produce low quality even when producing high quality would provide firm 2 with a positive profit.

Since consumers value firm 1's bundle, then under product bundling it is more difficult for firm 2 to attain the necessary scale to invest. Indeed, we find that $q_{S2}^{ah} > q_{S2}^{bh}$ and $p_{B2}^{ah} > p_{B2}^{bh}$. This entails that $F^{bh} < F^{ah}$. It follows that $F' < F^{ah}$. Thus, we can state the following proposition.

Proposition 1. Product bundling reduces the rival firm's ability to invest in quality.

3.3.2 The dominant firm's choice and equilibrium of the game

At the first stage, firm 1 decides whether or not to bundle products while anticipating the outcomes of stages 2 and 3. Proposition 2 shows that product bundling is a profitable strategy for firm 1 independent of firm 2's choice.[21] Thus, bundling is a credible strategy.

When the rival firm provides low quality, bundling raises firm 1's profit since it introduces vertical differentiation between systems and softens price competition. In such a case, product bundling also benefits the low-quality rival firm.

When the rival firm invests in quality, bundling reduces vertical differentiation between systems, but enables firm 1 to gain from price discrimination. Indeed, firm 1 sets a high stand-alone price for the monopoly component and a relatively low price for the bundle. This provides firm 1 with a mechanism to attract more consumers to the bundle, while concurrently extracting surplus from high-wtp consumers buying system 2. Since those consumers have to buy the monopoly component from firm 1, then raising the stand-alone price of that component is in a sense a raising rival's cost strategy. Therefore, product bundling harms the high-quality rival firm.

Proposition 2. Product bundling is the preferred strategy of the dominant firm.

Since firm 1 always chooses to bundle, then there are only two possible equilibria of the game: bundling with low-quality, or with high-quality production. Corollary 1 follows from section 3.3.1.

Corollary 1. At the equilibrium of the game, the dominant firm bundles products. If the sunk investment cost is sufficiently low, and the incremental wtp for quality is high enough then the rival firm provides high quality, otherwise it provides low quality.

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[21] If $\beta = 1$, then bundling is still a profitable strategy, but the case of commercial bundling cannot be distinguished from stand-alone selling. If $\beta > 1$, but we relax non-negativity price constraints under stand-alone selling, then technological bundling is a profitable strategy provided that $V \leq \sqrt{5}/3$, or $V > \sqrt{5}/3$ and $\beta \geq 9V^2/5$. On the other hand, if firm 1 incurs a fixed cost of bundling *K*, then technological bundling is a profitable strategy as long as $K \leq \min\{K_1, K_2\}$, where $K_1 = (\beta(5\beta + 4\gamma - 9) - 9V^2(\beta - 1))/36\beta$ and $K_2 = (9\beta - 5V^2)(\beta - 1)/36\beta$ derive from comparing firm 1's profit respectively when firm 2 is high-quality and when is low-quality.

4 Welfare analysis

In this section, we assess welfare implications of product bundling. We define social welfare *W* as the sum of consumer surplus *CS* and firms' profits, namely, $W = CS + \pi_1 + \pi_2$. Consumer surplus is defined as $CS = \int_{ind}^{1} U_{Sj} dx + \int_{mar}^{ind} U_{Si} dx$, where *ind* is the indifferent consumer, that is, the consumer for which $U_{Si} = U_{Sj}$, and *mar* is the marginal consumer, that is, the consumer for which $U_{Si} = 0$. System S_i, $i \in \{1, 2\}$, is system 1 when firm 2 is high-quality, and is system 2 when firm 2 is low-quality, while system S_j, $j \in \{1, 2\}$, is such that $j \neq i$.[22]

In our model, bundling has no *a priori* clear-cut effects on welfare. In fact, firm 1's bundle raises consumer gross surplus, but it is also a price discrimination device. Moreover, bundling raises firm 1's profit, but reduces the high-quality rival's profit. We solve this potential conflict largely against bundling. First, we show that bundling reduces consumer surplus (Proposition 3). Indeed, firm 1's bundle reduces market participation. When firm 2 invests, bundling extracts surplus from high-wtp consumers buying the high-quality system, and induces some consumers to prefer the low-quality system. When investment is blockaded, consumers have a lower quality system at their disposal.

Proposition 3. Consumer surplus is higher under stand-alone selling than under product bundling.

Then we show that, if investment is viable when firm 1 bundles (namely, if $F \leq F^{bh} < F^{ah}$), then bundling negatively affects welfare. Indeed, bundling harms the high-quality rival firm, and may even deny firm 2 the necessary scale to invest in quality. Even if firm 1's profit rises, this is not enough to offset the loss in consumer surplus and firm 2's profit. Nonetheless, we show that, when $F > F^{bh}$, there are some cases where bundling improves welfare. These occur since firm 1's bundle

[22] Under stand-alone selling, if firm 2 is low-quality then systems are perfect substitutes, so that the indifferent consumer is indeterminate. Thus, consumer surplus can be rewritten as $CS = \int_{mar}^{1} U_{S1}^{al} dx = \int_{mar}^{1} U_{S2}^{al} dx$.

prevents the rival firm from making inefficient investment, which would take place under stand-alone selling (i.e. if bundling is prohibited). Proposition 4 summarizes the results.

Proposition 4. If quality investment is feasible under product bundling, then welfare is higher under stand-alone selling than with bundling. Otherwise welfare is higher with bundling when the sunk cost of investment is high enough, while the incremental wtp for quality is sufficiently low.

We have shown that firm 1's bundle reduces firm 2's ability to invest (Proposition 1). Since welfare implications depend on the investment cost and consumers' valuation of quality, then a *per se* rule against bundling is not justified. Indeed, antitrust agencies can better adopt a rule of reason standard. In this framework, as we will show in the following section, they can effectively investigate possible anticompetitive effects of bundling by using a suitable price test.

5 A price test for bundled offers

In this section, we introduce a simple price test that controls the stand-alone price of the monopoly component under product bundling. Basically, this test requires that firm 1 do not raise the price of component A under product bundling over the monopoly price of that component so as to limit firm 2's market share when it is high-quality, or blockade firm 2's investment at all.

Formally, the test imposes that $p_A^{bk} \le (1+V)/2$, $k \in \{l,h\}$, where $(1+V)/2$ is the monopoly price of component A, provided that the price of component B is cost-oriented. Note that, in our stylized model, this is the same price as firm 1 sets under stand-alone selling (sections 3.2.1 and 3.2.2).[23]

In what follows, we show that the proposed test preserves efficiencies from both bundling and quality investment, provided that it is socially beneficial. We also show that such test does not comply with the logic of predatory pricing.

[23] In the absence of a reliable estimate of the monopoly price of product A (given a cost-oriented price of product B), the effectiveness of the test depends on monitoring firm 1's prices before and after the introduction of the bundled offer.

5.1 Equilibrium under the price test regime

Assume that firm 1's bundled offer is subject to the price test (superscript *t* denotes the test regime) and firm 2 is low-quality. In such a case, the price test is not binding. If firm 2 is high-quality, then from constrained profit maximization we obtain the following equilibrium prices and profits:

$$p_{AB}^{th} = \left(\beta(2\beta+V-3)-2\gamma(2V+\beta)\right)/2(\beta-4\gamma)$$

$$p_{A}^{th} = (1+V)/2 \qquad p_{B2}^{th} = (\beta-\gamma)(2\gamma-1)/(\beta-4\gamma);$$

$$\pi_1^{th} = \left(\beta^2(1+V)(V+2\beta-1)-4\gamma\left(\beta\left(2+2V^2+4V\beta+\beta^2\right)+\gamma\left(4V^2+8V\beta+4\beta+\beta^2\right)\right)\right)/4\beta(\beta-4\gamma)^2$$

$$\pi_2^{th} = (\gamma-\beta)\left(4\gamma(\gamma-1)+1\right)/(\beta-4\gamma)^2,$$

while quantities are $q_{S1}^{th} = \left(V(\beta-4\gamma)+\beta(1-2\gamma)\right)/2\beta(\beta-4\gamma)$ and $q_{S2}^{th} = (1-2\gamma)/(\beta-4\gamma)$.[24]

We find that, compared with the do-nothing scenario, the prices of both firm 1's bundle and of system 2 decrease under the price test regime. Consequently, there is higher market participation. We find that the stand-alone price of the monopoly component decreases, while the price of firm 2's superior component increases, as well as the implicit price of product B within the bundle. We also find that firm 2's profit rises under the test regime. This means that applying the price test improves the rival firm's ability to invest in quality.

Clearly, since firm 1 acts in a constrained environment then it earns lower profit than when it can freely set prices. Nonetheless, we find that product bundling is still the preferred strategy of firm 1 under the test regime. Proposition 5 summarizes the results.

Proposition 5. Under the test regime, product bundling is the preferred strategy of the dominant firm. Moreover, the rival firm has a higher ability to invest compared with the do-nothing scenario.

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[24] For $1<\beta\leq 2$, we need to ensure that $V\in\left(0,\beta(3-2\beta+2\gamma)\right)/(4\gamma-\beta)$ holds to have market sharing equilibria with partial market participation under technological bundling, where the upper bound on *V* is not lower than $1/2$.

5.2 Welfare effects of the price test regime

We show that, given that the rival firm invests under the price test regime, both consumer surplus and social welfare are higher when the price test is active than when is not (Proposition 6). First, assume that firm 2 invests both under the test regime and in the do-nothing scenario. In such a case, the price test enables firm 2 to keep more rents from investment, and consumers to retain more surplus. Although firm 1 is worse off, we find that the net welfare effect is positive. Now, assume that firm 2 is high-quality under the test regime, but is low-quality in the do-nothing scenario. Consumer surplus rises under the test regime since the bundle price is lower and there is a higher demand for the high-quality system. Clearly, firm 2's profit rises under the test regime, while firm 1 can be better off (when β is low and γ is high, as in the do-nothing scenario) or worse off (for the remaining parameter values). In any case, we find that the net welfare effect is positive.[25]

Proposition 6. Given that the rival firm invests under the price test regime, both consumer surplus and social welfare are higher when the price test is active than when is not.

The results obtained show that social welfare is higher (or not lower) when the price test is active than when is not, while it may be higher when firm 1 freely sets its bundled offer than when bundling is prohibited. This entails that, in a world with asymmetric information, prohibiting bundling may be socially costly since an authority faces a not negligible risk of error. On the other hand, a price test regime is a less intrusive and beneficial remedy.

Having said that, let us compare the welfare effects of the price test regime with the alternative case of a ban on bundling. We find that, when bundled offers are prohibited, firm 2 manages to invest in more cases. Indeed, we can easily check that both $\pi_2^{bh} < \pi_2^{th} < \pi_2^{ah}$ and $\pi_2^{bl} = \pi_2^{tl} > \pi_2^{al}$ hold. Nonetheless we show that, when firm 2 invests under the test regime, both consumer surplus and

[25] When firm 2 chooses low-quality production both with and without the price test, social welfare is not affected.

welfare are higher than when bundling is prohibited. Indeed, the price of system 2 decreases so as high-wtp consumers retain more surplus, while low-wtp consumers benefit from efficiency gains from bundling. Since bundling is a profitable strategy for firm 1, then firm 1 is worse off when bundling is prohibited. Although firm 2 is better off with a ban on bundling, this does not outweigh the loss in consumer surplus and firm 1's profit.[26] Thus, we can state the following proposition.

Proposition 7. Given that the rival firm invests under the price test regime, both consumer surplus and social welfare are higher than in the case when there is a ban on bundling.

5.3 Policy implications

Antitrust agencies in Europe and in the US generally employ price-cost tests that follow the logic of predatory pricing to detect restriction of competition due to tying and bundling. Under multiproduct pricing, a crucial issue is the aggregation level of the price test. When there is bundle to bundle competition the test may be applied at the bundle level, otherwise a disaggregated test should be preferred. In the latter case, bundling is deemed not to be anticompetitive when an equally efficient competitor offering only some of the components can compete profitably against the dominant firm's bundle. Thus, authorities will usually not intervene if the implicit price of each product in the bundle remains above the dominant firm's long run average incremental cost (see e.g. EC, 2008).[27]

We have shown that, in our model, all bundled offers are such that the bundle price exceeds the cost of providing the bundle, so that they would pass a predatory test at the bundle level. However, these offers might allow the dominant firm to blockade efficient investment by a specialized rival.[28]

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[26] Assume that firm 2 does not invest under the test regime. If firm 2 invests when bundling is prohibited then consumer surplus rises, but social welfare can be higher or lower. Thus, a ban on bundling may allow some inefficient investment.

[27] Price tests for bundled offers in regulated electronic communications markets follow the same line of reasoning, but the relevant cost is that of a *reasonably efficient* rather than equally efficient competitor (see e.g. ERG, 2009).

[28] The case when bundling achieves foreclosure of an efficient single-product rival without pricing below cost is known as *no cost predation* (see e.g. Nalebuff, 2005). In our case, the rival remains active, but is low- instead of high-quality.

In order to prevent this outcome it is necessary to apply a disaggregated test that controls the implicit price of the competitive component in the bundle. In this framework, a predatory pricing test would force a margin that is not below firm 1's average incremental cost of producing the complementary component. Thus, in our setting a predatory pricing test would impose the dominant firm to set a zero margin, independent of β.

It is worth noting that our test is not consistent with a predatory pricing approach to bundling. Indeed, assume that firm 2 invests under our test, and let $\Delta^{th} = p_{AB}^{th} - p_{A}^{th}$ be the related margin between the bundle price and the stand-alone price of the monopoly component (i.e., the implicit price of product B in the bundle). We find that $\Delta^{th} < 0$ when $1 < \beta < 2$,[29] while $\Delta^{th} \geq 0$ when $\beta \geq 2$. Thus, when the incremental wtp for the bundle is low, firm 2 can effectively invest and provide a superior complementary component even if firm 1 sets an aggressive price for the bundle. On the other hand, when the incremental wtp for the bundle is high enough, a strictly positive margin is necessary to create room for firm 2's efficient investment.

It follows that, in our setting, using a predatory pricing test is not theoretically grounded, since such test does not take account of vertical product differentiation. Indeed, it is not clear what *equally efficient competitor* means when products are vertically differentiated. Moreover, the competitive problem here is not related to market foreclosure but to limiting, or preventing technology adoption (although both issues concern scale, they are different in nature and effects).

Thus, it is not surprising that applying such test may be socially detrimental in our model. This

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[29] This case is ruled out under commercial bundling. If the bundle is commercial, then, when $1 < \beta < 2$, the constraint $p_{AB}^{bh} \geq p_{A}^{bh}$ is binding both on firm 1 and the public agency. We thus find that, if the price test is active, then prices in this region are $p_{AB}^{bh} = p_{A}^{bh} = (1+\beta)/2$ and $p_{B2}^{bh} = (\gamma - \beta)/2$, while the corresponding quantities are $q_{S1}^{bh} = (V + \beta - 1)/2\beta$ and $q_{S2}^{bh} = 1/2$. Compared with technological bundling, when $1 < \beta < 2$, the stand-alone monopoly component price is the same, while the bundle price, firm 2's component price, and the price of system 2 do increase. Furthermore, the quantity sold by firm 2 rises while the quantity sold by firm 1 decreases, with a negative net effect on market participation. Consequently, firm 1's profit decreases while firm 2's profit increases.

is indeed the case when the incremental wtp for the bundle is low, and passing the predatory pricing test implies setting an implicit price of product B in the bundle that is as high as it induces inefficient investment. We also show that, when firm 2 invests under our test, it is socially desirable to perform the proposed test instead of a predatory pricing test. Since the latter controls only the implicit price of product B in the bundle then it allows higher prices relative to the proposed test, with a negative effect on market participation. Proposition 8 summarizes the results.

Proposition 8. Compared with the do-nothing scenario, a predatory pricing test reduces welfare when it induces inefficient investment. Furthermore, given that the rival firm invests under the proposed test, consumer surplus and welfare are higher than under a predatory pricing test.

Since in our model firm 1's bundle raises consumers' valuation, and thus provides firm 1 with an effective tool to price discriminate, then it would be theoretically appropriate to set a stricter cap on the monopoly component stand-alone price under product bundling relative to stand-alone selling. Assume that the price test imposes $p_A^{bk} \le (1+V)/2-\mu$, $k \in \{l,h\}$, where $0<\mu\le(1+V)/2$. We can prove that consumer surplus and social welfare rise with μ in the feasible region, provided that firm 1 still bundles at equilibrium.[30] However, since the "optimal" μ inevitably depends on demand parameters such as β and γ, then it would be difficult to implement such test in practice, and we do not provide additional details here.

6 Model extension: endogenous bundling strategy

We now extend firm 1's strategy space by including pure bundling (henceforth denoted as *m*), where firm 1 provides only the bundle, and complete mixed bundling (denoted as *c*), where firm 1 provides both the bundle and each component on a stand-alone basis. The main purpose is to

[30] If the price test imposes $p_A^{bk} \le (1+V)/2-\mu$, then we have $\Delta^{th} > 0$ for $\mu > 1/4$. Thus, when there is a sufficiently tight cap on the stand-alone price of product A, the implicit price of product B in the bundle is above cost.

investigate welfare effects when we endogenize firm 1's choice of bundling strategy, both in the do-nothing scenario and under the price test regime.

For simplicity, in this section we deal only with the case of technological bundling.[31] Thus, if firm 1 practices pure bundling, then firm 2 is foreclosed. If firm 1 practices complete mixed bundling, then there are two alternative cases. When firm 2 sells low quality, system 2 and the system composed by firm 1's stand-alone products are perfect substitutes purchased by low-wtp consumers, while high-wtp consumers buy the bundle. When firm 2 sells high quality, firm 2 offers the superior system while firm 1 offers the two inferior systems.[32]

First, consider the do-nothing scenario. We find that firm 1 prefers to practice mixed bundling, either partial or complete, rather than offering only a technological bundle and thus excluding the rival. Indeed, mixed bundling provides firm 1 with a price discrimination device that enables firm 1 to extract surplus from the high-quality rival and its consumers. Let $F^{ch} = 4(\gamma-\beta)(\gamma-1)^2/(3+\beta-4\gamma)^2$ be the critical value of the sunk cost that reduces firm 2's profit to zero when it invests while firm 1 practices complete mixed bundling. Note that $F^{ch} > F^{bh}$. We find that, for $F \leq F^{ch}$, firm 1 chooses partial mixed bundling and the equilibrium of the game is exactly the same as in the basic model. If $F > F^{ch}$, then firm 1 chooses complete mixed bundling and firm 2 provides low quality. Welfare implications are qualitatively the same as in the basic model. Thus, consumer surplus is higher under stand-alone selling, and so is social welfare when quality investment is feasible under complete mixed bundling (otherwise welfare may be higher under complete mixed bundling).

When the price test is active, firm 1 cannot freely price discriminate. Hence, firm 1 can find it profitable to choose pure bundling and thus exclude firm 2 when it would have invested under mixed bundling. In such a case, consumer surplus and welfare at equilibrium are at the lowest level.

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[31] See Appendix 2 for formal details about the third stage of the game.

[32] In such a case, the system composed by firm 1's stand-alone products has a positive demand when $V \in (1/2,\ 1)$ and $\gamma > (\beta - 3 + V(3+\beta))/(4V-2)$. Outside this region, firm 1's strategy collapses to partial mixed bundling.

Therefore, a public authority should require firm 1 to provide the monopoly component on a stand-alone basis.[33] If this occurs, then firm 1 may opt for complete rather than partial mixed bundling in some cases when firm 2 invests.[34] Nonetheless, as in the basic model, both consumer surplus and social welfare are higher under the test regime than in the do-nothing scenario.

7 Concluding remarks

We have shown that product bundling is the preferred strategy of a dominant firm in a primary market that faces competition from a single-product rival firm in a complementary market. Thus, in our model product bundling does not hinge on commitment ability of the multiproduct firm. On the one hand, given that the rival firm provides a perfect substitute, bundling introduces vertical differentiation between systems of complements and thus softens price competition. On the other hand, given that the rival firm invests in improving quality of the complementary component, bundling is an effective price discrimination device to extract surplus from the rival's customers. In addition, given that there is a sunk cost of investment, the dominant firm's bundle denies scale and thus reduces the rival firm's incentives to invest. Hence, product bundling may drive high-quality systems out of the market, while creating room for low-quality alternatives.

Although we have explicitly modelled some efficiency gains from bundling, we have shown that bundling reduces consumer surplus and, when quality investment is feasible under bundled sales, social welfare. It follows that product bundling may be socially detrimental even when the rival firm is not foreclosed, and when investment is not blockaded.

Our model setting incorporates many features that have been identified as essential to build a case against bundling, due to potential harm on competition, consumers, and welfare. Nonetheless,

[33] In some countries, such as Spain and Italy, Sky initially proposed a contract that forced consumers to buy or rent the decoder jointly with its exclusive content, thus closing a potentially lucrative competitive market (which in Spain could be worth more than €900 million), but this practice was judged illegal. A similar case is being investigated in Germany.

[34] If firm 2 invests under complete mixed bundling, then the non-negativity constraint on p_{B1} in the do-nothing scenario has the same effect as the proposed test on p_A, so that we have $p_{B1} = 0$ and $p_A = (1+V)/2$.

we have found that product bundling does improve welfare when it prevents inefficient investment that would occur under stand-alone selling. It follows that a *per se* rule against bundling would not be appropriate. Indeed, prohibiting bundling would mean sacrificing related efficiencies.

We have thus considered a different scenario where the dominant firm is allowed to bundle products, but the bundled offer has to be consistent with a simple price test. Such test denies the dominant firm the possibility to strategically raise the stand-alone price of the monopoly component over the monopoly price of that component (which, in our stylized model, is exactly the price that the dominant firm sets under stand-alone selling). We have shown that such test enhances consumer surplus and welfare when it enables us to preserve efficiencies from both bundling and the rival firm's quality investment (while replicating the do-nothing scenario when the rival does not invest).

When efficiency gains from bundling are relatively low, the proposed test tolerates a margin between the bundle price and the stand-alone price of the monopoly component that is lower than the relevant cost of producing the competitive component. Conversely, if bundling creates large efficiency gains, then the test results in a strictly above-cost margin, which is essential to provide the rival firm with the correct incentives to invest. In both cases, the proposed test is in contrast with a predatory pricing test, which in our model would induce the dominant firm to set a cost-oriented margin independent of efficiencies from bundling. We have shown that, under vertical product differentiation, a predatory test is not consistent with consumer surplus or welfare maximization.

In the main part of our paper, we have focused on partial mixed bundling. Then, we have endogenized the dominant firm's choice of bundling strategy (partial mixed, complete mixed, or pure bundling). We have found that in the do-nothing scenario the dominant firm chooses mixed bundling (either partial or complete), and welfare effects are qualitatively the same as in the basic model. We have also found that under the test regime the dominant firm could profit from excluding the rival by offering only a technological bundle. It is thus socially desirable that the dominant firm be forced to provide the monopoly component on a stand-alone basis.

The results obtained suggest some policy implications. From an antitrust perspective, product bundling by a dominant firm has typically been deemed anticompetitive when used as a method of predation that deters entry or induces exit. However we have argued that, in a setting of vertically differentiated products, predatory pricing is not the correct framework to employ in the face of the dominant firm's bundle. Furthermore, it follows from our results that antitrust cases about bundling in technologically evolving industries should take account of the effects of bundling on innovation even when the rival firm remains active. Indeed, it would be possible that, due to product bundling, the rival firm has lost scale that has caused, or will cause product quality to decrease. In such cases, if antitrust policy is based on short-term pricing and related welfare effects, then it could be socially harmful in the long run. On the other hand, pursuing dynamic rather than static efficiency goals would move antitrust policy closer to regulatory principles and tools.

Appendix 1

Proof of Proposition 1. If firm 1 opts for stand-alone selling at the first stage, then at the second stage firm 2 chooses to invest when $\pi_2^{ah} - \pi_2^{al} = \pi_2^{ah} \geq 0$, that is when $F \leq F^{ah}$. If firm 1 decides to bundle, then firm 2 chooses to invest when $\pi_2^{bh} - \pi_2^{bl} = \left(\beta(\gamma - \beta) - V^2(\beta - 1)\right)/9\beta - F > 0$, that is when $F \leq F' = \left(\beta(\gamma-\beta)-V^2(\beta-1)\right)/9\beta$ and $\gamma > \gamma' = \left(V^2(\beta-1)+\beta^2\right)/\beta$, where $\gamma > \gamma'$ ensures that $F' > 0$. Since we have that $F^{ah} - F' = \left(4V^2(\beta-1)+\beta(5\gamma+4\beta-9)\right)/36\beta > 0$ and $\gamma' > 1$, then firm 1's bundle reduces the scope for firm 2's quality investment. ■

Proof of Proposition 2. Assume that firm 2 provides low quality. Then, we find that $\pi_1^{bl} - \pi_1^{al} = (\beta-1)\left(9\beta - 5V^2\right)/36\beta > 0$. Assume now that firm 2 provides high quality. Then we find that $\pi_1^{bh} - \pi_1^{ah} = \left(\beta(5\beta+4\gamma-9) - 9V^2(\beta-1)\right)/36\beta > 9(\beta-1)\left(\beta - V^2\right)/36\beta > 0$. Since firm 1 chooses to bundle products regardless of firm 2's choice, then bundling is the preferred strategy of firm 1. ■

Proof of Proposition 3. Let $F \in \left(0, F^{ah}\right]$. Consequently, firm 2 invests under stand-alone selling. We find that $CS^{ah} = \left(V\left(2+V\right)+\gamma\right)/8$, $CS^{bl} = \left(9\beta\left(2V+\beta\right)+V^{2}\left(5+4\beta\right)\right)/72\beta$ and $CS^{bh} = \left(9V\left(V+2\beta\right)+\beta\left(5\beta+4\gamma\right)\right)/72\beta$. Since we have that $CS^{ah} - CS^{bl} = \left(5V^{2}\left(\beta-1\right)+9\beta\left(\gamma-\beta\right)\right)/72\beta > 0$ and $CS^{ah} - CS^{bh} = \left(9V^{2}\left(\beta-1\right)+5\beta\left(\gamma-\beta\right)\right)/72\beta > 0$, then bundling reduces consumer surplus. ■

Proof of Proposition 4. First, assume that $F \in \left(0, F'\right]$. Then, firm 2 invests under product bundling. We find that $W^{ah} = 3\left(V\left(2+V\right)+\gamma\right)/8 - F$ and $W^{bh} = \left(27V\left(V+2\beta\right)+\beta\left(7\beta+20\gamma\right)\right)/72\beta - F$. It follows that $W^{ah} - W^{bh} = \left(27V^{2}\left(\beta-1\right)+7\beta\left(\gamma-\beta\right)\right)/72\beta > 0$. Now, let $F \in \left(F', F^{bh}\right]$. Then, although investment is viable, firm 2 provides low quality under product bundling. We find that $W^{bl} = \left(27\beta\left(2V+\beta\right)+V^{2}\left(7+20\beta\right)\right)/72\beta$. Now, let $F = F^{bh}$, that is the highest value of *F* in the feasible interval. We find that $W^{ah} - W^{bl} = \left(7V^{2}\left(\beta-1\right)+19\beta\left(\gamma-\beta\right)\right)/72\beta > 0$. Finally, let $F \in \left(F^{bh}, F^{ah}\right]$. Then, investment is not viable under product bundling. We find that $W^{bl} - W^{ah} = -\left(7V^{2}\left(\beta-1\right)+27\beta\left(\gamma-\beta\right)\right)/72\beta + F > 0$ when $F'' = \left(7V^{2}\left(\beta-1\right)+27\beta\left(\gamma-\beta\right)\right)/72\beta < F \leq F^{ah}$ and $\gamma \leq \min\{\bar{\gamma}, \bar{\bar{\gamma}}\}$, where the critical value $\bar{\bar{\gamma}} = \left(7V^{2}\left(1-\beta\right)+9\beta\left(3\beta-2\right)\right)/9\beta$ ensures that $F'' \leq F^{ah}$, while $\bar{\gamma} = \left(\left(9+10V+9V^{2}\right)+3\sqrt{9+20V+22V^{2}+20V^{3}+9V^{4}}\right)/8$ ensures market sharing equilibria under stand-alone selling when firm 2 is high-quality. We conclude that bundling raises welfare provided that *F* is high enough (and such that investment is not viable with bundling), and γ is sufficiently low. ■

Proof of Proposition 5. Assume that firm 2 provides low quality. Since the price test is not binding, then it follows from Proposition 2 that $\pi_1^{tl} = \pi_1^{bl} \geq \pi_1^{al}$. Assume now that firm 2 provides high quality. We find that $\pi_1^{th} \geq \pi_1^{ah}$ always holds. Indeed, we have that:

$$\pi_1^{th}/\pi_1^{ah} = 1 + \left(\left(\beta-1\right)\left(\beta^{2}\left(1-V^{2}\right)+8\beta\gamma\left(1+V^{2}\right)-16V^{2}\gamma^{2}\right)+4\gamma\beta^{2}\left(\gamma-\beta\right)\right)/\beta\left(1+V\right)^{2}\left(\beta-4\gamma\right)^{2} >$$

$$> 1+\left((\beta-1)\left(8\beta\gamma\left(1+V^2\right)-16V^2\gamma^2\right)+4\gamma\beta^2(\gamma-\beta)\right)/\beta(1+V)^2(\beta-4\gamma)^2 >$$
$$> 1+\left(16V^2\gamma(\beta-\gamma)(\beta-1)+4\gamma\beta^2(\gamma-\beta)\right)/\beta(1+V)^2(\beta-4\gamma)^2 =$$
$$= 1+4\gamma(\gamma-\beta)(\beta-2V)^2/\beta(1+V)^2(\beta-4\gamma)^2 > 1.$$

Thus, bundling is the preferred strategy of firm 1 independent of firm 2's choice.

If firm 2 invests, then it gets higher profit under the test regime than in the do-nothing scenario. Indeed, we find that $\pi_2^{th}-\pi_2^{bh}=(\gamma-\beta)(\beta+2\gamma-3)(10\gamma-\beta-3)/9(\beta-4\gamma)^2>0$. Since firm 2's profit is not affected when firm 2 is low-quality, then there is a region where firm 2 invests when the price test is active and does not invest when it is not. ■

Proof of Proposition 6. Assume that firm 2 provides high quality under the price test regime. Let us first consider consumer surplus. We find that:

$$CS^{th}=\left((5+V-10\gamma)(1+V-2\gamma)+16V^2\gamma^2+4\beta\gamma\left(1-2V(3+V)-4\gamma+12V\gamma+4\gamma^2\right)\right)/8\beta(\beta-4\gamma)^2.$$

If firm 2 provides high quality in the do-nothing scenario, then we find that:

$$CS^{th}-CS^{bh}=(\beta+2\gamma-3)\left(4\gamma(18V+10\gamma-3)+\beta(46\gamma-5\beta-18V-15)\right)/72(\beta-4\gamma)^2>0.$$

If firm 2 is low-quality in the do-nothing scenario, then we find that $CS^{th}\geq CS^{bl}$. Indeed, we have:

$$CS^{th}-CS^{ah}=V^2(1-\beta)/8\beta+V(\beta+2\gamma-3)/4(4\gamma-\beta)+\left(5\beta+4\gamma-\beta\gamma(20+\beta)+4\gamma^2(7\beta-4)\right)/8(\beta-4\gamma)^2>$$

$$>V^2(1-\beta)/8\beta+\left(5\beta+4\gamma-\beta\gamma(20+\beta)+4\gamma^2(7\beta-4)\right)/8(\beta-4\gamma)^2.$$

Factorizing and rearranging, the expression above can be rewritten as:

$$\left(\left((\beta-1)\left(8\gamma^2\left(\beta-V^2\right)+V^2\beta(8\gamma-\beta)\right)+(\gamma-1)\beta(5\beta\gamma-\beta-4\gamma)+15\beta^2\gamma(\gamma-1)-8V^2\gamma^2(\beta-1)-4\beta\left(\gamma^2-\beta\right)\right)/8\beta(\beta-4\gamma)^2\right)>0,$$

given that the first two terms are positive, and so is the sum of the last three terms. Since we have shown in Proposition 3 that $CS^{ah}>CS^{bl}$, then it follows that $CS^{th}>CS^{bl}$.

Let us now consider social welfare. We find that:

$$W^{th}=5\beta+4(7V-1+3\gamma)+12V^2/\beta+(\beta-2)\left(6\beta(\beta-2)+(\beta-4\gamma)(\beta-2-12V)\right)/32(\beta-4\gamma)^2-F.$$

If firm 2 provides high quality in the do-nothing scenario, then we find that:

$$W^{th}-W^{bh}=(\beta+2\gamma-3)\left((\gamma-\beta)(22\gamma+7(\gamma+\beta))+27\gamma^2+18V(4\gamma-\beta)+3(4\gamma+5\beta)\right)\big/72(\beta-4\gamma)^2>0.$$

Let $F^{th}=(\gamma-\beta)(1-2\gamma)^2\big/(\beta-4\gamma)^2$ be the critical value of the sunk cost that reduces firm 2's profit to zero when firm 1's bundled offer is subject to the price test. If firm 2 is low-quality in the do-nothing scenario, then we find that $W^{th}\geq W^{bl}$ holds for $F\leq F^{th}$. Indeed, let $F=F^{th}$, that is the highest feasible value of *F* given the assumption that firm 2 invests under the test regime. We have:

$$W^{th}-W^{bl}=\left((\beta-1)\left(20V^2(\beta-4\gamma)+27\beta^2\right)+9\beta(\gamma-\beta)(1+4\gamma)+(\gamma-1)27\beta+18V\beta(\beta+2\gamma-3)\right)\big/72\beta(4\gamma-\beta)>$$
$$>\left((\beta-1)\left(20V^2(\beta-4\gamma)+27\beta^2+27\beta+54V\beta\right)+9\beta(\gamma-\beta)(1+4\gamma)\right)\big/72\beta(4\gamma-\beta),\quad \text{since}\quad \gamma>\beta.$$

The expression above can be rewritten as:

$$\left((\beta-1)\left(20V^2\beta-80V^2(\gamma-\beta)-80V^2\beta+27\beta^2+27\beta+54V\beta\right)+9\beta(\gamma-\beta)(1+4\gamma)\right)\big/72\beta(4\gamma-\beta)>$$
$$\left((\beta-1)\left(20V^2\beta+27\beta^2\right)+9\beta(\gamma-\beta)(1+4\gamma)-80V^2(\gamma-\beta)(\beta-1)\right)\big/72\beta(4\gamma-\beta)>0.$$

We conclude that, when firm 2 invests under the test regime, consumer surplus and welfare are higher when the price test is active than when is not. ■

Proof of Proposition 7. Assume that firm 2 invests under the price test regime. This may occur for $F\in\left(0,F^{th}\right]$. Since $F^{ah}-F^{th}=\left((\gamma-1)\left(\beta^2+8\beta\gamma-4\right)-4(\beta-1)\right)\big/4(\beta-4\gamma)^2>0$, then from section 3.3.1 firm 2 would also invest under a ban on bundling. We have shown in Proposition 6 that $CS^{th}>CS^{ah}$. In addition, by some tedious algebra we obtain that:

$$W^{th}-W^{ah}=\left(4(V-1)-12V^2(\beta-1)/\beta+5\beta+(\beta-2)(\beta-2-12V)/(\beta-4\gamma)-6\beta(\beta-2)^2/(\beta-4\gamma)^2\right)\big/32>0.$$

Thus, if firm 2 invests under the test regime, then both consumer surplus and welfare are higher than in the case where bundling is prohibited. ■

Proof of Proposition 8. Assume that firm 1's bundled offer is subject to a predatory pricing test (superscript *T* denotes such test regime). If firm 2 is low-quality, then the predatory pricing test is not binding. If firm 2 is high-quality, then firms' profits respectively are $\pi_1^{Th} = (V+\beta)^2/4\beta$ and $\pi_2^{Th} = (\gamma-\beta)/4 - F$, while social welfare is $W^{Th} = 3(2V\beta + \gamma\beta + V^2)/8\beta - F$. Since we have $\pi_1^{Th} - \pi_1^{ah} = (\beta - V^2)(\beta-1)/4\beta > 0$, then bundling is the preferred strategy of firm 1. Since we also have $\pi_2^{Th} - \pi_2^{bh} = 5(\gamma-\beta)/36 > 0$, then firm 2 has a higher ability to invest compared with the do-nothing scenario. It follows that, at equilibrium, firm 2 may invest under the predatory pricing test, but not in the do-nothing scenario. One such region is found when $\gamma \in \left(\left(4V^2(\beta-1)+9\beta^2\right)/9\beta, \left(V^2(\beta-1)+\beta^2\right)/\beta \right]$ and $F \in \left(0, \left(4V^2(1-\beta)+9\beta(\gamma-\beta)\right)/36\beta\right)$. Let $\gamma = \left(V^2(\beta-1)+\beta^2\right)/\beta$ and $F = V^2(\beta-1)/10\beta$ be two parameter values in this region. Since we find that $W^{bl} - W^{Th} = V^2(\beta-1)/360\beta > 0$, then the predatory pricing test induces some inefficient investment.

Now, assume that firm 2 invests under our price test. Then, consumer surplus and welfare are higher under our price test than with the predatory pricing test. Indeed, we have that:

$CS^{th} - CS^{Th} = \left((\beta-1)(16\gamma^2 - 4\gamma + 4V\gamma - 2V\beta) + (\gamma-1)(12\beta\gamma + 16V\gamma - 5\beta) + (\gamma-\beta)(\beta\gamma - 4V)\right)/8(\beta-4\gamma)^2 > 0$, and

$W^{th} - W^{Th} = \left((\beta-1)\gamma(16\gamma + 4V - 11\beta) + 4\left(4V\gamma(\gamma-1) + \gamma(\beta\gamma-1) - V(\gamma-\beta)\right) + \beta(4\beta + \gamma + 2V - 5)\right)/8(\beta-4\gamma)^2 > 0$. ■

Appendix 2

Assume that firm 1 provides only a technological bundle. Hence, firm 2 is foreclosed from the market and the demand curve for the bundle is $q_{S1}^m = 1 + V - p_{AB}^m$. Firm 1's profit maximization leads us to obtain the equilibrium monopoly price $p_{AB}^m = (V+\beta)/2$ and profit $\pi_1^m = (V+\beta)^2/4\beta$. Consumer surplus is $CS^m = (V+\beta)^2/8\beta$ and welfare is $W^m = 3(V+\beta)^2/8\beta$.

Now, assume that firm 1 practices complete mixed bundling, and firm 2 provides low quality. We refer to firm 1's bundle by using subscript $BS1$ and to the system of stand-alone products offered by firm 1 using subscript $IS1$. Demand curves for the bundled system 1 and for the two low-quality systems as a whole respectively are $q_{BS1}^{cl} = 1 - \left(p_{AB}^{cl} - p_{B2}^{cl} - p_{A}^{cl}\right)/(\beta - 1)$ and $q_{IS1}^{cl} + q_{S2}^{cl} = \left(p_{AB}^{cl} - p_{B2}^{cl} - p_{A}^{cl}\right)/(\beta - 1) - \left(p_{B2}^{cl} + p_{A}^{cl} - V\right)$, with $p_{B1}^{cl} = p_{B2}^{cl}$. Since firms provide perfect substitutes in market B, then product B is priced at marginal cost (i.e. $p_{B1}^{cl} = p_{B2}^{cl} = 0$). First-order conditions of profit maximization give equilibrium prices $p_{AB}^{cl} = (V + \beta)/2$ and $p_{A}^{cl} = (1 + V)/2$, and profits $\pi_1^{cl} = \left(V(2 + V) + \beta\right)/4$ and $\pi_2^{cl} = 0$. Note that the implicit price of product B in the bundle, that is, the margin $\Delta^{cl} = p_{AB1}^{cl} - p_{A1}^{cl}$, is always positive. Consumer surplus is $CS^{cl} = \left(V(2 + V) + \beta\right)/8$ and welfare is $W^{cl} = 3\left(V(2 + V) + \beta\right)^2/8$.

Finally, assume that firm 1 provides complete mixed bundling, and firm 2 invests in quality. Demand curves for system 2, the bundled system 1 and the independent system 1 respectively are $q_{S2}^{ch} = 1 - \left(p_{B2}^{ch} + p_{A}^{ch} - p_{AB}^{ch}\right)/(\gamma - \beta)$, $q_{BS1}^{ch} = \left(p_{B2}^{ch} + p_{A}^{ch} - p_{AB}^{ch}\right)/(\gamma - \beta) - \left(p_{AB}^{ch} - p_{B1}^{ch} - p_{A}^{ch}\right)/(\beta - 1)$ and $q_{IS1}^{ch} = \left(p_{AB}^{ch} - p_{B1}^{ch} - p_{A}^{ch}\right)/(\beta - 1) - \left(p_{B1}^{ch} + p_{A}^{ch} - V\right)$. First-order conditions of profit maximization give equilibrium prices $p_{A}^{ch} = (1 + V)/2$, $p_{B1}^{ch} = 0$, $p_{AB}^{ch} = (1 + 2V + \beta)/4 + 3(\beta - 1)^2/4(3 + \beta - 4\gamma)$ and $p_{B2}^{ch} = 2(\gamma - \beta)(\gamma - 1)/(4\gamma - 3 - \beta)$. Note that the margin $\Delta^{ch} = p_{AB1}^{ch} - p_{A1}^{ch}$ is always positive. Hence, firms' profits are $\pi_1^{ch} = \left(9 + 2\beta + 5\beta^2 - 4\gamma\left(5 + \beta(2 + \beta)\right) + 4(3 + \beta) + \left(2V + V^2\right)(3 + \beta - 4\gamma)^2\right)/4(3 + \beta - 4\gamma)^2$ and $\pi_2^{ch} = \left((\gamma - \beta)(\gamma - 1)^2/(3 + \beta - 4\gamma)^2\right) - F$. We have that consumer surplus is:

$CS^{ch} = \left(\left(2V + V^2\right)(3 + \beta - 4\gamma)^2 - 27 + \beta^2 + 4\gamma\left(16 + \gamma(4\gamma - 13)\right) + \beta\left(26 + 4\gamma(5\gamma - 12)\right)\right)/8(3 + \beta - 4\gamma)^2$, and welfare is $W^{ch} = \left(\left(6V + 3V^2\right)(3 + \beta - 4\gamma)^2 - 9 + \beta(11\beta - 2) + 8\gamma\left(7 - \beta^2 + 6\gamma^2\right) - 4\gamma^2(23 + \beta)\right)/8(3 + \beta - 4\gamma)^2 - F$.

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