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“Anticompetitive bundling when buyers compete”

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Anticompetitive Bundling when Buyers Compete*

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Abstract

We study the profitability of bundling by an upstream firm who licenses complementary technologies to downstream competitors, and who faces a superior competitor for one of its technologies. In an otherwise standard "Chicago-style" model, we show that the existence of downstream competition can make inefficient bundling profitable. Forcing downstream firms to use a less efficient technology can soften competition, thus allowing the upstream firm to extract more profit through the licensing of its monopolized technology. Bundling is more likely to be profitable if downstream competition is intense and if technologies are strongly complementary. The mechanism requires a public commitment to bundling (e.g. technical bundling) and the unobservability of the contracts offered to downstream firms. A similar logic can make it profitable for the upstream firm to degrade the interoperability between its technologies and those of its rivals, even without foreclosing competition.

1 Introduction

Competition authorities regularly seek to assess whether a dominant firm could profitably exclude competitors through bundling, tying, or incompatibility.[1] Such concerns arise both when bundling is directly considered as an abuse of dominance, and in assessing proposed conglomerate mergers where there is a concern that the merged entity might leverage its market power by bundling products that were sold independently before the

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[1] Bundling products a and b means that they are only sold together. Tying means that a is only sold with b, but that b can be bought on its own. In the case of complementary products, incompatibility means that a can only be used with the firm's own version of product b.

merger.[2] An important step in investigating such cases is to show that there is an *incentive* to engage in the alleged anti-competitive conduct. According to the well-known Chicago critique, this is not typically the case, meaning bundling is more likely to arise because it produces efficiency gains than because it exerts an anti-competitive effect.

In this paper we revisit the Chicago argument in the common situation where the bundled products are inputs sold to competing downstream firms. We then show that, even in a very simple "textbook" treatment, the Chicago critique fails and anti-competitive bundling can be profitable under the plausible assumption that inputs are sold via secret bilateral contracts. The profitability of bundling does not depend on forcing a rival to exit the market, or on blocking entry.

Inputs sold to downstream oligopolists are often bundled, and such arrangements show up frequently in cases. For example, in the merger between General Electric and Honeywell, the parties supplied components (such as engines and avionics) used in the manufacture of aircraft. The European Commission blocked the merger in part because of concerns related to leverage through bundling these components.[3] The mergers between Intel and McAfee,[4] or between Qualcomm and NXP,[5] are more recent examples of cases where buyers were themselves competitors, and where concerns about bundling required the firms to offer behavioral commitments. In the high profile abuse cases involving Microsoft and Google, the situation was one where upstream firms licensed bundles of applications as inputs to downstream equipment manufacturers.[6]

Suppose an upstream seller of two input goods, a and b, faces competition from a superior version of b. What are the effects of a commitment to bundle the two inputs? Each buyer's profit is reduced by being forced to take the inferior version of b as part of the bundle—this is the standard Chicago effect. But the buyer's profit is *increased* if the same constraint is imposed on its competitors. We show that this second effect dominates and can suffice to make bundling profitable under plausible conditions, namely that the

[2]See for instance the European Commission Guidelines for Non-Horizontal Mergers: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2008:265:0006:0025:en:PDF, para. 91-118.

[3]Interestingly, in the appeal process, the General Court ruled that the Commission had not proven that the parties would have an incentive to bundle their products after the merger. The decision was nevertheless upheld because of horizontal concerns in some of the relevant markets.

[4]Case M.5984. Intel is a CPU and chipset producer, while McAfee is a security technology provider. Customers of both firms included desktop and laptop manufacturers.

[5]Case M.8306. Both firms sell different types of semiconductors used, among others, in mobile devices.

[6]In U.S. v. Microsoft Corp., the infringing practice forced PC manufacturers to install Internet Explorer alongside Windows. In the Google Android case (AT.40099), the licensing of Google's Play App store to phone handset manufacturers was made contingent on them also pre-installing a suite of other Google applications. Microsoft was also found to have anticompetitively bundled Windows in the EU—this time alongside Windows Media Player, and to have degraded the interoperability of its operating system (OS) with competing working group server OS by witholding information (Case T-201/04). Other papers have proposed theories of harm that could apply in these cases, and that do not rely on downstream competition (e.g. Carlton and Waldman, 2002; de Cornière and Taylor, 2021; Choi and Jeon, 2021).

producer of the superior input captures enough of the value that it creates. Bundling, although profitable, can be anti-competitive in the sense that it leads to the use of an inefficient input while also reducing industry profit, consumer surplus and total welfare.

Although the mechanism described in the previous paragraph is our main focus, there is sometimes a second force that would separately be enough to make bundling profitable. If downstream firms compete away the profits from the superior input then input choice may have a prisoner's dilemma flavor. Bundling then induces downstream firms to coordinate around an input mix that is better from the industry's point of view. If such a situation applies then bundling is guaranteed to be profitable. Although bundling increases industry profit in this case, it can nevertheless be inefficient by forcing downstream firms to use an inferior technology, thereby reducing final consumers' surplus and total welfare, so antitrust concerns remain.

To cleanly make the above logic formal, we begin in Section 2 with a very simple model in which inputs a and b are perfect complements sold via lump-sum fees. This model is akin to those typically used to demonstrate the Chicago critique; indeed, with downstream monopoly we show that the critique applies and bundling is unprofitable. However, introducing downstream competition creates the conditions for bundling to be profitable. We obtain this result using a general reduced-form setup that is relatively agnostic about the form of downstream competition, but also illustrate it using standard formulations such as Cournot, Hotelling and differentiated Bertrand (Section 3).

This analysis assumes that the supplier of a bundles its two inputs (or makes a fully incompatible with competing inputs). But a similar logic can also make a partial degradation in the interoperability between a and the rival version of b profitable (see Section 4). As with bundling, a downstream firm's profit is reduced by a small decrease in the interoperability of the inputs it uses, but increased by having the same friction imposed on its rival. The overall effect can be that the supplier of a captures more surplus when interoperability is reduced. Unlike bundling or incompatibility, a small reduction in interoperability results in downstream firms using the efficient version of b, albeit with wasteful interoperability costs.

In Section 5 we discuss extensions that allow us to test the limits of the mechanism. First (Section 5.1), we show that it is important that contracts be negotiated in secret. Indeed, if upstream firms can make public offers then new deviations become possible that impose a lower bound on profit without bundling, and the Chicago critique holds. We think the focus on secret contracts is reasonable given the widespread use of such contracts and the problems inherent in committing not to engage in secret bilateral negotiations.

In Section 5.2 we relax the perfect complementarity assumption. When inputs are sufficiently strong complements (in a sense we make precise below), the conditions for profitability of bundling are very similar to the baseline model. When complementarity is weak, or when inputs are substitutes, bundling can still be profitable but only if the prisoner's dilemma situation applies. Received wisdom holds that bundling is less likely to be profitable when products are complements because this creates strong gains from combining them in the most efficient way possible (Posner, 1976; Whinston, 1990). In our model the reverse holds: bundling is most likely to be profitable under strong complementarity. In any case, since finished goods are normally produced by combining multiple inputs in fixed proportions, we think the case with a relatively high degree of complementarity should not be that unusual.

We allow upstream firms to offer two-part tariffs in Section 5.3. To address the well-known technical challenges associated with out-of-equilibrium beliefs, we follow recent literature in adopting (a slightly extended version of) the Nash-in-Nash solution concept. We then show that our baseline results apply and bundling can be profitable. Lastly, Section 5.4 introduces competition on the market for a and shows that the results go through, provided competition on a is not too strong.

1.1 Related literature

Economists of the Chicago School (e.g. Director and Levi, 1956) criticize the so-called "leverage theory of tying", arguing that using tying or bundling to extend monopoly power would often be unprofitable. As Posner (1978) puts it: "A tie-in [. . .] is not a rational method of obtaining a second source of monopoly profits, because an increase in the price charged for the tied product will, as a first approximation, reduce the price that the purchaser is willing to pay for the tying product." In their view, tying could be better explained by a desire to price-discriminate or to exploit economies of joint production. Even though some in the Chicago School concede that leverage might be a valid concern in some cases (Bowman, 1957),[7] Robert Bork, in his influential "Antitrust paradox", writes: "the entire theory of tying arrangements as menaces to competition is completely irrational in any case", and "there is no viable theory of a means by which tying arrangements injure competition" (Bork, 1978).[8]

More recently, a number of economists have called into question the analysis of the Chicago School, by relaxing some of its assumptions (see Fumagalli et al., 2018, for a survey). Whereas the Chicago School argument takes market structure as given, several papers show that tying may deter entry in market b (Whinston, 1990; Nalebuff, 2004; Peitz, 2008), which, in the case of complementary products, may also deter subsequent entry in market a (Choi and Stefanadis, 2001; Carlton and Waldman, 2002). Our paper, in contrast, takes market structure as given. This implies, in particular, that bundling can be profitable in the short run and does not rely on a "predatory" logic of short-run

[7] Bowman (1957) gives the example of complementary products used in variable proportions. Posner (1978) also criticizes Bork's overly optimistic views about the welfare effects of price-discrimination.

[8] Leslie (2013) notes that Bork does not acknowledge Whinston (1990)'s influential theory of leverage in the second edition of his book in 1993.

losses leading to long-run monopoly position.

Some papers show that tying can soften price competition among sellers when buyers are heterogenous (Carbajo et al., 1990; Chen, 1997; Hurkens et al., 2019). In the latter paper, whether competition is softer or more intense with bundling depends on the extent of the dominant firm's advantage, and bundling can also deter entry.[9] Even though bundling leads to less intense competitive pressure, the logic is quite different in our paper as it does not rely on buyers having heterogenous preferences.

Another stream of papers highlights that contractual frictions or buyer power may prevent the dominant firm from extracting enough surplus using independent pricing, and that tying can be a way to circumvent these frictions (Greenlee et al., 2008; Choi and Jeon, 2021; de Cornière and Taylor, 2021; Chambolle and Molina, forthcoming). Our paper can be understood as belonging to this last literature insofar as we rule-out public contracts. Our contribution is then to show that this relatively mild restriction suffices to make bundling profitable via a novel mechanism when downstream buyers compete.

Our approach is reminiscent of the literature on exclusive dealing and exclusion, also structured around a Chicago/Post-Chicago opposition (see in particular Rasmusen et al., 1991; Segal and Whinston, 2000). Fumagalli and Motta (2006) argue that, under downstream Bertrand competition, exclusive contracts cannot deter entry. Abito and Wright (2008), on the other hand, find that downstream competition makes exclusion more likely (when firms use linear contracts). This relies on an exclusionary logic that is not necessary for our theory of harm to work. Simpson and Wickelgren (2007) find that, when buyers can breach an exclusive contract and pay expected damages, competition makes exclusive contracts more profitable. We do not require breach of contract for bundling to be profitable.

Similarly, our work shares some themes with the literature on vertical integration and vertical foreclosure (e.g., Hart and Tirole, 1990; Ordover et al., 1990; Allain et al., 2016). This literature focuses on situations where an upstream firm forecloses some of the firms active downstream (e.g., by refusing to supply them). This relaxes competition for the remaining downstream firms, whose profit can be extracted. In contrast, our model does not rely on (partial) foreclosure downstream. Indeed, all downstream firms in our model are supplied on equal terms, and their profit can be higher under bundling.

[9] See Matutes and Regibeau (1988) for an early analysis of competitive bundling in duopoly, and Zhou (2017) for a recent general treatment.

2 Baseline model: perfect complements, fixed fees only

2.1 Model

The market is composed of two upstream and two symmetric downstream firms. Downstream firms are labelled D_1 and D_2 and use two kinds of input, a and b, which we refer to as "technologies". Technologies a and b are used in fixed proportions and, in the baseline model, we assume that they are perfect complements: downstream firms need both technologies to operate. Upstream firm U_M is a multiproduct supplier of both kinds of technology and we denote its version of b by b_L. Upstream firm U_S only offers technology b, denoted b_H. At most one of each type of technology can be used by each downstream firm. Upstream firms make simultaneous secret take-it-or-leave-it offers which, for simplicity, take the form of fixed fees only (we relax this assumption below). Once downstream firms have chosen their technologies they compete with each other. The quality of firm D_i's technology is denoted $\theta_i \in \{0, L, H\}$, where $\theta_i = L$ when D_i uses $\{a, b_L\}$, $\theta_i = H$ when D_i uses $\{a, b_H\}$, and $\theta_i = 0$ otherwise.

We model downstream competition through the reduced form gross profit of D_i, $\pi(\theta_i, \theta_{-i})$, where θ_{-i} is the quality of the technology used by D_i's rival. Perfect complementarity implies $\pi(0, \theta_{-i}) = 0$. We additionally assume that technology b_H is superior to b_L. More precisely:

Assumption 1. (i) $\pi(H, \theta_{-i}) > \pi(L, \theta_{-i}) > 0$ for $\theta_{-i} \in \{0, H, L\}$.

(ii) $\pi(\theta_i, L) > \pi(\theta_i, H)$ for $\theta_i \in \{H, L\}$.

In words, a firm's profit is: (i) increasing in the quality of its technology, and (ii) decreasing in that of its rival. As we will see below, this is consistent with many standard models, such as Cournot competition where technologies allow firms to reduce their marginal cost or differentiated Bertrand competition where technologies reduce costs or increase quality. One class of models that do not satisfy Assumption 1 are models of vertical differentiation where consumers have heterogeneous tastes for quality (Shaked and Sutton, 1982).[10]

We consider two cases. In the first, U_M licenses its two technologies independently: it offers fixed fees F_a and F_{b_L}, and downstream firms choose which technologies to use, given U_S's offer F_{b_H}. In the second case, U_M publicly commits to bundle the two technologies, and offers a fee F_{ab_L}.

The timing is as follows:

1. U_M publicly commits to bundle or not.

[10]In these models a firm with a low quality might benefit if its rival's quality increases.

2. U_M and U_S simultaneously make secret contract offers to the downstream firms and downstream firms choose which technologies to use.

3. Downstream firms observe their competitor's technological choice. Downstream competition occurs and payoffs are realised.

Upstream firms' offers are secret, and can thus be buyer-specific. However, the decision to bundle is public and common to both downstream firms. The public nature of bundling is important, as otherwise bundling could never be optimal for U_M.[11] In practice, U_M could achieve this either through incompatibility of a and b_H, or through building a reputation for only making bundled offers.[12] In the case of bundling, we assume that if a downstream firm accepts U_M's offer, it cannot use technology b_H alongside a. In Section 5 we relax this assumption by considering the case of degraded interoperability, which could be interpreted as the downstream firm having to bear an extra cost to use b_H when b_L is already provided. The assumption that firms can observe which technology is used by their rival but not which contracts it has signed seems plausible. Information about the identity of suppliers is often more readily available than details about the sums involved.

We look for perfect Bayesian equilibria in undominated strategies. We assume that downstream firms have passive beliefs: upon receiving an out-of-equilibrium offer by an upstream firm U_j, D_i's belief about U_j's offer to D_{-i} is unchanged.[13]

2.2 Downstream monopoly

Although our main interest is the case where D_1 and D_2 compete, a useful benchmark will be the case in which there is a downstream monopoly. Denote the downstream monopolist's profit by $\pi(\theta)$ with $\pi(H) > \pi(L) > \pi(0) = 0$.

Independent pricing Suppose U_M offers a and b_L separately. We have the following Lemma:

Lemma 1. *With independent licensing and downstream monopoly, there exists a continuum of equilibria. In each equilibrium, D uses technologies a and b_H. U_M's equilibrium payoffs range from $\pi(L)$ to $\pi(H)$.*

Proof. The proof proceeds in six steps. First, in any equilibrium, D gets zero profit. Indeed, if that were not the case, U_M could increase its price for a slightly without inducing

[11] Indeed, for a fixed expected θ_{-i}, U_M and D_i's joint profit would be maximized with independent licensing, following the logic of Section 2.2.

[12] In the Android case, the Mobile Applications Distribution Agreements, whereby Google tied its application store with its search engine and browser, were public knowledge within the industry. Note that the details of revenue sharing agreements were not common knowledge, which is consistent with our assumption of secret offers.

[13] With secret fixed fees, passive beliefs are consistent: deviating in its offer to D_i does not create any new incentive for an upstream firm to also change its offer to D_{-i}.

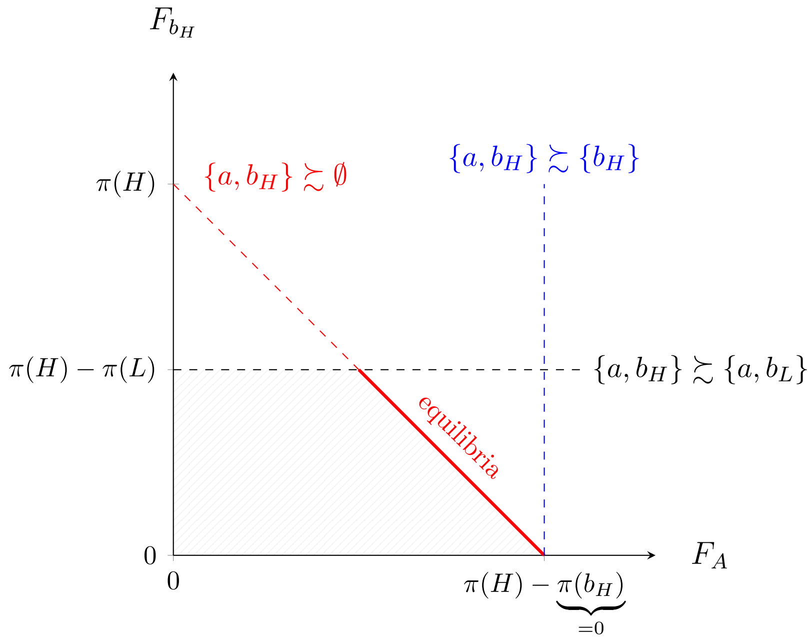

Figure 1: Without bundling, the equilibrium fees must lie below three constraints, each specifying that $\{a, b_H\}$ is preferred to some alternative technology mix. Since each firm wishes to increase its fee as much as possible, the set of equilibria lie on the diagonal frontier (solid line segment).

D to change its choice. Second, all technology fees must be non-negative. If this were not the case then there would be a deviation in which D accepts only technologies with a negative fee, earning profit of at least $\pi(0) - \sum_z F_z > 0$. Third, U_M cannot get less than $\pi(L)$: if its payoff was $\pi_M < \pi(L)$, it could deviate by offering $F_a \in (\pi_M, \pi(L))$ and $F_{b_L} = 0$, which would induce D to choose $\{a, b_L\}$ as it would give it a positive profit. Fourth, U_M cannot get more than $\pi(H)$, since this is the maximal industry profit. Fifth, we necessarily have $\theta = H$ in equilibrium. Indeed, starting from $\theta = L$ and $F_a \leq \pi(L)$, U_S can always make an offer attractive enough for D to pick b_H. Sixth, for any $\pi_M \in [\pi(L), \pi(H)]$ the following strategy profile is an equilibrium: $F_a = \pi_M$, $F_{b_H} = \pi(H) - \pi_M$, $F_{b_L} = 0$. ■

The construction of equilibrium can be understood graphically (Figure 1). Given that $\{a, b_H\}$ is used in equilibrium, the fees must be such that this combination of technologies is preferred to $\{a, b_L\}$, $\{b_H\}$, and to remaining inactive. This implies three constraints that limit fees to the shaded area. Firms will increase their fees so long as it is feasible to do so, meaning the set of equilibrium fees lie on the diagonal frontier of the feasible set.

The multiplicity of equilibria corresponds to different degrees of "price squeeze" by U_M. With perfect price squeeze, U_M extracts the whole value created by b_H (i.e. $\pi(H) - \pi(L)$) and its profit is $\pi(H)$. In the other polar case, U_M exerts no price squeeze and U_S captures the whole value it creates. Following Choi and Stefanadis (2001), we introduce a parameter $\lambda \in [0, 1]$ that measures the degree of price squeeze, and we select the equilibrium where U_M's profit is equal to $\lambda\pi(H) + (1 - \lambda)\pi(L)$.

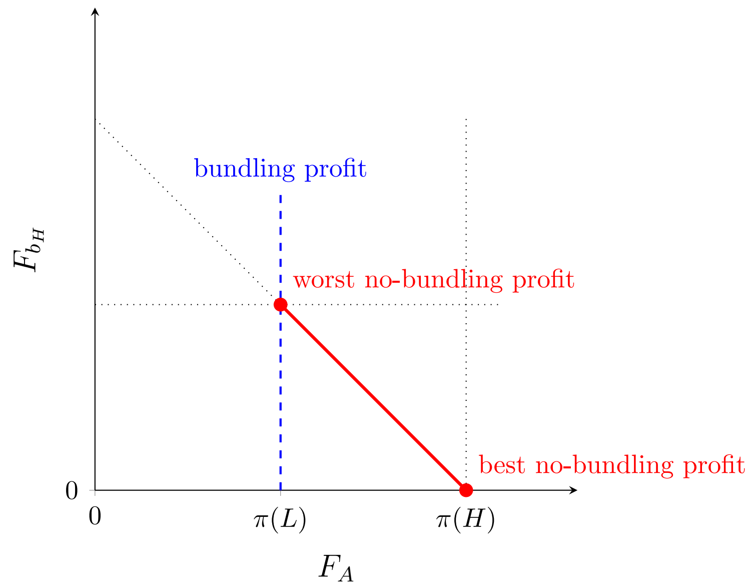

Figure 2: With downstream monopoly, U_M's profit under bundling (dashed line) coincides with its profit in the worst equilibrium under no-bundling. Bundling is never profitable.

Bundling Now suppose that U_M sells a and b_L as a bundle.

Lemma 2. *With bundling and downstream monopoly, U_M's equilibrium profit is equal to $\pi(L)$.*

Proof. With perfect complements the downstream firm's outside option is zero. The downstream firm will therefore accept the bundle so long as $\pi(L) - F_{ab_L} \geq 0$. ■

Comparison Comparing Lemmas 1 and 2, we obtain the following:

Proposition 1. *With downstream monopoly, bundling is never strictly profitable.*

The intuition of this result (illustrated in Figure 2) is the familiar single monopoly profit logic attributable to the Chicago School. The marginal value of a is higher under independent pricing than under bundling because, in the latter case, a is associated with a lower quality b technology. U_M is therefore able to achieve a (weakly) higher profit by offering its two technologies independently.

2.3 Downstream competition

Suppose now that there is competition on the downstream market.

Independent pricing Suppose that D_i expects its rival D_{-i} to use technologies of quality θ_{-i}. Given that upstream offers are secret, U_M and U_S compete to serve D_i without the ability to affect D_i's belief about θ_{-i}. Therefore the analysis is the same as in the case of monopoly, where we replace $\pi(\theta_i)$ by $\pi(\theta_i, \theta_{-i})$. By lemma 1, for any θ_{-i}, D_i

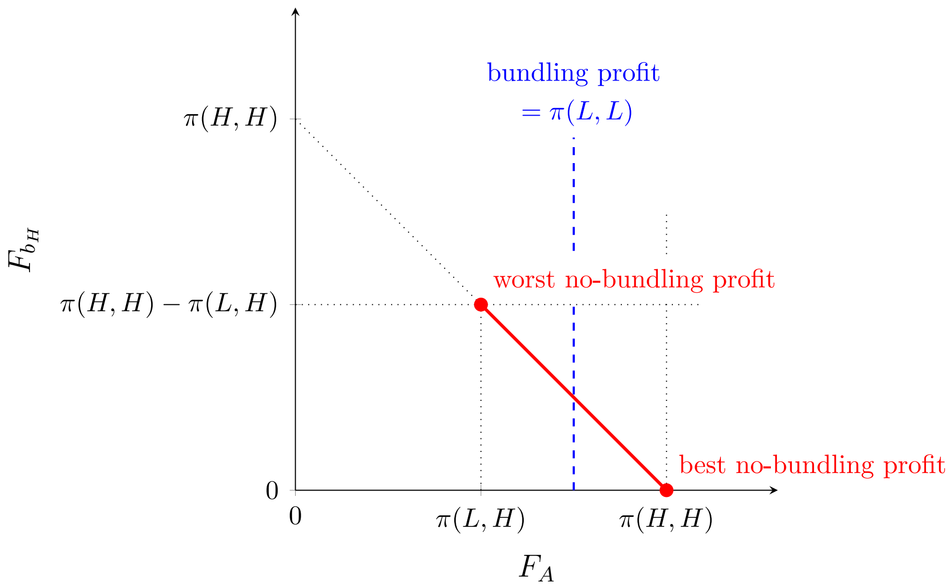

Figure 3: With downstream competition, U_M's profit under bundling (dashed line) exceeds that in equilibria that arise without bundling.

ends up using technologies a and b_H. This implies that, in equilibrium, both downstream competitors have $\theta = H$. We thus have the following Lemma:

Lemma 3. *With downstream competition and independent licensing, both downstream firms use technologies a and b_H. There are a continuum of equilibria of the subgame, with U_M's payoffs ranging from $2\pi(L, H)$ to $2\pi(H, H)$.*

As before, we select the equilibrium where the degree of price squeeze is λ, so that U_M's profit is $2\left(\lambda\pi(H, H) + (1 - \lambda)\pi(L, H)\right)$.

Bundling Consider now the subgame where U_M has decided to bundle a and b_L. Again, for a given θ_{-i}, U_M's profit with respect to D_i is $\pi(L, \theta_{-i})$. However, the key difference between the monopoly and the competition cases is that, under bundling, D_i knows that D_{-i} will use technologies a and b_L, so that $\theta_{-i} = L$.

Lemma 4. *With downstream competition and bundling, both downstream firms use technologies a and b_L. U_M's payoff is $2\pi(L, L)$*

Comparison Figure 3 shows this bundling profit relative to the no-bundling case. Comparing the previous two lemmas, we obtain:

Proposition 2. *With downstream competition, bundling is profitable if the degree of price squeeze is $\lambda < \overline{\lambda}$, where*

$$\overline{\lambda} \equiv \frac{\pi(L, L) - \pi(L, H)}{\pi(H, H) - \pi(L, H)} > 0. \tag{1}$$

Bundling has two opposite effects on D_i's gross profit. The negative effect is that bundling prevents D_i from combining a with the more efficient b_H, thus reducing a's marginal value. This effect is present irrespective of downstream competition. The positive effect is that bundling also prevents D_{-i} from using $\{a, b_H\}$. When the degree of price squeeze is low, U_M does not lose much value from the negative effect, and bundling is likely to be profitable. Because $\overline{\lambda} > 0$, bundling is necessarily profitable when the degree of price squeeze is low enough.

It is instructive to discuss two cases depending on whether $\pi(L, L)$ is larger than $\pi(H, H)$.

First, when $\pi(H, H) < \pi(L, L)$, bundling is efficient from the point of view of the industry (although typically not so from a total welfare standpoint). This corresponds to situations where the choice of technologies is a prisoner's dilemma: the best technology b_H intensifies competition and leads to profit dissipation. In this case, $\overline{\lambda} > 1$: bundling is always profitable for U_M. An example is given in Section 3.3.

When $\pi(H, H) > \pi(L, L)$, bundling reduces industry profit. This situation is more common in standard models (see examples below). Nevertheless, bundling may still be profitable when λ is small enough. The reason is that the use of bilateral contracts does not allow downstream firms to internalize the competitive externality they exert on one another: by forcing D_i to use the inefficient technology mix $\{a, b_L\}$, bundling increases the joint surplus of D_{-i} and U_M, given that U_S extracts a large fraction of the trio's joint surplus (when λ is small).

In practice, the value of λ may not be directly observable. In a market corresponding exactly to our assumptions, data about the profit margins for a and for b_H could provide an indication, but one would need information about the off-equilibrium profit $\pi(L, H)$ to assess the degree of price squeeze. An indirect way to assess λ would be to look at the degree of competition on the B market. It is easy to extend our model by adding other providers of the B technology. The price charged by U_S to downstream buyers would be constrained by the second best B technology, so that intensifying competition on the B market would facilitate price squeeze, thereby reducing the scope for profitable bundling.

An alternative approach consists not in trying to evaluate λ, but instead in studying the features of the market that affect the threshold $\overline{\lambda}$. Anticompetitive bundling would then be more likely to be profitable in markets whose characteristics imply a high value of $\overline{\lambda}$. This approach requires putting more structure on downstream competition, and this is what we do in the next section.

2.4 Asymmetric bundling

For the sake of brevity we have focused on the case of symmetric pure bundling, but it can be optimal for U_M to use asymmetric bundling, by making a bundled offer to D_1

while allowing D_2 to license the technologies independently. Such a strategy is optimal when the degree of price squeeze is intermediate, and when industry profit is higher with asymmetric technologies. More details can be found in Appendix A.

3 Examples: Cournot and Differentiated Bertrand competition

Let us now illustrate Proposition 2 using standard IO models. Putting more structure on the downstream market will allow us to study the welfare effects of bundling as well as how the profitability of bundling is affected by the intensity of downstream competition. Suppose that the cost of downstream firm i is $c(\theta_i) = \underline{c}$ if $\theta_i = \{a, b_H\}$, $c(\theta_i) = \overline{c} > \underline{c}$ if $\theta_i = \{a, b_L\}$, and $c(\theta_i) = \infty$ otherwise.

3.1 Cournot

Suppose downstream firms compete à la Cournot. To allow us to study the intensity of downstream competition, we suppose there are $n \geq 2$ downstream firms and interpret $\pi(\theta_i, \theta_{-i})$ as the profit of D_i when it uses technologies θ_i and *all* of its rivals use θ_{-i}. The analysis of the preceding section goes through under such a modification to the model and, in particular, Proposition 2 holds.

Inverse demand is $A - \sum_i q_i$, where q_i is the quantity choice of D_i. Computing the downstream equilibrium yields

$$q(\theta_i, \theta_{-i}) = \max\left\{0, \frac{A - (1-n)c(\theta_{-i}) - nc(\theta_i)}{n+1}\right\}, \tag{2}$$

implying profit

$$\pi(\theta_i, \theta_{-i}) = \begin{cases} \dfrac{(A - nc(\theta_i) + (n-1)c(\theta_{-i}))^2}{(n+1)^2} & \text{if } q(\theta_i, \theta_{-i}) > 0 \\ 0 \text{ otherwise.} \end{cases} \tag{3}$$

If $\overline{c}$ is too large relative to $\underline{c}$ then $\pi(L, H) = 0$ and the firm with the inferior b technology optimally shuts down. Given symmetric costs, an industry-wide reduction in costs increases downstream profits. We therefore have $\pi(H, H) > \pi(L, L)$, meaning $\bar{\lambda} < 1$.

More generally, substituting (3) into (1),

$$\bar{\lambda} = \begin{cases} \dfrac{(n-1)\left(2A - \overline{c} - \underline{c} - n(\overline{c} - \underline{c})\right)}{n\left(2A - n\overline{c} + (n-2)\underline{c}\right)} & \text{if } n < \dfrac{A - \underline{c}}{\overline{c} - \underline{c}} \\ \dfrac{(A - \overline{c})^2}{(A - \underline{c})^2} \text{ otherwise.} \end{cases}$$

As long as $n < \frac{A-\underline{c}}{\bar{c}-\underline{c}}$, we find that $\bar{\lambda}$ is increasing in n. In other words, it is more likely that bundling is profitable if the downstream market is more competitive.[14] We remark that although bundling is more likely to be profitable when n is large, the absolute gain to U_M from bundling[15] is non-monotonic and quasi-concave in n. Indeed, as $n \to \infty$ downstream competition becomes so intense that there is little profit for U_M to extract regardless of whether it bundles or not.

Turning to welfare, it is immediate from (2) that forcing firms to adopt the high-cost technology reduces output. It follows that bundling lowers consumer surplus and total welfare as well as total industry profit. The only agent that can possibly gain from bundling is U_M. The following proposition summarises the main insights from the Cournot model.

Proposition 3. *In the model with Cournot competition, $\bar{\lambda}$ is weakly increasing in the number of downstream firms, n. Bundling unambigiously reduces consumers surplus, total welfare, and total industry profit.*

Although the potential gain to U_M from bundling vanishes as n grows large, the same need not be true of the harms it causes. Indeed, the harm to consumers is increasing in n and there is a significant and persistent efficiency loss associated with bundling if $\bar{c} - \underline{c}$ is large.

3.2 Differentiated Bertrand competition

Suppose now that there are two firms, and that the demand for D_i is $q_i = \alpha - \beta p_i + \gamma p_{-i}$, with $\alpha, \beta > 0$. The intensity of competition is measured by $\gamma \in [0, \beta]$. Suppose that $\bar{c} - \underline{c}$ is small enough that both firms are active in the subgame where they have different costs. Straightforward calculations lead to the equilibrium profit:

$$\pi(\theta_i, \theta_{-i}) = \frac{\beta \left(\alpha(1+2\beta) - (2\beta^2 - \gamma^2)c(\theta_i) + \beta\gamma c(\theta_{-i})\right)^2}{\left(4\beta^2 - \gamma^2\right)^2}$$

Figure 4 shows $\overline{\lambda}$ as a function of γ.

The threshold under which bundling is profitable is again increasing in the intensity of downstream competition. Intuitively, as competition intensifies, the effect on D_i's profit of forcing D_{-i} to use b_L increases, which makes bundling more likely to be profitable. When both firms use the same technology, the symmetric price is $p^* \left(c(\theta), c(\theta)\right) = \frac{\alpha + \beta c(\theta)}{2\beta - \gamma}$, which is increasing in $c(\theta)$. This implies that, whenever it is used, bundling leads to higher prices and lower consumer surplus. Using the symmetric equilibrium price to compute

[14] We also find that $\bar{\lambda}$ is decreasing in $\bar{c}$ and increasing in $\underline{c}$. Bundling is more likely to be profitable when U_S's technology advantage is small.

[15] I.e., $\pi(L, L) - [\lambda\pi(H, H) - (1 - \lambda)\pi(L, H)]$.

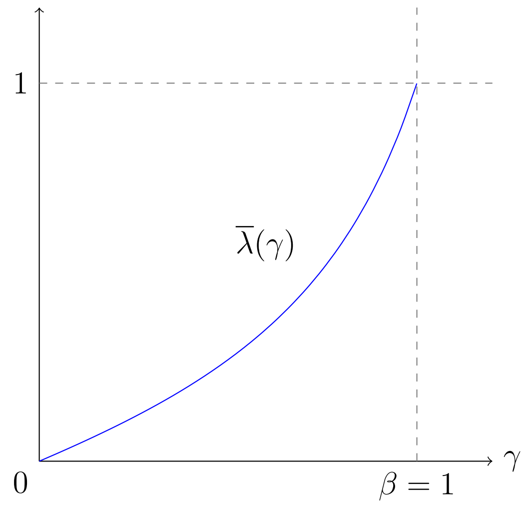

Figure 4: Threshold $\overline{\lambda}$ as a function of γ, for $\alpha = \beta = 1, \underline{c} = 0.2, \overline{c} = 0.4$. Bundling is profitable for $\lambda < \overline{\lambda}$.

downstream profit, it is easy to verify that an industry-wide reduction in marginal cost results in weakly higher industry profits (strictly higher when $\gamma < \beta$).

Two values of γ deserve a particular emphasis. When $\gamma = 0$, each firm is a downstream monopoly and bundling is never profitable ($\overline{\lambda} = 0$). This is the Chicago result described in Proposition 1. When $\gamma = \beta$, the model is equivalent to the Hotelling model, where the market is covered. In this case, the equilibrium price in the subgame where both firms have the same marginal cost c is $c + \alpha/\beta$, so that the savings from going from $\theta_1 = \theta_2 = L$ to $\theta_1 = \theta_2 = H$ are fully passed on to consumers: $\pi(L, L) = \pi(H, H)$. This implies that $\overline{\lambda} = 1$, so that bundling is always profitable. Bundling then decreases consumer surplus and total welfare, but leaves industry profits constant. The following result summarizes.

Proposition 4. *In the model with differentiated Bertrand competition, $\bar{\lambda}$ is increasing in the degree of downstream substitutability, γ. Bundling unambigiously reduces consumers surplus and total welfare. Total industry profit also falls if $\gamma < \beta$.*

Although we have couched this discussion in terms of technologies that reduce firms' marginal costs, we could alternatively have assumed that the technologies increase the quality of firms' products. Indeed, suppose that the demand for D_i is $q_i = \alpha - \beta(p_i - v(\theta_i)) + \gamma(p_{-i} - v(\theta_{-i}))$, where $v(\theta)$ is the quality that results from technology mix θ, and $p_i - v(\theta_i)$ is D_i's quality-adjusted price. Such a setup yields qualitatively identical results to those described above.

3.3 Hotelling with adjustment costs

In the previous subsection we discussed how the Hotelling model can be interpreted as a special case of differentiated Bertrand competition when $\gamma = \beta$. In that case we have $\pi(L, L) = \pi(H, H)$. A simple way to generate the strict inequality $\pi(L, L) > \pi(H, H)$

and to therefore have a proper prisoner's dilemma is to use the Hotelling model with the extra assumption that dealing with two different suppliers for a and b generates a small cost k for the downstream firm, such that $\pi(H, \theta_{-i}) - k > \pi(L, \theta_{-i})$. Absent bundling, both downstream firms would choose H and obtain a (gross) profit of $\pi(H, H) - k$. With bundling, the industry profit is $\pi(L, L) = \pi(H, H) > \pi(H, H) - k$ so that bundling is efficient from the industry point of view but harmful to consumers and total welfare.

4 Degraded interoperability

In a model with perfect complements, bundling can be interpreted as technical incompatibility between products a and b_H. But one could also imagine situations in which firm U_M could degrade the level of interoperability without making the products incompatible. Such a practice, which is more discreet than pure bundling, is a regular concern for competition authorities (see for instance the mergers between Intel and McAfee, or between Qualcomm and NXP). In some situations, the reduced interoperability could correspond to the cost of removing (or uninstalling) component b_L to replace it with b_H, or simply the cost of having a redundant component b_L which takes up physical space or digital memory.

Interestingly, the logic of Proposition 2 extends to degraded interoperability, even if downstream firms use technology b_H in equilibrium. To see this formally, suppose that U_M can degrade the interoperability between a and b_H so that using the two together leads to a profit of $\pi(\tilde{H}, \theta_{-i})$, where $\tilde{H}$ is such that $\pi(\tilde{H}, \theta_{-i}) \in (\pi(L, \theta_{-i}), \pi(H, \theta_{-i}))$ and $\pi(\theta_{-i}, \tilde{H}) \in (\pi(\theta_{-i}, H), \pi(\theta_{-i}, L))$. Using similar arguments to Lemmas 1 and 3, both downstream firms choose $\{a, b_H\}$ in equilibrium, so that their gross profit is $\pi(\tilde{H}, \tilde{H})$. There is again a multiplicity of equilibria and, selecting the one with a degree of price squeeze λ, we find that the profit of U_M is $2\left(\lambda\pi(\tilde{H}, \tilde{H}) + (1 - \lambda)\pi(L, \tilde{H})\right)$. Comparing this to the profit with perfect interoperability, $2\left(\lambda\pi(H, H) + (1 - \lambda)\pi(L, H)\right)$, we see that degraded interoperability leads to higher payoffs for U_M when λ is small (because $\pi(L, H) < \pi(L, \tilde{H})$).

Proposition 5. *There exists $\tilde{\lambda}$ such that, for $\lambda < \tilde{\lambda}$, degraded interoperability is profitable for U_M, even if it does not lead downstream firms to use b_L.*

Three remarks are in order here. First, the logic is the same as in the previous section: degrading the interoperability between a and b_H weakens the competitive pressure on D_i, and, when U_M cannot extract the value generated by b_H (i.e. λ is small), this effect dominates the loss of value of the bundle $\{a, b_H\}$. Second, we see that, for degraded interoperability to be profitable, it is not necessary for buyers to switch to b_L. What matters is that the degraded interoperability does not affect b_L (or, more generally, not as much as it affects b_H), so that the marginal value of a is at least $\pi(L, \tilde{H})$. Third, degraded interoperability is often socially inefficient, as it leads downstream firms to use an inferior technology in equilibrium. The result of this section is reminiscent of Carlton et al. (2010), who show that a firm may want to tie a product even though consumers do not use it in equilibrium. However the logic is different, since in that paper tying amounts to increasing the quality of the inferior b product, and downstream competition is not required to make the strategy profitable.

5 Discussion

In this section, we discuss how relaxing some assumptions of the baseline model would affect the results.

5.1 Public offers

In the baseline model, the offers made by upstream firms to each downstream firm are secret, i.e. not observed by its downstream rival. While such an assumption is realistic in many cases, we consider in Appendix B the alternative scenario where upstream firms' offers are public. We maintain the assumption that contracts take the form of fixed fees.

Proposition 6. *With public offers, U_M's profit is at least as large under independent pricing as under bundling.*

The possibility of offering public contracts eliminates the incentive for U_M to bundle a and b_L through two distinct channels. First, public contracts enable U_M to commit to exclusively licence a to one downstream firm. It may be the case that the industry profit under downstream monopoly is larger than under duopoly, in which case the standard Single Monopoly Profit Theorem holds and bundling is not profitable.

The argument is different when industry profits are higher under downstream duopoly (for instance due to strong tastes for variety). Then, as we show in Appendix B, public contracts enable a richer set of deviations for U_M under independent pricing. U_M could for instance induce D_1 to select $\{a, b_L\}$ and simultaneously raise the price of a for D_2, who would be willing to accept such an increase because of the degradation of D_1's quality. Such strategies put additional constraints on how much U_S can charge for b_H, and we show that U_M is then at least as well off under independent pricing as under bundling.

5.2 Strong complements, weak complements, and substitutes

The assumption that a and b are perfect complements helps us to simply demonstrate the main idea, but is not necessary for bundling to be profitable.

Suppose that $\theta_i = l$ if D_i uses b_L only, that $\theta_i = h$ if it uses b_H only.[16] Let us extend Assumption 1:

[16] The case where a is used alone is irrelevant since at least one b technology is offered for free.

Assumption 2. For any $\theta_i, \theta_{-i} \in \{0, l, h, L, H\}$,

(i) $\pi(H, \theta_{-i}) > \pi(L, \theta_{-i}) > \pi(h, \theta_{-i}) \geq \pi(l, \theta_{-i}) \geq \pi(0, \theta_{-i}) \geq 0$.

(ii) $\pi(\theta_i, L) \geq \pi(\theta_i, H)$.

Reflecting the spirit of Assumption 1, the two parts of Assumption 2 respectively say that: (i) Technology a increases profit, and b_H is superior to b_L (but not so much that $\{b_H\}$ dominates $\{a, b_L\}$). (ii) A better technology makes a rival a tougher competitor.

Two regimes deliver qualitatively different results, depending on whether a and b_H are *strong* complements, as defined below:

Definition 1. Technologies a and b_H exhibit *strong complementarity* if

$$\pi(h, H) - \pi(0, H) < \pi(H, H) - \pi(L, H).$$

Technologies are strong complements if the presence of a enhances the additional value of b_H enough. If definition 1 fails then technologies are said to be weak complements or substitutes.[17] Technologies are always strong complements if a is essential or if a and b are perfect complements. In Appendix C we establish the following result, showing that bundling can be profitable without perfect complementarity.

Proposition 7. *(i) If a and b_H are strong complements, bundling is profitable if the degree of price squeeze λ is below $\widehat{\lambda}$, defined as*

$$\widehat{\lambda} \equiv \frac{\pi(L, L) - \pi(h, L) - (\pi(L, H) - \pi(0, H))}{\pi(H, H) - \pi(h, H) - (\pi(L, H) - \pi(0, H))}.$$

(ii) Otherwise, bundling is profitable if and only if $\pi(h, L) - \pi(h, H) \leq \pi(L, L) - \pi(H, H)$.

When a and b_H are strong complements, we still have a multiplicity of equilibria under independent pricing, and bundling is profitable if U_M's ability to price squeeze is low enough (i.e., a result analogous to Proposition 2 holds). The main difference with the case of perfect complementarity (which is a special case of strong complementarity) is that the threshold $\overline{\lambda}$ may sometimes be negative, in which case bundling is not profitable.

When a and b_H are not strong complements (i.e. are either weak complements or substitutes), there is a unique equilibrium under independent pricing, in which U_M extracts the marginal value of a. Bundling can still be profitable in that case, but a necessary condition is that industry profits be higher if both downstream firms use $\{a, b_L\}$, i.e. that technology choice be a prisoners' dilemma.

An interesting albeit informal observation is that bundling is "more likely" to be profitable the higher the degree complementarity between a and b, which is in contrast to the

[17]Weak complements if $\pi(h, H) - \pi(0, H) \in (\pi(H, H) - \pi(L, H), \pi(H, H) - \pi(a, H))$; substitutes if $\pi(h, H) - \pi(0, H) > \pi(H, H) - \pi(a, H)$.

view expressed by Posner (1976) or Whinston (1990). For instance, in Whinston (1990)'s post-Chicago model, bundling is not profitable when a and b are perfect complements.[18] Heuristically, an increase in the degree of complementarity will lead to a decrease in downstream firms' outside option under bundling, thereby improving U_M's position.[19]

5.3 Two-part tariffs

In practice, contracts are often richer than the simple fixed fees of the baseline model. In Appendix D, we study a model where upstream firms make secret two-part tariff offers. With two-part tariffs, a downstream firm D_i's optimal price and its profit depend on the terms negotiated between D_{-i} and its supplier(s), and in particular on the agreed unit fees. When offers are secret, a well-known difficulty lies in specifying out-of-equilibrium beliefs should a downstream firm receive an unexpected offer. Reasonable beliefs, such as passive or wary ones, may present existence or tractability issues (Rey and Vergé, 2004).

We follow Rey and Vergé (2020)'s approach, which consists in adopting the Nash-in-Nash bargaining framework (see Collard-Wexler et al., 2019) while taking into account the effects of negotiated contracts on downstream competition. Generically, Nash-in-Nash bargaining assumes that each technology product is sold independently via bilateral Nash bargaining between an upstream and downstream firm, taking the equilibrium outcome of other bilateral negotiations as given. The fact that other bargaining outcomes are taken as given means that issues with out of equilibrium beliefs about those negotiations do not arise.

Because not all potential pairs of players end up signing a contract,[20] we rely on the Nash-in-Nash with Threat of Replacement (NNTR) concept, developed by Ho and Lee (2019) (and used by Chambolle and Molina (forthcoming) to study bundling) in order to allow for endogenous choice of trading partners.[21] We additionally extend the NNTR concept to allow the model to accommodate strong complements.

This solution concept allows us to introduce two-part tariffs in a rigorous way while producing contract outcomes consistent with received wisdom. In particular, as is standard in the vertical contracting literature, and as in Rey and Vergé (2020), equilibrium unit fees are set to the marginal cost (zero) so as to maximize the joint profit of negotiating

[18]Except if there is competition in market a, because then M cannot extract all the profit under independent pricing. Choi and Stefanadis (2001) and Carlton and Waldman (2002) describe bundling of complementary products, but the logic is to deter entry in both markets a and b.

[19]The increased complementarity also increases downstream firms' bargaining position under independent licensing, but this effect tends to be smaller.

[20]Downstream firms can only use one b technology.

[21]In Chambolle and Molina (forthcoming) a downstream firm has buyer power, which reduces the compensation necessary to induce it to buy a bundle and can suffice to make bundling profitable. Their theory assume a downstream monopoly and that inputs are substitutes or weak complements. In our model there is downstream competition and bundling is most likely to be profitable when the inputs are strong complements (see Section 5.2).

parties. The analysis is therefore equivalent to that of the baseline model where only fixed fees are used, and we obtain exactly the same conditions for bundling to be profitable.

5.4 Competition on the market for a

The analysis can also easily be extended to incorporate competition on market a, provided that U_M's advantage on market a is larger than U_S's advantage on market b. In Appendix E we show that there exists a threshold $\tilde{\lambda}$ below which bundling is profitable. Unlike in the baseline model, $\tilde{\lambda}$ may be negative, in which case bundling is never profitable. We find (using a Cournot model) that bundling is more likely to be profitable (i.e. $\tilde{\lambda}$ increases) the larger U_M's advantage on market a is. Interestingly, this is in contrast with Whinston (1990)'s result that bundling of perfectly complementary products is more likely to be profitable if strong competition on the a market prevents the dominant firm from exploiting its market power under independent pricing.

6 Conclusion

Many bundling or tying practices occur within vertical relations, where some competition exists at the downstream level. Using an otherwise canonical "Chicago School" model where the Single Monopoly Profit Theory would hold, we show that introducing downstream competition may restore the profitability of bundling for an upstream firm U_M. Bundling an inferior b technology with the monopolized a one has two opposite effects on a downstream firm's profit, by forcing the inferior technology on the firm and its rival. Two related yet distinct mechanisms can then make bundling profitable for U_M. The first mechanism relies on the inability of U_M to exert a price squeeze. When products are strongly complementary, upstream firms U_M and U_S cannot both capture their marginal value under independent pricing. If U_M is not able to price squeeze U_S, it does not profit much from downstream firm D_i using the more efficient b technology. In that case, bundling is profitable through its weakening of D_{-i}. Second, a stronger condition for bundling to be profitable, which also holds when products are not strong complements, is when the choice of the b technology constitutes a prisoners' dilemma. Bundling then forces downstream firms to coordinate on the industry-profit-maximizing technology, and the extra profit can be captured by U_M.

Implications for policy

The ability of dominant firms to exert anti-competitive effects through bundling has long been recognized. The important question is therefore whether they have an incentive to do so. This question arises when considering an allegation of abusive bundling, but also when evaluating a proposed conglomerate merger that might lead to bundling in the future. Our first implication for policy is to broaden the range of circumstances under which bundling is problematic, to include cases where it is used to soften downstream rivalry (without any need to deter entry or induce exit). Under such circumstances, the paper provides a theory of harm that can be used to justify prevention of abusive bundling or to support a behavioral remedy prohibiting bundling by merging parties.

Secondly, the model gives us insight into when such bundling is most likely to arise. This is the case if inputs exhibit strong complementarity, if there is relatively weak competition upstream, and if downstream competition is quite intense. In the case of a merger, a key risk factor for anticompetitive bundling is that the merging b firm is not the current market leader.

Thirdly, attention should also be paid to practices whose effect is similar to bundling. These include not only complete incompatibility with competing technologies, but also partial degradation of interoperability. Vigilance is especially important in the latter case because a firm that chooses to reduce interoperability with a rival can profitably exert anti-competitive effects even without preventing downstream firms from using the rival's input.

Bundling is profitable because it softens downstream competition. Of course, there are are other ways the upstream monopolist could relax downstream competition, such as refusing to supply one of the downstream firms (as discussed in the subsection on public contracts).[22] Here we make two remarks. First, our objective is to establish a new theory of harm potentially applicable to cases involving bundling or incompatibility. This does not require bundling to be the most profitable strategy. Indeed, if anticompetitive conduct is to be avoided, it is necessary to prohibit *every* abusive strategy that is more profitable than the desired competitive benchmark. The relevant exercise is therefore to compare the profit under bundling to the case without anticompetitive conduct, as we have done above. Second, even if the authorities would for some reason allow both anticompetitive bundling and foreclosure via refusal to deal, the upstream monopolist sometimes prefers the former strategy. This is the case, in particular, if consumers value downstream variety a lot so that foreclosing a downstream firm destroys a lot of surplus.[23]

[22]Another possibility would be to use a vertical restraint such as resale price maintenance or exclusive sales territories. However, such restraints that overtly reduce downstream competition and implement cartel-like outcomes are subject to strict prohibition in many jurisdictions.

[23]See Appendix B on public contracts for a formal analysis.

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A Asymmetric bundling

So far we have only allowed U_M to offer a bundle to both firms. While this assumption makes sense in the context of technical bundling, we now consider the alternative where U_M is allowed to offer a bundle to one firm only, and to offer a and b_L on a standalone basis to the other.

The timing is as follows:

1. For each downstream firm, U_M publicly commits to bundle or not.
2. U_M and U_S simultaneously make secret contract offers to each downstream firm and downstream firms choose which technologies to use.
3. Downstream firms observe their competitor's technological choice. Competition occurs and payoffs are realised.

The only case that is different from the analysis above is when U_M makes a bundled offer to D_1 only. Even then, we can use similar arguments to obtain U_M's profits. First, the maximal profit that can be extracted from D_1 is $\pi(L, H)$. Second, there is a multiplicity of equilibria in the negotiation between upstream firms and D_2, depending on the extent of price squeeze by U_M. If we select the equilibrium with price-squeeze degree λ, U_M's profit from its interaction with D_2 is $\lambda\pi(H, L) + (1 - \lambda)\pi(L, L)$.

Proposition 8. *U_M's profit is maximal under asymmetric bundling if the following conditions hold:*

(i) $\pi(H, L) + \pi(L, H) \geq 2\pi(L, L)$

(ii) $\pi(H, L) - \pi(L, L) \geq 2 (\pi(H, H) - \pi(L, H))$

(iii) $\lambda \in [\tilde{\lambda}, \breve{\lambda}]$, *where* $\tilde{\lambda} = \frac{\pi(L,L)-\pi(L,H)}{\pi(H,L)-\pi(L,L)}$ *and* $\breve{\lambda} = \frac{\pi(L,L)-\pi(L,H)}{\pi(H,L)-\pi(L,L)-2(\pi(H,H)-\pi(L,H))}$

Proof. The thresholds $\tilde{\lambda}$ and $\breve{\lambda}$ are such that U_M is indifferent between asymmetric bundling and (respectively) pure bundling and independent pricing. For asymmetric bundling to be optimal, we need $\lambda \in [\tilde{\lambda}, \breve{\lambda}]$.

Note that, if the denominator of $\breve{\lambda}$ is positive, we have $\breve{\lambda} > \tilde{\lambda}$. The condition for the denominator to be positive is condition (ii) of the Proposition.

Finally, we need to check that $\tilde{\lambda} \leq 1$, which corresponds to condition (i) of the Proposition. ∎

Intuitively, the three conditions for asymmetric bundling to be optimal correspond to the ideas that

(i) Industry profit is higher when one firm (only) uses b_S than when none do. This ensures that there is an efficiency gain (from the industry standpoint) to having one firm use b_S.

(ii) The marginal value of b_S over b_M is at least twice as large when the rival downstream firm uses b_M than when it uses b_S. Technology b_S is much more valuable when used exclusively by one firm.

(iii) The degree of price squeeze is intermediate. This ensures that U_M can capture enough of the value created by b_S for D_2, but not so much that it would prefer to let both downstream firm use b_S.

In the Hotelling example above,[24] where pure bundling dominates independent pricing, asymmetric bundling is optimal if $\lambda \geq \tilde{\lambda} = \frac{6t-(c_H-c_L)}{6t+(c_H-c_L)}$. This threshold is between 0 and 1, which means that there is a non-empty region where asymmetric bundling is optimal. In the Cournot example, the conditions for asymmetric bundling to be optimal are $\lambda \in [\frac{2A-3c_H+c_L}{4(A-c_L)}; \frac{2A-3c_H+c_L}{4(A-2c_H+c_L)}]$ and $A - 2c_H + c_L > 0$.

B Public contracts: Proof of Proposition 6

Public contracts as a way to achieve downstream monopoly. First, public contracts allow U_M to implement a downstream monopoly, by setting an arbitrarily large fee F_a^2 and selling a to D_1 alone. When $\pi(L) > 2\pi(L, L)$, the worst equilibrium profit under independent pricing with exclusion of D_2 ($\pi(L)$) is weakly larger than the profit under bundling, with or without exclusion ($\pi(L)$ or $2\pi(L, L)$ respectively).

Public contracts and downstream duopoly Suppose now that it is optimal for U_M to allow both downstream firms to be active ($\pi(L) < 2\pi(L, L)$). We will show that any strategy profile in which U_M gets less than $\pi(L, L)$ per downstream firm is not an equilibrium under independent pricing. Because $2\pi(L, L)$ is the equilibrium profit under bundling, this will prove that bundling is not profitable. We will consider two cases, depending on whether $\pi(H, L) - \pi(L, L) \geq \pi(H, H) - \pi(L, H)$ or not.

Case 1: $\pi(H, L) - \pi(L, L) \geq \pi(H, H) - \pi(L, H)$. Consider a strategy profile in which both downstream firms use $\{a, b_H\}$ and $F_a^i = \pi(L, L) - x_i$, with $x_i > 0$ for at least one D_i. For this to be an equilibrium, we must have

1. $F_{b_H}^i = \pi(H, H) - \pi(L, L) + x_i$ (so that D_i gets zero profit)

2. $F_{b_H}^i \leq \pi(H, H) - \pi(L, H) + F_{b_L}^i \Leftrightarrow F_{b_L}^i \geq \pi(L, H) - \pi(L, L) + x_i$ (so that D_i prefers $\{a, b_H\}$ to $\{a, b_L\}$).

We will show that this cannot be an equilibrium.

If $\pi(L, H) - \pi(L, L) + x_i > 0$, i.e. $x_i > \pi(L, L) - \pi(L, H)$ which implies $F_a^i < \pi(L, H)$, then U_M could deviate by offering $F_{b_L}^{i'} = 0$ (which would induce D_i to switch to b_L because

[24] That is, in the differentiated Bertrand example with $\gamma = \beta$.

we would have $F^i_{b_H} > \pi(H,H) - \pi(L,H) + F^{i'}_{b_L}$) and $F^{i'}_a = \pi(L,L) - \epsilon$ (which would lead to a higher payoff than F^i_a).

Therefore the initial strategy profile cannot be an equilibrium: it cannot be the case that, in equilibrium, U_M gets less than $\pi(L,L)$ per downstream firm.

Suppose now that $\pi(L,H) - \pi(L,L) + x_i \leq 0$. The only potential way for U_M to increase its profit would be to induce D_i to switch to b_L (only increasing the price of a would lead D_i to not buy anything). In order to do so, U_M would need to satisfy two conditions

$$\pi(L,H) - F^{i'}_a - F^{i'}_{b_L} \geq \pi(H,H) - F^{i'}_a - F^i_{b_H},$$
$$\pi(L,H) - F^{i'}_a - F^{i'}_{b_L} \geq 0.$$

U_M's profit from its dealings with D_i is given by the second constraint, which must bind (otherwise it would increase $F^{i'}_a$). Suppose, without loss, that the first constraint also binds. Using $F^i_{b_H} = \pi(H,H) - F^i_a = \pi(H,H) - \pi(L,L) + x_i$, the first constraint yields $F^{i'}_{b_L} = \pi(L,H) - \pi(L,L) + x_i$. Substituting this into the second constraint, we have $F^{i'}_a = \pi(L,L) - x_i$ (so the fee for a doesn't change). This deviation, in turn, allows U_M to raise the price of a to D_j by $\pi(H,L) - \pi(H,H)$ (because D_j will face a competitor using b_L). The net gain of this deviation by U_M is

$$F^{i'}_{b_L} + \pi(H,L) - \pi(H,H) = \underbrace{\pi(H,L) - \pi(L,L) - (\pi(H,H) - \pi(L,H))}_{\geq 0,\text{ by case 1 assumption}} + x_i > 0$$

Therefore the initial strategy profile cannot be an equilibrium: it cannot be the case that, in equilibrium, U_M gets less than $\pi(L,L)$ per downstream firm.

Case 2: $\pi(H,L) - \pi(L,L) < \pi(H,H) - \pi(L,H)$**.**

Consider an equilibrium in which both downstream firms use $\{a, b_H\}$, $F^{i*}_{b_H} = \pi(H,H) - \pi(L,H) - y_i$ and $F^{i*}_a = \pi(L,H) + y_i$. For this to be an equilibrium, it must be that it is not profitable for U_M to induce one or two downstream firms to switch to $\{a, b_L\}$ and to adjust its prices accordingly. There are two cases to consider, depending on whether $y_i > \pi(H,H) - \pi(L,H) - (\pi(H,L) - \pi(L,L))$.

Case 2.1: $y_i < \pi(H,H) - \pi(L,H) - (\pi(H,L) - \pi(L,L))$ *for* $i = 1, 2$. Consider a deviation by U_M that leads both downstream firms to switch to $\{a, b_L\}$. This deviation requires offering a lower price for b_L, and, for it to be profitable, U_M needs to recoup this "subsidy" through a higher price for a.

If D_i expects D_j to switch to $\{a, b_L\}$, D_i finds it optimal to also switch if

$$\pi(L,L) - F^{i'}_a - F^{i'}_{b_L} \geq \pi(H,L) - F^{i'}_a - F^{i*}_{b_H} \Leftrightarrow F^{i'}_{b_L} \leq \pi(H,H) - \pi(L,H) - (\pi(H,L) - \pi(L,L)) - y_i$$

Note that the right-hand side of the constraint is positive, so U_M can still charge a positive price for b_L. One way to induce D_i to switch is thus to charge $F_{b_L}^{i'} = \pi(H,H) - \pi(L,H) - (\pi(H,L) - \pi(L,L)) - y_i$ and to set $F_a^{i'}$ so that $F_a^{i'} + F_{b_L}^{i'} = \pi(L,L)$ (so that D_i makes a non-negative profit).

The net gain for U_M from such a deviation is $\sum_{i=1,2} F_a^{i'} + F_{b_L}^{i'} - F_a^{i*} = 2\left(\pi(L,L) - \pi(L,H)\right) - y_1 - y_2$. For the initial strategy profile to be an equilibrium, it must be that this net gain is negative. In other words, we must have $y_1 + y_2 \geq 2\left(\pi(L,L) - \pi(L,H)\right)$. This implies that the equilibrium profit of U_M is $\Pi_M^* = 2\pi(L,H) + y_1 + y_2 \geq 2\pi(L,L)$: bundling cannot help U_M increase its profit.

Case 2.2 $y_i < \pi(H,H) - \pi(L,H) - (\pi(H,L) - \pi(L,L))$ *for at least one* i. Suppose that this is the case for $i = 1$. The previous deviation would not be profitable, because we would have $F_{b_L}^{1'} < 0$ and U_M could not increase $F_a^{1'}$ up to $\pi(L,L) - F_{b_L}^{1'}$ since D_1 would then only pick $\{b_L\}$ and pocket the subsidy. Instead, consider a deviation by U_M that induces D_1 only to switch to $\{a, b_L\}$. Anticipating that D_2 will stay with $\{a, b_H\}$, D_1 is willing to switch to $\{a, b_L\}$ if

$$\pi(L,H) - F_a^{1'} - F_{b_L}^{1'} \geq \pi(H,H) - F_a^{1'} - F_{b_H}^{1*} \Leftrightarrow F_{b_L}^{1'} \leq -y_1$$

Take $F_{b_L}^{1'} = -y_1 < 0$. The maximal price that D_1 is willing to pay for a is $F_a^{1'} = \pi(L,H)$. Moreover, U_M can increase the price of a to D_2 by $\pi(H,L) - \pi(H,H)$. U_M's net gain from the deviation is then $F_{b_L}^{1'} + F_a^{1'} - F_a^{1*} + \pi(H,L) - \pi(H,H) = \pi(H,L) - \pi(H,H) > 0$: the deviation is always profitable, so the initial tariffs $F_{b_H}^{i*} = \pi(H,H) - \pi(L,H) - y_i$ and $F_a^{i*} = \pi(L,H) + y_i$ do not constitute an equilibrium.

C Proof of Proposition 7: Strong complements, weak complements, and substitutes

To show that bundling can be profitable when a and b are not perfect complements, we begin with the following Lemma.

Lemma 5. *Suppose U_M does not bundle. In any equilibrium, both downstream firms use technologies $\theta_i = \{a, b_H\}$.*

Proof. There is no equilibrium in which $\theta_i \in \{\emptyset, \{b_L\}\}$. If $F_{b_L} \geq 0$ then such an equilibrium would leave an opportunity for U_S to offer $F_{b_H} = \epsilon$ (ϵ small) and profitably induce adoption of b_H. If $F_{b_L} < 0$ then such an equilibrium must have $\theta_i = \{b_L\}$, leaving a profitable deviation for U_M to $F_{b_L} = 0$. There is also no equilibrium in which $\theta_i = \{b_H\}$ because such an equilibrium would leave an opportunity for U_M to deviate to $0 < F_a < \pi(H, \theta_{-i}) - \pi(h, \theta_{-i})$ and profitably induce adoption of a.

Suppose there were an equilibrium with $\theta_i = \{a, b_L\}$. We must have $F_{b_L} \leq \pi(L, \theta_{-i}) - \pi(H, \theta_{-i}) + F_{b_H}$ for D_i to choose b_L over b_H. Indeed, this constraint must bind, otherwise U_M could increase F_{b_L} a little. Moreover, it must be the case that $F_{b_H} \leq 0$, otherwise U_S could induce adoption of b_H by deviating to a lower F_{b_H}. We must also have $F_a \leq \pi(L, \theta_{-i}) - \pi(l, \theta_{-i})$, otherwise D_i would want to drop a. This implies that U_M's profit from selling to D_i is at most

$$F_a + F_{b_L} \leq 2\pi(L, \theta_{-i}) - \pi(l, \theta_{-i}) - \pi(H, \theta_{-i}) < \pi(L, \theta_{-i}) - \pi(l, \theta_{-i}).$$

But U_M could guarantee itself a profit of $\max\{\pi(H, \theta_{-i}) - \pi(h, \theta_{-i}), \pi(L, \theta_{-i}) - \pi(l, \theta_{-i})\}$ by charging $F_{b_L} = 0$ and $F_a = \max\{\pi(H, \theta_{-i}) - \pi(h, \theta_{-i}), \pi(L, \theta_{-i}) - \pi(l, \theta_{-i})\}$. ■

Lemma 6. *Under independent licensing:*

(i) If a and b_H are strong complements, there exist a continuum of equilibria. U_M's profit ranges from $2\left(\pi(L, H) - \pi(0, H)\right)$ to $2\left(\pi(H, H) - \pi(h, H)\right)$.

(ii) Otherwise there exists a unique equilibrium, such that U_M's profit is $2\left(\pi(H, H) - \pi(h, H)\right)$.

Proof. In an equilibrium without bundling in which downstream firms adopt $\{a, b_H\}$, we must have

$$\pi(H, H) - F_a \geq \pi(h, H), \tag{4}$$

$$\pi(H, H) - F_{b_H} \geq \pi(L, H) - F_{b_L}, \tag{5}$$

$$\pi(H, H) - F_a - F_{b_H} \geq \pi(0, H). \tag{6}$$

Moreover, it must be the case that $F_{b_L} = 0$ by the usual Bertrand logic.

Suppose, first, that technologies are strong complements. There are a continuum of equilibria. The best equilibrium for U_M is such that (4) binds and U_M extracts the full marginal value of a. The worst equilibrium is the one in which (5) and (6) bind and U_S extracts the full marginal value of b_H. Thus, the no bundling profit for U_M satisfies

$$\Pi_M \in \Big[2[\pi(L, H) - \pi(0, H)], 2[\pi(H, H) - \pi(h, H)]\Big].$$

If technologies are weak complements or substitutes then satisfaction of (4) implies (5) and (6). Thus, equilibrium profits are uniquely determined by (4): $\Pi_M = 2[\pi(H, H) - \pi(h, H)]$. ■

In case (i), we again select the equilibrium corresponding to a degree of price squeeze λ, which delivers a payoff of $2\big[(1-\lambda)\left(\pi(L, H) - \pi(0, H)\right) + \lambda\left(\pi(H, H) - \pi(h, H)\right)\big]$ to U_M.

If U_M bundles a and b_M, we have the following result:

Lemma 7. *Under bundling, there is a unique equilibrium. U_M's profit is* $2\left(\pi(L,L)-\pi(h,L)\right)$.

Proof. If U_M bundles its technologies then downstream firms choose $\{a, b_L\}$ and the outside options of adopting $\theta_i \in \{0, \{b_H\}\}$ imply

$$\pi(L,L) - F_{ab_L} \geq \pi(h,L) - F_{b_H}, \tag{7}$$

$$\pi(L,L) - F_{ab_L} \geq \pi(0,L). \tag{8}$$

By the usual Bertrand logic, $F_{b_H} = 0$. It is clear that (8) is implied by (7). Thus, the bundling profit for U_M is that given in the statement of the Lemma. ■

Comparing the results from Lemmas 6 and 7 yields Proposition 7.

D Two part tariffs

We now extend the model by allowing upstream firms to charge two-part tariffs. As in Section 5.2, we allow technologies to be strong complements, weak complements, or substitutes. It will be convenient to introduce a dummy technology, $\not{a}$ (priced at zero), meaning D_i does not have a. A two-part tariff has the form $w^i_\tau q_i + F^i_\tau$, where q_i units are sold by D_i, and w^i_τ and F^i_τ are respectively the unit fee and the fixed fee charged to D_i for technology product, $\tau \in T$. Under independent licensing the available technology products are $T = \{\not{a}, a, b_H, b_L\}$; under bundling $T = \{\{\not{a}, b_H\}, \{a, b_L\}\}$. We assume that technologies are produced at constant marginal costs, which we normalize to zero, and that tariff offers are secret: while firm D_i can observe which technologies D_{-i} uses, it cannot observe the negotiated contracts.

We use general downstream demand functions of the form $q_i(p_i, p_{-i}, \theta_i, \theta_{-i})$. Let $\pi(\theta_i, \theta_{-i})$ be the equilibrium profit when each firm chooses price p_i to maximize $p_i q_i(p_i, p_{-i}, \theta_i, \theta_{-i})$—that is, the profit achieved if both downstream firms could obtain their technology at cost. We assume that the equilibrium exists and is unique for any (θ_i, θ_{-i}). Following Rey and Vergé (2020), we also assume that retail behavior is "smooth". This means that best-response prices are differentiable with respect to the unit fees and that the diversion ratio matrix is non-singular (see Section D.3 for the details).

The structure of the analysis is as follows: we introduce the solution concept in Section D.1, with a focus on the case where unit fees are zero (allowing us to temporarily sidestep some tedious details). We solve the model in Section D.2 and show that our result on the profitability of bundling (Proposition 7, which is just a generalized version of Proposition 2) survives. Section D.3 completes the argument by showing that the focus on zero unit fees is without loss.

D.1 Nash-in-Nash with threat of replacement or exit (NNTRE)

With two-part tariffs, a downstream firm D_i's optimal price and its profit depend on the terms negotiated between D_{-i} and its supplier(s), and in particular on the agreed unit fees. When offers are secret, a well-known difficulty lies in specifying out-of-equilibrium beliefs should a downstream firm receive an unexpected offer. Reasonable beliefs, such as passive or wary ones, may present existence or tractability issues (Rey and Vergé, 2004). We follow Rey and Vergé (2020)'s approach, which consists in adopting the Nash-in-Nash bargaining framework (see Collard-Wexler et al., 2019) while taking into account the effects of negotiated contracts on downstream competition. Generically, Nash-in-Nash bargaining assumes that each technology product is sold independently via bilateral Nash bargaining between an upstream and downstream firm, taking the equilibrium outcome of other bilateral negotiations as given.

In many bargaining environments only some of the possible bilateral bargains take place, leaving the others as an outside option. Indeed, this is the case here because each downstream firm only buys at most one version of each technology. This has led Ho and Lee (2019) to propose an extension, Nash-in-Nash with threat of replacement (NNTR), and Chambolle and Molina (forthcoming), in particular, use this concept to analyse the profitability of bundling and exclusive dealing. NNTR proceeds in a similar fashion to Nash-in-Nash, with the additional requirement that D_i's payoff when bargaining over $\tau \in T$ is at least equal to the payoff it could get by making a take it or leave it offer for the relevant alternative to τ. Under independent licensing b_H and b_L are each others' relevant alternatives, as are a and $\not{a}$. Under bundling, $\{a, b_L\}$ is the relevant alternative to $\{\not{a}, b_H\}$ and vice-versa. Notationally, we write $\tilde{\theta}_i^\tau$ for the θ_i that would result when technology product $\tau \in T$ is replaced by its relevant alternative.[25]

We extend NNTR to allow for strong complements by giving downstream firms an exit option, yielding NNTRE as a solution concept. Informally, an NNTRE equilibrium is an NNTR equilibrium in which each downstream firm is weakly better-off than if it were to walk away from all technology negotiations. We provide a complete definition of an NNTRE equilibrium in Section D.3. However, the following lemma (also proved in that section) will allow us to restrict our attention to NNTRE equilibria with fixed fees only, which we define below.

Lemma 8. *In any NNTRE equilibrium, tariffs are cost based:* $w_\tau^{i*} = 0$ *for any* τ *accepted by* D_i*.*

The idea that the equilibrium contract does not use distortionary fees is familiar from the contracting literature and carries over to this environment. The assumption that

[25] As a concrete example, under independent licensing suppose $\theta_i = H$. Then we have $\tilde{\theta}_i^{b_H} = L$ (b_H is replaced with its alternative b_L), and $\tilde{\theta}_i^a = h$ (a is replaced with $\not{a}$). Under bundling, if $\theta_i = L$ then $\tilde{\theta}_i^{\{a,b_L\}} = h$ ($\{a, b_L\}$ is replaced by its alternative $\{\not{a}, b_H\}$).

the diversion ratio matrix is non-singular ensures that this is the unique equilibrium (an earlier version of this result can be found in Rey and Vergé, 2020).

Lastly, we adopt the notational convention that if technology product τ is not among those D_i chooses to negotiate over then $F^i_\tau = 0$. Using Lemma 8 to restrict attention to fixed fees, we can then define NNTRE as follows.

Definition 2. A fixed-fees NNTRE equilibrium consists in: (i) a pair of technology mixes (θ^*_1, θ^*_2), (ii) a set of fixed fees, F^{i*}_τ, such that when D_i chooses $\tau \in T$

$$\begin{aligned} F^{i*}_\tau &= \underset{F^i_\tau}{\operatorname{argmax}}\, F^i_\tau \\ \text{s.t. } & \pi_i(\theta^*_i, \theta^*_{-i}) - F^i_\tau \geq \pi_i(\tilde{\theta}^\tau_i, \theta^*_{-i}) \\ & \pi_i(\theta^*_i, \theta^*_{-i}) - \sum_{z \in T} F^i_z \geq \pi_i(0, \theta^*_{-i}) \\ & F^{i*}_\tau \geq 0. \end{aligned} \tag{9}$$

The objective function of (9) is U_j's profit from supplying τ to D_i. The first constraint is the threat of replacement: D_i must be better-off than if it were to replace τ with the relevant alternative and capture the resulting surplus. The second constraint captures the exit option of downstream firms: D_i must be no worse off than if it walked away from buying any technology. The last constraint is the upstream firm's participation constraint.

We focus on the case where all of the bargaining power rests with upstream firms because Chambolle and Molina (forthcoming) already show downstream firm bargaining power can make bundling profitable. Removing this force allows us to isolate the novel role of downstream competition.

D.2 Equilibrium under two-part tariffs

We are now in a position to show that bundling can be profitable in an NNTRE equilibrium with two-part tariffs. As a first step we show that firms adopt the efficient technology combination under independent licensing.

Lemma 9. *Suppose U_M does not bundle. In any NNTRE equilibrium, both downstream firms use technologies a and b_H.*

Proof. By Lemma 8, tariffs are cost-based. Equilibria with $\theta_i = h$ are ruled-out by the threat-of replacement. Indeed, D_i could threaten to replace $\not{a}$ with a at a cost of zero, which would increase its profit by $\pi(H, \theta_{-i}) - \pi(h, \theta_{-i}) > 0$. A similar argument holds if $\theta_i = l$. If $\theta_i = L$ then the threat-of replacement requires that D_i cannot profitably replace b_L with b_H: $\pi(L, \theta_{-i}) - F^i_a - F^i_{b_L} \geq \pi(H, \theta_{-i}) - F^i_a$. This implies $F^i_{b_L} \leq \pi(L, \theta_{-i}) - \pi(H, \theta_{-i}) < 0$, which violates U_M's participation constraint in the negotiations over b_L. ■

Lemmas 8 and 9 jointly imply that the incentives and equilibrium outcomes under NNTRE are the same as those already presented in Section 5.2 (so the same conditions for bundling to be profitable apply). The derivation of profit under independent licensing and bundling is almost identical to the proofs of Lemmas 6 and 7 and is omitted.

D.3 Proof of Lemma 8: tariffs are cost-based

We have shown that bundling can be profitable under the assumption that tariffs are cost-based. We complete the analysis of two-part tariffs by showing that $w_\tau^i = 0$ indeed necessarily holds in equilibrium. First, we must extend Definition 2 to allow for non-zero unit fees.

D.3.1 Formal definition of NNTRE equilibrium

Objective function of the bargaining stage Suppose that D_i chooses θ_i^*, and that D_{-i} chooses p_{-i}^* and θ_{-i}^*. We denote by W^i the sum of the unit fees paid by firm D_i across all of the technology products it chooses. Let $p_i^R(W^i) \equiv \text{argmax}_p (p - W^i) q_i(p, p_{-i}^*, \theta_i^*, \theta_{-i}^*)$ be i's pricing best-response.

Consider the negotiation between D_i and U_j over technology product τ, given the other equilibrium contracts. D_i's profit in case of an agreement at a tariff (w_τ^i, F_τ^i) is

$$\pi_{D_i}^{agreement}(w_\tau^i, F_\tau^i) \equiv (p_i^R(W^i) - W^i) q_i \left(p_i^R(W^i), p_{-i}^*, \theta_i^*, \theta_{-i}^*\right) - \sum_{z \in T} F_z^i.$$

In case of an agreement, firm D_i's marginal cost is W^i. This marginal cost affects D_i's price p_i^R, which in turn affects the demand q_i, given that D_{-i} uses technologies θ_{-i}^* and sets a price p_{-i}^* (remember that, since offers are secret, the negotiated w_τ^i will not affect D_{-i}'s price).

We also define D_i's profit without agreement over x_j, letting $\theta_i^* \backslash \tau$ be the technology combination that results from omitting τ from θ_i^*, and $W_{-\tau}^i = \sum_{z \in T \backslash \tau} w_z^{i*}$ be the unit fees i expects to pay for technology products other than τ:

$$\pi_{D_i}^{no\ agreement} \equiv \left(\widetilde{p}_i - W_{-\tau}^i\right) q_i \left(\widetilde{p}_i, \widetilde{p}_{-i}, \theta_i^* \backslash \tau, \theta_{-i}^*\right) - \sum_{z \in T \backslash \tau} F_z^{i*}.$$

Downstream firms' prices are then denoted $\widetilde{p}_i$ and $\widetilde{p}_{-i}$.[26]

Similarly, U_j's profit in case of an agreement with D_i over technology product τ when

[26] That is, $\widetilde{p}_i = \text{argmax}_p \left(p - W_{-\tau}^i\right) q_i(p, \widetilde{p}_{-i}, \theta_i^* \backslash \tau, \theta_{-i}^*)$ and similarly for $\widetilde{p}_{-i}$.

U_j offers the set of technology products $\hat{T} \subseteq T$ is

$$\pi_{U_j}^{agreement}(w_\tau^i, F_\tau^i) \equiv F_\tau^i + w_\tau^i q_i\left(p_i^R(W^i), p_{-i}^*, \theta_i^*, \theta_{-i}^*\right) + \sum_{l=i,-i}\sum_{z\in\hat{T}\setminus\tau}\left[F_z^{l*} + w_z^{l*} q_l\left(p_i^R(W^i), p_{-i}^*, \theta_i^*, \theta_{-i}^*\right)\right].$$

The first two terms correspond to the profit from D_i's sales, associated to τ's fees. The sum of other terms corresponds to all the other fees collected by U_j (from its other technology products and/or the other downstream firm).

In case of no agreement with D_i over τ, U_j's profit is

$$\pi_{U_j}^{no\ agreement} \equiv \sum_{l=i,-i}\sum_{z\in\hat{T}\setminus\tau} F_z^{l*} + w_z^{l*} q_l\left(\widetilde{p_i}, \widetilde{p_{-i}}, \theta_i^*\setminus\tau, \theta_{-i}^*\right).$$

In that case U_j only collects fees corresponding to its other technology and/or the other downstream firm. Quantities are then modified to take into account that D_i doesn't use technology product τ (and that firms adjust their prices accordingly).

In the Nash-in-Nash bargaining model, $(w_\tau^{i*}, F_\tau^{i*})$ maximizes $G_{i,\tau}(w_\tau^i, F_\tau^i)$, defined as follows:

$$G_{i,\tau}(w_\tau^i, F_\tau^i) \equiv \left(\pi_{D_i}^{agreement}(w_\tau^i, F_\tau^i) - \pi_{D_i}^{no\ agreement}\right)^{1-\alpha}\left(\pi_{U_j}^{agreement}(w_\tau^i, F_\tau^i) - \pi_{U_j}^{no\ agreement}\right)^{\alpha},$$

where α denotes the bargaining power of the supplier of τ, U_j. As explained in the text, we focus on the case where $\alpha = 1$. Indeed, we know from Chambolle and Molina (forthcoming) that, when $\alpha < 1$, downstream competition is not necessary for tying to be profitable. The case with $\alpha = 1$ also mirrors our baseline model more closely.

Threat of replacement Suppose that D_i negotiates with U_j over technology product τ, and that D_i also independently negotiates with M for technology a. The threat of replacement constraint vis-a-vis U_j is the following:

$$\pi_{D_i}^{agreement}(w_\tau^i, F_\tau^i) = (p_i^R(W^i) - W^i) q_i\left(p_i^R(W^i), p_{-i}^*, \theta_i^*, \theta_{-i}^*\right) - \sum_{z\in T} F_z^i \geq (\widehat{p}_i - \overline{w} - W_{-\tau}^i) q_i\left(\widehat{p}_i, \widehat{p}_{-i}, \tilde{\theta}_i^\tau, \theta_{-i}^*\right) - \left(\overline{F} + \sum_{z\in T\setminus\tau} F_z^{i*}\right) \quad (10)$$

The left-hand side of the inequality in (10) is D_i's profit if reaches an agreement with U_j to buy τ at (w_τ^i, F_τ^i). The right-hand side of (10) is D_i's profit if it were to replace

τ by its relevant alternative at a tariff $(\overline{w}, \overline{F})$ that would make the supplier indifferent between this deal and the alternative where D_i uses τ. In the case where τ is replaced by its relevant alternative, we denote the corresponding equilibrium downstream prices by $\widehat{p}_i$ and $\widehat{p}_{-i}$.

Exit We also impose that, if $\tau = \{a, b_j\}$ is chosen by D_i then D_i must be better-off than if it were to give up both technologies:

$$(p_i^R(W^i) - W^i)q_i\left(p_i^R(W^i), p_{-i}^*, \theta_i^*, \theta_{-i}^*\right) - \sum_{z\in T} F_z^i \geq \pi_i(\emptyset, \theta_{-i}^*) \tag{11}$$

Definition 3. An *Nash-in-Nash with Threat or Replacement and Exit (NNTRE) equilibrium* (with $\alpha = 1$) consists in (i) a pair a technology mixes (θ_1^*, θ_2^*), (ii) a set of two-part tariffs $(w_\tau^{i*}, F_\tau^{i*})$, (iii) a pair of equilibrium prices (p_1^*, p_2^*), (iv) a set of price-responses $p_i^R(\cdot)$, such that

1. For any $W \in \mathbb{R}$, $i \in \{1, 2\}$, we have $p_i^R(W) = \text{argmax}_p(p - W)q_i(p, p_{-i}^*, \theta_i^*, \theta_{-i}^*)$.
2. For any $i \in \{1, 2\}$, $p_i^* = p_i^R(W^{i*})$.
3. If i agrees to buy τ, $(w_\tau^{i*}, F_\tau^{i*})$ maximizes $G_{i,\tau}(w_\tau^i, F_\tau^i)$ under the constraints (10) and (11).
4. Any upstream firm whose technology is used by D_i in equilibrium is better-off than if it were to unilaterally stop dealing with D_i.

Possible microfoundation for NNTRE First, each downstream firm decides which technology products it wants to use, and sends one negotiator to the relevant upstream firm for each technology product. Upstream firms also send one negotiator for each technology product and for each interested downstream firm. Pairs of negotiators negotiate without observing the outcome of other negotiations. For each pair, the upstream negotiator makes a take-it-or-leave-it (TIOLI) two-part tariff offer. Upon receiving an offer for technology product τ, the downstream negotiator then has the option to switch suppliers and to make a TIOLI offer for the relevant alternative. After negotiators have accepted an offer or made an offer that has been accepted, they go back to their headquarters, where the managers decide whether to approve the offers or not, but cannot propose any change.

We introduce the last stage to deal with cases where technologies are strong complements.[27] Indeed, with complements, we could have situations where each downstream negotiator receives an offer for a technology $x \in \{a, b_S, b_M\}$ such that the price is below

[27] Such a possibility is usually ruled-out. See, for example, Assumption A.WCDMC of Collard-Wexler et al. (2019), and the "limited complementarity" assumption of Chambolle and Molina (forthcoming).

the marginal value of x, yet the sum of the two prices is above the combined value of the two technologies. We call this the threat of exit by the downstream firm.

Smooth behavior Following Rey and Vergé (2020), we assume that price reaction functions $p_i^R(W)$ are continuously differentiable, and that the diversion ratio matrices are non-singular. Such matrices are defined below.

Fix θ_i^* and θ_{-i}^*, and let W_i^* be the equilibrium sum of unit fees paid by D_i. Let

$$q_l^i(w_i) \equiv q_l(p_i^R(W_i^* + w_i), p_{-i}^*, \theta_i^*, \theta_{-i}^*)$$

The diversion ratio matrix $\boldsymbol{\delta}$ is defined as

$$\delta_{i,k} = -\frac{\frac{dq_k^i}{dw_i}(0)}{\frac{dq_i^i}{dw_i}(0)} \tag{12}$$

D.3.2 Proof of Lemma 8: tariffs are cost-based

Suppose technologies are licensed independently and that both downstream firms use a and b_S in equilibrium. We study the choice of w_a^1 and w_a^2. The other cases follow a similar reasoning. Let $\widetilde{p}_i$ be the price that D_i would charge in the subgame where D_1 buys b_S only, while D_2 uses technologies $\{a, b_S\}$.

The fee w_a^1 is the solution to

$$\max_{w_a^1, F_a^1} w_a^1 q_1(p_1^R(w_a^1 + w_{b_S}^{1*}), p_2^*, H, H) + F_a^1 + w_a^{2*} q_2(p_2^*, p_1^R(w_a^1 + w_{b_S}^{1*}), H, H) + F_a^{2*} - \left[w_a^2 q_2(\widetilde{p}_2, \widetilde{p}_1, H, h) + F_a^{2*}\right]$$

such that (threat of replacement of a by $\emptyset$)

$$(p_1^R(w_a^1 + w_{b_S}^{1*}) - w_a^1 - w_{b_S}^{1*}) q_1(p_1^R(w_a^1 + w_{b_S}^{1*}), p_2^*, H, H) - F_a^1 - F_{b_S}^{1*} \geq (\widetilde{p}_1 - w_{b_S}^{1*}) q_1(\widetilde{p}_1, \widetilde{p}_2, h, H) - F_{b_S}^{1*}$$

and (exit)

$$(p_1^R(w_a^1 + w_{b_S}^{1*}) - w_a^1 - w_{b_S}^{1*}) q_1(p_1^R(w_a^1 + w_{b_S}^{1*}), p_2^*, H, H) - F_a^1 - F_{b_S}^{1*} \geq \pi_1(\emptyset, H).$$

One of the two above constraints must be binding, meaning that we can write

$$F_a^1 = (p_1^R(w_a^1 + w_{b_S}^{1*}) - w_a^1 - w_{b_S}^{1*}) q_1(p_1^R(w_a^1 + w_{b_S}^{1*}), p_2^*, H, H) + [\text{term not depending on } w_a^1].$$

Substituting this expression in the objective function, we see that the optimal unit fee w_a^1 must be the solution to

$$\max_{w_a^1} \Big\{ (p_1^R(w_a^1 + w_{b_S}^{1*}) - w_{b_S}^{1*}) q_1(p_1^R(w_a^1 + w_{b_S}^{1*}), p_2^*, H, H) + w_a^{2*} q_2(p_2^*, p_1^R(w_a^1 + w_{b_S}^{1*}), H, H) \Big\}. \tag{13}$$

By the envelope theorem (subtracting and adding $w_a^1 q_1$), the first-order condition is

$$w_a^{1*} \frac{dq_1^1}{dw_a^1}(0) + w_a^{2*} \frac{dq_2^1}{dw_a^1}(0) = 0.$$

By symmetry, the first-order condition for w_a^2 yields

$$w_a^{2*} \frac{dq_2^2}{dw_a^2}(0) + w_a^{1*} \frac{dq_1^2}{dw_a^2}(0) = 0.$$

Dividing the first equation by $\frac{dq_1^1}{dw_a^1}(0)$ and the second by $\frac{dq_2^2}{dw_a^2}(0)$, we obtain $\boldsymbol{\delta}(w_a^{1*}, w_a^{2*})^T = 0$. By the assumption that $\boldsymbol{\delta}$ is non-singular, this implies that $(w_a^{1*}, w_a^{2*}) = (0, 0)$.

E Competition on the market for a

Suppose there are two versions of technology a: a superior version a_H and an inferior version a_L, produced by a third upstream firm. We write $\theta_i = HL$ for the input quality enjoyed by D_i when it has technologies $\{a_H, b_L\}$, $\theta_i = LH$ when it has $\{a_L, b_H\}$, and analogously for other configurations. U_M controls a_H as well as b_L. We assume that $\pi(HH, \theta_{-i}) > \pi(HL, \theta_{-i}) > \pi(LH, \theta_i) > \pi(HL, \theta_{-i})$. In particular, the middle inequality, which requires the advantage of a_H to be larger than that of b_H, ensures that the bundle is chosen if a_H and b_L are bundled. Lastly, we assume that

$$\pi(HH, \theta_{-i}) - \pi(LH, \theta_{-i}) \geq \pi(HL, \theta_{-i}) - \pi(LL, \theta_{-i}), \tag{14}$$

i.e., that technologies are complementary in the sense that the quality advantage of a superior version of one technology can only be enhanced by the presence of the other.

The analysis largely parallels the case with a monopoly on a and the following proposition summarises the result.

Proposition 9. *With competition on market b bundling is profitable if the degree of price squeeze λ is below $\tilde{\lambda}$, defined as*

$$\tilde{\lambda} \equiv \frac{\pi(HL, HL) - \pi(LH, HL) - \pi(HL, HH) + \pi(LL, HH)}{\pi(HH, HH) - \pi(LH, HH) - \pi(HL, HH) + \pi(LL, HH)}. \tag{15}$$

E.1 Proof of Proposition 9

Bundling We begin with the case of bundling. In order to sell the bundle, U_M needs to make an offer that is more attractive than $\{a_L, b_H\}$: $\pi(HL, HL) - F_{a_H b_L} \geq \pi(LH, HL) - F_{a_L} - F_{b_H}$. The suppliers of a_L and b_H would be willing to compete their fees down to zero, to the most that U_M can extract under bundling is $F_{a_H b_L} = \pi(HL, HL) - \pi(LH, HL)$.

Independent licensing: choice of technologies Now turn to the case of independent licensing. As a first step, we establish that $\theta_i = HH$ in equilibrium.

First, suppose D_i takes a_L. If $F_{a_L} \geq 0$ then there is a profitable deviation for a_H to be sold to D_i at a price of $F_{a_L} + \epsilon$ for ϵ small. If $F_{a_L} < 0$ is accepted then the supplier of a_L earns negative profit and would prefer to deviate to $F_{a_L} = 0$. Thus, a_H is taken in equilibrium.

Now suppose D_i takes b_L. If $F_{b_L} \geq 0$ then there is a profitable deviation for b_H to be sold to D_i at a price of $F_{b_L} + \epsilon$ for ϵ small. If $F_{b_L} < 0$ is accepted then, U_M's profit is $F_{a_H} + F_{b_L} \leq \pi(HL, \theta_{-i}) - \pi(LL, \theta_{-i}) + F_{a_L} + F_{b_L} < \pi(HL, \theta_{-i}) - \pi(LL, \theta_{-i}) + F_{a_L}$ (where the first inequality follows because D_i needs to prefer a_H to a_L). But U_M could earn a profit of $\pi(HL, \theta_{-i}) - \pi(LL, \theta_{-i}) + F_{a_H}$ by deviating to $F_{a_H} = \pi(HL, \theta_{-i}) - \pi(LL, \theta_{-i}) + F_{a_H}$ and $F_{b_L} = 0$.[28]

Independent licensing: equilibrium prices In equilibrium, D_i must prefer $\theta_i = HH$ to LH, HL, LL, and zero. This respectively yields the following constraints.

$$\pi(HH, HH) - F_{a_H} - F_{b_H} \geq \pi(LH, HH) - F_{a_L} - F_{b_H}, \tag{16}$$

$$\pi(HH, HH) - F_{a_H} - F_{b_H} \geq \pi(HL, HH) - F_{a_H} - F_{b_L}, \tag{17}$$

$$\pi(HH, HH) - F_{a_H} - F_{b_H} \geq \pi(LL, HH) - F_{a_L} - F_{b_L}, \tag{18}$$

$$\pi(HH, HH) - F_{a_H} - F_{b_H} \geq \pi(0). \tag{19}$$

The best equilibrium for U_M is when (16) binds. We then have $F_{a_H} = \pi(HH, HH) - \pi(LH, HH) + F_{a_L}$ (with F_{a_L} necessarily equal to zero, otherwise it would be profitable to reduce F_{a_L} and have a_L be chosen). The worst equilibrium for U_M is when (17) and (18) bind. We then have (from (17)) $F_{b_H} = \pi(HH, HH) - \pi(HL, HH) + F_{b_L}$ (with F_{b_L} necessarily equal to zero, otherwise it would be profitable to reduce F_{b_L} and have b_L be chosen). Substituting this into (18) yields $F_{a_H} = \pi(HL, HH) - \pi(LL, HH) + F_{a_L}$ (with F_{a_L} necessarily equal to zero as before).

[28] Equation 14 guarantees that a_H will be accepted alongside one of the two b-variants after such an offer.

Independent licensing: profits and comparison to bundling Taking λ as the degree of price squeeze, we therefore find that U_M earns a profit of

$$\lambda[\pi(HH, HH) - \pi(LH, HH)] + (1 - \lambda)[\pi(HL, HH) - \pi(LL, HH)].$$

Comparing this to the bundling profit yields (15).

E.2 Discussion

To illustrate, consider a model of downstream Cournot duopoly with inverse demand $1 - q_i - q_j$ and where D_i has cost $C(\theta_i)$. Suppose that $1 > C(LL) = C(HL) + \alpha = C(LH) + \beta = C(HH) + \alpha + \beta$. Thus, α and β respectively measure the quality advantage of a_H and b_H. Substituting the standard Cournot profit into (15) yields

$$\tilde{\lambda} = \frac{8\alpha}{2(1 - C(LL)) + 6\alpha + 3\beta}.$$

It is immediate that $\tilde{\lambda} > 0$ (so there always exist equilibria in which bundling is profitable). Moreover, $\partial\tilde{\lambda}/\partial\alpha > 0$. In words, bundling is more likely to be profitable if U_M's advantage on market a is large. Interestingly, this is the opposite finding to Whinston's (1990) exclusionary logic, where bundling under perfect complementarity is only profitable if the competitive threat on market a is strong enough.