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The industrial organization of horizontal subcontracting with applications to electricity markets

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Summary in Dutch

Dit doctoraat behandelt horizontale leveringscontracten, gedefinieerd als leveringscontracten tussen concurrerende bedrijven. Het doctoraat bestaat uit vier hoofdstukken.

De twee eerste hoofdstukken van mijn doctoraat hebben gemeenschappelijk dat ze samen zijn geschreven met Jan Bouckaert, de promotor van mijn doctoraat. Daarnaast behandelen ze beiden horizontale leveringscontracten die getekend worden *na* de concurrentiefase. Ik volg Spiegel (1993) en zal naar dit soort omgeving verwijzen als *ex post* horizontale leveringscontracten.

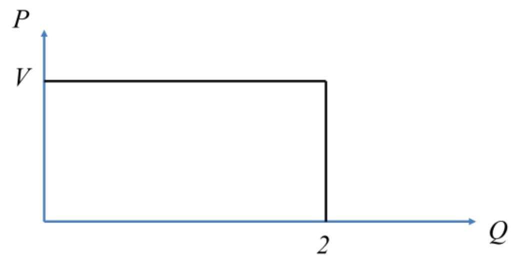
De laatste twee hoofdstukken van mijn doctoraat hebben gemeenschappelijk dat ik als enige auteur optreed, en dat ze beiden kijken naar horizontale leveringscontracten die getekend worden *voor* de concurrentiefase. Ik volg opnieuw Spiegel (1993) en zal hiernaar verwijzen als *ex ante* horizontale leveringscontracten.

Deze samenvatting volgt de structuur van mijn doctoraat. Ik start met een eenvoudig raamwerk van ex post horizontale leveringscontracten, en zal rapporteren over de belangrijkste inzichten die volgen uit de twee eerste hoofdstukken. Daarna zal ik het raamwerk omvormen in een raamwerk van ex ante horizontale leveringscontracten. Dat omgevormde raamwerk geeft me de kans een overzicht te geven van de laatste twee hoofdstukken.

Ex post horizontale leveringscontracten

Ex post horizontale leveringscontracten zijn relevant in verschillende industrieën. Twee belangrijke voorbeelden zijn elektriciteitsmarkten en de markt voor het plaatsen van financiële effecten. De prikkel om ex post horizontale leveringscontracten te tekenen volgt uit de mogelijkheid voor concurrenten om kosten te verminderen door hun werklast onder elkaar te herverdelen.

Beschouw het volgende eenvoudige raamwerk. Figuur 1 beeldt de vraagcurve uit. De horizontale as toont vraag Q en de verticale as toont prijs P. Er is een consument met een vraag naar twee eenheden. Echter, zijn bereidheid te betalen is maximaal V per eenheid.

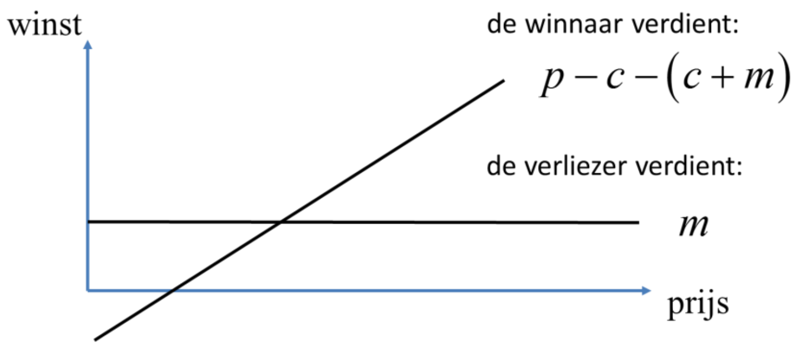


Figuur 1: de vraagcurve.

Er zijn twee concurrenten, bedrijf A en bedrijf B, met elk dezelfde marginale productiekost c. Er is echter beperkte productiecapaciteit per bedrijf, $k=1$. Dus, een enkel bedrijf kan slechts één van beide eenheden zelfstandig bedienen.

Het spel is als volgt. Eerst concurreren de bedrijven in prijzen. Meer bepaald, elk bedrijf kiest een totaalprijs p. Het bedrijf dat de laagste prijs kiest wint de consument. In het geval van een gelijke prijs wordt de winnaar willekeurig gekozen. Daarna kunnen bedrijven een horizontaal leveringscontract met elkaar tekenen. Aangezien de winnaar enkel één eenheid onafhankelijk kan bedienen, heeft hij zijn concurrent nodig om de tweede eenheid te bedienen. De onderaannemer verdient een marge van m bovenop zijn productiekost om de tweede eenheid te produceren, c. Het tarief dat de winnaar dus aan de onderaannemer betaalt is gelijk aan $c+m$. Die marge m weerspiegelt de handelsvoorwaarden op de markt voor onderaannemers. Als de marge laag is, zijn de handelsvoorwaarden in het voordeel van de hoofdaannemer. Als de marge hoog is, zijn de handelsvoorwaarden in het voordeel van de onderaannemer.

De analyse is als volgt. Figuur 2 weerspiegelt de winstfuncties van de bedrijven. De horizontale as toont de prijs aangeboden door het winnende bedrijf. De verticale as toont de winsten. De winst van het winnende bedrijf wordt groter naarmate de omzet groeit. Meer bepaald, de winnaar verdient een omzet p, betaalt een kost c om de eerste eenheid zelf te produceren, en betaalt een kost $c+m$ om de tweede eenheid van zijn concurrent te kopen. Let op, de verliezer heeft geen winst gelijk aan nul. Inderdaad, hij verdient positieve winsten door als onderaannemer op te treden en een marge m te vragen aan de hoofdaannemer.



Figuur 2: winstfuncties

In evenwicht dient elk bedrijf indifferent te zijn tussen winnen en verliezen. Inderdaad, elke hogere prijs kan geen evenwicht zijn omdat de verliezer dan een prikkel zou hebben om een lagere prijs aan te bieden aan de consument. Elke lagere prijs kan ook geen evenwicht zijn omdat de winnaar dan een prikkel zou hebben om een hogere prijs aan te bieden. Daarom is de evenwichtsprijs gelijk aan

$$p^* = \underbrace{c}_{\substack{\text{productiekost} \\ \text{eerste eenheid}}} + \underbrace{(c+m)}_{\substack{\text{tarief betaald} \\ \text{aan} \\ \text{onderaannemer}}} + \underbrace{m}_{\substack{\text{opportuniteits-} \\ \text{kost}}} .$$

In evenwicht dient de winnaar gecompenseerd te worden voor drie types van kosten. Ten eerste moet hij zijn productiekost van de eerste eenheid terugverdienen. Ten tweede moet hij de kosten die hij maakt als hoofdaannemer terugverdienen. Ten laatste moet hij ook vergoed worden voor zijn verloren kans om geld te verdienen als onderaannemer. We leren hieruit dat een hogere marge voor de onderaannemer tot een hogere evenwichtsprijs leidt via twee aparte kanalen. Ten eerste verhoogt het de kost voor de hoofdaannemer. Ten tweede maakt een hogere marge het aantrekkelijker om als onderaannemer op te treden, in plaats van direct de consument te bedienen.

Hoofdstuk één van dit doctoraat toont aan dat het installeren van back-up capaciteit kosten kan verlagen (Bouckaert en Van Moer, 2017). De reden is dat back-up capaciteit de hoofdaannemer een alternatief oplevert voor het leveringscontract. Op die manier kan back-up capaciteit de marge verlagen die de onderaannemer in evenwicht aanrekent. Het kostenverlagende effect vereist niet dat back-up capaciteit in evenwicht wordt geactiveerd. De strategische prikkel om back-up capaciteit te installeren vermindert het publiek goed probleem van bevoorradingszekerheid in elektriciteitsmarkten. Het benadrukt ook het belangrijke verschil tussen winstgevendheid op centrale-niveau dan wel op portfolio-niveau.

Hoofdstuk twee van dit doctoraat onderzoekt de effecten van een fusie. Een belangrijke component in de analyse is hoe de fusie de handelsvoorwaarden beïnvloedt op de markt voor onderaannemers. Enerzijds kan een verhoogde marktconcentratie verkopersmacht genereren, en zo de marges doen stijgen die aangerekend worden door onderaannemers. Anderzijds kan een verhoogde marktconcentratie kopersmacht genereren, en zo de marges doen dalen die aangerekend worden door onderaannemers. Omwille van dat laatste effect kan een fusie die geen kosten-synergieën omvat toch de prijs verlagen die de eindconsument betaalt. Dat resultaat verschilt van de klassieke artikels over fusies die geen horizontale leveringscontracten analyseren, zoals Williamson (1968), Deneckere en Davidson (1985), Perry en Porter (1985), en Farrell en Shapiro (1990).

Ex ante horizontale leveringscontracten

We schakelen nu over naar de analyse van ex ante horizontale leveringscontracten. Zulke leveringscontracten zijn ook relevant in vele industrieën. Er zijn vele termijnmarkten voor grondstoffen en financiële effecten waar handel tussen concurrerende bedrijven belangrijk is.

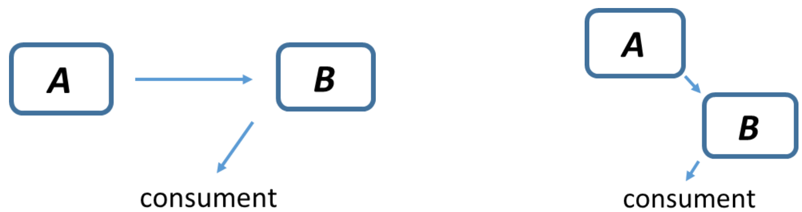
Het raamwerk dat we juist hebben ontwikkeld kan omgevormd worden tot een raamwerk over ex ante horizontale leveringscontracten. Ik maak twee aanpassingen. Ten eerste, veronderstel nu dat de productiecapaciteit per bedrijf gelijk is aan $k=2$. Dat betekent dat een enkel bedrijf nu beide eenheden zelfstanding kan bedienen. Ten tweede, veronderstel dat de fases in het spel omgekeerd verlopen; bedrijven tekenen eerst een horizontaal leveringscontract, vooraleer ze voor de consument concurreren.

Om de prikkels te bestuderen voor bedrijven om een horizontaal leveringscontract te tekenen, laat ons starten met de analyse van het alternatieve scenario. Dat alternatieve scenario is gemakkelijk te analyseren omwille van de veronderstelling dat beide bedrijven beide eenheden zelfstandig kunnen bedienen ($k=2$). Zonder overeenkomst is er hevige concurrentie voor de consument. Prijsconcurrentie drijft de prijs omlaag naar marginale kost c, en de bedrijven verdienen nul winsten in evenwicht.

Veronderstel nu dat de bedrijven samen beslissen dat bedrijf A, ex ante, twee eenheden produceert voor bedrijf B. Dan, wanneer de bedrijven zich in de concurrentiefase bevinden, zal bedrijf A geen resterende capaciteit meer hebben om de klant te bedienen. Bedrijf B is dus een monopolist en vraagt de monopolieprijs van V per eenheid. De bedrijven hebben er belang bij om het leveringscontract te tekenen, omdat ze baat hebben bij verminderde concurrentie. In evenwicht zijn de industriewinsten strikt positief.

Hoofdstuk drie draagt bij tot het begrijpen van ex ante leveringscontracten. Ten eerste formuleert het een schadetheorie. Het vindt dat de effecten van een termijncontract gelijkaardig kunnen zijn aan de effecten van een fusie. Het verschil is natuurlijk dat, wanneer twee bedrijven fuseren, zij de eigendomsrechten van hun productie-eenheden overdragen. Dat is niet het geval wanneer bedrijven een termijncontract tekenen. Bij het termijncontract verkoopt bedrijf A enkel producten aan bedrijf B, geen productie-eenheden.

Ten tweede toont hoofdstuk drie een identificatieprobleem aan. De overeenkomst tussen bedrijven A en B is horizontaal, wat wil zeggen dat het plaatsvindt tussen concurrerende bedrijven. Echter, de overeenkomst hoeft niet geobserveerd te worden als horizontaal. Integendeel, in evenwicht kan het gebeuren dat niet-geïnformeerde buitenstaanders het akkoord als verticaal observeren, zoals voorgesteld in figuur 3. Inderdaad, aangezien bedrijf A bedrijf B bedient aan volle capaciteit, wordt het niet geobserveerd als een bedrijf dat mee concurreert voor de eindklant. Daarnaast kan het overbodig zijn voor bedrijf *B* om zijn eigen productiecapaciteit aan te spreken, omdat het immers al aankoopt bij bedrijf *A*. Zo kan het gebeuren dat bedrijf *A* wordt geobserveerd als een verticaal gerelateerde inputleverancier. Het identificatieprobleem stelt een uitdaging voor concurrentieautoriteiten, omdat zij verticale overeenkomsten gewoonlijk als meer efficiënt beschouwen dan horizontale overeenkomsten.



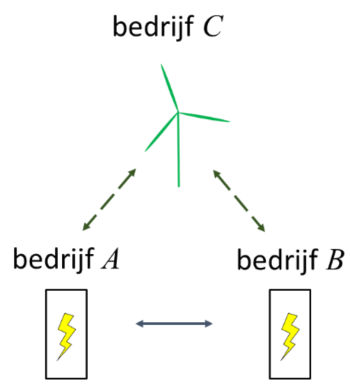
Figuur 3: het identificatieprobleem.

Ten laatste onderzoekt hoofdstuk drie de beslissing om te investeren in productiecapaciteit, en vindt het als resultaat dat anti-competitieve horizontale leveringscontracten een evenwichtsfenomeen zijn. Ze werden nog niet gerapporteerd in de literatuur over verticale integratie, bijvoorbeeld in Hart en Tirole (1990) en Ordover et al. (1990), waar bedrijven worden verondersteld constante marginale kosten en onbeperkte capaciteit te hebben. Ik draag bij aan deze literatuur door te tonen dat bedrijven eenzijdige prikkels hebben om slechts een beperkte productiecapaciteit te bezitten. Wanneer beide bedrijven onbeperkte productiecapaciteit zouden bezitten, zouden bedrijven immers geen anti-competitief horizontaal leveringscontract kunnen tekenen. De Bertrand-Edgeworth literatuur wordt ook gekenmerkt door prikkels voor concurrerende bedrijven om horizontale leveringscontracten met elkaar te tekenen. Ik toon aan dat, in het raamwerk van Kreps en Scheinkman (1983), zulke contracten kunnen leiden tot minder competitieve uitkomsten.

Hoofstuk vier van dit doctoraat behandelt korte termijn elektriciteitsmarkten. Het spel verloopt als volgt. Bedrijven kunnen eerst met elkaar handel drijven op de termijnmarkt, waarna ze concurreren op de balanceringsmarkt.

Het hoofdstuk ontdekt een belangrijk onderscheid tussen twee types bedrijven. Bedrijven met toegang tot flexibele productie, bijvoorbeeld komend van batterijen, worden aangeduid als flexibele bedrijven. Ze kunnen kiezen om hun productie al dan niet aan te bieden op de balanceringsmarkt, en zijn dus concurrenten. Bedrijven zonder toegang tot flexibele productie, daarentegen, worden aangeduid als niet-flexibele bedrijven. Zij hebben geen flexibiliteit om aan te bieden op de balanceringsmarkt. Ze hebben misschien wel productie- of consumptieeenheden, bijvoorbeeld komend van windmolenparken of huishoudens, respectievelijk. Echter, ze hebben niet de flexibiliteit om hun consumptie of productie van die eenheden aan te passen. Bijgevolg gedragen niet-flexibele bedrijven zich als louter financiële spelers wanneer ze posities innemen op de termijn- en balanceringsmarkt.

We kunnen twee types termijnhandel onderscheiden, zoals voorgesteld in figuur 4. Horizontale termijnhandel vindt plaats tussen twee flexibele bedrijven. Het wordt weergegeven door de ononderbroken lijn tussen bedrijf *A* en bedrijf *B*. Verticale termijnhandel is handel tussen een flexibel bedrijf en een niet-flexibel bedrijf. Het wordt weergegeven door de onderbroken lijnen tussen bedrijven *A* en *C*, en bedrijven *B* en *C*.



Figuur 4: horizontale en verticale termijncontracten.

Eerder onderzoek heeft horizontale en verticale termijncontracten apart geanalyseerd. Bijvoorbeeld, Spiegel (1993) heeft als eerste naar horizontale termijncontracten gekeken. De literatuur over verticale termijnhandel bouwt voornamelijk voort op het artikel van Allaz en Vila (1993), en heeft de meeste aandacht gekregen. Beide types van termijnhandel zijn relevant in elektriciteitsmarkten. Hoofdstuk vier draagt bij tot het begrijpen van de interacties tussen de twee types van termijnhandel, en rapporteert ook over de implicaties voor het organiseren van balanceringsmarkten.

Het belangrijkste inzicht is dat de interacties tussen de twee types termijnhandel afhangen van de mate waarin horizontale contracten als substituut optreden voor verticale contracten, of eerder onafhankelijk van verticale contracten getekend worden.

Het eerste scenario weerspiegelt een veiling op de termijnmarkt. Door een ander bedrijf te overbieden op de termijnmarkt, zal een bedrijf niet enkel zijn eigen positie, maar ook de positie van het andere bedrijf beïnvloeden. Aangezien verticale contracten geassocieerd worden met pro-competitieve effecten, zijn horizontale contracten dus een instrument voor bedrijven om het aantal verticale contracten in de industrie te verminderen. Hoofdstuk vier toont aan dat er winstgevende afwijkingen bestaan van het evenwicht dat geanalyseerd wordt in Allaz en Vila (1993). Met andere woorden, wanneer de termijnmarkt als een veiling plaatsvindt, en wanneer we horizontale termijncontracten meenemen in het raamwerk, zijn het evenwicht en de analyse van Allaz en Vila (1993) niet meer geldig.

Het tweede scenario weerspiegelt een over-the-counter termijnmarkt. Wanneer bilaterale efficiëntie geldt, handelt elk paar van bedrijven bilateraal om hun bilaterale winsten te maximaliseren, rekening houdend met de andere bilaterale contracten in de industrie. Op die manier worden horizontale contracten onafhankelijk van verticale contracten afgesloten. Wanneer bilaterale efficiëntie geldt, kan het evenwicht van het spel wel samenvallen met dat van Allaz en Vila (1993). Dat positieve resultaat verdedigt het concept van bilaterale efficiëntie als een intuïtieve manier om termijnhandel tussen zowel horizontaal gerelateerde als verticaal gerelateerde bedrijven te omvatten.

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Introduction

This doctoral thesis deals with horizontal subcontracting agreements, i.e., outsourcing agreements between competing firms. It consists of four chapters. Two of the four chapters focus on electricity markets. Importantly, these two chapters are *not* applications of the other two chapters. To the contrary, each chapter makes individual, theoretical contributions to the field of industrial organization.

This introduction is not meant to cover everything that can be written about my thesis. Nonetheless, I believe that it is useful, as it highlights a number of connections between the different chapters.

Outline

The first two chapters of my thesis have in common that they are written jointly with Jan Bouckaert, my advisor. Also, they both deal with horizontal subcontracts that are signed *after* the competition stage. Following Spiegel (1993), I will refer to that type of setting as *ex post* horizontal subcontracting.

The final two chapters of my thesis have in common that they are single-authored, and that they both deal with horizontal subcontracts that are signed *before* the competition stage. Following Spiegel (1993), I will denote that type of setting as *ex ante* horizontal subcontracting.

This introduction will follow the structure of my thesis. I will start by developing a simple setting of ex post horizontal subcontracting, and report on the most important insights that follow from the first two chapters. I will then modify the setting into one of ex ante horizontal subcontracting. That modified setting will enable me to give an overview of the final two chapters.

Ex post horizontal subcontracting

Ex post horizontal subcontracting is relevant in a wide set of industries. Two important examples are electricity markets and the market for securities underwriting services. The motivation behind ex post horizontal subcontracting is that reallocating the workload across competing firms can reduce costs.

Consider the following simple framework. Figure 1 represents the demand function. The horizontal axis denotes demand Q and the vertical axis represents price P. There is a consumer that has a demand for two units. However, his willingness to pay is at most V per unit.

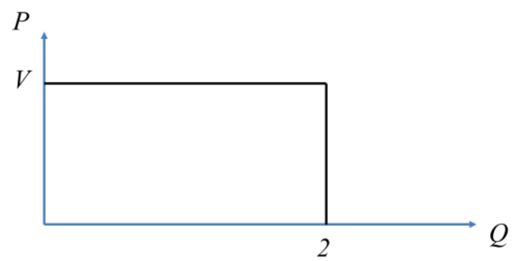

Figure 1: the demand function.

There are two competitors, firm A and firm B, that each have the same marginal production cost c. There is, however, limited production capacity per firm, $k=1$. So, a single firm can only serve one of both units on a stand-alone basis.

The game is as follows. First, firms compete in prices. More precisely, each firm chooses a total price p. The firm choosing the lowest price wins the consumer. In case of a tie, the winner is randomly chosen. Second, firms can sign a horizontal subcontract with each other. Since the winner can only serve one unit in-house, he needs to call upon his competitor to serve the second unit. The subcontractor receives a markup m on top of its marginal cost of producing the second unit, c. So, the tariff paid by the winner to the subcontractor equals $c+m$. That markup m represents the terms of trade on the subcontracting market. If the markup is low, the terms of trade favor the contractor. If the markup is high, the terms of trade favor the subcontractor.

The analysis is as follows. Figure 2 represents firms' profit functions. The horizontal axis denotes the price charged by the winning firm. The vertical axis denotes profits. The winner's profits are increasing in his revenues. More precisely, the winner earns revenues, p, incurs a cost of c to produce one unit in-house, and incurs a cost of $c + m$ to contract the second unit from his competitor. Importantly, the loser does not earn zero profits. Indeed, he earns positive profits from acting as a subcontractor and charging markup m to the contractor.

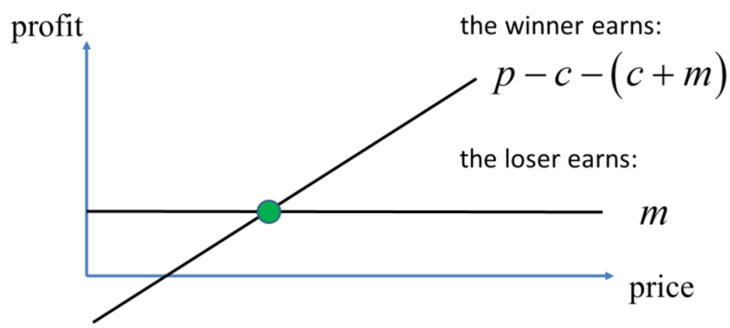

Figure 2: profit functions

In equilibrium, we find that firms should be indifferent between winning and losing. Indeed, any larger price cannot be an equilibrium because the loser would have an incentive to undercut the winning firm. Also, a lower price cannot be an equilibrium because the winner would have an incentive to charge a higher price. The equilibrium price therefore equals

$$p^* = \underbrace{c}_{\substack{\text{production} \\ \text{cost incurred} \\ \text{in-house}}} + \underbrace{(c+m)}_{\substack{\text{contracting} \\ \text{cost}}} + \underbrace{m}_{\substack{\text{opportunity} \\ \text{cost}}} .$$

In equilibrium, the winner is remunerated for three types of costs. First, he is compensated for the cost of producing the first unit in-house. Second, he is remunerated for the cost of contracting from the rival firm. Finally, he is compensated for the lost opportunity of profiting as a subcontractor. We learn that a higher markup by the subcontractor raises the equilibrium price via two distinct channels. First, a higher markup implies more expensive contracting. Second, a higher markup makes it more attractive for a firm to act as subcontractor instead of serving the consumer directly.

Chapter one of this thesis shows that installing back-up capacity can reduce costs (Bouckaert and Van Moer, 2017). The reason is that back-up capacity can provide the contractor with an outside option to the subcontract. As such, it can decrease the markup paid to the subcontractor in equilibrium. The cost-reducing effect does not require that back-up capacity is activated in equilibrium. The strategic incentive to install back-up capacity mitigates the public good problem of securing supply in electricity markets. It also highlights the important distinction between plant-level profitability and portfolio-level profitability.

Chapter two of this thesis investigates the effects of a merger. An important component of the analysis is how the merger affects the terms of trade on the subcontracting market. On the one hand, increased concentration can generate seller power on the subcontracting market, which raises the markup charged by subcontractors. On the other hand, increased concentration can also generate buyer power on the subcontracting market, which decreases the markup charged by subcontractors. Due to the latter effect, a merger that does not involve cost-synergies can reduce the consumer price. This result differs from the classic articles about merger analysis that do not incorporate horizontal subcontracting, such as Williamson (1968), Deneckere and Davidson (1985), Perry and Porter (1985), and Farrell and Shapiro (1990).

Ex ante horizontal subcontracting

We next turn to the analysis of ex ante horizontal subcontracting. Ex ante horizontal subcontracting is also relevant in many industries. There are many forward markets for commodities and forward markets for financial securities that are characterized by trade between competing firms.

The framework just developed can be modified to analyze ex ante horizontal subcontracting. I make two modifications. First, suppose now that the production capacity per firm equals $k=2$. So, a single firm can now serve both units on a stand-alone basis. Second, the staging of the game is reversed: firms can sign a horizontal subcontract with each other, before competing for the consumer.

To investigate the incentives for firms to sign a horizontal subcontracting agreement, let us start by analyzing the counterfactual scenario. The counterfactual is easy to analyze because of the assumption that both firms can each serve both units in-house ($k=2$). Absent an ex ante agreement, there is fierce competition for the consumer. Price competition drives the price down to marginal cost, and the firms earn zero profits in equilibrium.

Suppose now that firms decide that firm *A* will produce two units for firm *B*. Then, when firms move on to the competition stage, firm *A* does not have any residual production capacity left to serve the consumer. It follows that firm *B* is a monopolist and can charge the monopoly price. Firms benefit from signing the agreement because they gain from reducing competition. In equilibrium, industry profits are strictly positive.

Chapter three contributes to our understanding of ex ante horizontal subcontracting. First, it formulates a theory of harm. It finds that, from an effects-based point of view, a forward contract between competitors can be similar to a merger. Of course, the distinction is that, when two firms merge, they trade production assets with each other. In contrast, when firms sign a forward contract, the ownership of their production assets does not change. Firm *A* simply sells products to firm *B*.

Second, chapter three uncovers an identification problem. The agreement between firms *A* and *B* is horizontal. However, it need not be observed as horizontal. Instead, in equilibrium, uninformed outsiders to the industry may observe the agreement as vertical, as depicted in figure 3. Indeed, firm *A* supplies firm *B* at full capacity, and is therefore not observed as competing for the consumer. Firm *B*, since it already contracts from firm *A*, may choose not to produce in-house. The identification problem poses a challenge for competition authorities because vertical agreements are usually presumed to be more efficient than horizontal agreements.

Figure 3: the identification problem.

Finally, chapter three investigates production capacity choices and finds that anti-competitive ex ante horizontal subcontracting is an equilibrium phenomenon. It has not yet been reported in the vertical integration literature, e.g. in Hart and Tirole (1990) and Ordover et al. (1990), where firms are assumed to have constant marginal costs and infinite capacities. I contribute by showing that firms have unilateral incentives to be capacity-constrained. Intuitively, if all firms would have infinite capacities, firms would not be able to sign anti-competitive horizontal subcontracting agreements. The Bertrand-Edgeworth literature, too, is characterized by incentives for rival firms to sign subcontracting agreements with each other. I show that introducing a horizontal subcontracting stage into the Kreps and Scheinkman's (1983) framework can lead to less competitive outcomes.

Chapter four of this thesis deals with short-term electricity markets. The staging is as follows. Firms first trade on the forward market, after which they compete on the balancing market.

The chapter finds that there is an important distinction between two types of firms. Firms with access to flexible production, coming for example from batteries, are denoted by flexible firms. They can choose to offer their production on the balancing market. It follows that these firms act as competitors on the balancing market. In contrast, firms without access to flexible production, denoted by inflexible firms, do not have any flexibility to offer on the balancing market. They may have production or consumption assets, for example from wind farms or households, respectively. However, they do not have the flexibility to adjust the consumption or production coming from their assets. It follows that inflexible firms behave as purely financial firms when they take positions on the forward and balancing market.

We can distinguish two types of forward trade, depicted in figure 4. Horizontal forward trade occurs between two flexible firms. It is illustrated by the uninterrupted line between firm *A* and firm *B*. Vertical forward trade is trade between a flexible and an inflexible firm. It is illustrated by the interrupted lines between firms *A* and *C*, and firms *B* and *C*.

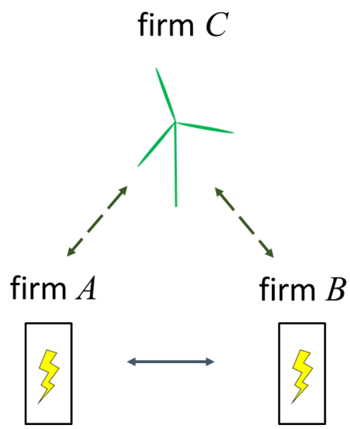

Figure 4: horizontal and vertical forward trade.

Previous work has seperately analyzed horizontal and vertical forward trade. For example, horizontal forward trade was first analyzed by Spiegel (1993). The literature on vertical forward trade largely builds on the article by Allaz and Vila (1993), and has received most attention. Both types of forward trade are relevant in electricity markets. Chapter four contributes to understanding the interactions between both types of forward trade. It also reports on the implications for balancing electricity market design.

The main finding is that the interactions between both types of forward trade depend on whether horizontal forward contracts can substitute for vertical forward contracts, or whether horizontal and vertical contracts are signed independently from each other.

The first scenario represents an auction on the forward market. When a firm outbids another firm on the forward market auction, doing so not only affects its own position on the forward market, but also affects the position of the other firm. Since vertical forward trade is associated with pro-competitive effects, horizontal forward trade is an instrument for firms to reduce the amount of vertical forward trade in the industry. Chapter four shows that there exist profitable deviations from the equilibrium analyzed in Allaz and Vila (1993). In other words, in a forward market auction setting, the Allaz and Vila (1993) analysis is not robust to the introduction of horizontal forward trade.

The second scenario represents an over-the-counter forward market. Under bilateral efficiency, each pair of firms trades bilaterally to maximize bilateral profits, taking as given the other bilateral contracts in the industry. As such, horizontal forward contracts are signed independently from vertical forward contracts. Under bilateral efficiency, the equilibrium can coincide with Allaz and Vila (1993). This positive result argues in favor of bilateral efficiency as an intuitive way to incorporate trade between vertically related firms as well as between horizontally related firms.

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Horizontal subcontracting and investment in idle dispatchable power plants

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We analyze horizontal subcontracting and show how idle production facilities can reduce contracting costs by credibly protecting against hold-up. Our analysis contributes to understanding competition between power firms that increasingly use intermittent generation sources. Their unilateral incentives to invest in maintaining underused units, such as dispatchable gas-fired plants, are underrated by plant profitability indicators. From a policy perspective, decentralized strategic investment incentives reduce the possible need for centralized security of supply measures. Our welfare analysis indicates that quantity competition can lead to a lower market clearing price than price competition.

Keywords: horizontal subcontracting, security of supply, strategic investment, intermittent energy sources

JEL-code: D43, L13, L14, L94

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1. Introduction

Horizontal subcontracting refers to the practice where competing firms engage in trade with each other. This paper (i) analyzes firms' investment incentives in idle production facilities and (ii) delivers welfare results by comparing price and quantity competition.

We phrase our analysis in a power market setting, where the integration of renewable energy sources motivates firms to sign horizontal subcontracts. A typical characteristic of important renewable energy sources, like wind or solar, is their intermittent component. Power generation from these sources only follows from favorable exogenous weather conditions like wind speed or sunlight, which are outside the control of the supplier.

At least two consequences have resulted from the introduction of intermittent power generation. First, it has *increased* the need for flexible back-up facilities to ensure security of supply. As an example, the New York Independent System Operator (2010) estimates that the addition of 1 MW of wind only removes 0.2-0.3 MW of existing dispatchable resources to still meet adequate reserve criteria. Second, intermittent energy sources typically have low to zero marginal generation costs and often enjoy priority of dispatch. As a consequence, they have *reduced* the capacity factor, the ratio of actual over potential generation, of conventional, dispatchable units. For example in Spain, where about 20% of power production comes from an intermittent source like wind, the capacity factor of Combined Cycle Gas Turbine (CCGT) plants dropped from 40% in 2004 to 11% in 2015 (Red Eléctrica de España, 2015).[3] Similarly, in Denmark, another frontrunner in intermittent power, wind farms generated 42% of total electricity

[3] The Red Eléctrica de España 2015 data cover market outcomes until November 2015. The 2014 data show a similar capacity factor for CCGT's.

consumption during 2015 at the expense of conventional power plants (Energinet, 2016).

The *direct* effect is that residual load profiles of conventional power plants have decreased considerably and therefore diminished profitability at the plant level. Low plant profitability undermines firms' incentives to maintain or install dispatchable units. Accordingly, public interventions, e.g. capacity payments, have been proposed or implemented to guarantee sufficient returns from adequate capacity needed to secure power supply. For instance, National Grid in the UK published capacity auction results of £2.2 per MW per hour, to be delivered in 2018 and beyond (National Grid, 2014). In the Northeast of the United States, the transmission organization PJM's reliability pricing model returned a price of \$6.87 per MW of capacity per hour in 2018/2019 (PJM, 2015).

Our analysis uncovers an *indirect* opposite effect that favors investments. Before the introduction of large-scale intermittent power, portfolio diversification followed mainly from a non-strategic tradeoff between fixed costs and variable costs. Our paper shows that, in a world with intermittent power sources, firms have *strategic* incentives to install or maintain dispatchable units. The reasoning is as follows. Since weather conditions are location-specific, not all intermittent units are always available. For instance, one firm can be wind-abundant, while at the same time its rival is windless and needs to rely on its expensive dispatchable units. In such a framework, competing firms can gain from *horizontal* subcontracting. The (prime) *contractor*, instead of activating its expensive gas-fired plants, purchases low-cost power from the rival's intermittent units (the *subcontractor*). If a firm cannot generate power from its intermittent source, and only has access to its dispatchable units, its willingness to pay for outsourcing equals at most its opportunity cost of in-house generation. Accordingly, the mere ability to dispatch conventional coal or gas-fired plants credibly puts an upper bound on the contracting cost. As a result, dispatchable units, even if *never* used for power generation, serve as credible protection against hold-up and reduce contracting costs. An exclusive measure of plant profitability, such as the capacity factor, is therefore insufficient to assess a firm's returns from investing in a dispatchable portfolio that complements its intermittent portfolio. From a policy perspective, there are indirect returns from dispatchable units that favor investments and thereby contribute to the security of adequate supply.

Horizontal subcontracting among power-generating firms typically takes place close to delivery, for example on a day-ahead or intraday market, after firms have undertaken long-term commitments with customers or retailers. Horizontal subcontracting is likely to gain significance because intermittent power generation, which is growing, is imperfectly correlated across borders. Indeed, Monforti et al. (2016) analyze EU country-to-Europe wind power correlation factors. They range from 0.07 for Cyprus to 0.34 for Germany. In 2012, around two thirds of the power traded on Elbas, an important European intraday market, crossed borders (Scharff & Amelin, 2016).

Importantly, the subcontracting terms alter firms' equilibrium behavior. Consistent with the horizontal subcontracting literature, we have that consumers are worse off (little competition) if and only if contracting is expensive. The intuition stems from two distinct effects:

(i) *Contracting costs*: there are less incentives to compete fiercely for consumers when the expected contracting costs are high.

(ii) *Opportunity costs:* by competing fiercely, a firm may forego subcontracting profits in the event it has wind power available and its rival does not. These subcontracting profits may act as an opportunity cost of serving consumers. For instance, consider price-competing firms. The high-price firm serves no consumers, so it never contracts power from the low-price rival. It does, however, benefit from significant subcontracting profits in the event the low-price firm has no wind power available. The

> low-price firm, in contrast, serves consumers but foregoes any subcontracting revenues. The equilibrium price takes account of the subcontracting profits as an opportunity cost and requires that firms are indifferent between serving the market or earning subcontracting revenues.

We contribute by showing that in our framework, the opportunity cost effect of subcontracting profits does not apply when firms compete in quantities rather than prices. A quantity-competing firm's expected subcontracting profits depends on its rival's output choice. The firm therefore does not reduce its subcontracting profits by competing more fiercely. For this reason, the market-clearing price can be lower when firms compete in quantities rather than prices. For horizontal subcontracting between price-competing firms to favor consumers, subcontracting payments should be sufficiently low so as to offset the price-increasing opportunity cost effect.

Related literature — Our paper relates to the literatures on horizontal subcontracting and power markets design with intermittent generation.

A number of papers explain horizontal subcontracting—the selling and buying positions between rival firms—by asymmetries or convexities in their production functions. Signing subcontracts to shift production from one firm to the other can therefore result in production efficiencies. Kamien, Li, and Samet (1989) study two price-competing firms with convex costs. Costs are reduced when the winner contracts part of the output to the rival losing bidder. If the winner determines the terms of the subcontract, there is fierce competition for the contract and firms make zero profits in equilibrium. Conversely, if the loser determines the terms of the subcontract, firms set higher prices and make positive profits.[4] Spiegel (1993) relies on convex upstream and downstream cost asymmetries across firms to rationalize horizontal subcontracting between rival firms. He studies ex ante and ex post subcontracts, signed before and

[4] See Marion (2015) for an empirical approach to study the effects of subcontracting.

after firms engage in quantity competition, respectively. Interestingly, only ex post agreements between horizontally subcontracting firms realize full production efficiency. To enhance welfare, subcontracts should generate sufficient production efficiencies. Gale et al. (2000) study sequential procurement and find that the possibility to subcontract can lead to lower profits.[5]

Our contribution to the subcontracting literature is threefold.

First, in our setting, the motivation for subcontracting between firms originates from production technologies that are only intermittently available.

Second, our framework examines—and compares—both price *and* quantity competition in order to obtain welfare insights. We find that subcontracting profits only act as an opportunity cost for price-competing firms. Subcontracting profits do not act as an opportunity cost for quantity-competing firms, because their strategy does not affect the offered quantity of the competitor, as explained earlier.[6]

Third, as a main result, our paper stresses the importance for firms to have access to dispatchable units, even when they are never used. Namely, when a firm contracts power from the rival, having excess capacity available avoids hold-up by the subcontractor.

As such, our paper contributes by offering a framework to analyze competition between generators that increasingly use intermittent power sources.[7] We reveal the important

[5] Our paper is also related to the literature focusing on strategic, vertical outsourcing and its effects on downstream competition (see e.g. Nickerson and Vanden Bergh (1999) and Shy & Stenbacka (2003)). In our framework, however, deciding to invest does not rule out the possibility to outsource. To the contrary, investing preserves efficient outsourcing while serving as a protection against hold-up.

[6] Our finding contrasts to the standard results as reported by Singh and Vives (1984). Our result, though, relates to Fauli-Oller and Sandonis (2002), who study price and quantity competition with patent licensing and royalties. In a similar fashion, a firm can increase its licensing revenues by charging a high price. Another related contribution studies a vertically integrated supplier who produces an upstream input for a retail rival (Arya et al. 2008).

[7] Ambec and Crampes (2012) study the optimal energy mix with reliable and intermittent energy sources. Gowrisankaran et al. (2015) empirically assess the social cost of solar power generation in a setting of

distinction between profitability at the *firm* level, as opposed to profitability at the *plant* level. Firms are willing to install dispatchable facilities that operate few or even zero hours per year, because it limits the contracting costs paid to the rival.[8] Thus, the revenues generated by peaking plants need not cover the investment and variable costs. Plant profitability is not a necessary condition for profit maximization. A firm can maximize its profits by holding *idle* generation capacity.[9]

Other applications — Though we phrase our analysis in a power market setting, other industries are also characterized by comparable subcontracting agreements. While there is often a common logic, one-to-one comparisons with our analysis should be taken with the necessary caution. We provide one example from the cargo industry and another from the banking industry.

Cargo companies (for maritime shipping or transport by air or road) sign binding contracts with their clients to ship goods on time. However, transporting conditions and customers' specific needs vary intermittently. As a result, it is often difficult to meet precise contractual obligations in space and time. One alternative is to foresee costly reserve capacity that is always available for all possible contingencies. At the same time, other competing cargo companies may have idle capacity at the right time and the right location. Horizontal subcontracting between rivals may then enable firms to obtain better load factors.

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welfare maximization based on Joskow and Tirole (2007). They disentangle the cost of unpredictability, the cost of varying availability and the installation cost, but do not consider market power. For more work on capacity payment mechanisms, see also e.g. Cramton and Stoft (2006) and Joskow (2006, 2008).

[8] Lambin (2016) finds a strategic effect in the opposite direction by investigating mothballing, the practice of temporarily withdrawing generation capacity, as a predatory strategy.

[9] Several papers provide other reasons why firms can benefit from holding idle capacity. For instance, incumbent firms can be willing to install excess capacity in order to deter entry (see Dixit 1979). In a dynamic setting, Maskin and Tirole (1988) find that holding excess capacity can sustain collusion because it discourages the rival from triggering a price war. Our analysis, in contrast, shows that firms can sometimes increase profits by jointly *divesting* idle dispatchable units.

In the financial sector, banks undertake contractual commitments to supply liquidity towards customers. Depositors, however, intermittently provide or request liquidity, so that banks may suffer from unexpected liquidity imbalances. This calls for efficient ways for banks to manage liquidity shocks to meet e.g. reserve requirements. Competing banks can gain from setting up a platform for horizontal subcontracting, e.g. an interbank lending market (see Freixas and Parigi, 1998) or a liquid Over-The-Counter market.

Section 2 describes the model. As a benchmark, section 3 provides the analysis when firms sign no horizontal subcontracts. Section 4 studies horizontal subcontracts, after which we offer a welfare analysis in section 5. Section 6 presents our main result on investment in idle production facilities. Section 7 presents further insights from oligopoly. Section 8 concludes and derives policy implications. The appendix is found in section 9.

2. The model

Two symmetric, risk-neutral, profit-maximizing firms i, with $i=1,2$, offer power, a homogeneous good. There is sufficient transmission capacity to guarantee that competition leads to a single market clearing price. Market demand originates from non-strategic final consumers or competitive power retail suppliers. The inverse market demand is linear and equal to

$$P = 1 - Q$$

where P denotes the market price and q_i firm i's output such that $Q = q_1 + q_2$. We use a price-responsive demand curve because consumers and retailers buy their power well before actual delivery, e.g. by making use of long-term contracts.

Each firm has a generating technology characterized by zero marginal cost, e.g. a wind park. This technology is, however, only intermittently available, depending on the state of nature. Hence, we refer to this technology as the *intermittent technology*.

Every firm also has a second technology that serves as reliable back-up, the *dispatchable technology*.[10]

Firms must deliver their output q_i independent of the state of nature. If the intermittent energy source is unavailable, they can use their dispatchable technology that is characterized by the linear cost function

$$C(q) = cq$$

with $0 < c < 1$.[11] The marginal cost of the dispatchable technology, c, is constant. It could easily be interpreted so as to include an environmental (carbon) tax or subsidy.[12]

The dispatchable technology should contribute to a firm's capacity adequacy by being available when needed, i.e., when its wind park is not. Several flexible technologies such as gas-fired plants fit this description well. Marginal cost c can then be interpreted as a fuel cost. Also, many nuclear power plants are dispatchable but may not be able to meet requests on short notice because they are typically less flexible. Combined heat and power plants are adequately dispatchable if they can adjust their power generation,

[10] Note that the dispatchable units need not be owned by the firms. It is equally possible that firms buy the access and usage of dispatchable units from a competitive fringe, for instance in return for a fixed and variable fee.

[11] The marginal cost does not exceed the maximal willingness to pay. We endogenize the investment decision in section 6.

[12] We use linear costs to ease computations and interpretations only. Our qualitative results do not change when we opt e.g. for a quadratic rather than a linear cost function. A convex cost function would capture that firms generate power with the lowest marginal generation cost first, also referred to as the "merit order" or "dispatch curve" (Joskow, 2011). If more generation is required, they must turn to more expensive generation units.

which is e.g. facilitated by the ability to store heat. Storage facilities such as batteries or hydro units are other examples. The marginal cost c can then be interpreted as the opportunity cost of not offering power later when the storage facility needs to be recharged.

To start, we will assume that, if a firm is wind-abundant, its wind park can meet total industry demand. Similarly, a firm can also use its dispatchable technology to generate sufficient power. [13]

The dispatchable technology is perfectly reliable. It is available in all states of nature. In contrast, the availability of each firm's intermittent technology is random. For simplicity, we assume that it takes a Bernoulli distribution. Let w and $\bar{w}$ refer to wind availability and wind unavailability, respectively. The four states of nature are then denoted by (w,w), $(w,\bar{w})$, $(\bar{w},w)$ and $(\bar{w},\bar{w})$. For our analysis of price competition, we use the convention to let the first element refer to the wind state of the winning firm and the second element refer to the wind state of the losing firm.

Let the probability that both firms' wind parks are *u*navailable, i.e. that state $(\bar{w},\bar{w})$ occurs, equal u. With probability s, either $(w,\bar{w})$ or $(\bar{w},w)$ occurs and only one firm is wind-abundant.[14] So, both firms' wind availability does not coincide at all times. To avoid that our results follow from ex ante asymmetries, we let state $(w,\bar{w})$ and $(\bar{w},w)$ occur each with the same probability $0.5s$. Each firm's wind park is then characterized by the same availability factor $1-u-0.5s$. Finally, both firms are simultaneously wind-abundant in state (w,w), which occurs with the remaining probability $1-u-s$.

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[13] Since our results do not require possible capacity constraints, we do not include capacity constraints in the basic model. Capacity constraints are, however, an important feature of our oligopoly analysis in section 7.

[14] As we will see below, in these states of nature, firms can benefit from horizontal *s*ubcontracting. These states of nature are therefore denoted to occur with probability s.

Wind complementarity: given that one firm is wind-abundant, the probability that the rival is wind-abundant too exceeds the probability that the rival is windless, or $1-u-s \geq 0.5s$.

This wind complementarity restriction is in line with Monforti et al. (2016) who find EU country-to-Europe wind power correlations are imperfect but positive. As we will see, its purpose is to guarantee that price competition leads to a symmetric equilibrium.

The staging of the game is as follows. In stage one, both firms compete to serve the market, uncertain about the state of nature. When firms compete in prices, they simultaneously announce their price. If firm i is the low-price firm, it serves market demand $Q=1-p_i$, with p_i firm i's price, and the market-clearing quantity Q results. In the event of a tie, the firm serving the whole market is chosen by the toss of a fair coin.[15] In contrast, when firms compete in quantities, each firm simultaneously announces its output q_i and the market-clearing price P results.

In stage two, firms are completely informed about stage one outcomes. The state of nature is revealed and each firm must serve its consumers. Firms charge consumers the same price independent of the state of nature, so each firm's sales are fixed.[16] Firms can, however, outsource generation to one another using horizontal subcontracts. Subcontracting of power generation enables firms to reallocate generation in order to reduce costs. The gains from trade (henceforth surplus from subcontracting) equal the reduction in industry generation costs made possible by subcontracting. If both firms are windless, state $(\overline{w},\overline{w})$, there is no surplus from subcontracting because each firm's dispatchable technology is characterized by the same marginal cost c. If only one firm

[15] Alternatively, each firm could serve half of market demand in the event they set equal prices. This settlement rule leads to the same unique symmetric equilibrium price when firms sign horizontal subcontracts.

[16] See Borenstein and Holland (2005) on time-invariant retail prices.

is windless, in state $(w,\bar{w})$ or $(\bar{w},w)$, that firm can either call on its own expensive dispatchable units or, alternatively, contract power generation from the rival firm. If both firms are wind-abundant, there is no surplus from subcontracting because variable costs are zero.

Our two-stage setting fits the power generation industry well. Stage one can be interpreted as a futures market where firms sell long-terms contracts for power to be delivered the next month or year. Stage two, then, can be regarded as the spot market close to delivery, where firms exchange power as a response to weather forecast updates. Spot power exchange can take place bilaterally Over-The-Counter, or alternatively, on a day-ahead or intraday market.

We analyze strategic effects when firms can subcontract power generation to one another. As a benchmark, we start with the standard analysis where firms cannot sign horizontal subcontracts. Since both firms may benefit from trade, we then analyze horizontal subcontracting.

Because the effects of subcontracts on competition and consumers are distinct for price and quantity competition, we provide both analyses.

3. No horizontal subcontracting

Price competition – Firm i 's profit function can be written as

$$\begin{cases} p_i(1-p_i)-(u+0.5s)c(1-p_i) & \text{if firm } i \text{ wins} \\ 0 & \text{if firm } j \text{ wins.} \end{cases}$$

Firm i wins if $p_i < p_j$, with $j=1,2$ and $i \neq j$. In the event of a tie ($p_i = p_j$), a winner is randomly chosen by the toss of a fair coin. The winner sells at price p_i and serves market demand $Q=1-p_i$. Since firm i uses its dispatchable technology only with probability

$u+0.5s$, its expected costs are $(u+0.5s)c(1-p_i)$. If firm j wins, firm i 's profits are zero as it does not serve any consumer at all. The analysis is standard: the equilibrium price is unique and equals the expected average cost $(u+0.5s)c$.

Quantity competition – Firm i 's profit function can be written as

$$(1-q_i-q_j)q_i-(u+0.5s)cq_i,$$

where the first term reflects firm i 's revenues from selling q_i units and the second part equals expected costs. The necessary and sufficient first-order conditions for profit maximization result in each firm offering $\frac{1-(u+0.5s)c}{3}$. The resulting market-clearing price is $\frac{1}{3}+2\frac{uc+0.5sc}{3}$. Per firm profits are $\frac{(1-(0.5s+u)c)^2}{9}$.

We check that, without subcontracting, we have that the market-clearing price is lower for price competition than for quantity competition.[17]

4. Horizontal subcontracting

This section studies horizontal subcontracts. Since we look for the subgame perfect Nash equilibrium, we start our analysis in the subcontracting stage (stage two), where firms can trade electricity to reduce costs.

In state (w,w), there is no surplus from subcontracting because both firms have access to the zero-cost generation from their intermittent technology. There is also no surplus

[17] Indeed, we have that $(u+0.5s)c\leq\frac{1}{3}+2\frac{uc+0.5c}{3}$ if and only if $\frac{1}{3}(u+0.5s)c\leq\frac{1}{3}$, which is satisfied since $\underbrace{(u+0.5s)}_{\leq 1}\underbrace{c}_{\leq 1}\leq 1$.

from subcontracting in state $(\bar{w},\bar{w})$. Both firms are then windless and rely on their dispatchable technology characterized by a common constant marginal cost.

There is surplus from subcontracting if firms experience asymmetric generation conditions, as in states $(\bar{w},w)$ and $(w,\bar{w})$. In our framework, the wind-abundant firm generates at zero marginal cost and offers a uniform wholesale tariff t at which the windless firm can buy electricity. The windless firm is willing to buy at any price up to c, because it must otherwise incur fuel cost c to deliver with the dispatchable technology. This reflects that the contractor is willing to pay its opportunity cost of in-house generation. If the wind-abundant subcontractor charges c, the winner is indifferent between contracting or not. We break the tie by assuming that the subcontractor is called upon because it is most efficient.[18] We also include the possibility that the tariff is not allowed to exceed an upper bound $\bar{t} \leq 1$, a finite positive number.[19] The wind-abundant firm will therefore charge

$$t = \min\{c, \bar{t}\}.$$

In our framework, subcontracting is efficient, meaning that firms take advantage of all potential surplus from subcontracting.

We now turn to stage one, where firms compete to serve the market. We study price and quantity competition, respectively.

Price competition — Firm i's profit function can be written as

[18] This tie-breaking rule guarantees the existence of a pure strategy equilibrium (see also Fabra et al. (2006)).

[19] We interpret $\bar{t}$ as a regulated wholesale tariff cap. Regulators often impose a price cap at the wholesale or the retail level, see e.g. Fabra et al. (2006) and Joskow and Tirole (2007). By letting $\bar{t} \leq 1$ we guarantee that the regulated tariff cap does not exceed the willingness-to-pay of the most-valuing consumer.

$$\begin{cases} (1-p_i)\,p_i - uc(1-p_i) - 0.5st(1-p_i) & \text{if } i \text{ wins} \\ 0.5st(1-p_j) & \text{if } j \text{ wins.} \end{cases}$$

If firm i wins (by charging the lowest price or, in the event of a tie, by winning the toss of a fair coin) and serves the market, its customer revenues are captured by the first term. The second term reflects its expected costs if both firms are windless. The last term represents its expected contracting cost, i.e., the cost of buying wind power from rival firm j at tariff t in state $(\overline{w}, w)$.

If firm i loses and does not serve the market, it still expects to make positive profits as opposed to the no subcontracting benchmark. The reason is that it can earn subcontracting revenues in state $(\overline{w}, w)$.

In equilibrium, a firm's incentive to increase its price — and earn subcontracting revenues only — should be offset by sufficient consumer revenues during stage one. The possibility to earn subcontracting revenues is foregone by the firm that serves consumers. Profits from subcontracting therefore act as an opportunity cost of winning.

This is clearly reflected when we analyze the equilibrium price. The equilibrium price in pure strategies is unique and equals

$$p^* \equiv \underbrace{uc}_{\substack{\text{expected unit}\\ \text{generation}\\ \text{cost}}} + \underbrace{0.5st}_{\substack{\text{expected unit}\\ \text{contracting}\\ \text{cost}}} + \underbrace{0.5st}_{\substack{\text{expected unit}\\ \text{opportunity}\\ \text{cost}}} .$$

Price p^* consists of three components. The first term represents the expected generation cost per unit. The second term represents the expected contracting cost per unit. The third term captures the foregone subcontracting revenues, and thereby reflects the opportunity cost of winning rather than losing.

At p^*, firms are indifferent between winning and losing. Our wind complementarity restriction $1-u-s \geq 0.5s$ guarantees that the winner cannot profitably deviate from p^*

by charging a lower price.[20] Neither can they increase profits by charging a higher price instead. As a result, price p^* is an equilibrium. Any lower price cannot be an equilibrium because then firms would prefer to lose for sure by charging a higher price. Any higher price can also not be an equilibrium because firms would then prefer to win for sure by undercutting. Therefore the equilibrium price p^* is unique.

In equilibrium, each firm's expected profits are positive and equal

$$\frac{st(1-uc-st)}{2}.$$

Note that the tariff paid for subcontracting alters the equilibrium price since it determines (i) firms' contracting costs and (ii) firms' opportunity cost of serving consumers in terms of foregone subcontracting revenues. This holds true even when expected subcontracting payments cancel out in equilibrium because of symmetry.[21]

Quantity competition — Firm i 's profit function can be written as

$$(1-q_i-q_j)q_i-ucq_i-0.5stq_i+0.5stq_j.$$

The first term displays firm i 's revenues from serving its customers. The second term represents its costs if both firms' wind parks are unavailable. In particular, with probability u, the firm incurs a marginal cost of c to generate its power. The third and fourth terms equal the expected contracting costs and subcontracting revenues, respectively.

[20] Indeed, profits from winning are concave with respect to the price, and the marginal profits from winning at the equilibrium price, $1-2p^*+uc+0.5st=1-uc-1.5st\geq 0$, are positive from the wind complementarity restriction, $c\leq 1$, and $t\leq\bar{t}\leq 1$.

[21] Note that, even when firms' payments cancel out in equilibrium, profits differ from a setting where firms do not charge each other for horizontal subcontracting ($t=0$). The intuition also relates to two-way access competition in industries with a bottleneck like in telecommunications (see Armstrong (1998) and Laffont, Rey, and Tirole (1998)). A "bill-and-keep" system is not profit-neutral.

We maximize firm i's profits with respect to q_i. Using the necessary and sufficient first-order conditions, we find that equilibrium quantities equal

$$q_i^* = q_j^* = \frac{1-uc-0.5st}{3}.$$

The resulting market-clearing price is $\frac{1}{3}+\frac{2}{3}[uc+0.5st]$. A firms' profits can be written as

$$\frac{(1-uc-0.5st)(1-uc+st)}{9}.$$

Our set-up assumed price or quantity competition in stage one. In many markets, including power markets, firms compete by submitting supply schedules.[22] Every firm submits a non-decreasing schedule which specifies, for each price, the quantity it is willing to offer. The possible prices that result from supply function competition are known to be bounded by the Cournot and the Bertrand price equilibria (Klemperer and Meyer (1989)). The appendix shows that the outcomes that we obtain for price and quantity competition can also be sustained as an equilibrium when firms are allowed to submit non-decreasing supply schedules.

5. Welfare results: price versus quantity competition

This section presents and discusses the welfare implications that follow from our analysis. We show that the standard welfare ordering between price and quantity competition can be reversed when firms sign horizontal subcontracts. As such, this section contributes to understanding not only electricity markets, but also other markets where horizontal subcontracting is important. We refer readers only interested in

[22] Supply function equilibria under uncertainty were first studied by Klemperer and Meyer (1989). Green and Newbery (1992) applied supply function analysis to model electricity spot markets. Supply or demand schedules are also observed in markets for government bonds.

investment incentives in idle dispatchable power facilities to the following sections 6 and 7.

The first proposition compares consumer surplus and total surplus for both modes of competition with horizontal subcontracts, and finds that quantity competition can outperform price competition.

Observe from section 4 that industry profits, both for price and quantity competition, are concave with respect to the tariff paid by the contractor. They are maximized at tariff

$$t = \frac{1-uc}{2s},$$

which we label as the monopoly tariff t^M.[23]

Proposition 1*: Quantity competition outperforms price competition with regard to consumer and total surplus if the tariff* t *sufficiently favors the wind-abundant subcontractor (*$t > t^M$*).*

Proof: Consumer welfare is strictly decreasing in the market-clearing price. Quantity competition leads to a lower market-clearing price than price competition if and only if

$$\frac{1}{3} + \frac{2}{3}[uc + 0.5st] < uc + st,$$

or, equivalently $t > \frac{1-uc}{2s} = t^M$. If the expected subcontracting payment is sufficiently large, quantity competition leads to a lower price in equilibrium. Since expected

[23] Note that tariff t can be smaller than, equal to, or larger than t^M, without contradicting our assumptions. For example, $t > t^M$ if we consider $\bar{t} \geq c$, $c = 0.90$, $s = 0.5$ and $u = 0.2$. Indeed, then, the wind complementarity restriction $1-u-s \geq 0.5s$ is satisfied, the tariff equals $t = c = 0.9$ and exceeds the monopoly tariff $t^M = \frac{1-uc}{2s} = 0.82$.

marginal costs are constant, a price move towards the expected marginal cost also improves total surplus. ■

Proposition 1 finds that, if $t > t^M$ so that market-clearing prices are *too high* from an industry profit maximization perspective, the standard welfare order is reversed.

The intuition behind proposition 1 is as follows. When firms compete in prices, the low-price firm serves the whole market. Consequently, it never earns subcontracting revenues since the high-price firm sells zero output. The high-price firm, in contrast, *does* benefit from subcontracting payments in the event it is wind-abundant and the low-price firm is windless. The possible profits from subcontracting wind power therefore act as an opportunity cost of winning and is part of the effective marginal cost. A firm has less incentives to serve consumers if it thereby reduces its subcontracting revenues. This effect, which makes consumers worse off, does not play in a quantity-competition framework. Then firm i 's subcontracting profits are given by $0.5stq_j$ and therefore are independent of q_i. By serving more consumers, firm i does not reduce its subcontracting revenues from selling wind power to firm j. For quantity-competing firms, subcontracting profits are lump sum and are not part of firms' effective marginal cost. Therefore the effective marginal cost is lower under Cournot than under Bertrand competition.

The second proposition measures, for both modes of competition, consumer welfare with horizontal subcontracting as compared to no subcontracting.

Proposition 2: *Horizontal subcontracting only benefits consumers if the tariff t sufficiently favors the windless contractor. Contractors should be favored more under price than under quantity competition.*

Proof: When firms compete in prices, consumers are better off when firms sign horizontal subcontracts if and only if

$$\underbrace{uc + st}_{\substack{\text{price}\\ \text{subcontracting}}} < \underbrace{uc + 0.5sc}_{\substack{\text{price}\\ \text{no subcontracting}}},$$

or equivalently, when $t < 0.5c$. This is satisfied if and only if the regulated tariff cap $\bar{t} < 0.5c$. This corresponds to the condition that the contractor should obtain a sufficiently large share of the subcontracting surplus.

Suppose firms compete in quantities. Then, consumers are better off when horizontal subcontracts are signed if and only if

$$\underbrace{\frac{1}{3} + \frac{2}{3}\left[uc + 0.5st\right]}_{\substack{\text{market-clearing price}\\ \text{subcontracting}}} \leq \underbrace{\frac{1}{3} + \frac{2}{3}\left[uc + 0.5sc\right]}_{\substack{\text{market-clearing price}\\ \text{no subcontracting}}},$$

which is always satisfied because $t = \min\{c, \bar{t}\}$. The strict inequality is satisfied if $\bar{t} < c$.■

Subcontracting is potentially harmful for consumers because it involves an opportunity cost of serving consumers under price competition. This opportunity cost does not arise in our quantity competition model, since firms take the output decision of the rival as given.[24] Therefore, the condition that subcontracts should sufficiently favor the contractor in order to benefit consumers is more stringent for price competition than for quantity competition.

[24] If cost functions are non-linear, a firm's output decision could affect the subcontracted quantity, and thereby the subcontracting profits. We have checked that our results do not change if costs are quadratic rather than linear. A quadratic cost function is convex and captures the merit-order effect in electricity markets, see footnote 12.

6. Investment in idle dispatchable units

This section investigates whether horizontally subcontracting firms have *strategic* motivations to provide back-up power supply by installing or maintaining dispatchable units. To isolate the strategic effects of back-up power generation, we set $u = 0$. This sets the utilization factor of the dispatchable technology equal to zero, because state $(\overline{w}, \overline{w})$ never occurs. In this setting, dispatchable units *only* impact each firm's profits by the strategic effect they have on the tariff paid for contracting. If we would analyze $u > 0$, the incentive for firms to install back-up facilities for security of supply reasons would interfere with the strategic effects we want to analyze.

Each firm simultaneously decides whether to invest in the dispatchable technology. When a firm invests, it incurs a fixed investment cost $I \geq 0$ to maintain back-up power supply. The investment cost allows both the interpretation of an installation cost and a maintenance cost. For instance, in European electricity markets, the maintenance cost interpretation is relevant because many conventional production facilities are withdrawn, i.e., they retire or are being mothballed. The strategic incentive to invest in maintenance then contributes to security of supply by resulting in fewer withdrawn dispatchable facilities.

There are two possibilities, either the regulated tariff cap $\overline{t} \leq c$ or $\overline{t} > c$.

If $\overline{t} \leq c$, the contractor always pays tariff $t = \overline{t}$ for contracting, regardless of investment decisions. Hence, since the utilization factor of the dispatchable technology is zero, investing or not does not raise profits. Strategic reasons do not provide firms with incentives to invest.

If $\overline{t} > c$, a firm that invests reduces its tariff paid for contracting from $\overline{t}$ to c. Even though the dispatchable technology is idle, it affects profits through the tariff paid for contracting. We provide the analysis of the investment game for price-competing firms. The insights do not change if we consider quantity-competing firms. We summarize the investment game in figure 1, which we explain below.

		firm 2: no investment	firm 2: investment
firm 1	no investment	$\frac{s\bar{t}\left(1-s\bar{t}\right)}{2}, \frac{s\bar{t}\left(1-s\bar{t}\right)}{2}$	$\frac{sc\left(1-0.5s\left(c+\bar{t}\right)\right)}{2}, \frac{s\bar{t}\left(1-0.5s\left(c+\bar{t}\right)\right)}{2}-I$
	investment	$\frac{s\bar{t}\left(1-0.5s\left(c+\bar{t}\right)\right)}{2}-I, \frac{sc\left(1-0.5s\left(c+\bar{t}\right)\right)}{2}$	$\frac{sc\left(1-sc\right)}{2}-I, \frac{sc\left(1-sc\right)}{2}-I$

Figure 1: the investment game if $\bar{t} > c$.

Profits in the investment game

If no firm invests, the tariff charged for subcontracting equals $t = \bar{t}$. The equilibrium price is $s\bar{t}$ and each firm earns $\frac{s\bar{t}\left(1-s\bar{t}\right)}{2}$.

We further analyze the profits if one firm invests and the other does not. The tariff charged for subcontracting is c if the contractor has invested and $\bar{t}$ if the contractor has not invested. It is easily checked that the firm that invests wants to win rather than to lose if the market price P satisfies

$$\left(1-P\right)P-0.5sc\left(1-P\right)>0.5st\left(1-P\right),$$

and hence exceeds

$$\underbrace{0.5sc}_{\text{expected unit contracting cost investing firm}} + \underbrace{0.5s\bar{t}}_{\text{expected unit opportunity cost investing firm}}.$$

Conversely, the firm that does not invest wants to win rather than to lose if market price P satisfies

$$(1-P)P - 0.5st(1-P) > 0.5sc(1-P),$$

and hence exceeds

$$\underbrace{0.5s\bar{t}}_{\substack{\text{expected unit}\\ \text{contracting}\\ \text{cost firm that}\\ \text{does not invest}}} + \underbrace{0.5sc}_{\substack{\text{expected unit}\\ \text{opportunity cost}\\ \text{firm that does}\\ \text{not invest}}}.$$

Interestingly, the investing firm need not win in equilibrium. There are two opposing effects. On the one hand, the firm with access to the dispatchable technology incurs lower contracting costs if it wins. The investing firm would therefore be willing to offer a lower consumer price than the rival. On the other hand, however, the firm with access to the dispatchable technology foregoes higher subcontracting profits than the non-investing rival. This higher opportunity cost drives up the consumer price it is willing to offer.

In our model, both effects have the same size, so that firms offer the same price.[25] Price $0.5sc + 0.5s\bar{t}$ is the only equilibrium price in pure strategies. The firm that does not invest earns $\frac{sc(1-0.5sc-0.5s\bar{t})}{2}$. The firm that invests earns $\frac{s\bar{t}(1-0.5sc-0.5s\bar{t})}{2} - I$.

Finally, if both firms invest, we have the profits as analyzed in section 4. Price-competing firms each charge sc and each earn $\frac{sc(1-sc)}{2} - I$.

Equilibrium analysis of the investment game

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[25] Results indicate that the low-cost firm always wins if expected costs are strictly convex or if there are at least four firms. However, for the purpose of this section, it suffices to analyze the equilibrium price and profits.

The scenario where no firm invests is an equilibrium in pure strategies if and only if the investment cost is sufficiently large, $I \geq \frac{s^2\bar{t}(\bar{t}-c)}{4}$. This equilibrium leads to the highest equilibrium price of $s\bar{t}$.

The scenarios where one firm invests and the other does not is an equilibrium in pure strategies if and only if $\frac{s^2 c(\bar{t}-c)}{4} \leq I \leq \frac{s^2\bar{t}(\bar{t}-c)}{4}$. The first inequality requires that the investment cost is sufficiently high so that the firm that does not invest indeed prefers not to invest. The second inequality requires that the investment cost is not too high so as to guarantee that the investing firm prefers investing. This equilibrium leads to a lower equilibrium price of $0.5sc + 0.5s\bar{t}$. Even though the dispatchable technology is idle, i.e. never used for power generation, it is worthwhile for a single firm to invest in it. Being equipped with idle dispatchable units is profitable because it reduces the opportunity cost of generating in-house, and hence, the contracting payments made to the rival. As such, overcapacity in power markets can be explained by firms protecting themselves against hold-up by the rival.

The scenario where both firms invest is an equilibrium in pure strategies if and only if the investment cost is sufficiently small, $I \leq \frac{s^2 c(\bar{t}-c)}{4}$. This equilibrium leads to the lowest equilibrium price of sc. Given that the rival invests, investing as well is profitable because it reduces the equilibrium price, so that more consumers are served. A downstream demand increase benefits the losing firm by increasing the winner's demand for contracting.

We summarize our main result in proposition 3.

Proposition 3: *Firms have a unilateral incentive to invest in idle power generation facilities when the investment cost is not too large.*

The above analysis has also shown that investments reduce the consumer price.

We further discuss the effects of dispatchable units on industry profits, which are concave and only depend on the equilibrium price.[26] The perfectly competitive price equals the marginal cost of the cheaper technology, here zero. The price that maximizes industry profits equals 0.5.

If $s\bar{t} \leq 0.5$, the equilibrium price is always *below* the monopoly level. While investing raises the (post-investment) profits of the investing firm, it reduces industry profits because it moves the equilibrium price further below the monopoly level. Investing therefore exerts a negative externality on the competitor, so that the investment game has all features of a prisoner's dilemma if the investment cost $_I$ is sufficiently low: while unilaterally, firms have an incentive to install additional idle dispatchable units, firms can increase profits by *jointly* divesting idle dispatchable units. So, instances of numerous mothballed peaking plants could be the result of a joint action to raise prices.

Otherwise, if $s\bar{t} > 0.5$, the equilibrium market price without investment is *above* the monopoly price. From concavity of the industry profit function, investment can raise industry profits if the resulting price-decrease is sufficiently small.

Finally, the effects of investments on social welfare should be interpreted with caution because in our framework, investments are idle and do not contribute to security of supply ($u = 0$). Investments, therefore, raise social welfare if and only if the reduction in deadweight loss from the price decrease outweighs the investment costs. The positive effect on social welfare thus relies on the price-responsiveness of demand. In our analysis, we have checked that there is no socially excessive investment, though

[26] Generation costs are zero (since $u = 0$) and the subcontracting payments cancel out at the industry level.

there may be too little. If demand were fixed, all investments are socially excessive because there is no deadweight loss.

7. Investment in idle dispatchable units: oligopoly

This section investigates an oligopoly of $N > 2$ firms. Such a framework adds realism and enables us to analyze competition among multiple subcontractors. In general, if power is abundantly available to multiple subcontractors, price competition is fierce and leads to low contracting costs. If so, there is no hold-up potential and therefore no strategic incentive to invest in dispatchable production facilities. If instead, more realistically, power sources are capacity-constrained, subcontractors may charge a significant markup. Dispatchable facilities then take a strategic role by protecting the contractor against hold-up, as we will show.

Therefore, this oligopoly model takes into account that a firm, if it is wind-abundant, cannot meet total market demand with its wind park. In particular, each firm has a limited amount k of intermittent capacity. To capture that one firm's wind park is insufficient to meet market demand D, which we hold fixed in this section, we let $k < D$. So, the oligopoly model differs from the duopoly model by the introduction of capacity constraints and by holding demand fixed. The staging of the game follows the price-competition model described in section 2. As in the duopoly model, we will investigate the strategic incentives for a firm to install or maintain dispatchable units.

The number of possible states of nature quickly expands with the number of firms. We therefore look at $N = 3$ firms. Each firm's wind park can either be windless if its wind capacity k is unavailable, or wind-abundant if fully available. The state of nature where all firms are windless $(\overline{w}, \overline{w}, \overline{w})$, occurs with probability u. There is a single wind-abundant firm in states $(w,\overline{w},\overline{w})$, $(\overline{w},w,\overline{w})$, and $(\overline{w},\overline{w},w)$, which together occur with probability s_1. With probability s_2 there are two wind-abundant firms (states $(w,w,\overline{w})$, $(\overline{w},w,w)$, and $(w,\overline{w},w)$). Finally, with probability $1-u-s_1-s_2$, all firms are wind-abundant in state (w,w,w).

In stage one, whenever the investing firms is among the firms charging the lowest price, consumers prefer to buy from it. This tie-breaking rule guarantees an equilibrium.

In stage two, subcontractors compete by offering the winner a tariff and a quantity. In particular, each subcontractor offers the winner the possibility to contract at most the offered quantity at a per unit tariff t. In line with his demand for generation, the winner will contract from the cheapest subcontractors first, before moving to the more expensive offers. If the winner is indifferent between contracting or not, contracting occurs whenever the subcontractor is more cost-efficient. If two subcontractors charge the same tariff, we suppose that the winner contracts from the wind-abundant subcontractor first.

This type of competition between capacity-constrained firms typically does not lead to pure strategy equilibria. For the purpose of our analysis, the assumption that $2k = D$ proves useful for the following reasons:

(i) If all three firms are wind-abundant, one subcontractor is redundant to meet demand so that there is maximal competition among the subcontractors. There is a unique pure strategy equilibrium where the equilibrium tariff at which the winner can contract is $t = 0$. Indeed, there is no incentive for a subcontractor to charge a higher tariff for its capacity because it would then sell zero. Also, any higher tariff cannot be an equilibrium because subcontractors would then have an incentive to undercut and sell more. In state (w,w,w), fierce competition among subcontractors eliminates the hold-up problem.

(ii) If only two firms are wind-abundant (states $(w,\overline{w},w)$, $(w,w,\overline{w})$, and $(\overline{w},w,w)$), none of their intermittent power is redundant. It follows that there is minimal competitive pressure on the subcontracting market. Indeed, since intermittent units are capacity-constrained, two wind-abundant firms are needed to meet demand. Each of them is pivotal and all of their available capacities will be called upon, despite a high tariff. As a result, there is a pure strategy equilibrium where each wind-abundant subcontractor charges the maximal tariff $t=\overline{t}$. There is no incentive for a subcontractor to charge less because it already sells at full available capacity. The hold-up problem therefore remains.

Note that our fixed demand D guarantees that these pure strategy equilibria exist in stage two, regardless of the price charged in stage one.[27]

We investigate a firm's incentives to gain additional access to k dispatchable capacity, which can be activated at a marginal cost of c. In line with the duopoly model, we isolate the strategic incentives to invest by setting $s_1=0$ and $u=0$. We thereby rule out that security of supply reasons interfere with a firm's strategic incentive to invest. We again consider $\overline{t}>c$, meaning that the regulated tariff cap exceeds the marginal cost of the dispatchable units. Without investment, no firm has dispatchable units. The investment decision concerns the installation or maintenance of a plant with capacity k. While an investment of any size keeps the equilibrium tariff at $t=0$ in state (w,w,w), considering an investment of size k dispatchable capacity simplifies the equilibrium analysis when two firms are wind-abundant.

[27] The alternative for this assumption would be a price-responsive demand, which would lead to an unnecessary analysis of mixed strategy equilibria. An analysis of stage two would then require analyzing subcontracting market competition for different possible levels of demand. However, whether pure strategy equilibria exist in stage two depends on how the level of demand relates to the available capacities. The equilibria range from very competitive (pure strategies, low demand), to intermediately competitive (mixed strategies, intermediate demand), and uncompetitive (pure strategies, high demand).

The analysis is as follows. Two wind-abundant firms are sufficient to meet demand. However, if a firm invests k dispatchable capacity, only one of the wind parks is necessary to meet demand. There are two possibilities: either the investing firm wins in stage one, or not. When the investing firm wins, which occurs in equilibrium as shown in the appendix, there exists a pure strategy equilibrium where each wind-abundant subcontractor charges $t = c$.[28]

Indeed, in all three states with two wind-abundant firms, there is no incentive for a wind-abundant subcontractor to charge more. The reasoning is that the dispatchable technology with capacity k would then substitute for the full production of the subcontractor's wind park of capacity k.[29] Also, if the investing firm is windless, a pure strategy equilibrium where the two wind-abundant subcontractors charge a higher tariff does not exist. The investing firm would then contract only k in total, so that there would be a profitable incentive for the subcontractors to undercut and sell their capacity k for sure. Finally, a lower tariff can also not be an equilibrium because a wind-abundant subcontractor can guarantee to sell its wind capacity at a tariff up to c. So, if two firms are wind-abundant, the dispatchable capacity is idle but eliminates the hold-up problem by reducing the wholesale tariff from $\bar{t}$ to c.

Figure 2 summarizes the stage two analysis. The probabilities $s_2/3$ follow from symmetry.

state of nature	probability	no investment	investor wins
(w,w,w)	$1-s_2$	maximal competition $t=0$	maximal competition $t=0$

[28] The investing winner is willing to contract at tariff c because of the tie-breaking rule.

[29] An investment in a smaller capacity would lead to mixed strategies. However, a smaller investment still reduces the equilibrium expected tariff, leading to the same insights.

$(w, w, \overline{w})$ $(w, \overline{w}, w)$ $(\overline{w}, w, w)$	$s_2/3$ $s_2/3$ $s_2/3$	minimal competition $t = \overline{t}$	strategic effect $t = c$

Figure 2: stage two analysis.

Proposition 4. *Oligopolists have a unilateral incentive to invest in idle power generation facilities when the investment cost is not too large*.

The proof is in the appendix.

For capacity-constrained oligopolists, contracting from multiple subcontractors does not suffice to reduce contracting costs. As a consequence, the strategic role for idle dispatchable capacity remains.

8. Conclusions and policy implications

This paper analyzes horizontal subcontracting. The tariff paid for contracting is known to crucially determine equilibrium outcomes for two reasons. First, expensive contracting raises costs and therefore diminishes the incentive to compete fiercely. Second, the possibility to earn profits from subcontracting can act as an opportunity cost of winning that drives up the equilibrium price.

We contribute to the horizontal subcontracting literature by showing that from a welfare point of view, quantity-competing firms, as opposed to price-competing firms, need not forego subcontracting profits from fierce competition. The reason is that a firm’s profits from subcontracting mainly depend on its rival’s output choice, which a quantity-competing firm does not affect by competing fiercely. Quantity competition can therefore outperform price competition with respect to consumer surplus. Also, for horizontal subcontracts to benefit consumers, contractors should be favored more under price rather than quantity competition.

Our main result is that there are strategic incentives to invest in idle production facilities. The intuition is that having access to readily available production facilities provides a firm with an outside option that limits the contracting costs paid to the subcontractor.

This result has important policy implications for the current shift towards carbon-neutral, intermittent sources, like wind and solar, which continues to be a priority in many economies. On the one hand, intermittent power units have increased the need for dispatchable units to back-up power supply. On the other hand, intermittent units often run whenever available, thereby reducing the revenues generated by conventional dispatchable plants. Utilities complain about low dispatchable plant profitability and consider mothballing their underused units, unless the government introduces appropriate public policies, such as capacity payment mechanisms, to secure supply. Our framework provides the policy insight for the power industry that firms have strategic unilateral incentives to install dispatchable units such as gas-fired plants, hydro reservoirs or combined heat and power plants with heat storage. Due to firm-level variation in energy source availability, horizontally competing generators gain from subcontracting by outsourcing generation and buying low-cost power from a competitor's available units. Then, if a generator experiences unfavorable conditions to generate wind power, being equipped with gas-fired plants credibly exerts a disciplining effect on the contracting tariff. Profitability at the plant level does not capture that maintaining dispatchable units is strategically advantageous. This effect mitigates the public good problem of securing supply. It should accordingly be taken into account when countries choose whether and how to implement capacity payment mechanisms.

Finally, our main result is also of interest for other industries characterized by horizontal subcontracting. In the financial sector, having access to liquid assets, besides contributing to system security, reduces the cost of interbank lending by providing an outside option to the borrowing bank. The mobile telecommunications sector offers a concluding example. In 2011, a new mobile spectrum license was auctioned off by the Belgian government. It was granted to Telenet, which rented its spectrum capacity from Mobistar, a network-based competitor in the market for mobile services. Telenet made clear from the start that the objective never was to use the spectrum license. According to Telenet, the spectrum served only as a bargaining chip to continue renting capacity from Mobistar (Tibau, 2012). By using its license as a credible protection, it protected itself against hold-up.

9. Appendix

Supply schedules — Our duopoly set-up assumed price or quantity competition in stage one. We now consider the possibility that firms compete by submitting supply schedules. We check that our price and quantity equilibrium outcomes from section 4 are also equilibrium outcomes when firms compete by submitting supply schedules.

Price competition.

The equilibrium price $p^* = uc + st$, obtained in section 4, corresponds to both firms submitting a flat supply schedule. In particular, each firm supplies zero at a price below p^*, and is willing to supply any quantity if the price exceeds p^*. Assume firms equally share the market if both firms submit the same flat supply schedule, or each firm is chosen to serve the market with equal probabilities, so that both firms earn $0.5st(1-uc-st)$, as in section 4.

Let us check whether these supply schedules are indeed an equilibrium when firms are allowed to submit *any* non-decreasing supply schedule. To be precise, we check whether a competitor can do better by submitting a supply schedule that differs from the flat supply schedule at p^*. If not, p^* can be sustained as an equilibrium if firms compete by submitting supply schedules.

Importantly, because a firm is a monopolist over its residual demand, a firm's profits are determined only by the intersection of its supply schedule with residual demand. Both firms face residual demand $1-p$ for prices below p^* and zero residual demand for prices above p^*. There are three possibilities: either a firm submits a supply schedule that intersects residual demand above p^*, below p^* or at p^*.

The firm can choose to submit a supply schedule that intersects its residual demand above p^*. It then sells zero and earns subcontracting revenues only. Our analysis in section 4 shows that firms do not gain from this strategy because they would also earn $0.5st(1-uc-st)$.

A firm could also choose to submit a more competitive schedule that intersects residual demand at a price below p^*, in which case the firm is the only seller and does not profit from subcontracting. This corresponds to the possibility to undercut the rival in section 4. We know from that section that this is not profitable.

Finally, the firm can also submit a supply schedule that intersects its residual demand at p^*, serving a fraction $0 \le x \le 1$ of demand at price p^*. The firm then sells $x(1-p^*)$ and earns

$$x(1-p^*)p^* - ucx(1-p^*) - 0.5stx(1-p^*) + 0.5st(1-x)(1-p^*),$$

which can be written as $0.5st(1-uc-st)$. Observe that x does not affect profits because at price p^* a firm is indifferent between serving consumers or subcontracting to the rival.

We conclude that a firm cannot earn higher profits by submitting a supply schedule different from the flat schedule at $p^*=uc+st$. The price equilibrium outcome we analyzed can also be the result of supply schedule competition.

Quantity competition.

The equilibrium quantities $q_1^*=q_2^*=(1-uc-0.5st)/3$ obtained in section 4 correspond to each firm submitting a vertical price-inelastic supply schedule. Each firm earns $((1-uc-0.5st)(1-uc+st))/9$, as in section 4.

Let us check whether the same supply schedule is indeed an equilibrium when firms are allowed to submit *any* non-decreasing supply schedule. To be precise, we check whether a firm i can do better by submitting a supply schedule different from the vertical schedule at q_i^*.

Again, a firm's profits are determined only by the intersection of its supply function with its residual demand. Firm i's inverse residual demand function equals $1-q_j^*-q_i$. We obtain the profit function

$$q_i\left(1-q_j^*-q_i\right)-ucq_i-0.5stq_i+0.5stq_j^*,$$

which is maximized at a profit equal to $((1-uc-0.5st)(1-uc+st))/9$.

We conclude that firm i cannot earn higher profits by submitting a supply schedule different from q_i^*. The equilibrium outcome we analyze for quantity competition can also be an equilibrium when firms are allowed to submit supply schedules.

Proof of proposition 4 — To prove the investment incentive in idle power generation facilities, we compare a firm's profits before investment and after investment.

(i) no firm invests

A firm's profits are

$$\begin{cases} Dp-(2s_2/3)k\bar{t}-(s_2/3)2k\bar{t} & \text{if it wins} \\ (2s_2/3)k\bar{t} & \text{if it loses.} \end{cases}$$

The first term reflects revenues from serving D consumers. The next terms represents the expected costs. With probability $1-s_2$, all firms are wind-abundant and the winner can buy at tariff $t=0$ on the wholesale market so that costs are zero. With probability $2s_2/3$, the winner is wind-abundant and contracts k from the single other wind-abundant rival at tariff $\bar{t}$. With probability $s_2/3$, the winner is windless and contracts k from each of the two wind-abundant rivals at tariff $\bar{t}$. The loser's profits from subcontracting are zero if all firms are wind-abundant and $k\bar{t}$ if it is one of the two wind-abundant firms (with probability $2s_2/3$).

It follows that a firm prefers to win rather than to lose if and only if the price exceeds $s_2\bar{t}$. As such, it is the unique stage-one equilibrium price. In equilibrium, firms are indifferent between winning and losing, so that they earn $(2s_2/3)k\bar{t}$ each.

(ii) one firm invests

We make a distinction between the investing firm and the others. We will argue that the investing firm wins in equilibrium. The equilibrium price it charges must satisfy that the others do not want to undercut. The analysis requires characterizing profits on the subcontracting market off the equilibrium path, i.e., profits if a non-investing firm wins and the investing firm loses.

The stage two analysis is as follows.

When a non-investing firm wins and all firms are wind-abundant, competition among subcontractors is fierce so that the unique equilibrium tariff $t = 0$.

When a non-investing firm wins, and two firms are wind-abundant, the analysis is as follows. There are three possibilities: state $(w, w, \bar{w})$, state $(w, \bar{w}, w)$ and state $(\bar{w}, w, w)$, where we introduce the convention that the first element describes the winning firm and the second element describes the investing firm. In state $(w, w, \bar{w})$, the investing firm is pivotal and can sell its entire wind capacity at tariff $t = \bar{t}$. There is no incentive to reduce the tariff because the winning firm will never contract more than k. In state $(w, \bar{w}, w)$, the equilibrium is where the other subcontractor charges up to tariff $t = c$ for its wind-power. Indeed, it is a weakly dominated strategy for the investing firm to charge a tariff below c and risk selling below cost. The other subcontractor can therefore charge up to $t = c$.[30] Note that a higher tariff cannot be an equilibrium because then the investing firm would prefer to undercut. Finally, in state $(\bar{w}, w, w)$, subcontractors will not use a pure strategy. The argument is as follows. Suppose the non-investing subcontractor offers its wind power at a tariff $t = c$. The investing firm would then have an incentive to offer only its wind power at the regulated tariff cap $\bar{t}$. If so, the non-investing subcontractor would want to raise its tariff as well up to a level slightly below $\bar{t}$. But this cannot be a best-response either because then the investing firm would want to undercut and sell the capacities of both its dispatchable and intermittent technologies. This reasoning shows that subcontractors will not use pure strategies and will therefore randomize over their strategies. Figure 3 shows the stage two analysis if the investing firm loses.

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[30] At tariff c, the wind-abundant firm is called upon because of the tie-breaking rule.

state of nature	probability	investor loses
(w,w,w)	$1-s_2$	maximal competition $t=0$
$(w,w,\bar{w})$ $(w,\bar{w},w)$ $(\bar{w},w,w)$	$s_2/3$ $s_2/3$ $s_2/3$	$t=\bar{t}$ $t=c$ mixed strategies

Figure 3: stage two analysis.

Fortunately, to show that the investing firm wins in equilibrium, we do not need to solve for the mixed strategies that would arise off the equilibrium path in state $(\bar{w},w,w)$. Instead, as we will see, it suffices to infer (a) a lower bound on the investor's profits from winning, which will prove the incentive to invest, and (b) an upper bound on the investor's profits from losing, which will show that the investor wins in equilibrium.

(a) We will argue that a non-investing firm, by winning, incurs a contracting cost of more than $k\bar{t}+k0.5(\bar{t}+c)$ in state $(\bar{w},w,w)$. Since the investing firm is pivotal, it can guarantee $k\bar{t}$, the profits from offering only one of its available intermittent capacity at $\bar{t}$ and withholding its dispatchable capacity. The investing firm earns $2kt-kc$ from selling at full capacity and activating the dispatchable technology. Charging a tariff $t \le 0.5(\bar{t}+c)$ leads to at most $k\bar{t}$ profits and is therefore a (weakly) dominated strategy. It follows that the other subcontractor can guarantee a profit of $k0.5(\bar{t}+c)$ by offering its wind capacity at $0.5(\bar{t}+c)$. Subcontractors would never play mixed strategies where the investing firm expects to earn less than $k\bar{t}$ profits and the non-investing subcontractor expects to profit less than $k0.5(\bar{t}+c)$. The contracting cost of the non-investing winner is strictly higher than the subcontractors' profits $k\overline{t}+k0.5(\overline{t}+c)$, because the costly dispatchable technology is activated with positive probability.[31]

We proceed by analyzing the price that non-investing firms want to offer in stage one. When $(\overline{w},w,w)$, a non-investing firm, by winning, incurs a contracting cost of more than $k\overline{t}+k0.5(\overline{t}+c)$. In state $(w,w,\overline{w})$, its contracting cost is $k\overline{t}$ and when $(w,\overline{w},w)$ its contracting cost is kc. When (w,w,w), its contracting costs are zero. A non-investing firm, by winning in stage one, therefore expects to earn strictly less than $Dp-(s_2/3)\left(k\overline{t}+k0.5(\overline{t}+c)\right)-(s_2/3)k\overline{t}-(s_2/3)kc$. A non-investing firm would never want to win if the price is too low to cover its expected contracting costs and its opportunity cost of winning. The opportunity cost of winning is given by the profits from losing. By losing against the investing firm, the non-investing firm gets $(2s_2/3)kc$. By losing against the other non-investor, it gets at least $(s_2/3)k0.5(\overline{t}+c)+(s_2/3)kc$.It follows that the opportunity cost of winning is at least $(2s_2/3)kc$. The non-investing firm therefore charges more than $\underline{p}\equiv\dfrac{(s_2/3)k\overline{t}+(s_2/3)k0.5(\overline{t}+c)+(s_2/3)k\overline{t}+(s_2/3)kc}{D}+\dfrac{(2s_2/3)kc}{D}$. The first term underreports the per unit expected contracting cost if the firm wins. The second term reflects the per unit opportunity cost of losing against the investor.

So, the investing firm, by charging $\underline{p}$, can guarantee to win and earn $D\underline{p}-(2s_2/3)kc-(s_2/3)2kc$, which we rewrite as $2(s_2/3)k\overline{t}+(s_2/3)k0.5(\overline{t}+c)-(s_2/3)kc$.[32] This lower bound on post-investment profits exceeds the profits before investment $(2s_2/3)k\overline{t}$, which proves the incentive to invest.

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[31] In equilibrium, the investing loser undercuts the non-investing loser with positive probability, thereby activating the dispatchable technology with positive probability. This possibility is essential for the firms to be indifferent between charging a range of possible tariffs.

[32] An equilibrium exists because the tie-breaking rule favors the investing firm.

(b) We will argue that, if the investing firm loses, its stage-two profits are strictly less than $2k\bar{t}-k0.5(\bar{t}+c)$ in state $(\bar{w},w,w)$. The first term reflects that the non-investing winner incurs a total contracting cost of at most $2k\bar{t}$. The second term reflects that the other subcontractor receives at least $k0.5(\bar{t}+c)$ from this total, as argued in (a). Taking into account that the investing firm, by losing, also earns $k\bar{t}$ in state $(w,w,\bar{w})$ and zero in other states, its expected subcontracting revenues from losing equal at most $(s_2/3)(2k\bar{t}-k0.5(\bar{t}+c))+(s_2/3)k\bar{t}$. This upper bound of *revenues* from losing equals the investor's minimal profits from winning, $2(s_2/3)k\bar{t}+(s_2/3)k0.5(\bar{t}+c)-(s_2/3)kc$. However, the upper bound of *profits* from losing are strictly lower because the costly dispatchable technology is activated with positive probability.

As a result, the investing firm wins in equilibrium. The profit-increase results from eliminating the hold-up problem in the states with two wind-abundant firms. ■

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Mergers and Horizontal Subcontracting

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We investigate no-synergies mergers in industries where firms can act as horizontal subcontractors after competing on the main market. Horizontal subcontracting generates two anti-competitive merger effects. First, the merged entity enjoys increased seller power when subcontracting to outsiders, thereby increasing their contracting costs. Second, as a consequence, the merged firm earns larger profits from subcontracting, which indirectly reduces its willingness to compete for consumers instead of serving as subcontractor. Two other merger effects are pro-competitive. First, the merged entity's buyer power reduces its contracting costs. Second, outsiders earn lower subcontracting profits, which makes them more aggressive on the main market.

Keywords: horizontal mergers; horizontal subcontracting; countervailing buyer power; joint bidding

JEL-code: D43, L13, L14, L41

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1. Introduction

When competing firms merge, prices are typically expected to rise when insufficient cost synergies arise. This has been shown by Williamson (1968), by Deneckere and Davidson (1985) for price competition, and by Perry and Porter (1985) and Farrell and Shapiro (1990) when firms compete in quantities. Consumer welfare, a typical standard used by antitrust authorities to judge mergers, then goes up only if the merging entities enjoy *sufficient* synergies.

We investigate mergers in industries where firms can sign horizontal subcontracts after competing. Horizontal subcontracts are contracts between competing firms, where a firm (the contractor) outsources the production of goods or services to one or more of its competitors (the subcontractors).[3] Horizontal subcontracts can realize cost-efficiencies by reallocating production towards competing firms with access to more efficient production capabilities. We report how a no-synergies merger modifies the terms of trade on the subcontracting market, and how it alters firms' incentives to compete on the main market.

Antitrust authorities classify the practice of horizontal subcontracting as horizontal cooperation, and take into account that it can raise competitive concerns.[4] The combination of horizontal subcontracting and mergers has not been studied so far. Merger activity, however, is common in important oligopolistic industries that are characterized by horizontal subcontracting. We offer examples from the financial and the defense industry.

[3] Kamien, Li, and Samet (1989) analyze horizontal subcontracting between price-competing firms. Spiegel (1993) analyzes horizontal subcontracting with quantity competition. Other contributions are Gale et al. (2000) who study the bidding effects from sequential procurements, and Haile (2003) who considers equilibrium bidding with option values to buy or sell in the secondary market. Horizontal subcontracting should be distinguished from *vertical* subcontracting where the successful bidder contracts a part of the main contract from *non*-competing bidders. We refer to Marion (2015) and Huff (2012) for empirical analyses of horizontal subcontracting, and Marion (2009) and Moretti and Valbonesi (2015) for empirical analyses of vertical subcontracting.

[4] For more details, we refer to the US Antitrust Guidelines for Collaboration among Competitors (2000) and the EU Guidelines for Horizontal Cooperation Agreements (2010).

When firms issue capital, they often rely on financial institutions as underwriters. Potential underwriters compete with each other to guarantee the issuing firm the necessary amount of capital. The underwriter that offers the most favorable conditions, i.e., the most favorable interest rate or price, wins the main contract. Winning underwriters (lead arrangers), however, usually do not perform their contract on a stand-alone basis. They typically contract part of their underwriting commitment from a syndicate with multiple sub-underwriters (co-arrangers). The syndicate often includes non-winning underwriters. This practice increases the prospects for successful funding and reduces underwriting costs by moving risks towards banks that are more capable of taking it. Corwin and Schultz (2005) analyze the composition of these syndicates. They report that the probability of being selected as the winning underwriter correlates with being included in the syndicate. Their interpretation is that an issuing firm suggests the winning underwriter to "include in the syndicate other underwriters who vied for the lead position." This illustrates the practice of horizontal subcontracting in the market for underwriting services. Corwin and Schultz (2005) also report a large number of mergers between leading financial firms in the underwriting services industry. Major players like e.g. BankAmerica Merrill Lynch, JP Morgan and Citi are the result of mergers and together represent 29.3% of the Americas 2016 mandated arrangers loans market (Thomson Reuters, 2016).[5,6]

Horizontal subcontracting and mergers are also prominent in the defense industry. Aeroweb (2017) reports that "[a defense] company competing to be a prime contractor may, upon ultimate award of the contract to another competitor, become a subcontractor for the ultimate prime contracting company."[7] Miller (2005) reports the following example. In 1986, the US Air Force (USAF) received prototype design

[5] This market comprises $ 2,321 billion in 2016 (Thomson Reuters, 2016). Syndicated loans e.g. are becoming increasingly important for non-financial businesses in the US and Europe and nowadays represent higher volumes than the public issuing of corporate debt and equity together (Ferreira and Matos, 2012).

[6] Note that our study is distinct from Hatfield et al. (2016), who study collusion with horizontal subcontracting in syndicated markets for IPOs and debt issuance. Biais et al. (2002) study an optimal IPO mechanism under collusion. Our analysis does not study collusion.

[7] See also Alexander (1997) on horizontal subcontracting in competitions for prime contracts from the U.S. defense department. Her analysis does not investigate mergers.

proposals by Boeing, General Dynamics, Lockheed, Northrop, and McDonnell Douglas for developing the Advanced Tactical Fighter. Several firms had agreed to team up if one or two of the companies' designs was selected by USAF. In particular, Lockheed, General Dynamics and Boeing agreed that, if one of their independently submitted designs was selected, the other two firms would serve as subcontractors (Aronstein et al., 1998).[8] Northrop and McDonnell Douglas made a similar agreement (Aronstein et al., 1998).[9] Some of these key players were already the result of mergers at that time, and have further merged in the mid-1990s into The Boeing Company, Northrop Grumman, and Lockheed Martin.

An important feature of industries characterized by horizontal subcontracting is that all firms, next to purchasing inputs on the subcontracting market, may also sell inputs on the subcontracting market. We find that, as a result of the merger, the merged firm enjoys increased *seller* power as well as increased *buyer* power on the subcontracting market.

The increased seller power enters the analysis in two ways. First, outsiders pay more to contract from a more concentrated subcontracting market. This direct, anti-competitive effect reduces their ability to compete for consumers. Second, we find that the merged firm's increased seller power on the subcontracting market generates an additional, indirect anti-competitive effect. In particular, an important feature of our setting is that winning firms forego the possible profits from acting as subcontractors. As such, an increase in subcontracting profits for the merged firm increases its opportunity cost of serving consumers. This indirect, anti-competitive effect also causes the merged firm to compete less aggressively for consumers.

The merger, next to generating increased seller power, also generates increased buyer power on the subcontracting market. We find that increased buyer power results in two pro-competitive effects that counteract the previously described anti-

[8] Importantly, while the discussions to team up had started before the submission of proposals, they were only formalized afterwards (Miller, 2005). This is in line with our setting, where subcontracts are signed ex post, i.e., after competing on the main market.

[9] Eventually, Lockheed won the competition to develop the prototype of the Advanced Tactical Fighter.

competitive effects. First, there is a countervailing buyer power effect that directly reduces the costs at which the merged firm can contract inputs, and thereby allows the merged firm to compete more fiercely for consumers. This effect is pro-competitive and directly disciplines the consumer price. Second, as the outsiders to the merger suffer from reduced subcontracting profits, they forego fewer profits when serving consumers on the main market. This indirect, opportunity cost effect causes the outsiders to the merger to compete more fiercely for consumers. These pro-competitive effects are distinct from the existing countervailing buyer power arguments or the double marginalization principle, as these literatures vertically separate the main market from the subcontracting market.[10]

The net effect of a merger on the consumer price follows from an equilibrium analysis that accounts for the four competitive effects described, depicted in figure 1. In summary, the merged firm m enjoys increased seller power, which

(i) directly increases each outsider o's cost of contracting inputs (CC_o-effect);

(ii) indirectly increases the opportunity cost of the merged firm to compete for consumers (OC_m-effect).

The merged firm also enjoys increased buyer power, which

(iii) directly reduces its cost of contracting inputs (CC_m-effect);

(iv) indirectly reduces the opportunity cost of each outsider to compete for consumers (OC_o-effect).

	contracting costs	opportunity costs
seller power effects (anti-competitive)	CC_o-effect	OC_m-effect
buyer power effects (pro-competitive)	CC_m-effect	OC_o-effect

Figure 1: the competitive effects of a merger in industries with horizontal subcontracting.

[10] See Spengler (1950) on double marginalization, and Inderst and Shaffer (2008) on buyer power in the context of mergers.

A merger analysis that does not account for all changes in terms of trade between the contractors and subcontractors can result in an under- or over-assessment of the post-merger price. Our analysis finds that each of the pro-competitive effects, the CC_m-effect or the OC_o-effect, can be sufficient for a no-synergies merger to reduce the consumer price.

Main market

We analyze two modes of competition on the main market. First, we analyze price competition on the main market, which is well suited to describe public and private procurement.[11] Second, we analyze quantity competition on the main market. As such, we intend to incorporate a wide set of industries outside the context of procurement.[12]

When the main market is characterized by price competition, the price-effect of the merger depends crucially on the pricing strategy of non-merged entities (outsiders), as they constrain the equilibrium price charged by the merged firm. The merged firm's willingness to compete does not affect the consumer price in equilibrium, so that the CC_m-effect and the OC_m-effect are zero.

When the main market is characterized by Cournot competition, the indirect OC_o-effect and the indirect OC_m-effect are zero. The reason is as follows. Subcontracting profits are only driven by the quantity served by rivals. Under quantity competition, a firm takes as given the rivals' quantities; their outputs are not affected by the firm's quantity choice. Firms therefore do not forego subcontracting profits by serving the

[11] In the US, the Federal Acquisition Regulation (FAR, 2005) sets out the rules by which the executive agencies of the federal government must acquire their purchases. The US government should comply with the FAR, which involves competitively acquiring goods and services from its prime contractors. Our price competition framework adequately reflects such a compliance.

[12] For example, horizontal subcontracting is an instrument for electricity producers to shift generation towards a lower-marginal cost plant available in the industry (see Bouckaert and Van Moer, 2017). Competition in electricity markets is often modelled with a quantity competition or a supply function competition approach.

main market. Each firm's opportunity cost of serving the main market is zero, and therefore independent of the merger.[13,14]

Subcontracting market

We analyze three subcontracting market settings that vary in terms of competitiveness. This flexible approach intends to capture the rich variety of subcontracting institutions in practice.[15] In particular, subcontractors may compete à la Bertrand on the subcontracting market, whereas monopolistic subcontracting minimizes competition among subcontractors, and monopsonistic subcontracting leaves all bargaining power to the contractors.[16]

For Bertrand subcontracting, a merger does not affect the outsiders' opportunity cost of serving consumers (the OC_o -effect is inactive).

- For price competition on the main market, the reasoning is as follows. On the one hand, the merged firm disciplines the subcontractors' profits because it has a lower demand for subcontracting. Indeed, the merged firm brings together the production capabilities of two merging parties, and thereby reduces its need to call upon subcontractors. However, on the other hand,

[13] See also Chen (2001) and Arya et al. (2008).

[14] Note that the indirect effects can reappear when firms chose quantities sequentially. Indeed, the followers' quantity choices are then decreasing with respect to the leaders' quantity choices. As such, for a leader, competing aggressively can result in fewer subcontracting market revenues (see Chen, 2001, for a discussion in a vertical merger context).

[15] Turning to the procurement context, as an example, the Federal Acquisition Regulation (FAR, 2005) requires prime contractors to consider adequately how to acquire their goods and services from subcontractors. In particular, prime contractors should carefully consider whether "adequate price competition [was] obtained or its absence properly justified" (FAR 44.202-2 (5)). As such, subcontracting may or may not occur competitively. Another consideration is that competing bidders are sometimes obliged to announce ex ante the identity of the subcontractor they intend to call upon. Such an obligation is intended to guarantee that the winner will be able to deliver. The California Subcontracting and Subletting Fair Practice Act is an extreme example where the winner is prohibited by law to call upon other subcontractors than those that were taken up in the proposal when competing for the contract (See Miller, 2014, and Marion, 2015). Also, in our example from the Advanced Tactical Fighter, Boeing, Lockheed and General Dynamics agreed that, if two of these three firms would win a project, the remaining firm could choose who to serve as principal subcontractor (Aronstein et al., 1998). Such institutions may lead to less intense competition on the subcontracting market. Finally, there can be incentives for the industry to move away from fierce competition among subcontractors. In particular, the industry has an incentive to shape subcontracting institutions in favor of the subcontractors, to the extent possible, to increase the perceived cost of serving consumers.

[16] The analysis will provide micro-foundations for each subcontracting market setting.

absent the merger, there is an additional subcontractor competing à la Bertrand. Both effects cancel each other out: the increase in buyer power from acquiring a competitor coincides with the loss of competitive pressure among subcontractors. The outsiders' profits from subcontracting (opportunity costs) are therefore not affected by the merger.

- For quantity competition on the main market, as described, the opportunity cost of serving consumers is zero, both before and after the merger.

For monopolistic subcontracting, the merger

- keeps the outsiders' contracting cost constant, because the outsiders already contract at the worst possible terms pre-merger. Contracting costs, therefore, cannot further increase after a merger. This inactivates the CC_o-effect.
- keeps the merged firm's opportunity cost of serving consumers constant, so that the OC_m-effect is zero. For quantity competition on the main market, as described earlier, the indirect effects are zero. For price competition on the main market, the merged firm already subcontracts at the best possible terms pre-merger, so that there is no effect from merging.

We find that the monopsonistic subcontracting analysis acts as a benchmark where all four effects are inactive. The contractor has the ability to buy from subcontractors at the lowest production cost available. The costs of contracting perfectly reflect actual production costs, both before and after the merger. Moreover, since the subcontractors earn no surplus in any event, their opportunity cost from winning is zero, with or without the merger.

Remark that for the least competitive mode of subcontracting (monopolistic subcontracting), the anti-competitive effects of a merger analyzed, the CC_o-effect and the OC_m-effect, are inactive. We will find that the merger may have a more favorable effect on consumers when the subcontracting market is less competitive (monopolistic subcontracting) rather than more competitive (Bertrand subcontracting or monopsonistic subcontracting).

We complement our merger analysis by investigating contractor teaming arrangements, a practice that is common in industries such as e.g. construction or oil drilling.[17] Such an arrangement sets up a consortium that jointly hands in one bid, but the consortium dissolves if it does not win the main contract. As for a merger, contractor teaming arrangements allow firms to jointly compete for consumers. However, the consortium does not enjoy seller power on the input market. We find the positive result that, for contractor teaming arrangements, the pro-competitive effects analyzed for a merger remain at work, while the anti-competitive CC_o-effect and OC_m-effect are inactive.

2. The model

There are $N \geq 3$ risk-neutral, symmetric, competing firms that produce homogeneous goods.[18] Market demand originates from non-strategic final consumers, competitive retailers, or a non-strategic procurer. It equals $Q(p)$ and depends on p, the market price.[19] We assume that $Q(p)$ is differentiable, cuts both axes, is strictly downward sloping and concave so that

(A1) $$Q^{'}(p) < 0 \text{ and } Q^{''}(p) \leq 0.$$

We denote the price at which demand is zero by $\overline{p}$ such that $Q(\overline{p}) = 0$.

The timing of the game is as follows. In stage one, firms compete for consumers. In stage two, firms can sign horizontal subcontracts. The stage-one outcomes are common knowledge in stage two.

[17] Joint bidding has been subject to policy interventions in the Outer Continental Shelf (OCS) oil drilling industry. In this industry, contracts can be resold after acquisition (see Hendricks et al., 2003, and Haile et al., 2010). We discuss other examples in the conclusion and policy discussion section.

[18] The assumption of homogeneous goods is reasonable because subcontracting requires that producers are substitutable. We see no reason why our insights would not hold when firms market differentiated products, after which they horizontally subcontract a homogeneous input.

[19] For quantity competition on the main market, we write the inverse of this demand function as $P(Q)$.

An important empirical motivation for subcontracting is that firms are uncertain about their marginal costs. For example, Haile (2001) reports that contracts to harvest timber are typically executed at the end of the contract term, so that bidding firms are likely to be uncertain about their future costs at the moment of competing in the auction. For example, firms can be uncertain about the technology they will use to execute the contract. Cost uncertainty is also important in other procurement industries. Large projects in the defense industry are characterized by a substantial timespan between the design, development and production. For our earlier example, the US Air Force procured prototype designs in 1986, which led to a first flight in 1990 (Miller, 2005). Renewable energy construction projects are also subject to substantial technological uncertainty at the moment of procurement.

Cost uncertainty, while important in many industries, is not essential for our results. In an alternative analysis, following Kamien et al. (1989) and Spiegel (1993), we looked at deterministic, convex variable costs in a winner-take-all framework.[20] Just as ex ante cost uncertainty, convex variable costs can explain the practice of horizontal subcontracting and generate equivalent insights.

We proceed with constant, uncertain marginal costs for three reasons. First, competition among subcontractors can be modelled by letting the subcontractors offer a uniform tariff per unit. We show that a uniform tariff then leads to efficient subcontracting. With convex costs, firms' unit costs are not constant, and more complicated tariff schemes would be needed to guarantee efficiency. Second, a convex cost technology would raise optimal design elements. The reason is that the gains from horizontal subcontracting would depend on firms' market shares on the main market. Consumers or procurers may then have a preference for mechanisms that minimize or eliminate the gains from subcontracting. [21,22] In our framework with

[20] For instance, construction firms may lack the appropriate capacity or scale to manage very high workloads in a low-cost manner. As another example, power generating firms first dispatch their lowest marginal cost units. If more in-house generation is required, they must turn to more expensive generation units.

[21] For example, in a procurement context where firms compete in prices, it may be optimal to divide a contract into multiple smaller ones, as happened e.g. for the Suez Canal projects in 2014-2015.

[22] As an important opposing argument, a winner-takes-all framework can apply well for settings where consumers or procurers rather coordinate with just one supplier so as to avoid asymmetric information issues among multiple contractors. Sufi (2007) provides an application to the syndicated loans market. He studies

constant and uncertain marginal costs, the size of the subcontracting surplus is not affected by dividing the contract. Finally, the constant marginal cost setting provides an important technical advantage, without losing the essentials. It allows to treat each unit produced in an independent way, because the choice to produce one unit does not alter the marginal cost of producing another unit. It follows that we can work out the analysis at the unit level first, before aggregating all units up to total demand. The unit-analysis approach can be used to analyze several modes of competition on the main market: price competition, characterized by any tie-breaking rule, and quantity competition.

The N firms are characterized by constant, uncertain marginal costs as follows. After competing in stage one, firms each draw their marginal cost from the same probability distribution. In particular, firms independently draw a high marginal cost $0 < c_H < \bar{p}$ with probability $0 < k < 1$, and draw a zero marginal cost with the remaining probability $1 - k$.[23] We can summarize that each firm i's expected unit cost C_i is identical and equals

(A2) $$C_i = kc_H .$$

Of course, it is not cost-efficient to produce at a high cost if a zero-cost rival is available. If so, firms can reduce production costs by reallocating their production using horizontal subcontracts. Horizontal subcontracts enable firms to shift production towards zero-cost production technologies.

The expected minimal industry's (sum of all firms) unit cost after efficient subcontracting is

$$C_{IND} = k^N c_H .$$

syndicated loans from Loan Pricing Corporation's Dealscan during 1990-2013. He reports that, for 69 % of loans in the sample, there is only one lead arranger on the loan.

[23] As long as the cost draws are imperfectly correlated, firms can benefit from signing horizontal subcontracts, and our results remain.

Indeed, with efficient horizontal subcontracting, the industry only incurs a marginal cost of c_H when *all* N firms draw c_H, with probability k^N. If firm i serves a unit on the main market, the unit surplus from subcontracting S_i equals the expected cost-reduction made possible from subcontracting

$$S_i \equiv C_i - C_{IND} = \left(k - k^N\right) c_H ,$$

the difference between firm i's in-house cost C_i and the minimal industry's production costs C_{IND}.[24] Since each firm is symmetric, the expected unit subcontracting surplus is identical for each firm.

The remainder of the paper omits the clarification that costs, subcontracting surplus, and profits are an expectation.

The micro-foundations that we study will guarantee that firms take advantage of all potential surplus from subcontracting. In other words, firms use subcontracts to allocate production cost-efficiently. The merger effects that we find therefore do not follow from efficiency changes on the subcontracting market.

3. Subcontracting market analysis

Pre-merger analysis – There is a wide range of factors or institutions that determine the subcontractors' bargaining or market power. In general, let share σ of realized surplus from subcontracting be appropriated by the selling firms (subcontractors). The remaining share $1-\sigma$ goes to the buyers (contractors). We find that $0 \leq \sigma \leq 1$. Indeed, in stage two, the contractors would never be willing to buy from the subcontractors if $\sigma > 1$. In-house production would then outperform subcontracting. Similarly, the subcontractors would not be willing to sell if $\sigma < 0$. For duopoly

[24] The surplus from subcontracting is earlier modelled by e.g. Spiegel (1993) and Gale et al. (2000).

competition, Kamien et al. (1989) interpret the subcontractor as a Stackelberg leader if $\sigma = 1$. The symmetric two-player Nash-bargaining solution corresponds to $\sigma = 0.5$. Since our analysis involves more than two firms, share σ results from a more complex interaction on the subcontracting market. We therefore present three settings. [25] There is a need to specify the micro-foundation behind σ because the degree of competition among subcontractors is not exogenous to the merger.

1. Bertrand subcontracting. Let a firm's cost draw, c_H or zero, become common knowledge after stage one and before stage two.[26] Each firm simultaneously offers a unit tariff at which it wants to subcontract.

The probability that a given firm is the only one of all N firms drawing a zero cost equals $\left(1-k\right)k^{N-1}$. This is also the only event in which the firm can profit as a subcontractor. As a subcontractor, it can then capture all subcontracting surplus by offering a unit tariff that undercuts c_H by the smallest possible amount.[27] In all other events, there are at least two zero-cost firms, so that the given firm cannot profit as a subcontractor: (i) for consumers served by high-cost firms, the zero-cost subcontractors compete away all subcontracting profits; (ii) for consumers served by one of the zero-cost firms, there is no demand for contracting.

Per unit served by a rival firm on the main market, a firm earns c_H if it is the only zero-cost firm, which occurs with probability $\left(1-k\right)k^{N-1}$. Therefore, per unit served

[25] We do not model the subcontracting market à la Cournot. That approach would lead to inefficient subcontracting in equilibrium for the standard reason of allocative inefficiency from market power. A merger then affects the efficiency of the subcontracting market and thereby obfuscates the consumer price effects studied in this paper.

[26] Standard results on revenue equivalence indicate that our findings also hold in other settings. For instance, the outcome of the analysis is unchanged if competing subcontractors would have private knowledge about their marginal cost draw and receive the second-lowest offer, for example by an English auction. Subcontracting is often studied in a complete information setting (see Kamien et al. (1989) and Spiegel (1993)). The advantage is that firms can then easily identify the subcontracting opportunities. The merger effects we study therefore do not follow from asymmetric information. For an analysis of asymmetric information in auctions with resale, see Haile (2003). For incomplete contracts we refer to Miller (2014).

[27] We can assume that, in case two subcontractors charge the same tariff, the tie-breaking rule favors the most cost-efficient firm.

by a rival firm on the main market, the expected profits from subcontracting equal $(1-k)k^{N-1}c_H$.

The resulting share of surplus going to the subcontractors equals the subcontractors' unit profits, divided by the subcontracting surplus per unit. Since there are $N-1$ subcontractors, the subcontractors' unit profits are $(N-1)(1-k)k^{N-1}c_H$. The unit subcontracting surplus equals $S_i=(k-k^N)c_H$. We conclude that share $\sigma=\frac{(N-1)(1-k)k^{N-1}}{k-k^N}$.

It can be shown that $\frac{d\sigma}{dN}<0$, meaning that the larger the number of subcontractors, the lower the share of surplus they capture.[28] The contractors, in turn, can appropriate a larger share if subcontracting market competition gets more fierce. In the limit, as N grows, all surplus goes to the contractors.

2. Monopolistic subcontracting. Subcontractors obtain maximal subcontracting surplus, *as if* they were monopolists. Monopolistic subcontracting can follow from several micro-foundations. For example, an arbitrarily small search cost s to visit subsequent subcontractors can suffice to yield monopolistic outcomes (Diamond, 1971). Indeed, suppose that firms' marginal costs are common knowledge, and all zero-cost firms charge the same subcontracting tariff strictly below c_H. Then, when visited by a contractor, a zero-cost firm can slightly raise its tariff by $0<\Delta<s$ without losing the contractor to another subcontractor. The firm can always profit

[28] Indeed, the derivative

$$\frac{d\sigma}{dN}=\frac{\left[(1-k)k^{N-1}+(N-1)(1-k)k^{N-1}\ln(k)\right](k-k^N)-(N-1)(1-k)k^{N-1}\left(-k^N\ln(k)\right)}{\left(k-k^N\right)^2}<0 \text{ if}$$

and only if the numerator is negative. We can rewrite this condition as $1-\lambda<-\ln(\lambda)$ for $0<\lambda\equiv k^{N-1}<1$. This is always satisfied because at $\lambda=1$, we have $1-\lambda=-\ln(\lambda)$ and $\frac{d(-\ln(\lambda))}{d\lambda}<-1$ for $0<\lambda<1$.

from such a deviation. In equilibrium, all firms charge c_H. All surplus from subcontracting goes to the subcontractors, so that $\sigma = 1$.[29,30]

3. Monopsonistic subcontracting. The contractors obtain maximal subcontracting surplus, *as if* they were monopsonists. It can follow from a setting where the offers are made by the contractors. In particular, let each firm simultaneously offer a unit tariff at which it wants to contract. Then, a contractor can do no better than submitting a positive tariff as close as possible to zero. Indeed, if there is a zero-cost subcontractor, that subcontractor has an incentive to accept the tariff. As such, the contractors capture all subcontracting surplus, so that $\sigma = 0$.[31]

Observe that, for all three settings, σ is irrespective of how much demand is served by each of the firms, and hence irrespective of the tie-breaking rule.

Post-merger analysis – We start by investigating the cost conditions of the merged firm, the outside firms, and the industry. After two firms merge, there are only $N-1$ firms in the market, one merged firm m and $N-2$ outside firms o. Hence, we need to relax the assumption of symmetry. The post-merger analysis uses the

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[29] To preserve efficient subcontracting, we can assume a tie-breaking rule such that the contractors visit zero-cost firms first. Note also that the equilibrium argument remains even if the search friction *s* is arbitrarily small. Finally, note that we allow for several contractors. Indeed, we can analyze each contractor's search in isolation because every firm's marginal cost is constant. There are no interactions between multiple contractors' searches for subcontractors.

[30] Monopolistic subcontracting can also follow from another micro-foundation where subcontractors sequentially offer a tariff. Let a firm's cost draw, c_H or zero, be private knowledge. Suppose that each firm sequentially offers a (better) unit tariff at which it wants to subcontract, and that subsequent subcontractors observe the most favorable offer made so far. Each subcontractor makes only one offer, and the order at which the offers are made is random but common knowledge. Then, the last subcontractor, if zero-cost, always undercuts. Previous subcontractors anticipate that they can only profit in the event all subsequent subcontractors have drawn c_H. They therefore have an incentive to make an offer that undercuts all previous offers, but remains as close as possible to c_H. We can assume that the tie-breaking rule favors the most recently submitted offer, so that $\sigma = 1$ exactly holds.

[31] We can assume that, in case of a tie between the subcontractor's marginal cost and the tariff offered by the contractor, subcontracting occurs whenever efficient. It follows that $\sigma = 0$ exactly holds.

character "˜" in order to distinguish the notation from the symmetric model that applies pre-merger.[32]

No synergies. The merged firm's marginal cost equals the marginal cost that both pre-merger entities can obtain without the merger by signing horizontal subcontracts bilaterally. In other words, the merger does not affect the production possibilities available in the market. This corresponds to Farrell and Shapiro's (1990, p. 112) terminology "no synergies" from merging.[33] By ruling out synergies, e.g. originating from scale economies, learning effects, more efficient management, or endogenous investment decisions, we isolate the effects of a merger that do not follow from synergies.

Moreover, it follows from our analysis that firms allocate production *efficiently* using horizontal subcontracts, before as well as after the merger. Therefore, the merger does not affect the production cost of serving a consumer. Our results are thus not driven by cost synergies, nor by production cost effects.

The merged firm m combines two pre-merger entities and draws c_H twice with probability k^2. With the remaining probability, the merged firm has access to a zero-cost technology. The merged firm is therefore characterized by a unit cost of $\tilde{C}_m = k^2 c_H$. The subcontracting surplus per unit served by firm m on the main market equals

$$\tilde{S}_m \equiv \tilde{C}_m - \tilde{C}_{IND} = \left(k^2 - k^N\right) c_H .$$

[32] To be clear, the post-merger analysis is asymmetric. We write prices as $\tilde{p}$, profits as $\tilde{\pi}$, unit costs as $\tilde{C}$, unit surplus from subcontracting as $\tilde{S}$, and the share of surplus going to the subcontractors as $\tilde{\sigma}$.

[33] Farrell and Shapiro's (1990, p. 112) description of a merger *M* with no synergies is: "After the merger, the combined entity *M* can perhaps better allocate outputs across facilities ("rationalization") but *M*'s production possibilities are no different from those of the insiders (jointly) before the merger. In this case we say that the merger "generates no synergies."" This also corresponds to Perry and Porter (1985), who vary the industry structure while fixing the industry supply curve.

The $N-2$ outside firms remain symmetric and have the same unit cost as before the merger. Each outsider o draws c_H with probability k, as before, so that $\tilde{C}_o = C_i$. The subcontracting surplus per unit on the main market served by an outsider is

$$\tilde{S}_o = S_i \,.$$

Since subcontracting is efficient, a no-synergies merger does not affect the minimal industry production cost per unit, so that $\tilde{C}_{IND} = C_{IND}$. The merger does *not* lead to cost savings at the industry level. The reasoning is that firms already produce at the lowest possible cost pre-merger by using efficient horizontal subcontracts. Industry costs result exclusively from the production facilities that are in the market, not on the names of their owners.

To summarize, cost conditions satisfy

$$C_{IND} = \tilde{C}_{IND} < \tilde{C}_m < \tilde{C}_o = C_i \,.$$

We proceed via two Lemmas towards the post-merger equilibrium analysis of the subcontracting market. Lemma 1 investigates the maximal subcontracting surplus that could be divided among the subcontractors. Lemma 2 is complementary and investigates how the subcontracting surplus is shared among the firms in the subcontracting market equilibrium.

We first find that the merger reduces the subcontracting surplus to $\tilde{S}_m$ for units on the main market served by the merged firm. At the same time, the merger decreases the number of outsiders, causing an opposing and increasing effect on the surplus of subcontracting *per outsider*.

Lemma 1: *Per unit served on the main market by the merged entity, the subcontracting surplus divided by the number of outsiders decreases when the number of firms in the merged entity increases. When considering a merger between two firms, we can write*

$$\frac{\tilde{S}_m}{N-2} < \frac{\tilde{S}_o}{N-1} \ .$$

The proof is in the appendix.

We next analyze the share of surplus appropriated by each of the firms. To analyze the effects of a merger, we consistently apply the same subcontracting market setting before and after the merger. So, if subcontractors compete à la Bertrand before the merger, they continue to do so after the merger. The shares of surplus appropriated by each of the firms are therefore *endogenous* to the merger. This consistency also applies for monopolistic subcontracting and for monopsonistic subcontracting.

When subcontractors compete à la Bertrand, we find that a smaller number of subcontractors leads to a substantial increase in the surplus going to the subcontractors. This need not be the case, however, if subcontracting market institutions are more, or less, competitive. Indeed, our least competitive setting, monopolistic subcontracting, cannot turn less competitive on the supply side because subcontractors already capture all surplus from subcontracting. Also, monopsonistic subcontracting, our most competitive setting, leads to an invariant share of zero that is appropriated by the subcontractors.

To better understand how the share of surplus going to the subcontractors changes as a result of the merger, we write $\tilde{\sigma}$ as a function of the share that applies pre-merger (σ). As we will see, share $\tilde{\sigma}$ depends on who wins the unit on the main market. If the merged firm wins, we denote it by $\tilde{\sigma}_m$. If an outsider wins we denote it by $\tilde{\sigma}_o$. Also, we will limit notation by letting $B=\{0,1\}$ indicate whether or not subcontractors compete à la Bertrand during stage two. The indicator B equals one if subcontractors compete à la Bertrand. The indicator B equals zero if the subcontracting market is monopolistic or monopsonistic.

1. Bertrand subcontracting. Recall that, in this subcontracting market setting, the unique equilibrium tariff is zero if there are two or more subcontractors with zero costs, and c_H otherwise. For each unit served on the main market, we now distinguish whether the unit is served by the merged firm or an outsider.

a. The merged firm wins the unit.

A subcontracting outsider then earns $(1-k)k^{N-1}c_H$, just as before the merger. Indeed, with probability $(1-k)k^{N-1}$ a subcontractor is the only one drawing a zero cost, in which case it earns cost-difference c_H.

The resulting share of surplus going to the subcontracting outsiders equals the subcontractors' unit profits, divided by the unit subcontracting surplus. The $N-2$ subcontractors earn a total unit profit of $(N-2)(1-k)k^{N-1}c_H$. The unit subcontracting surplus if the merged firm wins the unit equals $\tilde{S}_m = (k^2 - k^N)c_H$. It follows that share $\tilde{\sigma}_m = \frac{(N-2)(1-k)k^{N-1}}{k^2-k^N}$. By plugging in pre-merger share σ, we get

$$\tilde{\sigma}_m = \underbrace{\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}}_{>1}\sigma .$$

The share of surplus going to the subcontractors is higher as compared to before the merger since from Lemma 1, we know that $\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m} > 1$. Indeed, given that there is subcontracting surplus, chances are higher that it goes to the subcontractors because there are fewer subcontractors that compete against each other. A merger that leads to only two firms in the industry provides an instructive example. Indeed, any subcontracting surplus after the merger is then always captured by the only subcontractor left.

b. An outsider wins the unit.

The subcontracting market consists of the merged firm, and the $N-3$ losing outsiders. The outsiders' unit profits from subcontracting again equal $(1-k)k^{N-1}c_H$

, just as before the merger. However, the merged firm's unit profits from subcontracting are higher and equal $\left(2(1-k)k^{N-1}+(1-k)^2 k^{N-2}\right)c_H$. The first term of the expression represents the probability that the merged firm is the only firm in the industry drawing a single zero cost. The second term adds the probability that the merged firm has two favorable cost draws. If so, the merged firm still captures the surplus since the merging parties do not compete with each other to subcontract.

The resulting share of surplus going to the subcontractors equals the subcontractors' profits, divided by the subcontracting surplus to be shared. The subcontractors, consisting of $N-3$ outsiders and one merged firm, now earn a total unit profit of $\left[(N-3)(1-k)k^{N-1}+2(1-k)k^{N-1}+(1-k)^2 k^{N-2}\right]c_H$. The subcontracting surplus to be shared if an outsider wins equals $\tilde{S}_o=\left(k-k^N\right)c_H$. It follows that share $\tilde{\sigma}_o=\frac{(N-3)(1-k)k^{N-1}+2(1-k)k^{N-1}+(1-k)^2 k^{N-2}}{k-k^N}$. By plugging in the pre-merger share, we can write

$$\tilde{\sigma}_o=\sigma+\frac{(1-k)^2 k^{N-2}}{k-k^N}\ .$$

So, each of the $N-3$ losing outsiders that subcontract get the same share as before the merger, $\frac{\sigma}{N-1}$, and the merged firm gets share $\frac{2\sigma}{N-1}+\frac{(1-k)^2 k^{N-2}}{k-k^N}$. The final term represents the scenario where the merged firm has two favorable cost draws, while the others draw high costs. By merging, firms can guarantee themselves more favorable terms of trade as subcontractors.

2. Monopolistic subcontracting. Monopolistic subcontracting can follow from a setting where subcontractors sequentially offer a tariff at which they want to subcontract.[34] All surplus from subcontracting goes to the subcontractors, so that $\tilde{\sigma}_m = \tilde{\sigma}_o = \sigma = 1$.

3. Monopsonistic subcontracting. All offers are made by the contractors and the equilibrium argument is the same as before the merger. A contractor can do no better than submitting a positive tariff as close as possible to zero, thereby capturing all subcontracting surplus, so that $\tilde{\sigma}_m = \tilde{\sigma}_o = \sigma = 0$.

Lemma 2 summarizes these results.

Lemma 2. *For Bertrand subcontracting, the merger does not affect the outsiders' unit profits from subcontracting. For monopolistic and monopsonistic subcontracting, the merger does not affect the share of subcontracting surplus going to the subcontractors.*

In particular, the post-merger share equals

- $\tilde{\sigma}_m = (1-B)\sigma + B\dfrac{N-2}{N-1}\dfrac{\tilde{S}_o}{\tilde{S}_m}\sigma$ if the merged entity wins;
- $\tilde{\sigma}_o = \sigma + B\dfrac{(1-k)^2 k^{N-2}}{k-k^N}$ if an outsider wins.

For Bertrand subcontracting, outsiders' unit profits are independent of the merger. This finding is robust if we would consider other marginal cost distributions. The reason is that Bertrand-competing subcontractors only profit if they draw the lowest cost in the market. They then earn the cost difference between their cost draw and the second-lowest cost draw in the market.

For monopolistic subcontracting, the merger does not affect the share of surplus. However, it reduces outsiders' unit profits if the merged entity wins because the

[34] The equilibrium argument is the same as before the merger. In line with our no-synergies assumption, we assume that the merged firm earns twice the subcontracting profits of an outsider. For the micro-foundation based on the search model, the merged firm attracts as many searches as two pre-merger entities.

merged entity has a lower demand for contracting.[35] For monopsonistic subcontracting, the subcontractors earn zero profits before and after the merger.

4. Main market analysis: Bertrand

Bertrand model — There are $N \geq 3$ risk-neutral symmetric price-competing firms that produce homogeneous goods. Firms simultaneously choose prices. The lowest-price firm must serve demand $Q(p)$ where p is the lowest price submitted. We examine two tie-breaking rules if several firms submit the lowest price. Under the winner-take-all assumption one of them is randomly selected, each with equal probability, to be the winner that serves the market. The other possibility is that each lowest-price firm serves an equal portion of market demand.[36]

Without horizontal subcontracting, all firms serve their main market consumers on a stand-alone basis. The no-subcontracting equilibrium price, p^{ns}, therefore equals the expected unit cost

$$p^{ns} = kc_H$$

and all firms earn zero expected profits in equilibrium.

We proceed by investigating the effects of a merger under horizontal subcontracting.

Pre-merger analysis — The analysis starts by investigating at what prices firms prefer to win a unit or to lose a unit against a competitor. The goal is to obtain, for each σ and therefore each subcontracting market setting, the equilibrium price.

[35] In fact, there are two possible interpretations that depend on the tie-breaking rule in the subcontracting market. Two firms, by merging, can improve their contracting terms, reduce their amount contracted, or both. In particular, when the merged firm draws zero costs and a subcontractor also draws zero costs, subcontracting may or may not occur. If it occurs, the merged firm has a zero willingness to pay and enjoys favorable terms of trade. In the other event, the merged firm does not contract.

[36] As we will see, both tie-breaking rules lead to the same equilibrium price.

The profits of winning a unit on the main market equal

$$W_i(p) \equiv p - C_i + (1-\sigma)S_i .$$

The first term, the price, represents the firm's revenues from serving a unit. The second term reflects its costs without subcontracting. The last term represents the share $1-\sigma$ of the surplus from subcontracting that is appropriated by the winning firm.

The profits of losing a unit to a rival are positive because a losing firm can extract surplus from subcontracting. Since all $N-1$ subcontractors are symmetric, they all capture an equal portion $1/(N-1)$ of the surplus from subcontracting that goes to the subcontractors. Therefore, the profits of losing a unit on the main market equal

$$L_i \equiv \frac{1}{N-1}\sigma S_i .$$

We denote the price at which firms are indifferent between winning and losing a unit by $p_i^*(\sigma)$ such that

$$W_i\left(p_i^*(\sigma)\right) = L_i\left(p_i^*(\sigma)\right).$$

We will argue that price $p_i^*(\sigma)$ is the equilibrium price. By using that $S_i = C_i - C_{IND}$, we can write that price $p_i^*(\sigma)$ equals

$$p_i^*(\sigma) = C_{IND} + \sigma S_i + \frac{\sigma}{N-1} S_i .$$

Price $p_i^*(\sigma)$ is the sum of three components. The first component is the industry unit production cost. The second is the per unit surplus paid to the subcontractors through the contracting cost. The third component is the unit opportunity cost, which captures the subcontracting profits the winner foregoes by winning. As a result, a firm wants to win a consumer only if the price is sufficiently high.

To restrict attention to situations where a symmetric equilibrium in pure strategies exists, we make the following assumption:

(A3) *Symmetric equilibrium in pure strategies (pre-merger):*

$$\frac{p_i^*(\sigma)-C_{IND}-\sigma S_i}{p_i^*(\sigma)}<\frac{1}{\varepsilon\left(p_i^*(\sigma)\right)}.$$[1]

It follows from (A3) that firms prefer to sell at $p_i^*(\sigma)$, rather than reducing the price to increase demand, or $\frac{d\left[W(p)Q(p)\right]}{dp}>0$ for all $p\le p_i^*(\sigma)$.[2,3]

It follows that price $p_i^*(\sigma)$ is the equilibrium. Indeed, at $p_i^*(\sigma)<\bar{p}$, firms are indifferent between winning and losing a unit, so that neither undercutting nor charging a higher price raises a firm's profits.[4] Also, a firm cannot profitably charge any other lower price $p<p_i^*(\sigma)$. Proposition 1 summarizes this result. The equilibrium price depends on the subcontracting market setting and is obtained by plugging in σ.

Proposition 1.

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[1] As usual, parameter ε denotes the absolute value of the price-elasticity of demand $\varepsilon\equiv-\frac{Q^{'}(p)p}{Q(p)}$.

[2] The proof is as follows. Since $W(p)$ is linear, $W(p)Q(p)$ is concave so that it suffices to show that $\left.\frac{d\left[W(p)Q(p)\right]}{dp}\right|_{p=p_i^*(\sigma)}>0$. We get $W\left(p_i^*(\sigma)\right)Q^{'}\left(p_i^*(\sigma)\right)+W^{'}\left(p_i^*(\sigma)\right)Q\left(p_i^*(\sigma)\right)>0$, or $\left(p_i^*(\sigma)-C_i+(1-\sigma)S_i\right)Q^{'}\left(p_i^*(\sigma)\right)+Q\left(p_i^*(\sigma)\right)>0$, which can be written as (A3).

[3] If the parameters are such that (A3) does not hold, the winner has an incentive to reduce the price from $p_i^*(\sigma)$ to the price that maximizes the winner's profits. The equilibrium is asymmetric. One firm charges the price that maximizes the winner's profits, while the others charge a sufficiently high price so as to discourage the winner from losing.

[4] Importantly, note that the willingness to win an extra unit does not depend on how many units a firm already serves, nor does it depend on how many units the rival firms already serve. It follows that the equilibrium price is irrespective of the tie-breaking rule.

The equilibrium price on the main market characterized by price competition equals $p_i^*(\sigma)$.

If the contractors capture a large portion of the surplus, they can contract production at a tariff close to the rivals' variable costs. These rivals, in turn, earn little profits from subcontracting. Since there is only a small opportunity cost from winning a unit, there is fierce competition on the main market, resulting in an equilibrium price close to the efficient industry cost.

If instead subcontractors capture a large portion of the surplus, the cost of contracting production is close to the contractor's in-house cost. Moreover, winning firms forego considerable profits from subcontracting, which act as an opportunity cost. Both effects together add a substantial markup to the equilibrium price on the main market.

For Bertrand subcontracting, contractors obtain more surplus as the number of firms goes up. Monopolistic subcontracting is the most extreme example where subcontractors get all surplus from subcontracting. Monopsonistic subcontracting is the most extreme example where contractors capture all surplus from subcontracting.

The effect of horizontal subcontracts on consumers — We use the symmetric model to study under what circumstances subcontracts are good for consumers. The effect on consumers crucially depends on share σ, the share of the surplus from subcontracting that goes to the subcontractors.[5]

Proposition 2.

For price competition on the main market, horizontal subcontracting

- *benefits consumers if and only if the number of firms is sufficiently large for Bertrand subcontracting;*
- *harms consumers for monopolistic subcontracting;*

[5] This subsection can be skipped by readers only interested in the effects of a merger when firms can sign horizontal subcontracts.

- *benefits consumers for monopsonistic subcontracting.*

The proof is in the appendix and shows that subcontracts reduce prices if and only if sufficient surplus from subcontracting goes to the contractor, or

$$p_i^*(\sigma) < p^{ns} \Leftrightarrow \sigma < \frac{N-1}{N}.$$

The cutoff value for σ is $(N-1)/N$, which equals 0.5 for a duopoly and approaches 1 as the number of firms increases.[6] The intuition behind proposition 2 is as follows. The first observation relates closely to Kamien et al. (1989) and is that consumers are more likely to benefit from subcontracts if the subcontractors have little bargaining or market power. The intuition is that, then, subcontractors earn little profits and are therefore willing to compete fiercely to serve consumers, which leads to lower prices. The second observation relates to Haile (2003) and is that the requirement on σ becomes less stringent as the number of firms goes up. Each subcontractor then captures only a smaller part of the surplus from subcontracting. A subcontractor's profits decrease, so that he is more willing to compete for consumers by charging lower prices. The third observation is a contribution of our analysis and is that, if subcontractors compete à la Bertrand, horizontal subcontracting benefits consumers if and only if the number of firms is sufficiently large.[7]

We now investigate (i) the effect of a merger on the equilibrium price and (ii) firms' incentives to merge.

[6] The same cutoff value also applies in an alternative model with convex costs.

[7] Indeed, for Bertrand subcontracting, we know that (i) for $N=2$, there is only one subcontractor that captures all surplus; (ii) $\frac{d\sigma}{dN} < 0$; and (iii) in the limit where $N \to \infty$, $\sigma = 0$. So, for a sufficiently large number of firms, the share of surplus drops below the cutoff value needed to make horizontal subcontracts beneficial for consumers.

Post-merger analysis — The equilibrium analysis starts by investigating at what prices firms o and m prefer to win or to lose a unit. The goal is to obtain, for each subcontracting market setting, the equilibrium price.[8]

Outsiders

If a firm o wins a unit on the main market, it earns

$$\tilde{W}_o\left(\tilde{p}\right) \equiv \tilde{p} - \tilde{C}_o + (1-\tilde{\sigma}_o)\tilde{S}_o .$$

By winning the unit, firm o earns $\tilde{p}$ revenues. Without subcontracting, it would incur in-house unit cost $\tilde{C}_o$. As a contractor, firm o captures share $1-\tilde{\sigma}_o$ of the subcontracting surplus.

Firm o's profits from losing a unit depend on which firm wins the unit, firm m or another firm o.

First, consider the situation where firm o loses and firm m wins the unit.

Firm o earns

$$\tilde{L}_{o-m} \equiv \frac{1}{N-2}\tilde{\sigma}_m \tilde{S}_m .$$

Indeed, if firm m wins the unit, the surplus from subcontracting is $\tilde{S}_m$. Each firm o captures an equal portion of the surplus from subcontracting.

From Lemma 2, we know that the profit from losing a unit is invariant to the merger for Bertrand subcontracting ($B=1$), and that the share of surplus going to the subcontractors is invariant to the merger otherwise ($B=0$). This can be seen by plugging in the expressions for $\tilde{\sigma}_m$ and rewriting these profits as

[8] For completeness, in case of a tie that involves the merged firm, the merged firm wins the unit.

$$\tilde{L}_{o-m} = B\frac{1}{N-1}\sigma\tilde{S}_o + (1-B)\frac{1}{N-2}\sigma\tilde{S}_m \ .$$

Second, we consider the situation where firm o loses a unit to another outsider.

Firm o earns the same profits as pre-merger, given by

$$\tilde{L}_{o-o} \equiv \frac{1}{N-1}\sigma\tilde{S}_o \, .$$

Define the price at which the outsider is indifferent between winning and losing a unit against m by $\tilde{p}^*_{o-m}$ such that $\tilde{W}_o\left(\tilde{p}^*_{o-m}(\sigma)\right) = \tilde{L}_{o-m}\left(\tilde{p}^*_{o-m}(\sigma)\right)$. We obtain that

$$\tilde{p}^*_{o-m}(\sigma) = \tilde{C}_{IND} + \tilde{\sigma}_o\tilde{S}_o + B\frac{1}{N-1}\sigma\tilde{S}_o + (1-B)\frac{1}{N-2}\sigma\tilde{S}_m \, .$$

The first term captures the industry unit production cost. The second term represents the surplus paid to the subcontractors if the outsider wins a unit. The final term captures the opportunity cost, i.e., the foregone profits a firm could have earned by losing the unit.

Define the price at which firm o is indifferent between winning and losing a unit against another outsider o by $\tilde{p}_{o-o}$ such that $\tilde{W}_o\left(\tilde{p}_{o-o}(\sigma)\right) = \tilde{L}_{o-o}\left(\tilde{p}_{o-o}(\sigma)\right)$. We obtain that

$$\tilde{p}_{o-o}(\sigma) = \tilde{C}_{IND} + \tilde{\sigma}_o\tilde{S}_o + \frac{1}{N-1}\sigma\tilde{S}_o \, ,$$

which again represents production costs, surplus paid to subcontractors through the contracting costs, and the opportunity cost of winning the unit, respectively. The opportunity cost differs from the scenario where the merged firm wins.

Merged firm

If firm m wins a unit, it earns

$$\tilde{W}_m(\tilde{p}) \equiv \tilde{p} - \tilde{C}_m + (1-\tilde{\sigma}_m)\tilde{S}_m \, .$$

Firm m receives $\tilde{p}$ by winning a unit. It enjoys in-house unit cost $\tilde{C}_m$. As a contractor, firm m captures share $1-\tilde{\sigma}_m$ of the unit surplus from subcontracting.

By losing a unit, the merged firm obtains

$$\tilde{L}_m(\tilde{p}) \equiv \frac{2\sigma}{N-1}\tilde{S}_o + B\frac{(1-k)^2 k^{N-2}}{k-k^N}\tilde{S}_o .$$

The last term captures that, for Bertrand subcontracting, the merged firm benefits from merging because it can earn rents when it has two favorable cost draws and all other firms draw high costs.

Define the price at which the merged firm is indifferent between winning and losing a unit by $\tilde{p}_m(\sigma)$ such that $\tilde{W}_m(\tilde{p}_m(\sigma)) = \tilde{L}_m(\tilde{p}_m(\sigma))$. We get

$$\tilde{p}_m(\sigma) = \tilde{C}_{IND} + \tilde{\sigma}_m\tilde{S}_m + \frac{2\sigma}{N-1}\tilde{S}_o + B\frac{(1-k)^2 k^{N-2}}{k-k^N}\tilde{S}_o .$$

We proceed by stating Lemma 3, which maps the prices $\tilde{p}_m(\sigma)$, $\tilde{p}^*_{o-m}(\sigma)$ and $\tilde{p}_{o-o}(\sigma)$, above which firms prefer to win a unit rather than to lose one. As before the merger, these prices refer to the unit level and are therefore irrespective of the tie-breaking rule.

Lemma 3. *The merged firm has more incentives to compete for consumers than the outside firms. The prices above which firms want to win rather than to lose a unit can be ranked as* $\tilde{p}_m(\sigma) \le \tilde{p}^*_{o-m}(\sigma) \le \tilde{p}_{o-o}(\sigma)$.

Figure 2 visualizes Lemma 3.

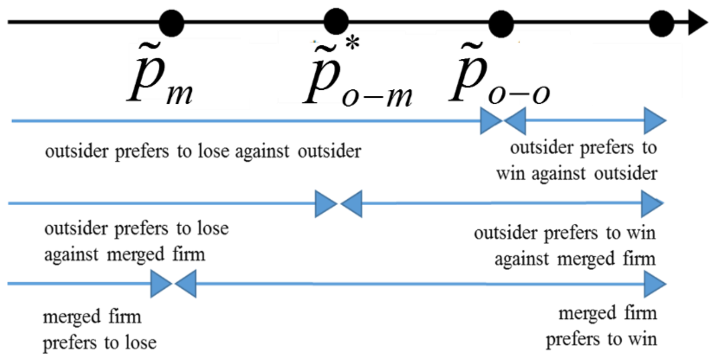

Figure 2. A visualization of lemma 3.

(A4). *Symmetric equilibrium in pure strategies (post-merger).* Analogous to assumption (A3), we restrict attention to parameters such that a symmetric equilibrium in pure strategies exists.[9]

Proposition 3. *The post-merger equilibrium price on the main market characterized by price competition is* $\tilde{p}^*_{o-m}(\sigma)$.

The appendix provides the proof.

The intuition is as follows. First note that (i) a price *above* $\tilde{p}^*_{o-m}(\sigma)$ cannot be an equilibrium because firms would want to profitably undercut, and that (ii) charging a price *below* $\tilde{p}^*_{o-m}(\sigma)$ is a weakly dominated strategy for an outsider, because an outsider always prefers to lose below that price.

It follows that, in equilibrium, the merged firm wins.[10] The merged firm takes into account that the outsiders should not be willing to undercut. Therefore, the

[9] Winning firms do not have an incentive to further reduce their price to increase demand. More precisely,

$$\frac{d\left[\tilde{W}_m(\tilde{p})Q(\tilde{p})\right]}{d\tilde{p}} > 0 \text{ for all } \tilde{p} \leq \tilde{p}_m(\sigma)\text{, and}$$

$$\frac{d\left[\tilde{W}_o(\tilde{p})Q(\tilde{p})\right]}{d\tilde{p}} > 0 \text{ for all } \tilde{p} \leq \tilde{p}^*_{o-m}(\sigma) \text{ and for all } \tilde{p} \leq \tilde{p}_{o-o}(\sigma).$$

[10] Since merging improves the merged entity's profits from winning *and* from subcontracting, it is not obvious that the merged firm prefers to win in equilibrium. In Spiegel's (1993) analysis, for example, the lowest-cost firm acts as a subcontractor. Pagnozzi (2007) finds a similar effect where, with resale, the strong bidder drops out of the auction before the weak bidder.

equilibrium price is crucially determined by the price the outsider wants to charge. So, the merged firm can charge up to $\tilde{p}^*_{o-m}(\sigma)$, the price at which the outsiders are indifferent between winning and losing. The merged firm wins by the tie-breaking rule.

The equilibrium price, $\tilde{p}^*_{o-m}(\sigma)$, is the sum of actual production costs, the rents going to the subcontractors if an outsider wins, and the outsiders' opportunity cost of winning in the form of foregone subcontracting profits.

Proposition 4 presents our main result for Bertrand competition on the main market by comparing the equilibrium price before and after the merger.

Proposition 4. *For price competition on the main market, a merger without synergies*

- *strictly increases the equilibrium price for Bertrand subcontracting;*
- *strictly decreases the equilibrium price for monopolistic subcontracting;*
- *does not affect the equilibrium price for monopsonistic subcontracting.*

The appendix shows that the price effect of the merger equals

$$\tilde{p}^*_{o-m}(\sigma) - p^*_i(\sigma) = \underbrace{B(1-k)^2 k^{N-2} c_H}_{CC_o\text{-effect}} + \underbrace{(1-B)\left(\frac{1}{N-2}\sigma\tilde{S}_m - \frac{1}{N-1}\sigma\tilde{S}_o\right)}_{OC_o\text{-effect}}.$$

The price effect depends on the outsiders' willingness to win a unit rather than to lose one. In general, the merger affects the main market price via two effects:

1. CC_o*-effect.* The merger can lead to higher contracting costs for a winning outsider because the subcontracting market includes the merged firm and can therefore turn less competitive. Higher contracting costs for the outsiders increase the equilibrium price.
2. OC_o*-effect.* The merger can lead to lower subcontracting profits for the outsiders. If so, the outsiders have a lower opportunity cost of winning. A lower opportunity cost for the outsiders decreases the equilibrium price.

For Bertrand subcontracting ($B=1$), the merger raises the equilibrium price.

1. CC_o*-effect.* The merger increases the contracting costs of a winning outsider. Indeed, if the outsider wins, the merged firm does not compete against itself if it is the only firm with favorable cost draws. The contracting costs of a winning outsider increase, thereby increasing the price it wants to offer on the main market.
2. OC_o*-effect.* The merger does not affect the outsiders' opportunity cost of winning. On the one hand, competition in the subcontracting market among the outsiders has decreased. On the other hand, the merged entity's chance to draw a favorable cost has increased. Both effects cancel out and leave the outsiders' opportunity costs unaffected.

The merger therefore raises the equilibrium price. The price rise coincides with the expected increase in contracting cost if the outsider wins.

For monopolistic subcontracting ($B=0$ and $\sigma=1$), the merger reduces the price.

1. CC_o*-effect.* The merger does not affect the contracting costs of an outsider. Indeed, contracting a unit is maximally expensive, and equally expensive, before as well as after the merger.
2. OC_o*-effect.* The merger reduces the opportunity cost of outsiders to serve consumers. The subcontracting surplus shared among the subcontracting outsiders decreases because the merged firm is characterized by a lower in-house cost. As a result, the merger reduces the outsiders' opportunity cost of winning—by foregoing subcontracting profits—so that they want to compete more fiercely for the main market.

The net effect under monopolistic subcontracting is that the merger reduces the equilibrium price. The price reduction coincides with the opportunity cost decrease of outsiders to serve a unit on the main market.

For monopsonistic subcontracting ($B=0$ and $\sigma=0$), firms are willing to compete equally fiercely for the market before and after the merger.

1. CC_o*-effect.* There is no contracting cost effect because firms can contract at the best possible terms, before as well as after the merger.
2. OC_o*-effect.* The opportunity cost is not affected by the merger, because subcontractors earn zero profits from subcontracting, before as well as after the merger.

Given that firms reallocate production efficiently using subcontracts, a merger only affects social welfare, i.e., the sum of consumer and produces surplus, through its price-effect. Since marginal costs are constant, a merger that brings the equilibrium price closer to the industry marginal cost improves social welfare. It therefore follows from proposition 4 that a merger without synergies

- reduces social welfare for Bertrand subcontracting
- increases social welfare for monopolistic subcontracting
- is social welfare-neutral for monopsonistic subcontracting.

We proceed with proposition 5 to study the profitability of mergers.

Proposition 5. *For price competition on the main market, a merger without synergies*

- *is strictly profitable for Bertrand subcontracting and monopolistic subcontracting;*
- *is profit-neutral for monopsonistic subcontracting.*

The proof is in the appendix.

Profitability results from the following two effects.

The first effect concerns the contracting costs. The merged firm enjoys more favorable contracting terms, because it has a lower demand for contracting.

We argue that this effect is small for Bertrand subcontracting and large for monopolistic subcontracting. The intuition is that, if competition among subcontractors is fierce, contracting costs are already low before the merger. Consequently, the additional effect of acquiring another firm is small. In particular, for Bertrand subcontracting, acquiring a firm avoids paying subcontracting surplus in the event that the acquired firm is the only one with a favorable cost draw (with probability $(1-k)k^{N-1}$). Otherwise, competition among subcontractors would have guaranteed favorable contracting terms before the merger as well. For monopolistic subcontracting, the reduction in contracting costs is larger. Indeed, before the merger, the subcontracting market is not competitive and always results in high contracting costs. The merger, by decreasing demand for contracting, disciplines contracting costs and as such substitutes for the lack of competition among subcontractors. As compared to before the merger, merging avoids paying subcontracting surplus if the acquired firm draws a favorable cost while the acquiring firm draws a high cost (with probability $(1-k)k$).

The second effect concerns the equilibrium price. For Bertrand subcontracting, the equilibrium price goes up. The price increase, combined with the contracting cost reduction, results in a profitable merger. For monopolistic subcontracting, the equilibrium price goes down. The negative effect of the price decrease on the merged firm's profits is, however, too small to offset the reduced contracting cost effect, which is large for monopolistic subcontracting.

Figures 3 and 4 illustrate our merger insights for a winner-take-all framework. They show the effects of the merger on prices and profits for Bertrand subcontracting and monopolistic subcontracting. Upper graphs show the effects for an outside firm. Lower graphs show the effects for the merged firm. The vertical axis shows profits and the horizontal axis shows the lowest price in the market. Before the merger, all firms are symmetric and indifferent between winning and losing at p_i^*.

Bertrand subcontracting — The merger increases the contracting cost of an outsider if it wins. Outsiders are therefore indifferent between winning and losing at a higher price $\tilde{p}_{o-m}^* > p_i^*$. The merged firm benefits twice. First, its profits from winning increase, because it enjoys lower contracting costs. Second, the merged firm can sell at a higher equilibrium price. Remark that, while the merged firm wins in equilibrium, it would also have enjoyed higher subcontracting profits in the event it loses. Even though firms compete in prices, the insiders increase their profits whereas the outsiders' profits go down. Outsiders are worse off because the increase in the equilibrium price leads to less consumers served, and hence the outsiders are called upon to subcontract production for fewer consumers.

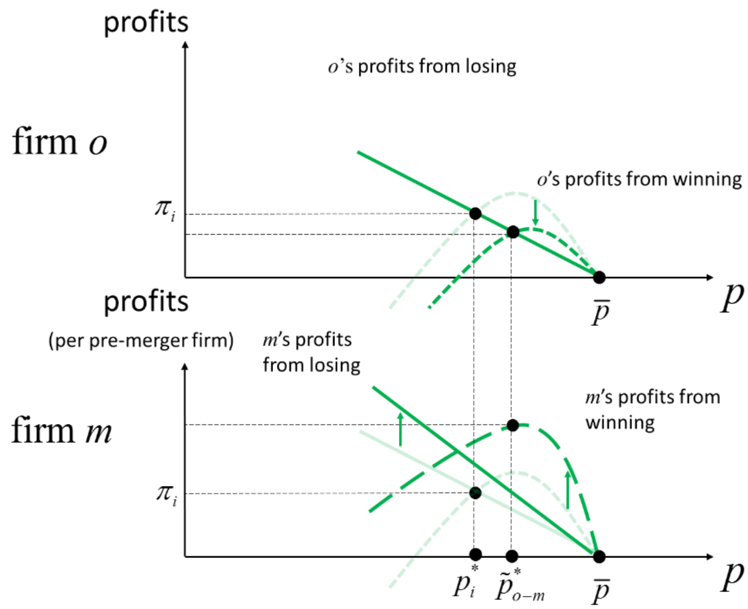

Figure 3: The effect of a merger on prices and profits for Bertrand subcontracting.

Monopolistic subcontracting — the merger reduces an outsider's profits if it loses. Their opportunity cost of winning goes down because they are called upon less frequently as subcontractors. They are therefore indifferent between winning and losing at a lower price $\tilde{p}_{o-m}^* < p_i^*$. The reasoning is different for the merged firm. The insiders benefit from merging by reducing their demand for contracting if they *win* the market. The merged firm charges $\tilde{p}_{o-m}^*$, the price at which an outside firm no longer wants to win. The outsiders' profits go down.[11] They suffer from being

[11] The proof is as follows. An outsider earns $\tilde{L}_{o-m}\left(\tilde{p}_{o-m}^*\right)Q\left(\tilde{p}_{o-m}^*\right)=\tilde{W}_o\left(\tilde{p}_{o-m}^*\right)Q\left(\tilde{p}_{o-m}^*\right)<\tilde{W}_o\left(\tilde{p}_{o-o}\right)Q\left(\tilde{p}_{o-o}\right)=\underbrace{W_i\left(p_i^*\right)Q\left(p_i^*\right)}_{\text{pre-merger profits}}$. The first equality follows from the indifference between winning and losing at $\tilde{p}_{o-m}^*$. The inequality follows from (A4) and uses that $\tilde{p}_{o-m}^* < \tilde{p}_{o-o}$. The second equality uses $\tilde{p}_{o-o} = p_i^*$ and $\tilde{W}_o = W_i$ for monopolistic subcontracting.

called upon less frequently for a given consumer, even though the price decrease results in higher market demand.

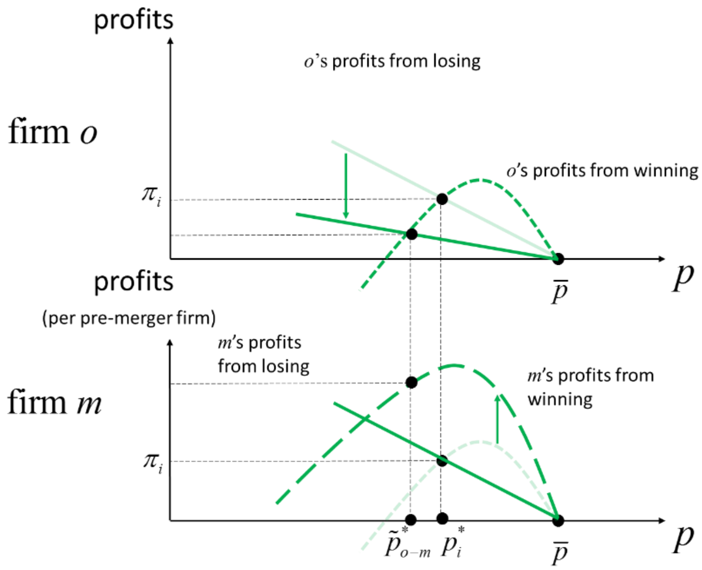

Figure 4. The effect of a merger on prices and profits for monopolistic subcontracting.

We end this section by discussing merger-specific synergies in the context of horizontal subcontracting. A synergy not only increases the merged entity's willingness to serve consumers on the main market, but also increases its willingness to lose the main market and serve as a subcontractor. The net effect of the synergy on the merged firm's competitiveness is therefore a priori ambiguous. We proceed with a numerical example. Suppose $N = 3$ and merging results in zero costs for the merged entity (a lot of synergies). We show in the appendix that, for this example, both the outsider and the merged firm have an incentive to charge a lower price as compared to the no-synergies setting. For Bertrand subcontracting, this finding is in line with the standard merger result that there is a critical amount of synergies needed for the merger to benefit consumers. For monopolistic subcontracting, the example suggests that a synergy is not needed for the merger to benefit consumers, but if present has a price-reducing effect. For monopsonistic subcontracting, in the example, a synergy is necessary and sufficient for the merger to strictly benefit consumers.

4. Main market analysis: Cournot

Cournot model — This section investigates the scenario where firms compete à la Cournot on the main market. As before, we consider three types of horizontal subcontracting: monopsonistic subcontracting, Bertrand subcontracting, and monopolistic subcontracting. For simplicity, we consider a linear inverse demand function $P = a - bQ$. Denote industry output by $Q = \sum q_i$, where q_i represents firm i ‘s output choice. To investigate the effect of a merger, we compare the industry output pre-merger and post-merger.

Pre-merger analysis — Firm i ’s profit function equals

$$\left(P\left(\sum q_i\right) - \left(C_i - (1-\sigma)S_i\right)\right)q_i + \frac{1}{N-1}\sigma S_i \sum_{j \neq i} q_j .$$

The first term of the expression equals firm i ’s revenues and costs from serving consumers. The second term represents firm i ’s subcontracting profits.

Importantly, there is no opportunity cost of serving consumers. Indeed, firm i ‘s subcontracting profits, $\frac{1}{N-1}\sigma S_i \sum_{j \neq i} q_j$, are independent of its quantity choice q_i. The interpretation is as follows. Firm i ’s subcontracting profits depend on its competitors’ demand for contracting. Their demand for contracting follows from their offered quantities on the main market, and these quantities, in line with the Cournot-Nash conjecture, are unaffected by firm i ’s quantity choice q_i. As such, firm i does not forego subcontracting profits by competing fiercely and serving extra consumers.

It follows that the first-order condition is $q_i^* = \dfrac{a - b\sum_{j\neq i} q_j - \left(C_i - (1-\sigma)S_i\right)}{2b}$.[12] In equilibrium, industry output equals $Q = \dfrac{N}{N+1}\dfrac{a - \left(C_i - (1-\sigma)S_i\right)}{b}$. Denote the pre-merger market-clearing price by $P^{\text{pre-merger}} \equiv a - bNq_i^*$.

The effect of horizontal subcontracts on consumers — For quantity competition on the main market, horizontal subcontracts unambiguously benefit consumers. The reason is that there is no opportunity cost of serving consumers, and contracting costs never exceed the alternative of in-house production, as in Spiegel (1993).

Post-merger analysis — We proceed with the post-merger analysis of the merged firm and the outsiders.

Outsiders

An outsider o 's profit function equals

$$\left(P\left(\sum \tilde{q}_i\right) - \tilde{C}_o + (1-\tilde{\sigma}_o)\tilde{S}_o\right)\tilde{q}_o + \frac{1}{N-1}\sigma\tilde{S}_o \sum_{\substack{i\neq m \\ i\neq o}} \tilde{q}_i + \frac{1}{N-2}\tilde{\sigma}_m\tilde{S}_m\tilde{q}_m .$$

Again, the first term represents the profits from serving consumers, and the other two terms represent the subcontracting profits.[13]

The first-order condition is $\tilde{q}_o^* = \dfrac{a - b\sum_{i\neq o}\tilde{q}_i - \tilde{C}_o + (1-\tilde{\sigma}_o)\tilde{S}_o}{2b}$.

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[12] The combination of linear demand with constant marginal costs guarantees that the Cournot model is well-behaved: there is a unique equilibrium and quantities are strategic substitutes.

[13] The per unit subcontracting profits follow from Lemma 2 and depend on whether the unit is served by another outsider, or by the merged firm. When served by another outsider, the subcontracting profits equal the pre-merger amount $\dfrac{1}{N-1}\sigma\tilde{S}_o$. When served by the merged firm, they equal $\dfrac{1}{N-2}\tilde{\sigma}_m\tilde{S}_m$.

Again, there is no opportunity cost effect because the opportunity cost of serving consumers is zero, before and after the merger. However, there can be a contracting cost effect for the outsiders.

CC_o*-effect.* The merger can increase contracting costs for an outsider because there is a more powerful subcontractor, the merged firm.

Merged firm.

The merged firm m's profit function equals

$$\left(P\left(\sum \tilde{q}_i\right)-\left(\tilde{C}_m-(1-\tilde{\sigma}_m)\tilde{S}_m\right)\right)\tilde{q}_m+\left(\tilde{\sigma}_o\tilde{S}_o-\left(N-3\right)\frac{1}{N-1}\sigma\tilde{S}_o\right)\sum_o \tilde{q}_o \ .$$

The first part of the expression represents its profits from its consumers served. The second part of the expression represents the merged firm's subcontracting profits.[14] Again, the subcontracting profits drop out in the first-order condition. As explained, they do not depend on $\tilde{q}_m$.

The first-order condition is $\tilde{q}_m^* = \dfrac{a-b\sum_o \tilde{q}_o-\left(\tilde{C}_m-(1-\tilde{\sigma}_m)\tilde{S}_m\right)}{2b}$.

The merger does not affect the merged firm's opportunity cost of serving consumers, which is zero before as well as after the merger. The merger can, however, affect the competitiveness of the merged firm via its contracting cost:

[14] The second part of the expression uses the subcontracting market analysis from Lemma 2. The subcontracting profits of the merged firm equal the total subcontracting surplus going to subcontractors for units served by outsiders on the main market, subtracted by the part of those profits going to the subcontracting outsiders. More precisely, when an outsider serves a unit, the subcontractors capture a total rent of $\tilde{\sigma}_o\tilde{S}_o$. The subcontractors consist of $N-3$ outsiders and the merged firm. The $N-3$ subcontracting outsiders each capture $\frac{1}{N-1}\sigma\tilde{S}_o$ profits per unit. Indeed, their subcontracting profits equal the pre-merger amount for Bertrand subcontracting ($\left(1-k\right)k^{N-1}c_H$), monopolistic subcontracting ($\frac{1}{N-1}\tilde{S}_o$), and monopsonistic subcontracting (zero).

CC_m*-effect.* The merger can lead to increased buyer power for the merged firm, and can thereby reduce its contracting costs. A reduction in contracting costs for the merged firm increases its competitiveness.

To investigate these effects in more detail, we fully work out the equilibrium analysis after the merger. We denote firms' pre-merger and post-merger perceived marginal costs of serving consumers on the main market as follows

$$w_i \equiv C_i - (1-\sigma)S_i\,,\ w_m \equiv \tilde{C}_m - (1-\tilde{\sigma}_m)\tilde{S}_m\,,\text{ and }\ w_o \equiv \tilde{C}_o - (1-\tilde{\sigma}_o)\tilde{S}_o\,.$$

The perceived marginal costs are crucially determined by the rents going to the subcontractors in the form of contracting costs. For the merged firm, the change in contracting cost equals

$$CC_m\text{-effect} \equiv \left|w_m - w_i\right| \geq 0\ .$$

The effect of the merger on each outsider's contracting cost equals

$$CC_o\text{-effect} \equiv w_o - w_i \geq 0\ .$$

We solve for the equilibrium and find that the merged firm produces $\tilde{q}_m = \dfrac{a+(N-2)w_o-(N-1)w_m}{bN}$ and each outsider produces $\tilde{q}_0 = \dfrac{a-2w_o+w_m}{bN}$.

Industry output is

$$\tilde{q}_m + \left(N-2\right)\tilde{q}_o = \frac{a+(N-2)w_o-(N-1)w_m}{bN} + \left(N-2\right)\frac{a-2w_o+w_m}{bN}\ .$$

Proposition 6 presents the main results for Cournot competition on the main market.

Proposition 6: *For quantity competition on the main market, a merger without synergies*

- *benefits consumers if and only if*

$$\underbrace{\left(P^{\text{pre-merger}} - w_i\right)}_{\text{pre-merger markup}} + \left(N-2\right)\underbrace{\left(w_o - w_i\right)}_{CC_o\text{-effect}} < \underbrace{\left|w_m - w_i\right|}_{CC_m\text{-effect}}\,;$$

- *can decrease or increase the market-clearing price for Bertrand subcontracting;*
- *can decrease or increase the market-clearing price for monopolistic subcontracting;*
- *increases the market-clearing price for monopsonistic subcontracting.*

The left-hand-side represents the effects that harm consumers. The right-hand side represents the effect that benefit consumers. For the merger to benefit consumers, the right-hand side should exceed the left hand side. We distinguish three terms.

1. *Pre-merger markup*. The first term equals the pre-merger markup at the firm level. It correlates with the market power increase that results from the merger: starting from a more concentrated market, the benchmark Cournot merger without synergies is more harmful for consumers. Accordingly, for the merger to benefit consumers, the requirements on the pro-competitive effects should be more demanding.
2. CC_o*-effect.* The second term represents the change in contracting cost for an outsider. With higher costs, the outsider competes less aggressively. This effect harms consumers.
3. CC_m*-effect.* The right-hand side represents that the merger can reduce the contracting cost of the merged firm. This effect benefits consumers.

For Bertrand subcontracting, all effects are active and jointly determine the net effect. A no-synergies merger can be profitable because merging reduces contracting costs.

For monopolistic subcontracting, the CC_o-effect is zero because the outsiders already contract at the worst possible terms pre-merger. Again, it can be shown that merging can be profitable because it reduces contracting costs.

For monopsonistic subcontracting, firms already contract at maximally favorable terms pre-merger. Therefore, monopsonistic subcontracting finds that the merger without synergies harms consumers, consistent with the standard Cournot merger analysis. Remark that, in line with the standard argument from Salant et al. (1983), merging would not be profitable for monopsonistic subcontracting.

For completeness, remark that a cost-synergy always benefits consumers, as it makes the merged entity unambiguously more aggressive.

5. Main market analysis: joint bidding and contractor teaming arrangements

This section investigates contractor teaming arrangements (CTAs). CTAs are horizontal agreements between competing firms to set up a consortium and jointly hand in a price on the main market. They are common practice in procurements, e.g. in the construction and oil drilling industry. CTAs are similar to a merger in the sense that firms jointly choose a price in stage one. However, different from a merger, CTAs dissolve if they do not win the main contract. Therefore, a winning outsider contracts from the same set of subcontractors as without the CTA.

We show in this section that such a CTA eliminates the anti-competitive contracting cost effect for the outsider, the CC_o-effect, and also eliminates the anti-competitive opportunity cost OC_m-effect for the merged firm. The pro-competitive CC_m-effect is inactive because the equilibrium price is crucially determined by outsiders to the CTA. The only remaining effect is the pro-competitive OC_o-effect, so that the CTA has an unambiguously favorable impact, if any, on the main market consumer price. We state and explain the following proposition.

Proposition 7*: a contractor teaming arrangement without synergies*

- *does not affect the equilibrium price for Bertrand subcontracting;*

- *strictly decreases the equilibrium price for monopolistic subcontracting;*
- *does not affect the equilibrium price for monopsonistic subcontracting.*

The CTA-analysis for Bertrand subcontracting is as follows. The equilibrium price crucially follows from the outsiders' indifference between winning and losing a unit on the main market.

- An outsider's profits from winning a unit is invariant to the CTA, and therefore equals the pre-CTA amount W_i. Indeed, an outsider does not suffer from a contracting cost increase if it wins because the CTA then dissolves. In other words, a dissolving CTA, as opposed to a merger, eliminates the CC_o-effect, thereby removing the price rise associated with it.
- If an outsider loses against the CTA, the CTA is active and the outsider earns $\tilde{L}_{o-m}$ as in the merger analysis. For Bertrand subcontracting, we know that outsiders' subcontracting profits equal $\tilde{L}_{o-m} = L_i$. This equality reflects that a subcontractor can only make positive profits if it is the only firm with a favorable cost draw, and this probability is independent of whether others have teamed up in a CTA or not.

It follows that an outsider is indifferent between winning and losing against the CTA at the pre-CTA price that satisfies $W_i\left(p_i^*\right) = L_i\left(p_i^*\right)$. The appendix completes the proof by showing that the CTA wins in equilibrium.

The CTA analysis coincides with the merger analysis for monopolistic and monopsonistic subcontracting. There is then neither a contracting cost effect nor an opportunity cost effect from dissolving after losing. In particular, the insiders (jointly) earn maximal subcontracting profits for monopolistic subcontracting, and minimal subcontracting profits for monopsonistic subcontracting. Therefore the merger results from proposition 4 apply. That is, a CTA strictly decreases the equilibrium price for monopolistic subcontracting and does not affect the equilibrium price for monopsonistic subcontracting.

Our analysis shows that CTAs may be regarded by competition authorities as an information-proof alternative to a merger. Merger authorities may find it difficult to disentangle the opposing effects of a merger on the main market price. It may be unclear whether the pro-competitive effects from the merger dominate its anti-competitive effects. Our analysis shows that both anti-competitive effects CC_o and OC_m are zero because the CTA dissolves after losing.

6. Conclusions and policy discussion

Horizontal subcontracting is important in many industries characterized by merger activity. We discussed examples from the defense industry and from underwriting services in the financial sector.

This paper investigates the unilateral effects of mergers in industries with horizontal subcontracting. We present various approaches with respect to the mode of competition on the main market, and with respect to the degree of competitiveness on the horizontal subcontracting market.

Our analysis finds that, in industries with horizontal subcontracting, the effects of a no-synergies merger differ from the existing merger analysis in several respects. We show that a merger analysis should account for the direct effects of the merger on *contracting costs* that firms incur on the subcontracting market, as well as the indirect effects on the *opportunity costs* that firms incur by serving the main market instead of profiting as subcontractors. For both channels, we uncover anti-competitive forces as well as pro-competitive forces.

Several recent mergers demonstrate the need for an in-depth analysis of agreements among competing suppliers. The contracting cost and opportunity cost effects are relevant channels, even for industries that do not fit our model one-to-one. For example, network-sharing agreements (NSAs) are important when considering mergers between competing mobile network operators (MNOs).[15] If NSAs allocate their investment costs to each MNO depending on usage or market share, a firm that steals a subscriber from a rival firm increases its cost share in the NSA (contracting cost), but also reduces the contributions of the rival firms (opportunity cost).[16] The price effect of a merger then depends on how the merger affects the terms of the NSAs. As another example, the recently cleared Siemens / Dresser Rand (DR) merger featured a supply agreement where DR sources an input from rival firm General Electric.[17] The European Commission argues that "the possible disappearance of the mixed GE-DR offer will not reduce significantly the competitive constraints exerted by Parties on GE." According to the European Commission, "[t]his is because GE can already, to a certain extent, limit the competitive constraint that DR exerts on it by choosing the price it charges to DR according to the bidding situation." Consistent with our findings, a high input price for DR raises its bid pre-merger (contracting cost). Moreover, the possibility for GE to profit as subcontractor reduces its willingness to compete for the main contract (opportunity cost). Understanding how the merger affects this contracting cost and opportunity cost is important to determine the net price effect.

We have shown that our insights are also reflected in horizontal agreements falling short of a merger. Instead of a merger, consider a consortium or a so-called contractor teaming arrangement between competing firms. If it cooperates only to serve consumers on the main market but breaks apart in the event of acting as subcontractor, it does not enjoy increased seller power on the subcontracting market. Therefore, the anti-competitive effects associated with increased seller power on the subcontracting market do not apply. Interestingly, our insights differ from current practice in a number of countries. In Denmark, Norway, and Sweden, firms are not allowed to engage in a CTA if they have the individual capacity to complete the contract, unless the CTA results in more competitive offers because of sufficient

[15] See Motta and Tarantino (2017).

[16] See OECD (2014) on the nature of cost sharing agreements.

[17] See http://ec.europa.eu/competition/mergers/cases/decisions/m7429_2961_3.pdf

CTA-specific efficiencies.[18] Our policy insight is that CTAs can improve competition, even if the CTA-firms have stand-alone capacity and the CTA does not generate CTA-specific efficiencies. E.g. in a European context, when the pro-competitive forces dominate, article TFEU 101(1) would not apply and there would be no need to refer to the efficiency defense exemption provided by TFEU 101(3). In an industry with asymmetric firms, the usual caution is needed for CTAs consisting of the largest firms, as a strong outsider is needed for competitive pressure.

A merger analysis that includes horizontal subcontracting raises new results. First, a merger does not need to involve synergies to reduce the equilibrium price. Increased concentration can be pro-competitive without reference to an efficiency defense. If so, merger remedies that require the merging parties to divest production capacity may be counterproductive. Of course, caution is appropriate. Pro-competitive effects from the merger should be weighed against anti-competitive effects. Second, the effect of the merger on the outsiders' profits also differs from the standard merger analysis. In particular, the outsiders can be worse off after the merger because they earn less subcontracting profits, or because they suffer from increased contracting costs. A second important policy message from our analysis is therefore that a profit-decrease for outsiders, possibly leading to an efficiency offense, does not necessarily imply a merger-specific synergy. Overall, our results highlight the need for an effects-based approach that considers all changes in terms of trade on the subcontracting market.

[18] Several recent court decisions have considered a lack of stand-alone capacity as a prerequisite for joint bidding. See e.g. the decisions taken on joint bidding by the Swedish Competition Authority on cement delivery (*Cementa AB og Aalborg Portland A/S mod Konkurrensverket*, 1997) or the Danish Competition Council on supply of tires (*Däckia Aktiebolag og Euromaster Aktiebolag*, 2014), the Danish Road marking consortium (*Dansk Vejmarkerings Konsortium, 2015*), or patient transportation by taxis in Norway (*Staten v/ Konkurransetilsynet mod Follo Taxisentral Ba, Ski Follo Taxidrift AS og Ski Taxi Ba*, 2015) where the High Court concluded that joint bidding was a "restriction by object."

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Appendix

Proof of Lemma 1.

The proof of lemma 1 will show that the unit subcontracting surplus *per outsider* is decreasing if the number of firms in the merger increases. We claim that, if the joint entity is smaller, the unit subcontracting surplus per outsider is larger.

The proof consists of two parts. The first part (1.) analyzes the unit subcontracting surplus. The second part (2.) analyzes the unit subcontracting surplus per outsider and shows the main result.

1.

Part one shows that the marginal contribution of a firm in the merged entity is decreasing in the merger size. In other words, if the joint entity is smaller, the reduction in unit subcontracting surplus from merging is larger. The intuition is that a firm is more likely to contribute to the merging entity if that merging entity has a larger probability of an unfavorable cost draw. To prove the result, we compare two mergers.

The first merger we consider is the merger from entity $\{n\}$ that consists of $1 \leq n \leq N-2$ firms to entity $\{n+1\}$ that consists of an extra firm. The entity $\{n\}$ has unit cost equal to $k^n c_H$. After the merger, the entity $\{n+1\}$ produces at cost $k^{n+1} c_H$. We can therefore write that the reduction in unit subcontracting surplus thanks to the first merger equals

$$\tilde{S}_{\{n\}} - \tilde{S}_{\{n+1\}} = k^n c_H - k^{n+1} c_H \ .$$

The second merger we consider is the merger from entity $\{n+1\}$ to entity $\{n+2\}$. Entity $\{n+1\}$ has a cost equal to $k^{n+1} c_H$. After the merger, the entity $\{n+2\}$ produces at cost $k^{n+2} c_H$. We can write that the reduction in unit subcontracting surplus from the second merger equals

$$\tilde{S}_{\{n+1\}} - \tilde{S}_{\{n+2\}} = k^{n+1}c_H - k^{n+2}c_H \ .$$

We prove that the reduction in unit subcontracting surplus $\tilde{S}_{\{n\}} - \tilde{S}_{\{n+1\}}$ resulting from the first merger exceeds the reduction in unit subcontracting surplus $\tilde{S}_{\{n+1\}} - \tilde{S}_{\{n+2\}}$ from the second merger. This can be written as

$$k^n c_H - k^{n+1}c_H > k^{n+1}c_H - k^{n+2}c_H \ ,$$

or equivalently $1-k > k(1-k)$, which always holds. So, if the joint entity is smaller, a merger with an extra firm always achieves a larger reduction in unit subcontracting surplus.

2.

The reduction in unit subcontracting surplus from merging entity $\{n\}$ to entity $\{n+1\}$ equals $\tilde{S}_{\{n\}} - \tilde{S}_{\{n+1\}}$. The remaining $N-(n+1)$ successive mergers to monopoly lead to an average reduction in unit subcontracting surplus of $\frac{\tilde{S}_{\{n+1\}} - \tilde{S}_{\{N\}}}{N-(n+1)}$. Note that $\tilde{S}_{\{N\}} = 0$ because a merger to monopoly eliminates all subcontracting surplus.

From part 1 we know that the reduction in unit subcontracting surplus must satisfy

$$\tilde{S}_{\{n\}} - \tilde{S}_{\{n+1\}} > \frac{\tilde{S}_{\{n+1\}}}{N-(n+1)} \ ,$$

which can be rewritten as $\frac{\tilde{S}_{\{n\}}}{N-n} > \frac{\tilde{S}_{\{n+1\}}}{N-(n+1)}$. We conclude that the unit subcontracting surplus per outsider is smaller if the number of firms in the merger increases. For the first merger we consider ($n=1$), we can rewrite the inequality as $\frac{\tilde{S}_m}{N-2} < \frac{\tilde{S}_o}{N-1}$. ■

Proof of proposition 2.

We prove that $p_i^*(\sigma) < p^{ns} \Leftrightarrow \sigma < \frac{N-1}{N}$. By plugging in the expressions for $p_i^*(\sigma)$ and p^{ns} we can write the equivalence

$$p_i^*(\sigma) < p^{ns} \Leftrightarrow C_{IND} + \frac{N}{N-1}\sigma S_i < C_i,$$

which we can write as

$$p_i^*(\sigma) < p^{ns} \Leftrightarrow \sigma < \frac{N-1}{N}\frac{C_i - C_{IND}}{S_i} = \frac{N-1}{N}$$

because $S_i = C_i - C_{IND}$. ■

Proof of Lemma 3.

First observe that $\tilde{p}^*_{o-m}(\sigma) \leq \tilde{p}_{o-o}(\sigma)$. Indeed, the inequality

$$\tilde{C}_{IND} + \tilde{\sigma}_o\tilde{S}_o + B\frac{1}{N-1}\sigma\tilde{S}_o + (1-B)\frac{1}{N-2}\sigma\tilde{S}_m \leq \tilde{C}_{IND} + \tilde{\sigma}_o\tilde{S}_o + \frac{\sigma}{N-1}\tilde{S}_o$$

can be written as

$$B\frac{1}{N-1}\sigma\tilde{S}_o + (1-B)\frac{1}{N-2}\sigma\tilde{S}_m \leq \frac{\sigma}{N-1}\tilde{S}_o.$$

For $\sigma = 0$, the condition is always satisfied. For $\sigma > 0$, we can write $(1-B) \leq (1-B)\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}$. Since Lemma 1 gives us $\frac{\tilde{S}_m}{N-2} < \frac{\tilde{S}_o}{N-1}$ and consequently $1 < \frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}$, and by using that $B = \{0,1\}$, this inequality is always satisfied.

Second, observe that $\tilde{p}_m(\sigma) - \tilde{p}^*_{o-m}(\sigma)$ can be written as

$$\tilde{C}_{IND} + \tilde{\sigma}_m \tilde{S}_m + \frac{2\sigma}{N-1}\tilde{S}_o + B\frac{(1-k)^2 k^{N-2}}{k-k^N}\tilde{S}_o - \tilde{C}_{IND} - (\sigma + B\frac{(1-k)^2 k^{N-2}}{k-k^N})\tilde{S}_o - \frac{1}{N-2}\tilde{\sigma}_m \tilde{S}_m,$$

which can be written as

$$\tilde{p}_m(\sigma) - \tilde{p}^*_{o-m}(\sigma) = -\frac{N-3}{N-1}\sigma\tilde{S}_o + \frac{N-3}{N-2}\underbrace{\left[(1-B)\sigma + B\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}\sigma\right]}_{=\tilde{\sigma}_m}\tilde{S}_m.$$

For $N = 3$ or $\sigma = 0$, we have $\tilde{p}_m(\sigma) = \tilde{p}^*_{o-m}(\sigma)$. For $N > 3$ and $\sigma > 0$, we can rewrite $\tilde{p}_m(\sigma) < \tilde{p}^*_{o-m}(\sigma)$ as $(1-B) < (1-B)\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}$, which always holds because of Lemma 1. ■

Proof of proposition 3.

We first show that the merged firm wins in equilibrium. Second, we rule out other possible equilibria apart from $\tilde{p}^*_{o-m}(\sigma)$. Finally, we show that $\tilde{p}^*_{o-m}(\sigma)$ is indeed an equilibrium.

In any equilibrium, there are two possibilities. Either firm m wins, or a firm o wins.

We first contradict that an outsider wins in equilibrium. The reason is that, if an outside firm wins in equilibrium, firm m should prefer not to win instead, meaning that the equilibrium price should be weakly lower than $\tilde{p}_m(\sigma)$ (from Lemma 3). The winning outsider should prefer not to lose instead, meaning that the equilibrium price should weakly exceed $\tilde{p}^*_{o-m}(\sigma)$ (from Lemma 3). This leaves only the possibility that the equilibrium price is , where $\tilde{p}_m(\sigma) = \tilde{p}^*_{o-m}(\sigma)$. But if all firms charge $\tilde{p}^*_{o-m}(\sigma)$, the merged firm wins because of the tie-breaking rule. Therefore the merged firm wins in equilibrium.

Second, if the merged firm wins, the equilibrium price should not exceed $\tilde{p}^{*}_{o-m}(\sigma)$ to make sure that the outsider(s) do not wish to undercut the winning merged firm. At the same time, any lower price cannot be an equilibrium either. Indeed, charging $\tilde{p}^{*}_{o-m}(\sigma)$ weakly dominates charging a lower price for firm o, because at lower prices firm o always prefers to lose rather than to win (from Lemma 3). As a consequence, the winning merged firm wants to charge up to $\tilde{p}^{*}_{o-m}(\sigma)$ from (A4). This leaves only the possibility that the equilibrium price is $\tilde{p}^{*}_{o-m}(\sigma)$.

Finally, price $\tilde{p}^{*}_{o-m}(\sigma)$ is an equilibrium for the following reason.

When $\tilde{p}_{m}(\sigma)=\tilde{p}^{*}_{o-m}(\sigma)$, which holds for $N=3$ or $\sigma=0$, the merged firm wins and charging a higher price or slightly undercutting is not profitable because all firms are indifferent between winning and losing at $\tilde{p}^{*}_{o-m}(\sigma)$. Moreover, from (A4), the merged firm neither wants to charge a lower price to increase demand.

When $\tilde{p}_{m}(\sigma)<\tilde{p}^{*}_{o-m}(\sigma)$, at least one outsider charges $\tilde{p}^{*}_{o-m}(\sigma)$ and firm m wins by the tie-breaking rule. The outsiders cannot gain for the following reasons. Raising the price lead to the same situation where they lose. Reducing the price is not profitable because they are indifferent at $\tilde{p}^{*}_{o-m}(\sigma)$, and winning at a lower price leads to lower profits (also from (A4)). Price $\tilde{p}^{*}_{o-m}(\sigma)$ is also an equilibrium from the perspective of the merged firm. Indeed, raising the price leads to lower profits since it would result in losing at $\tilde{p}^{*}_{o-m}(\sigma)$. Reducing the price is also not profitable from (A4). ■

Proof of proposition 4.

The price effect of the merger equals

$$\tilde{p}^*_{o-m}(\sigma) - p^*_i(\sigma) =$$

$$\tilde{C}_{IND} + (\sigma + B\frac{(1-k)^2 k^{N-2}}{k-k^N})\tilde{S}_o + \frac{1}{N-2}\left[(1-B)\sigma + B\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}\sigma\right]\tilde{S}_m - C_{IND} - \sigma S_i - \frac{\sigma}{N-1}S_i.$$

Since $\tilde{C}_{IND} = C_{IND}$ and $\tilde{S}_o = S_i$, we can write the price-effect as

$$B\frac{(1-k)^2 k^{N-2}}{k-k^N}\tilde{S}_o + \frac{1}{N-2}\left[(1-B)\sigma + B\frac{N-2}{N-1}\frac{\tilde{S}_o}{\tilde{S}_m}\sigma\right]\tilde{S}_m - \frac{\sigma}{N-1}\tilde{S}_o \ .$$

By using that $\tilde{S}_o = kc_H - k^N c_H$, and rewriting, we obtain that the price effect is

$$B(1-k)^2 k^{N-2}c_H + (1-B)\left(\frac{1}{N-2}\sigma\tilde{S}_m - \frac{1}{N-1}\sigma\tilde{S}_o\right). \blacksquare$$

Proof of proposition 5.

By merging, firms replace the profits of two pre-merger firms with the profits of only one merged firm. A profitable merger therefore requires that the merged firm can earn at least double the profits of a pre-merger firm. The profit effect for the merged firm depends on the subcontracting market institutions.

Bertrand subcontracting

Since from proposition 4, we know that the equilibrium price went up, we can use (A4) to write that the profits of the merged firm exceed

$$\underbrace{\tilde{W}_m\left(\tilde{p}^*_{o-m}(\sigma)\right)Q\left(\tilde{p}^*_{o-m}(\sigma)\right)}_{\text{profits merged firm}} > \tilde{W}_m\left(p^*_i(\sigma)\right)Q\left(p^*_i(\sigma)\right) \ .$$

We can rewrite the winner's profits as industry profits minus the surplus paid to the subcontractors, or

$$\tilde{W}_m\left(p^*_i(\sigma)\right)Q\left(p^*_i(\sigma)\right) = \underbrace{p^*_i(\sigma)Q\left(p^*_i(\sigma)\right) - C_{IND}Q\left(p^*_i(\sigma)\right)}_{N\pi_i} - \underbrace{\tilde{\sigma}_m\tilde{S}_m Q\left(p^*_i(\sigma)\right)}_{(N-2)\pi_i} \ .$$

At pre-merger price $p_i^*(\sigma)$, industry profits equal $N\pi_i$. Moreover, from Lemma 2, since subcontractors compete à la Bertrand, each of the $N-2$ outsiders earns the same unit profits pre- and post-merger ($\frac{\tilde{\sigma}_m \tilde{S}_m}{N-2} = L_i$). At pre-merger price $p_i^*(\sigma)$, their profits amount to $(N-2)\pi_i$. Merging is profitable since it covers more than *twice* the pre-merger profits.

Monopolistic subcontracting

The merger is strictly profitable because

$$\underbrace{\tilde{W}_m\left(\tilde{p}^*_{o-m}(\sigma)\right)Q\left(\tilde{p}^*_{o-m}(\sigma)\right)}_{\text{profits merged firm}} \geq \tilde{L}_m\left(\tilde{p}^*_{o-m}(\sigma)\right)Q\left(\tilde{p}^*_{o-m}(\sigma)\right) = 2\tilde{L}_{o-o}\left(\tilde{p}^*_{o-m}(\sigma)\right)Q\left(\tilde{p}^*_{o-m}(\sigma)\right)$$

$$= 2\frac{\sigma}{N-1}\tilde{S}_o Q\left(\tilde{p}^*_{o-m}(\sigma)\right) > \underbrace{2\frac{\sigma}{N-1}S_i Q\left(p_i^*(\sigma)\right)}_{\text{pre-merger profits}}.$$

The first inequality follows from the fact that firm m prefers to win rather than to lose in equilibrium (lemma 3). The next equality represents that firm m, from losing against o, earns twice the profits of an outside firm that would lose against o. These profits equal $\frac{1}{N-1}\sigma S_i Q\left(\tilde{p}^*_{o-m}(\sigma)\right)$. These profits exceed the last expression, which represents twice the pre-merger profits, because $\tilde{S}_o = S_i$ and from proposition 4 we know that the merger strictly decreased the price, and hence, strictly increased demand (from (A1)).

Monopsonistic subcontracting. The merger is profit-neutral because, before as well as after the merger, all firms charge the unit industry costs and earn zero. ■

Merger-specific synergies example.

We investigate the outsider and the merged firm.

The outsider has an incentive to decrease its price on the main market. In particular, profits from losing (weakly) decrease because of the cost-synergy, since it cannot profit from subcontracting to the merged firm. Also, an outsider's unit profits from winning weakly increase because of the cost-synergy. Indeed, for monopolistic subcontracting and Bertrand subcontracting, the merged entity is the only subcontractor and captures all surplus from subcontracting, so that profits from winning are not affected by the merger. For monopsonistic subcontracting, contracting costs become zero because of the cost-synergy of the merged firm. It follows that the outsider has increased incentives to charge a lower price compared to the no-synergies benchmark.

The merged firm also has an incentive to charge a lower price. Suppose first that there is Bertrand subcontracting. By winning, the merged firm incurs 0 rather than k^2c_H costs per unit because of the synergy. Indeed, the synergy eliminates both the production cost and the contracting cost. By winning, however, the merged firm also foregoes kc_H unit subcontracting profits rather than $k\left(1-k^2\right)c_H$ unit profits without the synergy. The price above which the merged firm is willing to win changes by $\left(0-k^2c_H\right)+\left(kc_H-k\left(1-k^2\right)c_H\right)$, rewritten as $\left(-k^2+k^3\right)c_H<0$, a negative amount. For monopolistic subcontracting, the merged firm also incurs zero rather than k^2c_H costs per unit because of the synergy. There is no change in subcontracting profits. Finally, the cost-synergy also decreases the costs from winning for monopsonistic subcontracting, while keeping the profits from subcontracting equal to zero. For all subcontracting market settings, the merged firm is increasingly willing to win because of the cost-synergy.

Proof of proposition 6.

We analyze the four statements in proposition 6.

1.

The merger increases industry output if and only if

$$\frac{a+(N-2)w_o-(N-1)w_m}{bN}+\frac{\left(N-2\right)a-2\left(N-2\right)w_o+\left(N-2\right)w_m}{bN}>\frac{N}{N+1}\frac{\left(a-w_i\right)}{b}\ .$$

We can rearrange, multiply by b and $N\left(N+1\right)$, and obtain

$$-a-\left(N-2\right)\left(N+1\right)w_o-\left(N+1\right)w_m+N^2w_i>0\,.$$

We write $N^2w_i=\left(N-1\right)\left(N+1\right)w_i+w_i$, divide by $\left(N+1\right)$, and rearrange to obtain

$$bq_i^*+\left(N-2\right)CC_o\text{-effect}<CC_m\text{-effect}\,.$$

We bring together two components. First, $b=-P^{'}=\frac{1}{\varepsilon}\frac{P^{\text{pre-merger}}}{Nq_i^*}$, where ε is the absolute value of the price-elasticity of demand evaluated at the pre-merger equilibrium. Second, from standard Cournot analysis we have that the Lerner index equals $\frac{P^{\text{pre-merger}}-w_i}{P^{\text{pre-merger}}}=\frac{1}{N\varepsilon}$. We can therefore write that $b=N\frac{P^{\text{pre-merger}}-w_i}{P^{\text{pre-merger}}}\frac{P^{\text{pre-merger}}}{Nq_i^*}$, so that $bq_i^*=P^{\text{pre-merger}}-w_i$.

2.

For Bertrand subcontracting, the condition for the merger to benefit consumers can be rewritten as

$$\frac{a-\left(kc_H-\left(1-\frac{\left(N-1\right)\left(1-k\right)k^{N-1}}{k-k^N}\right)\left(k-k^N\right)c_H\right)}{N+1}+\left(N-2\right)\left(1-k\right)^2k^{N-2}c_H<\left(1-k\right)k^{N-1}c_H\,.$$

A necessary condition for the market-clearing price to decrease is that the drop of the merged firm's contracting cost exceeds the increase of each outsider's contracting cost. We can write this condition as $N-2<\frac{k}{1-k}$.

Since the first term is positive, a sufficient condition for the market-clearing price to rise is that the increase of each outsider's contracting cost exceeds the drop of the merged firm's contracting cost. Formally, we have $N-2>\frac{k}{1-k}$. This is always satisfied for $k<0.5$, or when the number of firms is sufficiently large.

Finally, it can be checked that the merger can both benefit consumers and be profitable. As a numerical example, choose $k=3/4$, $N=3$, and $a=b=c_H=1$.

3.

For monopolistic subcontracting, the second effect is zero. The condition can be written as

$$\frac{a-C_i}{N+1}<C_i-\tilde{C}_m.$$

When the number of firms in the industry is sufficiently large, the requirement is always satisfied and the merger always benefits consumers.

4.

For monopsonistic subcontracting, the second and third effect are zero, so that the inequality never holds. The merger harms consumers. ■

Contractor teaming arrangements.

For completeness, it remains to show that, for Bertrand subcontracting, the CTA wins against the outsiders in equilibrium. To do so, it suffices to show that Lemma 3's ranking of prices also applies for a CTA. It follows that the same equilibrium argument of proposition 3 applies and that the CTA wins against the outsiders in equilibrium.

We investigate the CTA and the outsiders, respectively.

Contractor teaming arrangement.

As compared to a merged firm, a CTA has an increased incentive to win because it dissolves after losing. In particular, the CTA's profits from winning are equivalent.

However, since a losing CTA dissolves into two competing entities, losing yields lower profits for a CTA than for a merged firm. The reason is that two dissolved entities compete against each other in the event they both have favorable cost draws while the rest of the industry has unfavorable cost draws. It follows that the CTA's per unit decrease in profit from losing equals $(1-k)^2 k^{N-2} c_H$, and that the price above which the CTA is willing to win becomes $\tilde{p}_m^* - (1-k)^2 k^{N-2} c_H$.

Outsiders.

The outsiders have an increased incentive to win as well. Losing against a CTA or a merged entity yields the same profits. However, winning against a CTA results in lower contracting costs than winning against a merged entity. In particular, following the same reasoning, the per unit contracting cost decreases by $(1-k)^2 k^{N-2} c_H$. Hence, the outsiders are willing to win at a price above $\tilde{p}_{o-m}^* - (1-k)^2 k^{N-2} c_H$.

Since we have shown that $\tilde{p}_m^* \le \tilde{p}_{o-m}^*$ in the merger analysis, we can conclude that $\tilde{p}_m^* - (1-k)^2 k^{N-2} c_H \le \tilde{p}_{o-m}^* - (1-k)^2 k^{N-2} c_H$.

Finally, outsiders are willing to win against other outsiders at the pre-merger price p_i^*. Indeed, then, both when winning or when losing, the pre-merger expressions apply because the CTA is dissolved. Since $\tilde{p}_{o-m}^*(\sigma) - p_i^*(\sigma) = (1-k)^2 k^{N-2} c_H$ for Bertrand subcontracting, we can conclude that

$$\underbrace{\tilde{p}_m^* - (1-k)^2 k^{N-2} c_H}_{\substack{\text{price above which} \\ \text{CTA prefers to win}}} \le \underbrace{\tilde{p}_{o-m}^* - (1-k)^2 k^{N-2} c_H}_{\substack{\text{price above which} \\ \text{outsiders prefers to win against CTA}}} = \underbrace{\tilde{p}_{o-o}^*}_{\substack{\text{price above which} \\ \text{outsiders prefers to} \\ \text{win against outsiders}}}. \blacksquare$$

Vertical integration and horizontal outsourcing

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Abstract

This paper investigates the competitive effects of outsourcing between vertically integrated competitors. Outsourcing diminishes the residual capacity of the subcontractor to offer products independently downstream. As such, it is a means to reduce competition. Upstream production capacity serves a bargaining purpose. It threatens to compete on a stand-alone basis when firms would disagree about outsourcing. In equilibrium, outsourcing occurs and can inactivate the subcontractor as downstream competitor. Uninformed observers face an identification problem in distinguishing the horizontal agreement from a vertical one. This distinction, however, is crucial because vertical agreements are generally presumed to be less harmful for competition.

Keywords: vertical integration, outsourcing, industry structure, horizontal subcontracting.

JEL-codes: D23, D43, L13, L14, L22, L41

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1. Introduction

A vertically integrated firm has access to assets located upstream as well as assets located downstream in the value chain. Vertical integration can occur by means of a vertical merger, e.g. a merger between an upstream producer and a downstream retailer, or by internal growth (Riordan, 2005).

Vertical mergers have received a lot of attention in the context of vertical agreements. In an environment with linear wholesale tariffs, vertical integration can substitute for a vertical agreement and can overcome the double marginalization problem. Vertical integration has also been related to market foreclosure. In Hart and Tirole (1990), it is a way to alleviate contractual externalities. A firm with upstream market power, e.g. due to a cost advantage, may vertically integrate to commit not to secretly oversupply outside retailers. In Ordover et al. (1990), a vertically integrated firm has fewer incentives to compete for serving an outside downstream competitor. The outside downstream competitor's marginal cost rises in equilibrium, which increases the downstream price.

Vertical integration by internal growth can be modelled with a continuous capacity variable. Several studies have related endogenous capacity choices with horizontal competition issues. In Riordan (1998), a dominant firm vertically integrates by acquiring capacity. While a larger investment expands total capacity in equilibrium, a larger investment also reduces the size of the competitive fringe, so that vertical integration inherits features of a horizontal merger. In standard models of horizontal competition, production capacity also takes a strategic role. Kreps and Scheinkman (1983) show that firms have unilateral incentives to commit to a maximal production capacity before they engage in price competition. The intuition is that, by limiting one's own capacity to serve all consumers, the rival firm is guaranteed to profit from residual consumers. In this way, being capacity-constrained induces the rival to become less aggressive. In other words, installing too much capacity can backfire, as it leads to a more aggressive competitor. Firms therefore revert to a *puppy dog* strategy (Fudenberg and Tirole (1984) terminology). The main result from Kreps and Scheinkman (1983) is that, under endogenous capacity choices, the competitive outcome moves away from fierce Bertrand competition, and can for example equal the Cournot outcome, depending on the rationing rule.

This paper introduces the possibility for competing firms to sign outsourcing agreements with each other, henceforth *horizontal outsourcing*, into the Kreps and Scheinkman (1983) framework. The outsourcing decision occurs after the unilateral decision to invest in upstream production capacity, and before firms engage in downstream price competition. The horizontal outsourcing stage can reflect the possibility for competing firms to trade on forward markets. Such horizontal forward trade is important, not just for commodity markets such as natural gas and electricity, but also for financial securities markets.[2] Other industries such as manufacturing industries or markets for transportation services may not be characterized by liquid forward markets, but also commonly feature outsourcing agreements between (potentially) competing firms.

The analysis yields a striking result: horizontal outsourcing turns the downstream market into a monopoly. As such, the analysis reveals an anti-competitive motive for horizontal outsourcing agreements that has remained unreported so far, both in the vertical integration literature and the Bertrand-Edgeworth competition literature. The analysis also uncovers new interactions between the possible gains from signing anti-competitive horizontal outsourcing agreements and firms' decisions to invest in production capacity.

Outsourcing agreements between competing vertically integrated firms can weaken competition as follows. Outsourcing agreements are signed before the downstream competition stage. They specify a quantity to be subcontracted in return for a lump-sum transfer. As such, outsourcing reduces the residual capacity of the subcontractor to offer products independently downstream. When the subcontractor deploys its entire capacity to supply the rival, it is no longer able to compete for

[2] For example, treasury auctions are often preceded by when-issued markets, where competing dealers can trade with each other (see Coutinho, 2013).

consumers downstream. Gains from outsourcing arise from reduced downstream competition. The subcontractor is willing to sign the agreement when its profits from subcontracting exceed its outside option profits from competing without subcontracts. The contractor sourcing from the rival is willing to sign an expensive outsourcing agreement when it anticipates reduced downstream competition.

The choices to become active upstream and downstream are endogenous. The subcontractor can become inactive downstream because of its upstream capacity constraint. The contractor, even when vertically integrated, can become inactive upstream because of reduced marginal revenues on the downstream market.

The analysis shows that outsourcing affects the observed industry structure. In my framework, firms optimally sign an outsourcing agreement that requires the subcontractor to produce at full capacity. This agreement inactivates the subcontractor as downstream competitor. While the agreement is horizontal, it may not be assessed as horizontal by indicators that are exclusively based on production figures, market shares, or bidding data. If so, uninformed observers face an identification problem in distinguishing the horizontal agreement from a vertical one. Since vertical agreements are usually regarded as less harmful for competition, this finding suggests that potentially harmful outsourcing agreements may remain unnoticed in practice.

The outsourcing agreement considered in this paper is a *forward contract* (also sometimes labelled quantity-forcing contract): it pre-determines the amount of products supplied, together with the lump-sum transfer to be paid in return. Strikingly, forward contracts can, from an effects-based point of view, be similar to more sophisticated types of cooperation such as e.g. option contracts, exclusive dealing contracts, leasing or purchasing contracts for production assets, joint bidding agreements, mergers, or collusive agreements. Compared to other, more sophisticated horizontal outsourcing agreements, forward contracts are less likely to receive attention from competition authorities. As we will see, in my framework, there is no incentive for firms to turn to more sophisticated contracts.[3]

For antitrust purposes, it is important to emphasize that the anticompetitive effect described in this paper does *not* follow from a unilateral strategy by the contractor to foreclose a cost-efficient rival (see Rey and Tirole, 2007). Both parties, including the subcontractor who is inactive downstream, benefit from the outsourcing agreement. In the Treaty on the Functioning of the European Union, the relevant article is therefore Article 101 on agreements between firms rather than Article 102 on the abuse of dominant position. The anticompetitive effect should also be distinguished from Aghion and Bolton (1987), where the agreement extracts rents from an outside potential entrant. Here, there is reduced competition from the subcontractor taking part in the agreement, and surplus is extracted from the final consumer.

The analysis incorporates two pro-competitive effects that can offset the possible anti-competitive effects of horizontal outsourcing. First, the analysis allows for cost-efficiencies in the sense that outsourcing agreements allow firms to shift their production activity towards the lowest-marginal cost production technology. While cost-efficiencies can add to the gains from outsourcing, however, they are not required for the outsourcing agreement to be profitable in reducing competition.[4] Second, the analysis suggests an incentive to excessively invest in production capacity for strategic reasons. In particular, when firms bargain over an outsourcing

[3] As such, my analysis differs from Chen (2001), Sappington (2005), and Arya et al. (2008). A vertically integrated firm could sell its input using a contract that provides a rival retailer the option to buy the input after it has competed for consumers. These contracts have an anticompetitive effect because they create an opportunity cost of serving consumers downstream. Indeed, by serving final consumers, the vertically integrated firm foregoes subcontracting revenues received from the rival. My analysis of vertical integration and outsourcing does not rely on this opportunity cost.

[4] This result differs from Spiegel (1993)'s analysis of ex ante horizontal subcontracting. In Spiegel (1993), an outsourcing agreement that inactivates the subcontractor always benefits consumers. The driving assumption in that analysis is that gains from outsourcing are concave with respect to the subcontracted quantity (proposition 7, p. 581). My analysis shows that such concavity is naturally violated in the context of anticompetitive outsourcing. The reason is that firms gain from reducing competition both when one firm subcontracts at full capacity to its rival (positive subcontracted quantity), as well as vice versa (negative subcontracted quantity). Therefore, by assuming concave gains from outsourcing, Spiegel (1993)'s results understate the anticompetitive motive for horizontal outsourcing.

agreement, production capacity credibly threatens to act as a stand-alone competitor when firms would disagree. Both effects can benefit consumers. However, the latter effect suggests that firms may considerably waste resources to invest in idle production capacity.

The anticompetitive motive for horizontal outsourcing has not been incorporated in the vertical integration literature. It does not arise in the limiting case where competing vertically integrated firms have constant marginal costs and no capacity constraints (Hart and Tirole, 1990, Ordover et al., 1990, and more recently Chen, 2001, and Nocke and Rey, 2014). Indeed, the anticompetitive effect described here requires that supplying the rival reduces the ability of the subcontractor to serve consumers independently. The *scarce supplies* model in Hart and Tirole (1990) analyzes the other extreme where total capacity in the industry is smaller than the monopoly quantity. This assumption, too, removes the role for horizontal outsourcing to reduce competition. Indeed, there are no incentives for the industry to reduce industry output further below the monopoly quantity. Finally, the anticompetitive effect described in this paper requires sequentiality: the outsourcing agreement should be signed before the competition stage. That sequential order in which supplies are determined is not present in de Fontenay and Gans (2005), leading them not to find the anticompetitive effect described in this paper, despite the presence of increasing marginal costs.[5]

Importantly, I argue that intermediate levels of upstream capacity constraints, which lead to the anticompetitive effect, arise endogenously from the analysis of internal growth. When a firm decides how much to invest in capacity, it not only accounts for the outside option profits it would earn if it would refuse to sign an outsourcing agreement, but also accounts for the gains from outsourcing it can capture. That decomposition into outside option profits and gains from outsourcing

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[5] My findings also contribute methodologically by suggesting caution with the assumption of concave profits that is intended to guarantee a unique equilibrium. The assumption of concave profits biases the analysis towards symmetric outcomes. In my framework, however, ex ante similar (symmetric) firms have incentives to sign outsourcing agreements so that they undertake complementary (asymmetric) activities in the vertical supply chain. A setting that assumes concave profit functions would have overlooked this equilibrium phenomenon.

reveals that each firm is likely to invest in some capacity, though not too much. On the one hand, firms do not have incentives to build large capacities. Indeed, capacity constraints are needed for outsourcing to be anti-competitive, so installing a large amount of production capacity can reduce the gains from outsourcing. On the other hand, Hart and Tirole (1990)'s *scarce supplies* scenario is unlikely to be an equilibrium phenomenon either. The reason is that upstream capacity takes a strategic role in preserving a firm's outside option profits. It follows that firms have incentives to commit to act as horizontal competitor absent outsourcing, while signing an outsourcing agreement that reduces competition in equilibrium.[6] As the gains from outsourcing include the profits from reducing competition, cost-efficiency gains from outsourcing are not needed for vertical integration to complement outsourcing.[7]

The anticompetitive effects of horizontal outsourcing described in this paper have also remained unreported in the Bertrand-Edgeworth literature. Van Cayseele and Furth (1996, 2001) differ from my framework by analyzing a buyout possibility at the downstream price. My framework analyzes outsourcing at the wholesale level and has applications to a range of commonly observed outsourcing agreements between businesses. Bouckaert and Van Moer (2017) and Hunold and Muthers (2017) also analyze capacity constraints but differ from my analysis by

[6] The role upstream capacity investment resembles the role of vertical integration in Chen and Riordan (2007). They analyze a vertically merged firm that offers an exclusive dealing contract to an outside downstream retailer. Vertical integration affects firms' outside option profits, as well as the marginal profits from signing an exclusive dealing contract. More precisely, the vertical merger commits to a price war absent exclusive dealing, and exclusive dealing serves to reduce competition downstream. My analysis does not require the possibility to sign exclusive dealing contracts.

[7] This result does not arise from other settings where the horizontal outsourcing agreement is only a means to reduce production costs (see e.g. Hart and Tirole (1990) and Bouckaert and Van Moer (2017), among others). More generally, these insights highlight that vertical integration needs not substitute for outsourcing. That result differs from Shy and Stenbacka (2003) and Bühler and Haucap (2006), where outsourcing is a substitute for vertical integration. In their frameworks, a strategic interdependency arises because the input price from outsourcing exceeds the marginal cost after an in-house investment. Outsourcing from the input market then subjects a firm to a high input price that softens its incentive to compete fiercely downstream. For discussions and analyses of vertical integration and outsourcing in other contexts, I refer to the seminal works of Williamson (1979, 1985) on transaction cost economics and Klein et al. (1978) on the hold-up problem for relationship-specific investments.

investigating outsourcing agreements that are signed *after* the competition stage (ex post), yielding competitive effects that are distinct in nature.[8]

The extension of Kreps and Scheinkman (1983) with a horizontal outsourcing stage, besides altering the competitive outcome, has the potential to considerably simplify the duopoly analysis. The reason is that, in equilibrium, the subcontractor will turn inactive as a downstream competitor, possibly avoiding the need to analyze mixed strategies.

The topic of wholesale market foreclosure in the natural gas industry provides an example with an application to competition policy. To fix ideas, let the upstream segment represent the production and transportation of natural gas, which are capacity-constrained.[9] The downstream segment represents the wholesale market.

In many countries, upstream producers offer long-term contracts to supply incumbents. For example, in Denmark, a supply contract between three upstream producers (DUC consortium) and a vertically integrated incumbent (DONG, recently renamed Ørsted) has received a lot of attention. The vertically integrated incumbent has been active as an upstream producer and is dominant on the wholesale market. This paper contributes by showing that the supply contract in itself can harm competition; supply contracts decrease the capacity available by the suppliers to offer independently on the wholesale market.[10]

The theory of harm presented in this paper differs from the ones raised by competition authorities. Indeed, competition authorities have been concerned with

[8] For example, for price-inelastic demand, when two duopolists each have a production capacity equal to market demand, there is no anti-competitive role for ex post outsourcing, while outsourcing before the competition stage implements collusion, as we will see.

[9] The maximal capacity offered by natural gas producers is limited, both by their production equipment and by their acquired transportation rights.

[10] Producers (upstream) are potential Danish wholesale competitors (downstream). The following statement in the European Commission's DG competition report on the energy sector inquiry (2007) supports this claim: "[i]t cannot be excluded that certain producers [—subcontractors—] will develop into credible competitors that reduce concentration on European gas wholesale markets. The effects on competition of the entry of such companies must, however, be examined in detail in the light of the cooperation which exists between some of these producers and a number of incumbents players. In any case, the effects of long-term reservations by large gas producers remain the same for other potential new entrants".

this case for three reasons. First, they have investigated joint price setting in the consortium, which raises horizontal concerns. Second, clauses in the supply contract intended to reduce competition.[11] Finally, the duration of the supply contracts is considered an important barrier to enter for new potential entrants, raising exclusion concerns.[12] While the concerns raised by competition authorities are likely to have valid grounds, several interventions have not resulted in much entry. Indeed, the Danish Energy Regulatory Authority (DERA) reported in 2008 that DONG still had access to 85 % of the gas available in the wholesale market. Only one of the DUC partners, Shell, was active on the Danish wholesale market, with a market share below 5% (DERA, 2008).

The analysis also contributes to understanding the competitive effects of commodity forward markets. Allaz and Vila (1993) show that the possibility for firms to sell forward contracts to *financial firms* increases competition on a Cournot spot market.[13] However, installing a forward market also allows *competitors* to reallocate financial commitments.[14] In a setting where forward trade takes place between competing producers, I show that installing a forward market can reduce spot market competition. As such, my setting relates more closely to Coutinho (2013), who analyzes when-issued markets where inter-dealer trade occurs before competing on a treasury auction. In a similar fashion, the when-issued (forward) positions affect auction (spot) outcomes. In Coutinho (2013), however, the when-issued positions do not affect the auction price. My findings indicate that this is an artefact of the marginal utility (cost) functions imposed (linear and common slope).

[11] In particular, the supply contract included a 'necessary adjustment mechanism'. The mechanism is "[…] interpreted as providing that the DUC partners and DONG have to agree on adjustments to the gas supply agreements, e.g. the take-or-pay obligations of DONG, if the DUC partners start selling gas into Denmark" (Schnichels and Vallie, 2003). The mechanism discouraged the DUC partners to start selling gas independently.

[12] Aghion and Bolton (1987) show that below-marginal cost pricing can act as a barrier to entry. Polo and Scarpa (2013) analyze the anticompetitive effects of Take-Or-Pay contracts where marginal costs are very low up to a pre-agreed quantity.

[13] Mahenc and Salanié (2004) show the opposite result when the spot market is best characterized by price competition.

[14] Electricity markets are an important example. When an electricity producer experiences an unavailability of one of its production plants, it can either provide back-up production in-house, or buy production on the market. The counterparty is often a downstream competitor with access to cheaper production, e.g. a wind farm producer with favorable weather forecasts.

My analysis suggests that some firms may opt for an intermediary rather than to bid directly on the treasury auction. As such, introducing a when-issued market, next to serving a possible efficiency purpose, can reduce competition and participation in the main treasury auction, a finding that can help explain high concentration on the main auction.

2. The setup

There are two firms.[15] A vertically integrated firm has the ability to produce products upstream, as well as the ability to market products downstream.

The upstream cost function exhibits decreasing returns to scale. In particular, given capacity investments, each firm $i = 1, 2$ is characterized by marginal costs c_i up to its capacity constraint k_i.[16] Denote the lowest marginal cost by $c_L = \min(c_1, c_2)$ and the highest marginal cost by $c_H = \max(c_1, c_2)$. I will refer to the lowest-cost firm as the efficient (or cost-efficient) firm, and the highest-cost firm as the inefficient (or cost-inefficient) firm. When both firms have the same marginal cost, the distinction can simply be read as firm i and firm j.

Capacity provides a firm with the ability to produce. Capacity is industry-specific, i.e., a firm can only use its capacity to supply its downstream unit or to supply the rival's downstream unit. The capacity variable is continuous and investing in additional capacity is costly. Formally, when $r_i(k_i, c_i)$ represents firm i's cost of

[15] An important advantage of the duopoly setup is that it presents the results without relying on contractual externalities. As we will see, the main intuition extends to an N-firms oligopoly. The extension raises the issue of contractual externalities that is common in the literature, and requires a more detailed description of how firms establish horizontal outsourcing agreements.
[16] Manufacturing firms are often constrained by the production capacities of their plants. Also, the number of qualified workers is usually limited in the short run.

installing the capacity to produce at most k_i at marginal cost c_i , we have that $r_i(x,c_i) > r_i(y,c_i)$ when $x > y$.[17]

Downstream marketing costs are zero for simplicity. Since retail assets are often not industry-specific, I do not introduce retail capacity constraints. The underlying idea is that retail assets could be flexibly acquired if needed.[18]

There are three stages. In the investment stage, firms simultaneously choose to vertically integrate by building upstream production capacity. In the outsourcing stage, firms bargain with each other over an outsourcing agreement. The agreement specifies and settles a quantity to be produced in return for a transfer. To capture that supplier relationships are often flexible, the outsourcing stage takes as given the upstream capacities.[19] Finally, in the downstream competition stage, firms compete to offer homogenous products to final consumers.

Investment stage

In the investment stage, firms unilaterally and simultaneously invest in upstream production capacity k_i. The investment stage incorporates the possibility of zero capacity, in which case the firm only holds downstream assets. Every unit invested keeps constant the rival's upstream capacity, so the investment should be interpreted as the installation of new capacity, i.e., internal growth, rather than the takeover of existing capacity.

Outsourcing stage

Firms can sign a horizontal outsourcing agreement. In particular, firm 1 subcontracts quantity $\tilde{q}$ to firm 2 in return for a transfer. The standard analysis

[17] The capacity cost function does not depend on the capacity choice of the rival, to make sure that the raising rival's costs channel analyzed in Riordan (1998) is inactive.
[18] Remark that it is possible to construct an analogous framework for markets with upstream buyer power for inputs, and downstream capacity constraints.
[19] Arrunada and Vázquez (2006) report that "many strategic alliances end up devolving into temporary market-agreement relationships". They present the example of DaimlerChrysler, which asked Magna Steyr to assemble the Mercedes-Benz M-Class SUV eight months after the deal. They argue that, as a result of standardization and flexible manufacturing, contract manufactures can be replaced rather easily.

without outsourcing agreements corresponds to $\tilde{q}=0$. The sign of $\tilde{q}$ determines the direction of the outsourcing agreement; firm 2 acts as a subcontractor for negative values. Subcontracting for the rival firm implies a transaction cost $t \geq 0$ incurred by the subcontractor.[20]

Cost-efficient direction: The efficient firm acts as subcontractor.

Cost-inefficient direction: The inefficient firm acts as subcontractor.

The subcontracted quantity $\tilde{q}$ affects industry profits through the equilibrium quantities, prices and production levels. In contrast, the transfer does not affect the industry profits; it is sunk in the competition stage and cancels out. If firms can increase joint industry profits from horizontally outsourcing $\tilde{q}$, there always exists a transfer such that both firms want to sign the horizontal outsourcing agreement. I assume that firms share the gains from outsourcing using the symmetric Nash-Bargaining solution. This solution has the desirable property that, when firms invest symmetrically, they earn the same profits in equilibrium.[21]

We can summarize that firm i ‘s profits are

$$\pi_i^o = \underset{\substack{\text{outside option}\\ \text{no outsourcing}}}{\pi_i^{no}} + 0.5\underbrace{\left(\pi_1^o + \pi_2^o - \pi_1^{no} - \pi_2^{no}\right)}_{\text{gains from outsourcing}} \tag{1}$$

, where π_i^o equals i ’s profits under outsourcing and π_i^{no} equals i ’s profits under no outsourcing. Profits consist of the firm’s outside option profits, π_i^{no}, and its share of the gains from outsourcing according to the symmetric Nash-bargaining solution.

[20] It is possible to interpret the transaction cost as a relation-specific investment required for the outsourcing agreement. In my framework, this interpretation does not imply a hold-up problem because the transfer is agreed upon simultaneously with the decision to sign an outsourcing agreement.

[21] Whether firms share the surplus asymmetrically does not affect the results but may affect the magnitude of the investment incentives.

The profit functions include the costs of investing $r_i\left(k_i, c_i\right)$ and $r_j\left(k_j, c_j\right)$. However, those costs do not affect the gains from outsourcing since they cancel out; they are incurred regardless of whether firms sign an outsourcing agreement. The gains from outsourcing, when positive, are adjusted for the transaction cost t. The transfer paid from the contractor to the subcontractor cancels out.

Competition stage

As a prerequisite, the following concepts specify what happens when firms do not offer their acquired production downstream.

Prohibitive disposal: The contractor offers at least its contracted quantity. Prohibitive disposal requires that, if a firm contracts from its competitor, it must offer at least its contracted quantity downstream. In other words, the firm cannot pile up acquired production.[22]

Free disposal: The contractor can choose not to offer its contracted quantity downstream at no charge.[23] In case the contractor's in-house marginal cost is zero, the tie-breaking rule specifies that the contracted production is offered first.

The basic model investigates three modes of competition: price competition with price-inelastic demand, quantity competition, and price competition with price-elastic demand. The basic framework investigates homogeneous goods. The extension section discusses product differentiation.

Price competition with price-inelastic demand

Firms compete in prices to supply D divisible units. In particular, a non-strategic procurer or consumer wants to buy at most D units at per unit valuation V.[24] Quantity D is trivially equal to the monopoly quantity. The tie-breaking rule favors the efficient firm, if any, and randomly selects the winner otherwise.

[22] An example product is electricity, which cannot easily be stored.
[23] Free disposal is in line with Chen et al. (2011).
[24] Valuation V could represent the consumer's cost of acquiring a substitute product.

Note that a price competition framework cannot accommodate the assumption of prohibitive disposal. The reason is that the price-competing contractor's ability to offer downstream is subject to the rival's price. In particular, if the rival charges a lower price, the contractor sells zero and piles up its contracted quantity. The price competition framework therefore proceeds while allowing for free disposal.[25]

Cournot competition

Firms compete in quantities. Inverse demand equals $P(q_1+q_2)$. Label the monopoly quantity when a firm's marginal cost is c_i absent capacity constraint as $q^{m,c_i} \equiv \arg\max_q q\left[P(q)-c_i\right]$. The monopoly quantity increases when marginal costs decrease, or $q^{m,c_H} \leq q^{m,c_L} \leq q^{m,0}$. As usual, suppose that quantities are strategic substitutes, meaning that a firm's optimal offered quantity is a decreasing function of the rival's offered quantity. Also, the best response functions are not too steep so that an exogenous increase in a firm's offered quantity leads to an increase in industry output q_1+q_2 .

Note that the quantity competition framework can accommodate both the free disposal and the prohibitive disposal assumption because a quantity-competing contractor is always able to offer at least its contracted quantity downstream.

Price competition with price-elastic demand

This mode of competition mimics Kreps and Scheinkman (1983) and extends it by allowing for horizontal outsourcing. Denote the demand function by $Q(p)$, the inverse of the function $P(Q)$ we use in the Cournot model. Assume that the downstream marginal costs are constant and symmetric at $0=c_L=c_H$, and that the capacity cost functions are symmetric and written as $r(k_i,0)$ and $r(k_j,0)$. The demand function is well-behaved and there exists a monopoly price

[25] The main insights also hold for any bounded disposal cost.

$p^M \equiv \arg\max_p pQ(p)$. The monopoly quantity is the demand associated with the monopoly price, or $q^M \equiv Q(p^M)$. When the rival sells k_j, the optimal response is to offer $\rho_i\left(k_j\right) \equiv \arg\max_{q_i}\left(q_i P\left(q_i + k_j\right)\right)$ by charging $P\left(\rho_i\left(k_j\right) + k_j\right)$.

As the price competition framework with price-inelastic demand, this framework also proceeds by allowing for free disposal.

3. Analysis

The basic model investigates a homogenous product duopoly setting and provides a monopoly result. In particular, the duopoly model finds that the cost-efficient firm acts as subcontractor and deploys its entire capacity to supply the cost-inefficient firm. The contractor sourcing from the rival then becomes monopolist downstream.

The result arises from backward induction in two steps.

Outsourcing and competition stages

The first step investigates only the outsourcing and competition stage. It starts by giving an intuitive outline of the possible effects of outsourcing. It proceeds with a formal analysis and finds a sufficient condition for the downstream market to be a monopoly.

If we do not account for the investment stage, horizontal outsourcing can have ambiguous effects on costs as well as on competition (see Spiegel, 1993).

- Horizontal outsourcing agreements have the potential to reduce or increase production costs. In particular, production can shift between inefficient and efficient firms, total output can change, and an outsourcing agreement can involve a transaction cost. The cost effect crucially depends on the direction of the subcontract. Total costs tend to decrease when the cost-efficient firm acts as subcontractor for the cost-inefficient firm and tend to increase otherwise.

- Without considering endogenous investments, horizontal outsourcing agreements also have the potential to benefit or harm consumers. There are two opposing competitive effects. On the one hand, an outsourcing agreement *softens* the subcontractor on the downstream market. By acting as subcontractor, a firm reduces its capacity available to offer additional production downstream. On the other hand, an outsourcing agreement makes the contractor *aggressive* on the downstream market. The reason is that the contractor's cost of offering contracted production downstream is zero because the transfer paid to purchase this production is sunk. As such, the contractor does not account for the production costs incurred by the subcontractor. The net effect of horizontal outsourcing on consumer surplus could therefore be ambiguous.

Remark that the profitability of horizontal outsourcing depends on how the production cost effects balance against the competitive effects. Provided that the outsourcing agreement signed must have been profitable, the outsourcing agreement must have been cost-reducing, anticompetitive, or both.

Proposition 1 provides a sufficient condition for the downstream market to be a monopoly.

Proposition 1*: if each firm installs a production capacity that equals at most the monopoly quantity, and if the transaction cost is sufficiently low, the downstream market is a monopoly*.

The appendix provides the proof.

The intuition is that, when each firm installs at most the monopoly quantity, firms can always agree on the following outsourcing agreement:

- in the outsourcing stage, the efficient firm, who has the lowest marginal cost, acts as the subcontractor and sells an amount of products equal to its capacity constraint to its rival.

- in the competition stage, the contractor is monopolist.

This agreement always maximizes joint profits: revenues are optimal from a joint profit perspective, and production is efficient from a joint profit perspective.[26]

Since the contractor is monopolist, firms do not impose a competitive externality on each other downstream. In other words, in terms of revenue generation, the incentives of the contractor are aligned with the incentives of the industry. As a result, the contractor charges the monopoly price or, for the quantity competition model, offers the monopoly quantity.

In terms of production costs, the outsourcing agreement is efficient because the production technology with the lowest marginal cost receives priority and is deployed first. Indeed, the contractor incurs zero additional costs to offer its contracted production to the final consumer. The contractor will only activate in-house production after the efficient technology is maximally utilized.

Remark that, in the special case where both firms' production technology is characterized by the same marginal production cost, there are two optimal outsourcing agreements, one in each direction. The analysis remains unchanged; both outsourcing agreements are equivalent in terms of profits and consumer welfare.

Investment stage

The second step investigates the investment stage. Again, it starts with an intuitive overview of the possible effects, and proceeds with a formal result.

Firm i's profit function can be rewritten as

$$\pi_i^o = 0.5\pi_i^{no} - 0.5\pi_j^{no} + 0.5\left(\pi_1^o + \pi_2^o\right).$$

Installing upstream capacity affects a firm's profits via several channels. I next discuss the first two terms, which highlight firms' unilateral—and possibly

[26] Joint profit maximization refers to the outsourcing and competition stage and thus treats the investment choices and costs as given and sunk.

conflicting—interests to build capacity, as opposed to the final term, which highlights their joint interests.

- First, the effect of investing on a firm's own outside option profits π_i^{no} are as follows. Clearly, without investment, a firm fully eliminates its outside option profits. Indeed, without capacity, it is unable to offer any product downstream. An intermediate level of investment implies strictly positive gross profits under no outsourcing (excluding the investment cost). Indeed, strictly positive profits are predicted both by models of price competition with capacity constraints as well as Cournot competition models. Finally investing in a lot of capacity commits to compete aggressively. This commitment can be profitable in a quantity competition context with strategic substitutes, because the rival will respond by offering less. In contrast, the commitment to compete fiercely typically reduces profits in a price competition context with strategic complements, because the rival will respond by reducing its price. This creates a downward effect on π_i^{no}.[27]
- Second, additional production capacity reduces the rival's outside option profits π_j^{no}, and thereby the gains from outsourcing. In particular, both for quantity and price competition, installing a positive capacity implies that the rival faces an extra competitor. The larger the capacity installed, the larger the commitment to compete fiercely absent outsourcing. Hence, capacity investments always reduce the rival's outside option profits π_j^{no}.

The formal result requires to rule out dominated investment strategies: installing a capacity larger than the monopoly quantity always reduces a firm's outside option profits, and can decrease the gains from outsourcing.

Proposition 2: *monopoly result: in the investment equilibrium, each firm installs at most the monopoly quantity. It follows that, for a sufficiently low transaction cost,*

[27] This insight is illustrated by the standard Bertrand price competition model. Given that the rival invests in an infinite amount of capacity, following suit and investing an infinite amount of capacity in the same technology would lead to fierce competition and an equilibrium price down to marginal cost.

two vertically integrated competitors sign a horizontal outsourcing agreement such that

- *the cost-efficient firm subcontracts at full capacity;*
- *the cost-inefficient firm is monopolist downstream;*
- *consumer surplus decreases (for given capacities).*

The appendix provides the proof.

The intuition uses that a firm' profits consist of outside option profits and the gains from outsourcing it can capture, as displayed in equation (1). Installing capacity beyond the monopoly quantity reduces a firm's outside option profits, as doing so is costly on the margin and does not contribute to the standard duopoly profits. At the same time, firms benefit from having a capacity constraint that is at most equal to the monopoly quantity, as that allows for anticompetitive outsourcing agreements.

The investment stage rules out that the effect of horizontal outsourcing on consumers is ambiguous. The reason is that, in the investment equilibrium, the possible pro-competitive effect is zero on the margin. On the investment equilibrium path, firms invest in sufficiently small capacities because it is a dominated strategy to invest in capacity that will never be offered. For small capacities, it is always in the interest of the industry to fully deploy the capacity of the cost-efficient firm. Marginal sales by the contractor are covered with its in-house production assets. Consequently, the contractor responds to the actual marginal production cost in equilibrium.[28]

A more informal, perhaps too informal, way of understanding the monopoly result is as follows. First, since the gains from signing an outsourcing agreement are shared between the firms, profitable investment decisions are likely to be the ones that lead to profitable outsourcing agreements. Profitable outsourcing agreements, in turn, are the ones that reduce costs, reduce downstream competition, or both.

[28] As described, off the investment equilibrium path, the subcontractor's capacity could be larger than the monopoly quantity. The contractor would then act too tough on the downstream market: marginal sales are covered with contracted production, of which the perceived marginal cost is zero.

Therefore, the outsourcing agreements we see in equilibrium are likely to be the ones that reduce costs, reduce downstream competition, or both.

It is useful to note that the monopoly result does not rely on the presence of multiple downstream markets. Then, a monopoly outcome can also result because serving one market of consumers is cost-increasing for the remaining markets.[29] Finally, the monopoly outcome also does not rely on a Stackelberg-leadership effect by the contractor. The contractor could take a Stackelberg-leader role because the cost of acquiring production is sunk at the moment of competing. Chen (2011) shows that, in the presence of entry costs, this effect can prevent entry.[30]

Proposition 3 confirms that the result is robust to the introduction of more sophisticated contracts during the outsourcing stage.

Proposition 3. *Suppose that firms can sign more sophisticated contracts during the outsourcing stage. Then, firms can do no better than signing the forward contract analyzed in this paper, and the analysis remains unchanged.*

The intuition is that firms can already achieve the collusive outcome (given capacity choices), so they cannot improve their profits by signing a more sophisticated contract.

This section proceeds by comparing the consumer welfare level predicted by my framework with the consumer welfare level predicted by Kreps and Scheinkman (1983).

In Kreps and Scheinkman (1983), the equilibrium price equals the market-clearing price that follows from Cournot competition. The cost function upon which the

[29] Dudey (1992) analyzes capacity-constrained firms competing in multiple markets throughout time. Granting the rival a monopoly position on some markets exhausts its available capacity on other markets. A similar intuition holds in Polo and Scarpa (2013), where Take-or-Pay contracts imply that gas retailers have only limited access to cheap production. My framework differs in the sense that a firm exhausts its capacity, not by serving a downstream segment of consumers, but by serving a horizontal competitor.

[30] Interestingly, entry deterrence can then motivate a cost-inefficient sourcing agreement. Chen et al. (2011) show that cost-inefficient sourcing agreements can also arise without entry costs. The reason is that the subcontractor needs to be compensated not only for its production cost, but also for incurring the Stackelberg-follower disadvantage.

Cournot benchmark is based equals the sum of the capacity cost functions, $r(q,0)$, and the production cost functions, which are zero. Formally, a firm's duopoly quantity is implicitly defined as $q^d \equiv \arg\max_q \left[qP\left(q+q^d\right) - r(q,0) \right]$, and leads to a market-clearing price equal to $P\left(2q^d\right)$.

In my framework, the equilibrium price equals the monopoly price, or weakly exceeds it when firms install little capacity. The monopoly price in my framework, however, is only based on the production cost functions. In other words, it does not account for the marginal costs of investing in capacity. The reason is that investment costs are sunk at the moment of signing an outsourcing agreement. Therefore, the gains from outsourcing are independent of the incurred investment costs. Formally, we can write that, in my framework, the equilibrium quantity offered to consumers is weakly lower than $Q^M \equiv \arg\max_q \left[qP(q) \right]$, and leads to a price weakly higher than $p^M = P\left(Q^M\right)$.

Proposition 4 finds that the direction of the consumer welfare effect depends on how the duopoly quantities compare to the monopoly quantity.

Proposition 4. *Suppose that the transaction cost is sufficiently low. Then, introducing the outsourcing stage into Kreps and Scheinkman (1983) results in reduced consumer welfare if and only if the marginal cost of installing capacity is sufficiently small (* $2q^d > Q^M$ *)*

The proof is in the appendix.

When the marginal cost of installing capacity is small, $2q^d > Q^M$ holds and outsourcing reduces industry output from $2q^d$ to a level of at most Q^M.

When the marginal cost of installing capacity is large, $2q^d \le Q^M$, the introduction of the outsourcing stage does not harm consumers. That result follows from firms' incentives to invest in sufficient production capacity.

As an example, suppose that the inverse demand function equals $P(Q)=1-Q$ and that the marginal capacity cost is $r^{'}(k_i,0)=b$. It follows that the monopoly quantity is $Q^M=0.5$, and that the duopoly capacities are $q^d=\frac{1-b}{3}$. The condition that $2q^d>Q^M$ can be rewritten as $b<\frac{1}{4}$.

Remark that the Kreps and Scheinkman (1983) benchmark does not incorporate asymmetric marginal costs, and therefore does not allow for any cost-efficiencies from horizontal outsourcing.

This section concludes with a discrete investment game example. The purpose is to show that outsourcing can lead to an inefficiently large investment.

Discrete investment game example

Suppose that demand *D=1*, production is indivisible, and that the transaction cost is sufficiently low so that the gains from outsourcing are always positive. By investing in one unit of inefficient capacity with marginal cost c_H, a firm incurs a fixed cost f. Acquiring one unit of efficient capacity with marginal cost c_L requires a more costly investment of F, where $f<F$.

When only one firm invests in capacity, the other firm earns zero profits and there are no gains from outsourcing. Investment costs are assumed sufficiently low such that both firms invest in positive capacity. As we will see, there is a strategic incentive to vertically integrate; even if a firm holds idle capacity, it can still earn positive profits because it captures a portion of the gains from outsourcing.

For the outsourcing agreement to be profitable, the subcontracted quantity should equal the subcontractor's capacity, or $\tilde{q}^*\in\{k_1,-k_2\}$. The proof is by contradiction. When the subcontractor does not subcontract the quantity equal to its capacity, its marginal cost of offering an additional product is unchanged. The contractor acquires production at a sunk cost, and is therefore willing to compete more fiercely for the consumer. As such, a subcontracted quantity smaller than the subcontractor's capacity cannot increase the equilibrium price. It also does not reduce production costs, because the efficient firm already wins the consumer without the outsourcing agreement. Any strictly positive transaction cost t would make the outsourcing agreement strictly unprofitable. Therefore, any profitable outsourcing agreement involves a subcontracted quantity equal to the subcontractor's capacity.

Given that the subcontracted quantity equals the subcontractor's capacity, the outsourcing agreement always makes the contractor a monopolist downstream. As a result, the contractor charges V in equilibrium. The optimal direction of the outsourcing agreement is the one that is cheapest to implement. In particular, firms choose the outsourcing agreement costing $\min\{c_1k_1, c_2k_2\}$. Importantly, an outsourcing agreement in the cost-inefficient direction could be profitable when the capacity of the efficient firm is higher than the capacity of the inefficient firm.

The gains from outsourcing are $\max\{\underbrace{V-\min\{c_1k_1, c_2k_2\}-t-(c_H-c_L)}_{\pi_1^o+\pi_2^o-\pi_1^{no}-\pi_2^{no}}, 0\}$. The expression shows that investing more than $k_i = 1$ never increases the gains from outsourcing. Investing in extra capacity can only be unprofitable by increasing the subcontracted quantity needed to reduce downstream competition. In any investment equilibrium, therefore, installing $k_i = 1$ dominates installing more. We get that $\min\{c_1k_1, c_2k_2\} = \min\{c_1, c_2\}$. Firms always subcontract in the cost-efficient direction: the efficient firm subcontracts to the inefficient firm. Nonetheless, outsourcing can be cost-increasing because of the transaction cost.

When firms invest symmetrically, the no outsourcing profits π_i^{no} are negative because of the investment cost. Firms can then profit only from the gains from outsourcing. In the asymmetric setting where one firm invests in one unit of efficient capacity and the other firm invests in inefficient capacity, the outside option of the efficient firm equals $c_H - c_L - F$. Figure 1 displays the possible profits in the investment game, depending the choices by firm 1 and by firm 2 to invest in efficient capacity or to invest in inefficient capacity.

Firm 1 \ Firm 2	efficient	inefficient
efficient	$-F+0.5(V-c_L-t)$, $-F+0.5(V-c_L-t)$	$c_H-c_L-F+0.5(V-c_H-t)$, $-f+0.5(V-c_H-t)$
inefficient	$-f+0.5(V-c_H-t)$, $c_H-c_L-F+0.5(V-c_H-t)$	$-f+0.5(V-c_H-t)$, $-f+0.5(V-c_H-t)$

Figure 1: the investment game.

All scenarios presented are possible equilibria, depending on the investment costs. When firms invest asymmetrically, the efficient firm cannot profitably deviate when $F-f \leq c_H-c_L$. The inefficient firm cannot profitably deviate when $0.5(c_H-c_L) \leq F-f$. So, when $0.5(c_H-c_L) \leq F-f \leq c_H-c_L$, there is an asymmetric equilibrium. When both firms invest in the efficient capacity, no firm can profitably deviate when $F-f \leq 0.5(c_H-c_L)$. When both firms invest in the inefficient capacity, no firm can profitably deviate when $c_H-c_L \leq F-f$.

4. Extensions and robustness

The outline of this section, including main intuitions, is as follows.

The first extension investigates the incentives to build downstream assets (forward integration), as opposed to the basic model that analyzes the incentives to build upstream production assets (backward integration).

The second extension section investigates a vertical merger that takes as given the *existing* upstream assets (see e.g. de Fontenay and Gans, 2005, among others), as opposed to the basic model that analyzes investment in *new* capacity. By doing so, this paper captures two extremes. The basic model uses as a benchmark that there is no substitution between a firm's investment decision and the rivals' upstream capacities. A vertical merger occurring after firms' investment decisions captures the other benchmark: full substitution between the acquired capacity and the rivals' upstream capacities.[31]

The third extension investigates differentiated products and shows that, then, the downstream market can be a duopoly. Consumers value the presence of two independent suppliers downstream, so that the optimal outsourcing agreement may spare some of the subcontractor's production capacity. The insight that outsourcing agreements can reduce competition is remains valid.

The fourth extension is the oligopoly extension. It requires to specify how firms sign outsourcing agreements. A natural concept is bilateral efficiency: two firms should not be able to improve profits by trading with each other, taking as given the other trades in the industry (Crémer and Riordan, 1987). There is an important distinction between public and private (secret) contracting. Under private contracting, outsourcing agreements are not observed by outsiders to the agreement. Consequently, outsourcing agreements only affect the behavior of the firms engaging in the agreement, and are used to soften competition on the downstream market. Under public contracting, outsiders can react to the agreement signed. This generates a strategic Stackelberg effect, similar to the one studied in Jeon and Lefouili (2015), that depends on the mode of competition. Price-competing firms have a strategic incentive to commit to reduce competition as outsiders will respond by raising their prices. In contrast, quantity-competing firms have a strategic incentive to commit to compete aggressively in order to reduce the production offered by outsiders. Outsourcing agreements between quantity-

[31] As mentioned, in Riordan (1998), vertical integration by a dominant firm reduces capacity investments by the competitive fringe, while increasing total capacity investments.

competing firms can therefore improve competition, provided that the strategic Stackelberg effect is sufficiently large.

The fifth extension analyses learning by subcontracting. In some industries, by outsourcing, the contractor shares know-how and ability with the subcontractor. The sharing of knowledge can then lead to a stronger competitor. One could think that learning could discourage the contractor from signing such an agreement. The subsection on learning by subcontracting provides a counterargument to this claim: an efficiency improvement of the competitor can translate into increased gains from outsourcing.

The final extension deals with strictly increasing marginal cost functions. The analysis suggests that the anticompetitive effect of horizontal outsourcing does not rely on capacity constraints, but suggests a weaker requirement that the outsourcing agreement sufficiently raises the marginal cost of the subcontractor.

The strategic value of downstream assets

The insights on the strategic value of installing upstream assets extend to downstream assets. In particular, the ability to serve consumers downstream also serves a bargaining purpose. When a firm does not have access to downstream assets, the alternative to the outsourcing agreement implies the firm earns zero profits (excluding investment costs), and that the rival acts as a vertically integrated monopolist. There is no threat of fierce competition absent outsourcing. Downstream assets and upstream production capacity thus serve a similar strategic role in acting as a bargaining chip.

Downstream assets, however, may have different characteristics as compared to upstream assets. In particular, there is no need for forward integration when downstream assets are not industry-specific and can be flexibly acquired or hired ex post. Absent outsourcing, a firm could then sell production through an outside retailer. The basic model therefore focused on investment in upstream capacity. Upstream production capacities are often more rigid and require investments ex ante. However, in industries where downstream assets are equally industry-specific or inflexible, the strategic motive to build upstream assets extends to downstream assets.

Vertical merger

This subsection investigates the incentives to acquire existing capacity, as opposed to the basic model's investment in new capacity. A full-fletched merger game is beyond the scope of this paper. Nonetheless, it is useful to investigate whether the setting with two vertically integrated firms is an equilibrium. In particular, taking as given upstream capacities and the vertical integration decision by the rival, do firms prefer to merge or to be vertically separated?

Consider the discrete example price competition model where both upstream production plants can produce one indivisible unit ($k=1$). There is demand for one indivisible unit ($D=1$). The willingness to pay equals V and marginal costs are constant at c. Suppose that transaction costs are zero ($t=0$).[32]

When the upstream and downstream firms vertically merge, they earn $0.5(V-c)$, excluding the investment cost. There is an incentive to vertically merge when the upstream and downstream firm jointly earn less under vertical separation.

The analysis follows Crémer and Riordan (1987) by adopting bilateral efficiency. The definition of bilateral efficiency is similar to Jeon and Lefouili (2015), and relates to the Nash-in-Nash concept.[33] In particular, *bilateral efficiency* requires that, in the contract equilibrium, two firms sign a bilateral outsourcing agreement, if any, so as to maximize their joint profits, taking as given the other outsourcing agreements and the anticipated equilibrium outcome of the competition stage. I assume that contracts are public; rivals are aware of a deviation and respond to it in the competition stage. I will also impose that the terms of the outsourcing agreement satisfy *individual rationality*; no firm has an incentive to reject a

[32] A positive transaction cost from outsourcing would bias the analysis in favor of vertical integration.
[33] See e.g. Rey and Vergé (2016) for recent work on Nash-in-Nash.

contract, taking as given the other outsourcing agreements and the anticipated equilibrium outcome of the competition stage.

Suppose first that the upstream firm does not act as a subcontractor. Then, the vertically integrated rival can guarantee monopoly profits by declining any agreement. It follows from individual rationality that the vertically separated firms earn zero profits.

Suppose second that the upstream firm acts as a subcontractor. There are two possibilities: the upstream firm supplies the independent downstream firm or supplies the vertically integrated rival. I show that joint profits under vertical separation are lower, or no higher, than those under the vertical merger. Hence, given investments, the setting with two vertically integrated firms is an equilibrium.

1. First, consider the subcontract where the upstream firm subcontracts to the vertically integrated rival in return for a transfer denoted by $\tilde{t}$. The upstream firm's profits are $\tilde{t}-c$ and the integrated firm's profits are $V-\tilde{t}$. I argue that the contract equilibrium requires that $\tilde{t}=c$ using individual rationality. Indeed, when $\tilde{t}>c$, the integrated firm would be better off not signing the contract and earning $V-c$. Contracting would be too expensive for the integrated firm, so it would prefer to decline the outsourcing agreement and serve consumers on a stand-alone basis. When $\tilde{t}<c$, the upstream firm sells below marginal cost and would be better off not signing the contract. Finally, the contract equilibrium is an equilibrium. Indeed, the vertically separated firms cannot profitably deviate from $\tilde{t}=c$ as there is no product left available to trade. Their joint profits equal zero excluding their investment costs.

2. Second, consider the outsourcing agreement between the vertically separated firms. If this is the only outsourcing agreement, industry profits are zero because the downstream firm competes fiercely with the vertically integrated rival. The downstream price equals *c*. However, there is an incentive for the downstream firm to act as intermediary by selling its acquired production to the vertically integrated firm. By doing so, the vertically integrated firm becomes monopolist. Under symmetric Nash-bargaining, the vertically separated firms can replicate the profits they could have achieved by merging. Suppose instead that the independent downstream firm cannot act as a seller on the input market. This generates an incentive for the vertically integrated firm to supply the independent downstream firm when $V - 2c > 0$. Indeed, by incurring an extra cost c, the downstream firm would be monopolist downstream and charge V rather than c. Importantly, this equilibrium is not cost-efficient because there is excessive production. The vertically separated firms earn joint profits $0.5\max(V - 2c, 0)$. They benefit from merging because it avoids excessive production, and therefore the gains from outsourcing.

The above analysis shows that a vertical merger is an equilibrium phenomenon. It does not rule out that a non-linear contract could substitute for a vertical merger, provided that such a non-linear contract could be signed before the outsourcing stage.

Differentiated products

This section translates the previous insights in a setting with differentiated products. The extension to differentiated products makes two claims and proceeds by reporting the possible industry structures.

(i) outsourcing can reduce competition for sufficiently low product differentiation.

Consider a well-behaved symmetric Hotelling model with symmetric investments in capacity $k = D$, equal marginal costs, and zero transaction costs. Without outsourcing, each firm charges p_1 and p_2 for its end-product, respectively. Suppose that an equilibrium set of prices exists, and denote these prices by p_1^* and p_2^*. The resulting profits are denoted by $\pi_1^*\left(p_1^*\left(p_2^*\right), p_2^*\left(p_1^*\right)\right)$ and

$\pi_2^*\left(p_1^*\left(p_2^*\right), p_2^*\left(p_1^*\right)\right)$. In a symmetric equilibrium each firm serves $0.5D$ consumers.

Now consider the outsourcing agreement where the contractor contracts $\tilde{q} = D$ intermediary products from the subcontractor. The subcontractor is then unable to offer products independently. Let price $p_2 = \infty$ represent that firm 2 does not offer products downstream. Firm 1 is a monopolist and earns $\pi_1^*\left(p_1^*(\infty), \infty\right)$. The outsourcing agreement is profitable whenever

$$\pi_1^*\left(p_1^*(\infty), \infty\right) > \pi_1^*\left(p_1^*\left(p_2^*\right), p_2^*\left(p_1^*\right)\right) + \pi_2^*\left(p_1^*\left(p_2^*\right), p_2^*\left(p_1^*\right)\right).$$

The profitability of the outsourcing agreement depends on the amount of product differentiation. When product differentiation is low, competition without outsourcing agreements is fierce (low right-hand side).

Horizontal outsourcing can be profitable. Indeed, in the limit as we let firms' locations almost coincide, the condition reduces to $\pi_1^*\left(p_1^*(\infty), \infty\right) > 0$, which is always satisfied.

In the example, any profitable outsourcing agreement is signed with the purpose of reducing competition at the expense of consumers. Indeed, there are no other reasons to sign the outsourcing agreement. Absent outsourcing, production was already efficient because of symmetric marginal costs. Moreover, the product variety offered was already welfare-optimal because each firm served half of the consumers.

(ii) the downstream market can be observed as duopoly

The downstream monopoly result depends on the assumption of homogenous products. I present the argument intuitively and rely on a limiting case. Consumer taste for variety may make it profitable for firms to continue market two products. In particular, the optimal outsourcing agreement may leave some capacity available to the subcontractor. The subcontractor can then continue offering its independent brand to the consumers that value it the most. In the limit where the two firms serve two separated downstream markets, there is no anticompetitive motive for outsourcing and both firms are active downstream.

The upstream market structure can be observed as monopoly (full sourcing) or duopoly (partial or dual sourcing). As the contractor acquires and markets more production from the subcontractor, there are less incentives to produce and market additional goods. For example, in a symmetric quantity competition setting where $0.5q^{m,c} < k \leq q^{m,c}$ and $k_i = k_j = k$, the contractor has an incentive to produce an additional $q^{m,c} - k \geq 0$ in-house.

Figure 2 shows the possible industry structures. The left figures display the entire setup, whereas the right figure only displays the observables in equilibrium. The monopoly-full sourcing combination represents the vertical chain.

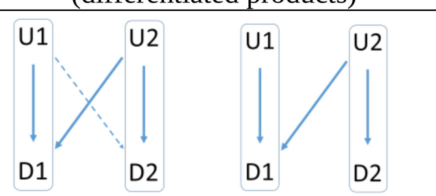
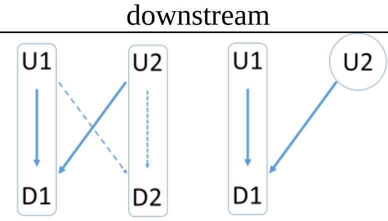
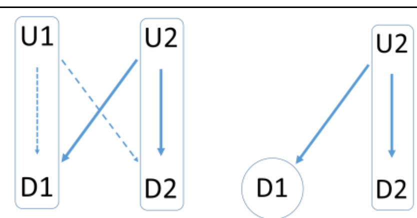
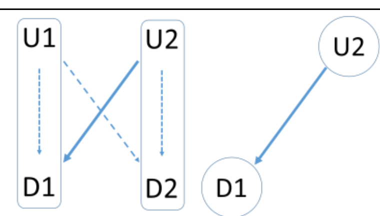
	DUOPOLY Subcontractor active downstream (differentiated products)	**MONOPOLY** Subcontractor inactive downstream
PARTIAL SOURCING Contractor active upstream		
FULL SOURCING Contractor inactive upstream		

Figure 2. possible industry structures with outsourcing.

Oligopoly

The same insights can extend to an oligopoly situation where more than two firms compete. The extension, however, requires to specify how firms horizontally outsource before competing.

Multilateral efficiency: firms take advantage of all gains from outsourcing.

Multilateral efficiency can for example arise from a cooperative setting, where firms share the gains from trade using the Shapley value. The Shapley value approach is multilaterally efficient by assumption. Hence, it will lead to outsourcing if and only if it is multilaterally efficient.

Bilateral efficiency: firms bilaterally bargain, and that each bilateral contract maximizes the gains from outsourcing, taking as given the other bilateral contracts and the anticipated outcome of competition stage.

There is an important distinction between private (secret) contracts and public contracts. Under secret contracting, firms always wish to sign contracts that reduce competition. Indeed, the bilaterally optimal contract will try to reduce the competitive externality between the two contracting parties. Firms intend to reduce their joint outputs or to increase their equilibrium prices. However, when firms outside the agreement can publicly observe the contracts signed, the outsiders will respond in equilibrium. A Stackelberg effect arises (see Jeon and Lefouili, 2015). Quantity-competing firms may use the contract to commit to a large output, in order to reduce the rivals' outputs. As such, outsourcing could serve to increase competition rather than reduce it. The intuition connects to Allaz and Vila (1993), but differs from it because the contract signed here is a bilateral one between competing producers. Importantly, analogous to Mahenc and Salanié (2004), the intuition reverses for price-competing firms. When prices are strategic complements, there is an incentive to commit to high prices, since outsiders will respond by increasing their prices as well.

Consider a price competition model with three symmetric firms characterized by marginal cost c and $k=1$ each. Without outsourcing, each firm earns zero (excluding the investment cost). Suppose that the bilateral contracts are publicly observable.

Figure 3 summarizes the setting.

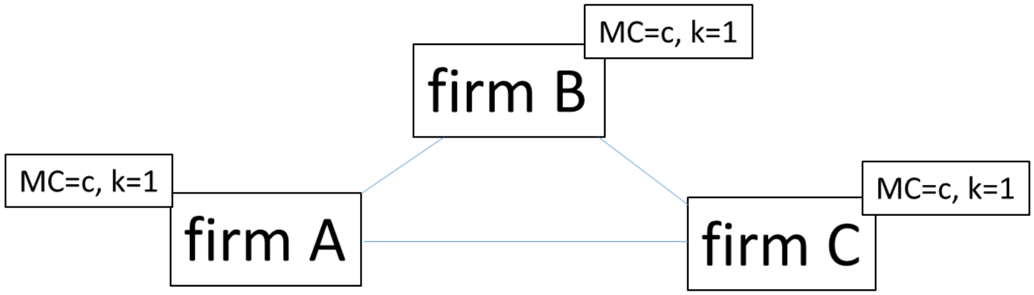


Figure 3: oligopoly

This extension makes two claims. The first one compares multilateral efficiency with bilateral efficiency (secret contracts).

(i) In the example, bilateral efficiency (secret contracts) can sustain no outsourcing when outsourcing is multilaterally efficient, and vice versa, it can sustain outsourcing when it is not multilaterally efficient.

No outsourcing refers to the situation without outsourcing. It leads to zero industry profits (excluding the investment cost). I argue that no outsourcing can always be a bilaterally efficient equilibrium. Given that the two rival firms do not sign outsourcing agreements, it is best not to sign an outsourcing agreement as well. Indeed, when only one firm acts as subcontractor, there is fierce competition between the contractor and the outside firm. The contractor wins in equilibrium by charging c and industry profits are $-t$. One bilateral contract is insufficient to raise the equilibrium price above c. So, no outsourcing can always be a bilaterally efficient equilibrium. Remark that no outsourcing is only multilaterally efficient when $V-2c-2t<0$. Indeed, as we will see, there are two possible ways to signing outsourcing agreements to eliminate downstream competition. Both of them can raise the price by $V-c$ at the extra incurred cost of $c+2t$.

Direct outsourcing: firm A → firm C & firm B → firm C; firm C acquires one unit from each of the other firms directly. Profits excluding investment costs are $V-2c-2t$: the equilibrium price is V and two firms are producing. Given that firm C contracts one unit from one firm already, the gains from contracting one unit from the other firm equal $\max(V-2c-t,0)$. Indeed, the outsourcing agreement raises the equilibrium price by $V-c$ but involves extra costs equaling $c+t$. So, whenever $V-2c-t \geq 0$, outsourcing can be a bilaterally efficient equilibrium. Remark that this solution is only multilaterally efficient whenever $V-2c-2t \geq 0$. Negative profits are a possibility, in which case the bilaterally efficient outsourcing agreements are not individually rational. In particular, firm C may benefit from a double-sided deviation by declining the two outsourcing agreements simultaneously. Remark also that the two subcontractors do not have an incentive to sign an outsourcing agreement, because they are capacity-constrained.

Indirect outsourcing: firm B → firm A → firm C; firm C acquires two units from firm A, and firm A acquires one unit from firm B. Given that firm C buys two units from firm A, the gains from having firm A contract one unit from firm B are infinity. The reason is that it needs the contract deliver upon its commitment because of its capacity constraint. Given the outsourcing agreement between firm A and B, the gains from trading for firm A with firm C equal $\max(V-2c-t,0)$. Indeed, without this contract, competition would be fierce and lead to a price equal to c. The outsourcing agreement raises the price by $V-c$ but involves extra costs equaling $c+t$. When $V-2c-t \geq 0$, indirect outsourcing can be a bilaterally efficient equilibrium. Again, this solution is only multilaterally efficient whenever $V-2c-2t \geq 0$. Firm A may earn negative profits, in which case it benefits from a double-sided deviation by declining the two outsourcing agreements simultaneously. Remark also that firm C does not have an incentive to sign a contract with firm A. Firm A cannot subcontract another unit because of the capacity constraint, and there is no incentive to subcontract to firm B because that would lead to fierce competition.

To summarize, the outsourcing agreement that eliminates downstream competition can be implemented when $V-2c-t \geq 0$. It is only multilaterally efficient, however, whenever $V-2c-2t \geq 0$. So, bilaterally efficiency can explain outsourcing when it is not multilaterally efficient.

(ii) In a quantity competition setting with bilaterally efficient public contracts, firms may have incentives to sign outsourcing agreements that increase competition.

The purpose of this subsection is to illustrate that there can be incentives to sign outsourcing agreements that commit to aggressive competition downstream. Importantly, I do not analyze a full game here. When multiple firms are active downstream, there is a myriad of competitive externalities. Depending on the setting, a bilaterally efficient equilibrium may not exists.

Consider the standard quantity-competition setting with N firms, symmetric marginal costs, and inverse demand function $P = 1 - Q$. Without outsourcing agreements, when capacity constraints do not bind, each firm produces $(1-c)/(N+1)$ in equilibrium. Two firms jointly produce $2(1-c)/(N+1)$.

Suppose that two firms could commit to producing the Stackelberg quantity q^S instead. Then the $N-2$ outsiders would respond by producing $(1-c-q^S)/(N-1)$ each. The bilateral profits of the firms committing to q^S equal $\left(1-c-q^S-(N-2)(1-c-q^S)/(N-1)\right)q^S$. The optimal Stackelberg quantity q^S to commit to thus equals $q^{S*} = (1-c)/2$. For $N \geq 4$, we have that the optimal Stackelberg quantity exceeds the joint quantities offered in the standard downstream equilibrium, or $q^{S*} > 2(1-c)/(N+1)$. This illustrates that the Stackelberg effect can be sufficiently large so that two firms wish to sign bilateral outsourcing agreements that commit to aggressive behavior downstream.

Learning by subcontracting

This subsection shows that contracting can be profitable even when it leads to a more efficient competitor. The reason is that a more efficient competitor increases the gains from outsourcing.

When the cost-reduction is subcontract-specific, learning by the subcontractor is profitable because of the production cost decrease. Indeed, suppose that under the outsourcing agreement, the subcontractor incurs a cost of only γc where $0 \le \gamma \le 1$. The parameter γ represents that the subcontractor incurs lower costs by subcontracting rather than if it were to produce on a stand-alone basis. Learning does not affect any of the firms' outside option profits under no outsourcing, but increases the gains from outsourcing. Therefore, learning makes both firms better off. Such learning could be interpreted as a cost-efficiency gain from outsourcing.

When the subcontractor's cost-reduction is not subcontract-specific, it has an ambiguous effect on the contractor's profits. While a cost reduction worsens the contractor's outside option, it increases the gains from outsourcing. Figure 4 summarizes the insights.

contractor's profits	**= outside option** π_i^{no}	**+ α *(gains from outsourcing)** $0.5\left(\pi_1^o + \pi_2^o - \pi_1^{no} - \pi_2^{no}\right)$
subcontract-specific cost reduction	does not affect outside option	improves the gains from outsourcing
not subcontract-specific cost reduction	worsens outside option	improves the gains from outsourcing

Figure 4. Learning by subcontracting

Strictly increasing marginal costs

The appendix works out a partial characterization of a symmetric quantity-competition setting with differentiable and strictly increasing marginal costs. The setting does not include an investment stage and closely reflects Spiegel (1993).

As in Spiegel (1993), under these assumptions, the effect of horizontal outsourcing agreements on cost-efficiency is unambiguously harmful. The reason is that a horizontal outsourcing agreement results in the subcontractor producing more than the contractor, while it would be cost-efficient to have each firm produce the same amount. The competitive effects of horizontal outsourcing are ambiguous.

The appendix shows that a critical condition for industry output to drop is convexity in the marginal cost function. In particular, the change in industry output follows from two effects. The subcontractor, by producing for the rival, moves up its marginal cost curve. This effect reduces its downstream equilibrium quantity. The magnitude of the effect depends on the slope of the marginal cost curve *beyond* the standard Cournot quantity. In contrast, the contractor acquires access to production ex ante, so that it moves down its marginal cost curve. The contractor therefore increases its downstream quantity. The magnitude of this effect follows from the slope of the marginal cost curve *below* the standard Cournot quantity. Whether the net effect of horizontal outsourcing on industry output is negative or positive, depends on whether the marginal cost curve is steeper for the subcontractor than the contractor (convex / increasing slope) or vice versa (concave / decreasing slope). The marginal cost increase that causes the subcontractor to offer less, should be larger than the marginal cost decrease that causes the contractor to offer more. The analogy with the baseline model is that the production inefficiency, for example from a transaction cost, should be balanced against the profits from reducing competition.

This partial characterization is useful because it suggests that the anticompetitive effect of horizontal outsourcing does not require capacity constraints. Instead, it points towards a weaker requirement that the slope of the subcontractor's marginal cost function in the relevant region is steeper than the slope of the contractor's marginal cost function in the relevant region. This weaker requirement would also be reflected in an investment stage that precedes the outsourcing stage. In particular, committing to be capacity-constrained is not needed to generate gains from outsourcing; it can suffice for firms to install production facilities that are characterized by a marginal cost function with a sufficiently steep slope.

5. Conclusion

This paper presents a theory of vertical integration and the competitive effects of horizontal outsourcing. A subcontractor producing at full capacity to supply a rival firm is unable to offer products independently downstream. The contractor may be inactive upstream because of decreasing marginal revenues on the downstream market. A horizontal outsourcing agreement can thus be perceived as vertical. As such, uninformed observers could overlook subcontractors as potential competitors. This poses a concern because vertical agreements are generally regarded as less harmful for competition than horizontal agreements. Possibly harmful outsourcing agreements may therefore remain under the radar screen of competition authorities.

From an effects-based point of view, outsourcing agreements can be similar to mergers. In a similar way, outsourcing agreements can reduce costs, for example when the subcontractor is more cost-efficient. At the same time, they can be used to reduce competition. The difference is that, when two firms merge, the ownership of the production assets changes. Under the outsourcing agreement, firms only trade products.

Vertical integration by internal growth serves a bargaining purpose. Building upstream capacity (backward integration) reduces the rival's outside option profits by credibly threatening to a price war absent outsourcing. As such, it leads to more favorable terms of trade, i.e., lower contracting costs or higher subcontracting revenues. In equilibrium, firms build upstream capacity while preserving the gains from outsourcing. The strategic motive for backward integration extends to forward integration because a credible commitment to a price war absent outsourcing requires upstream capacity as well as the ability to serve consumers downstream. Of course, a vertical relation could substitute for vertical integration when firms can call upon a competitive market for retail services ex post.

While the vertical integration literature has investigated vertical and horizontal outsourcing agreements, it has not yet reported an anticompetitive motive for horizontal outsourcing. The reason is that most of this literature focusses on vertical mergers. The decision of internal growth, which I model with an endogenous capacity choice, is complementary and uncovers that the anticompetitive motive for horizontal outsourcing is an equilibrium phenomenon.

The introduction of the horizontal outsourcing stage in Kreps and Scheinkman (1983) provides an elegant result: the downstream market is always a monopoly. Since the monopoly result can avoid the need to analyze mixed strategies, the analysis can considerably simplify when it is extended with a horizontal outsourcing possibility.

Two extensions provide a richer set of predictions. First, a differentiated product market can lead to a downstream duopoly rather than a monopoly. The reason is that firms can profit from signing an outsourcing agreement such that multiple firms stay active downstream. The main insight from this paper, the possible anticompetitive motive for horizontal outsourcing, remains valid for a differentiated product markets. Second, with more than two firms, public contracts take a strategic role by affecting the outsiders' behavior. The competitive effects of horizontal outsourcing then depend on the mode of competition and the number of firms.

The airline industry provides a concluding example. Code-sharing is common practice where firms market tickets from flights operated by competing airlines. The operation of a particular flight fits within the framework as the upstream segment. The marketing of the flight can be viewed as the downstream segment. As such, the analysis applies to markets for inter-hub flights, where the flights offered by competing firms are substitutes.[34] This paper provides new insights on the effects of code-sharing. [35] The extent to which inter-hub routes are *overlap*

[34] The analysis could also incorporate bundled flights by adding additional layers in the supply chain. Different flights can then be interpreted as complementary inputs needed to reach a particular destination.

[35] A recent merger remedy has used the possibility to sign a code-share agreement as a policy instrument. The Department of Justice (DoJ) received a merger request by Alaska Airlines and Virgin America. Pre-merger, Alaska Airlines had an extensive code-sharing agreement with third party American Airlines. Virgin America was a fierce competitor of American Airlines because it owns gates as well as takeoff and landing rights (slots) at constrained airports in some of American

routes, where several airlines offer competing flights, is endogenous to the possibility to sign code-share agreements. It is insufficient to argue in favor of a code-share agreement by assessing that its efficiency gains are large *given* the observed industry structure.

Airlines' strongholds (DoJ, 2016a). There was a concern that the code-share agreement could give incentives for the merged entity to discontinue using its slots to compete with American Airlines. The merger remedy required Alaska Airlines to scale back its code-share agreement with American Airlines (DoJ, 2016b).

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Appendix

Proof of proposition 1.

Price competition with price-inelastic demand

When firms invest in $k_i \leq D$ capacity, firms can implement the collusive outcome (treating the investment choices and costs as given and sunk) and the downstream market is a monopoly. Consider the following outsourcing agreement. In the outsourcing stage, the cost-efficient firm subcontracts at full capacity to the cost-inefficient firm.[1] In the competition stage, the cost-efficient firm is then unable to offer further production. The cost-inefficient firm is monopolist and charges unit price *V*. Its perceived cost of offering the contracted quantity is zero and its marginal cost of offering additional in-house production is c_H. Hence, the firm will offer the contracted production first. In-house production is only used to serve residual demand. When the transaction cost is sufficiently low to merit an outsourcing agreement, this outsourcing agreement maximizes the gains from outsourcing: revenues are maximal and production takes place efficiently, taking as given the investment choices.

Quantity competition

When firms invest in $k_i \leq q^{m,c_i}$ capacity, firms can implement the collusive outcome (treating investment choices and costs as given and sunk). Indeed, consider then the outsourcing agreement in the cost-efficient direction where the efficient firm subcontracts a quantity corresponding to its capacity to the inefficient firm.[2] The contractor is then a monopolist downstream. It starts by offering contracted production, which is optimal since the subcontractor's quantity is no larger than its monopoly quantity. The contractor proceeds by activating more expensive in-house

[1] This subcontract assumes vertical integration by both firms. When only one firm would invest in capacity, that firm can trivially implement the collusive outcome that treats capacity investments as sunk.

[2] Again, when only one firm builds capacity, it trivially implements the collusive outcome treating the investment choices and costs as given and sunk.

production to the extent that industry marginal revenues exceed the marginal production cost. When the transaction cost is sufficiently low to merit an outsourcing agreement, this outsourcing agreement maximizes the gains from outsourcing. For given capacities, the outsourcing agreement decreases consumer surplus because it eliminates the competitive externalities among the two firms.

Price competition with price-elastic demand

When firms invest in $k_i \leq q^M$ capacity, firms can implement the collusive outcome (treating the investment choices and costs as given and sunk) and the downstream market is a monopoly. Consider the following outsourcing agreement. In the outsourcing stage, one firm subcontracts at full capacity to the other firm.[3] In the competition stage, the subcontractor is then unable to offer further production. The contractor is monopolist, so that the price it charges exceeds p^M when $k_i + k_j < q^M$ and equals p^M when $k_i + k_j \geq q^M$. Its perceived cost of offering the contracted quantity is zero and its marginal cost of offering additional in-house production is also zero. From the tie-breaking rule, the firm will offer the contracted production first. In-house production is only used to serve residual demand. When the transaction cost is sufficiently low to merit an outsourcing agreement, this outsourcing agreement maximizes the gains from outsourcing: profits are maximal taking as given the investment choices.

Proof of proposition 2.

Price competition with price-inelastic demand

I prove that the investment equilibrium is such that $k_i^* \leq D$. Proposition 2 then follows from proposition 1.

In particular, when the rival invests in $k_j \leq D$, it is a dominated strategy to invest $k_i > D$. The proof looks at both components of a firm's profit function: (i) its

[3] This subcontract assumes vertical integration by both firms. When only one firm would invest in capacity, that firm can trivially implement the collusive outcome that treats capacity investments as sunk.

outside option profits under no outsourcing, and (ii) its share in the gains from outsourcing.

(i) Investing more than D reduces the no outsourcing profits π_i^{no}. Indeed, absent outsourcing, the competition game (players, possible strategies, payoffs) would be the same if the firm invests $k_i = D$. However, the no outsourcing profits would suffer from the additional cost of investing $r_i\left(k_i, c_i\right) - r_i\left(D, c_i\right)$.

(ii) Any further investment beyond $k_i = D$ keeps constant the gains from outsourcing, at best. To validate this statement, it suffices to look at profits excluding the investment cost (gross profits) because the cost of investing cancels out in the gains from outsourcing. As argued, the competition game under no outsourcing would lead to the same gross profits. Under outsourcing, by investing $k_i = D$, firms implement the collusive outcome (treating the investment choices and costs as given and sunk). Gross profits under outsourcing cannot increase by investing in capacity beyond $k_i = D$. Therefore, investment beyond $k_i = D$ never contributes to the gains from outsourcing.

Quantity competition

The investment equilibrium features that $k_i^* \leq q^{m,c_i}$. Proposition 2 then follows from proposition 1.

In particular, given that the rival invests in $k_j \leq q^{m,c_j}$ capacity, it is optimal for a firm to invest less than $k_i \leq q^{m,c_i}$ as well. Analogously to the price competition model, the proof looks at both components of the firm's profit function: its outside option profits and its share in the gains from outsourcing. First, investing more than q^{m,c_i} reduces the no outsourcing profits π_i^{no}: the cost of investing reduces the outside option profits, while the competition game would be the same if the firm invests q^{m,c_i}. Indeed, offering more than the monopoly quantity is a dominated strategy by the definition of monopoly quantity combined with strategic substitution. Second, the gains from outsourcing are already maximal when the firm invests $k_i = q^{m,c_j}$. Any further investments never contribute to the gains from outsourcing.

Price competition with price-elastic demand

I prove that the investment equilibrium is such that $k_i^* \leq q^M$. Proposition 2 then follows from proposition 1.

In particular, when the rival invests in $k_j \leq q^M$, it is a dominated strategy to invest $k_i > q^M$. The proof looks at both components of a firm's profit function: (i) its outside option profits under no outsourcing, and (ii) its share in the gains from outsourcing.

(i) Investing more than q^M reduces the no outsourcing profits π_i^{no}. The intuition is as follows. Installing a lot of capacity reduces the residual demand for the rival when the rival charges the highest price. The rival will respond to this threat by pricing more aggressively. This effect discourages firm i from installing capacity beyond q^M. The proof uses Kreps and Scheinkman (1983, p.335, proposition 1, part b). Since $k_i \geq k_j$ and $k_i > \rho(k_j)$, we know that firm i earns $\left(\rho_i(k_j) P\left(\rho_i(k_j) + k_j\right)\right) - r_i(k_i)$. For $k_i > q^M$, from strategic substitution, the first term is independent of k_i. The second term is decreasing in k_i. This shows that a firm's outside option profits are decreasing in k_i when $k_i > q^M$ and $k_j \leq q^M$.

(ii) Any further investment beyond $k_i = q^M$ keeps constant the gains from outsourcing, at best. To validate this statement, it suffices to look at profits excluding the investment cost (gross profits) because the cost of investing cancels out in the gains from outsourcing. As argued in (i), further investment reduces gross profits under no outsourcing. Under outsourcing, by investing $k_i = q^M$, firms implement the collusive outcome (treating the investment choices and costs as given and sunk). Gross profits under outsourcing cannot increase by investing in capacity beyond $k_i = q^M$. Therefore, investment beyond $k_i = q^M$ never contributes to the gains from outsourcing.

Proof of proposition 3.

Price competition with price-inelastic demand

I argue that the possibility to sign more sophisticated outsourcing agreements does not change the analysis. If firms invest in $k_i \leq D$ capacity, the analysis would be equivalent. Indeed, the outsourcing agreement under consideration can already implement the collusive outcome (treating the investment choices and costs as given and sunk). The outsourcing agreement under consideration is the unique maximizer when signing a more sophisticated contract would involve an extra transaction cost. It needs to be checked whether firms have incentives to install $k_i > D$ capacity. In that event, a more sophisticated contract can outperform the one studied. However, given that the rival invests $k_j \leq D$, investing $k_i = D$ dominates investing $k_i > D$. By (i) in the proof of proposition 2, investing more would reduce the no outsourcing profits. By (ii) in the proof of proposition 2, any further investment beyond $k_i = D$ keeps constant the gains from outsourcing, at best.

Quantity competition

Analogously to the price competition model with price-inelastic demand, the analysis does not change when firms can sign more sophisticated outsourcing contracts.

Price competition with price-elastic demand

I argue that the possibility to sign more sophisticated outsourcing agreements does not change the analysis. If firms invest in $k_i \leq q^M$ capacity, the analysis would be equivalent. Indeed, the outsourcing agreement under consideration can already implement the collusive outcome (treating the investment choices and costs as given and sunk). It is the unique maximizer when signing a more sophisticated contract involves an extra transaction cost. It needs to be checked whether firms have incentives to install $k_i > q^M$ capacity. In that event, a more sophisticated contract can outperform the one studied. However, given that the rival invests $k_j \leq q^M$, investing $k_i = q^M$ dominates investing $k_i > q^M$. By (i) in the proof of proposition 2, investing more would reduce the no outsourcing profits. By (ii) in the proof of proposition 2, any further investment beyond $k_i = q^M$ keeps constant the gains from outsourcing, at best.

Proof of proposition 4.

When the marginal cost of installing capacity is sufficiently small, for example when it approaches zero, it must be true that $2q^d > Q^M$.[4] That condition represents a sufficient condition for outsourcing to harm consumer welfare.

When the opposite relationship holds, $2q^d \leq Q^M$, the analysis is as follows. There are two possibilities.

First, suppose that, in equilibrium, firms invest such that they do not sign an outsourcing agreement in equilibrium ($k_i^* + k_j^* \leq Q^M$). Then, firms' equilibrium profits only consists of their outside option profits. For the capacity equilibrium to be an equilibrium, firms should not have incentives to deviate. The deviation profit functions equal at least firms' outside option profits, and may include positive gains from outsourcing. Therefore, while a necessary condition for the equilibrium to be valid is that is also an equilibrium in Kreps and Scheinkman (1983), it is not a sufficient condition as the exclusion of gains from outsourcing may understate firms' incentives to deviate. The only candidate equilibrium is the one where firms invest the Cournot duopoly capacities ($k_i^* = k_j^* = q^d$). If the equilibrium is valid, the introduction of the horizontal outsourcing stage does not affect consumer welfare. If the equilibrium is invalid, it must be true that $Q^M < k_i^* + k_j^*$.

Second, suppose that in equilibrium, firms invest such that $Q^M < k_i^* + k_j^*$. Then, firms sign an outsourcing agreement to offer the monopoly quantity Q^M. In this second scenario, firms sign an anticompetitive outsourcing agreement in equilibrium, but the pro-competitive effect from extra capacity more than offsets the anti-competitive effect from outsourcing.

Strictly increasing marginal costs

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[4] This statement uses two standard properties that are commonly assumed for Cournot competition: quantities are strategic substitutes and the best-response functions are not too steep.

Let firm i offer Q^i so that the total quantity offered equals $Q = Q^1 + Q^2$. Each firm incurs cost $C(x)$ to produce x units.[5]

Assumption 1: the inverse demand function $P = a + P^{'}Q$ is linear and decreasing. It follows that reaction functions are downward sloping.

Assumption 2: marginal costs $C^{'}(x)$ are continuous, non-negative and increasing. There are decreasing returns to scale.

Assumption 3: $P(0) > C^{'}(0)$. Production is profitable. It follows that, without subcontracts, both firms produce a strictly positive quantity in equilibrium.

No horizontal outsourcing.

Under the standard analysis without horizontal outsourcing, the equilibrium is standard. Denote the standard Cournot market-clearing price by P^C. The first-order condition is

(1) $$P^{'}q^C + P^C - C^{'}\left(q^C\right) = 0$$

Horizontal outsourcing.

Firms choose how much to offer in equilibrium. Firm 1's problem is to maximize its profit function

$$PQ^1 - C\left(Q^1 + \tilde{q}\right) + \tilde{t}$$

with respect to $Q^1 \geq 0$. The second term represents the cost of producing Q^1 for consumers and $\tilde{q}$ for the rival. Firm 2's problem is to maximize its profit function

$$PQ^2 - C\left(Q^2 - \tilde{q}\right) - \tilde{t}$$

with respect to $Q^2 \geq 0$.

[5] The superscript is omitted because firms have the same cost function.

The second term represents the cost of producing $Q^2 - \tilde{q}$, the additional production beyond the quantity already contracted from the rival. The stage-two equilibrium quantities are denoted by $Q^{1*}(\tilde{q})$ and $Q^{2*}(\tilde{q})$. Importantly, recall that the equilibrium quantities do not take account of the transfer $\tilde{t}$ because it is sunk at the moment of competing.

The first-order conditions depend on the industry structure in equilibrium. Table A1 lists the first-order conditions.

	DUOPOLY $Q^{1*}(\tilde{q}) > 0$	**MONOPOLY** $Q^{1*}(\tilde{q}) = 0$
PARTIAL SOURCING $Q^{2*}(\tilde{q}) > \tilde{q}$	$P'Q^{1*}(\tilde{q}) + P - C'\left(Q^{1*}(\tilde{q}) + \tilde{q}\right) = 0$ $P'Q^{2*}(\tilde{q}) + P - C'\left(Q^{2*}(\tilde{q}) - \tilde{q}\right) = 0$	$P'Q^{1*}(\tilde{q}) + P - C'(\tilde{q}) \le 0$ $P'Q^{2*}(\tilde{q}) + P - C'\left(Q^{2*}(\tilde{q}) - \tilde{q}\right) = 0$
FULL SOURCING $Q^{2*}(\tilde{q}) \le \tilde{q}$	$P'Q^{1*}(\tilde{q}) + P - C'\left(Q^{1*}(\tilde{q}) + \tilde{q}\right) = 0$ $P'Q^{2*}(\tilde{q}) + P - C'(0) \le 0$	$P'Q^{1*}(\tilde{q}) + P - C'(\tilde{q}) \le 0$ $P'Q^{2*}(\tilde{q}) + P - C'(0) \le 0$

Table A1. first-order conditions.

Lemma A1. *The subcontractor produces more than the Cournot quantity and the contractor produces less.*

Formally, Lemma A1 states that $Q^{1*}(\tilde{q}) + \tilde{q} > q^C$ and $Q^{2*}(\tilde{q}) - \tilde{q} < q^C$. It follows that the subcontractor's marginal cost increases and that the contractor's marginal cost decreases. Figure 1 visualizes Lemma 1.

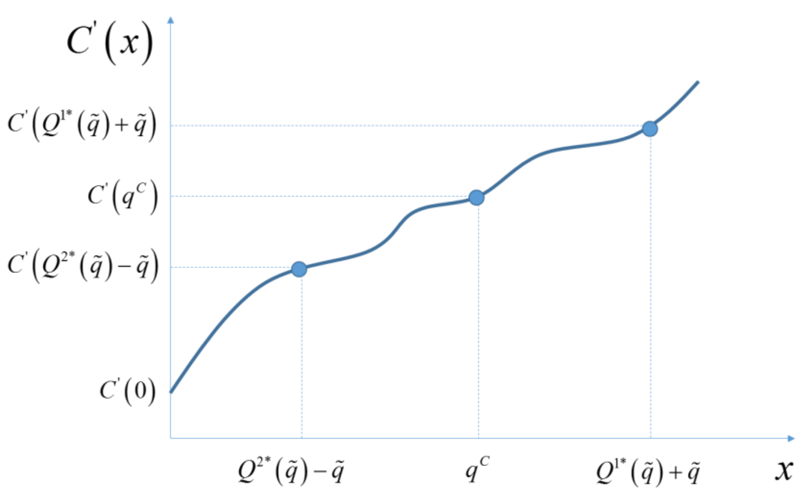

Figure 1. A visualization of Lemma A1.

Proof of Lemma A1.

Lemma 1 is in line with Spiegel's proposition 6 (p. 580). A proof is possible by contradiction. Suppose otherwise, then one of the following three scenarios must hold.

A situation where the subcontractor produces $Q^{1*}(\tilde{q})+\tilde{q}\leq q^{C}$ and the contractor produces $Q^{2*}(\tilde{q})-\tilde{q}<q^{C}$ would not be optimal for the subcontractor. As compared to standard Cournot with first-order condition (1), firm 1 now offers less and industry output is lower. Hence, firm 1's marginal revenues from increasing production, $P^{'}Q^{1*}(\tilde{q})+P$, are larger than $C^{'}\left(q^{C}\right)$. However, marginal costs $C^{'}\left(Q^{1*}(\tilde{q})+\tilde{q}\right)$ are (weakly) lower than $C^{'}\left(q^{C}\right)$. It follows that $P^{'}Q^{1*}(\tilde{q})+P>C^{'}\left(Q^{1*}(\tilde{q})+\tilde{q}\right)$, which contradicts firm 1's first-order condition, both for monopoly and duopoly.

A situation where the subcontractor offers $Q^{1*}(\tilde{q})+\tilde{q}>q^{C}$ and the contractor offers $Q^{2*}(\tilde{q})-\tilde{q}\geq q^{C}$ would not be optimal for the contractor. As compared to standard Cournot with first-order condition (1), firm 2 now offers more and industry output is higher. Hence, firm 2's marginal revenues from increasing production, $P^{'}Q^{2*}(\tilde{q})+P$, are lower than $C^{'}\left(q^{C}\right)$. However, marginal costs $C^{'}\left(Q^{2*}(\tilde{q})-\tilde{q}\right)$ are (weakly) higher than $C^{'}\left(q^{C}\right)$. It follows that $P^{'}Q^{2*}(\tilde{q})+P<C^{'}\left(Q^{2*}(\tilde{q})-\tilde{q}\right)$, which contradicts firm 2's first-order condition for partial sourcing. But full sourcing requires $Q^{2*}(\tilde{q})=\tilde{q}$, which violates $Q^{2*}(\tilde{q})-\tilde{q}\geq q^{C}$.

Finally, a situation where the subcontractor offers $Q^{1*}(\tilde{q})+\tilde{q}\leq q^{C}$ and the contractor offers $Q^{2*}(\tilde{q})-\tilde{q}\geq q^{C}$ also leads to a contradiction by comparing both firms' first-order conditions. Start from the contractor's first-order condition $P^{'}Q^{2*}(\tilde{q})+P=C^{'}\left(Q^{2*}(\tilde{q})-\tilde{q}\right)$ which must hold with equality because

$Q^{2*}(\tilde{q})-\tilde{q}\geq q^C$. Since the contractor offers more than the subcontractor, marginal revenues are larger for the subcontractor than for the contractor, so that $P^{'}Q^{1*}(\tilde{q})+P>P^{'}Q^{2*}(\tilde{q})+P$. At the same time, however, the subcontractor produces at a (weakly) lower marginal cost than contractor, so that $C^{'}\left(Q^{2*}(\tilde{q})-\tilde{q}\right)>C^{'}\left(Q^{1*}(\tilde{q})+\tilde{q}\right)$. It must follow that $P^{'}Q^{1*}(\tilde{q})+P>C^{'}\left(Q^{1*}(\tilde{q})+\tilde{q}\right)$, which contradicts the subcontractor's first-order condition, both for monopoly and duopoly. ■

Lemma A2. *Suppose firms have invested in marginal costs functions that are twice differentiable, weakly concave, and that disposal is prohibitive. Then, horizontal outsourcing benefits consumers.*

Proof of Lemma A2.

When marginal costs are twice differentiable and weakly concave, we can write $C^{'''}(x)\leq 0$. From Lemma A1, we know that the marginal cost of the subcontractor has increased, and that the marginal cost of the contractor has decreased.

From concavity, we know that the average rate at which the marginal cost of the contractor has decreased in absolute values (left hand side) is larger than the average rate at which the marginal cost of the subcontractor has increased (right hand side), or

$$\frac{C^{'}\left(q^C\right)-C^{'}\left(Q^{2*}(\tilde{q})-\tilde{q}\right)}{q^C-Q^{2*}(\tilde{q})+\tilde{q}}\geq\frac{C^{'}\left(Q^{1*}(\tilde{q})+\tilde{q}\right)-C^{'}\left(q^C\right)}{Q^{1*}(\tilde{q})+\tilde{q}-q^C}\ .$$

Both sides of the inequality are positive from Lemma A1. We use prohibitive disposal ($Q^2\geq\tilde{q}$) to guarantee that $C^{'}\left(Q^{2*}(\tilde{q})-\tilde{q}\right)$ exists.

Suppose by contradiction that it were true that consumers suffered from a decrease in equilibrium output. Then $Q^{1*}(\tilde{q})+Q^{2*}(\tilde{q})-2q^C\leq 0$, which can be written as $q^C-Q^{2*}(\tilde{q})+\tilde{q}\geq Q^{1*}(\tilde{q})+\tilde{q}-q^C$. By plugging in this inequality on the left hand side, we obtain that the concavity condition implies $\frac{C'\left(q^C\right)-C'\left(Q^{2*}(\tilde{q})-\tilde{q}\right)}{Q^{1*}(\tilde{q})+\tilde{q}-q^C} \geq \frac{C'\left(Q^{1*}(\tilde{q})+\tilde{q}\right)-C'\left(q^C\right)}{Q^{1*}(\tilde{q})+\tilde{q}-q^C}$, and hence

(2) $$C'\left(q^C\right)-C'\left(Q^{2*}(\tilde{q})-\tilde{q}\right) \geq C'\left(Q^{1*}(\tilde{q})+\tilde{q}\right)-C'\left(q^C\right) .$$

To see that this is a contradiction, use the first-order conditions and (1) to write

$$\begin{aligned} C'\left(Q^{1*}(\tilde{q})+\tilde{q}\right)-C'\left(q^C\right) &\geq P-P^C+P'\left(Q^{1*}(\tilde{q})-q^C\right) \\ C'\left(Q^{2*}(\tilde{q})-\tilde{q}\right)-C'\left(q^C\right) &\geq P-P^C+P'\left(Q^{2*}(\tilde{q})-q^C\right) \end{aligned} .$$

By summing both expressions, we obtain

$$C'\left(Q^{1*}(\tilde{q})+\tilde{q}\right)+C'\left(Q^{2*}(\tilde{q})-\tilde{q}\right)-2C'\left(q^C\right) \geq 2P-2P^C+P'\left(Q^{1*}(\tilde{q})+Q^{2*}(\tilde{q})-2q^C\right) .$$

Since $P'\left(Q^{1*}(\tilde{q})+Q^{2*}(\tilde{q})-2q^C\right)$ equals the price change $P-P^C$, we get $C'\left(Q^{1*}(\tilde{q})+\tilde{q}\right)+C'\left(Q^{2*}(\tilde{q})-\tilde{q}\right)-2C'\left(q^C\right) \geq 3\left(P-P^C\right)$. Since a decrease in industry output requires an increase in the equilibrium price (right hand side), the left hand side must be positive. But (2) implies the left hand side is negative, a contradiction. ■

Forward trade in short-term electricity markets: horizontal and vertical contracts

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Abstract

This paper investigates the competitive effects of forward trade on spot market competition. The analysis allows for both horizontal forward trade between competing firms, as well as vertical forward trade with non-competitors as counterparty. First, I find an incompatibility: Allaz and Vila (1993)'s pioneering analysis of vertical forward trade, when extended with horizontal forward trade, does not feature an equilibrium in pure strategies. Second, to restore compatibility, I analyze bilaterally efficient forward trade, which requires that no pair of firms can benefit from trading bilaterally. Horizontal and vertical forward trade are highly relevant in today's short-term electricity markets, and determine dispatch decisions as well as security-of-supply investment incentives.

Keywords: forward markets; horizontal subcontracting; bilateral efficiency; private contracts; public contracts; electricity markets

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1. Introduction

Balancing markets are the institutions that guarantee a physical balance between electricity injections and offtakes. They currently receive a lot of attention in Europe because their designs are being harmonized across countries.[2,3] They also act as the spot market, and therefore serve an important role as a reference market. First, they guide how firms dispatch their production and consumption units in the short run. Second, they guide investment decisions in the long run. Investments in stable generation capacity, so-called baseload generation, are mostly determined by the average price level. With the shift towards intermittent power sources, however, other indicators become increasingly important as well. For example, the profitability of peak units depends on whether prices are high during moments of scarcity. As another example, the profitability of storage depends on price movements throughout time, as storage takes off electricity when the price is low and injects electricity when the price is high. In sum, the ability of balancing markets to feature price movements that reflect changes in the true value of electricity is crucial to provide adequate investment incentives.

Forward markets are essential to the analysis of balancing markets.[4] The reason is that whenever a firm is faced with sudden favorable or unfavorable demand or supply conditions, it need not hold an unbalanced position on the balancing market.

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[2] The European Commission recently adopted guidelines on electricity balancing (see http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R2195&from=EN).
The harmonization process should contribute to diversifying the risks associated with renewable energy sources. A larger geographical market has the potential to reduce costs, to promote market liquidity, to improve competition between producers, and to promote new entry.

[3] Newbery et al. (2016) study potential benefits from market integration. However, despite the possible gains from cooperation, several factors slow down the process of harmonizing market designs. First, countries are careful to cooperate cross-border because they are concerned about security of supply. Second, there are many parties involved. The European Network of Transmission System Operators for Electricity consists of 42 TSOs from 35 countries. Their business models can depend on the outcomes of the harmonization process. Moreover, the Agency for the Cooperation of Energy Regulators consists of NRAs of 28 countries, and all National Regulatory Authorities should be willing to implement the decisions.

[4] Forward trade can occur on power exchanges, e.g. one day before physical delivery on the day-ahead market (DAM) or a few hours before physical delivery on the intraday market (IDM). Forward trade can also take place bilaterally Over-The-Counter (OTC).

Instead, the firm can adjust its position on the forward market already. In other words, the forward market is an important instrument for firms to absorb idiosyncratic shocks. That role for forward markets has gained importance with the recent large-scale introduction of wind and solar power. For instance, when a producer is faced with unfavorable generation conditions from its intermittent energy sources, it may purchase from another producer rather than to undertake expensive generation in-house.

In electricity markets, two distinct types of forward trade are important. Vertical forward trade (henceforth VFT) is trade between firms that have access to flexibility and counterparties that do not have access to flexibility. Horizontal forward trade (henceforth HFT) occurs between firms with access to flexibility.[5]

To make robust policy recommendations, there is a need to understand how VFT and HFT interact with each other. This paper provides an equilibrium analysis that jointly allows for VFT and HFT. The research questions addressed are whether vertical and horizontal forward trade are compatible with each other, under what circumstances their predictions differ or coincide, and whether there is a unified approach that we can adopt.

Horizontal trading partners have access to flexibility to adjust their physical position, and may choose to do so, depending on market conditions. As such, they act as competitors on the spot market. I will denote these firms as *flexible firms*. HFT has been analyzed in isolation, i.e., without incorporating the possibility of VFT. The first contribution is Spiegel (1993) on ex ante horizontal subcontracting. Later contributions are Coutinho (2013) on inter-dealer trade, and Van Moer (2018) on horizontal outsourcing in the context of vertical integration.

[5] VFT has already extensively been studied in the context of electricity markets. Important contributions are Green (1999), Wolak (2000), Bushnell (2007), Bushnell et al. (2008), and de Frutos and Fabra (2012). On the possible arbitrage between forward and spot prices, see Birge et al. (2014), Jha and Wolak (2015), Just and Weber (2015), and Ito and Reguant (2016). For a discussion of horizontal subcontracting in power markets, see Bouckaert and Van Moer (2017), who analyze horizontal subcontracting as a secondary (resale) market.

Vertically related counterparties can also take financial positions on the forward market and spot market. However, they do not have the flexibility to adjust their position physically. I will denote these firms as *inflexible firms*. They are price takers on the spot market to close their position.[6] VFT has received considerable attention following the article by Allaz and Vila (1993). Their main finding is that, when forward trade is publicly observable, it can act as a commitment device. In particular, by selling forward, a firm commits to compete aggressively on the spot market.[7] In a quantity competition setting, each firm has *incentives* to commit to aggressive competition. The reason is that, since quantity choices are usually strategic substitutes, a commitment to compete aggressively reduces the production offered by the rivals. Firms thus have unilateral incentives to sell forward in order to reduce the production offered by rival firms.[8]

The main insight from this paper is that compatibility between VFT and HFT depends on whether horizontal contracts can substitute for vertical contracts, or whether both types of contracts are signed independently from each other.

The first approach pursued in this paper models the forward market as an auction à la Allaz and Vila (1993), extended with the possibility for flexible firms to exchange production with each other on the forward market.

When an inflexible firm purchases the production offered on the forward market auction, that inflexible firm supplies it on the spot market, which leads to a low market-clearing price. However, since the forward bidding stage takes as given the

[6] An important example are purely financial firms that intend to profit purely from price differences. However, inflexible firms can also refer to insiders to the industry, provided that these insiders do not have the flexibility to adjust their physical position. For example, an electricity retailer may have to purchase electricity to supply a portfolio of households subject to pre-determined annual tariffs. Without access to physical flexibility, electricity retailers are required to close their positions on the market, so that they behave as purely financial firms. Other inflexible assets are must-run power facilities such as nuclear plants that are prohibitively expensive to shut down, or wind mills that always generate under favorable weather conditions (dispatch priority).

[7] The reason is that forward sales are not subject to the spot market price. Firms that have sold a large portion of their production on the forward market therefore have increased incentives to offer their remaining production competitively on the spot market.

[8] Mahenc and Salanié (2004) show the opposite result in a price competition setting with strategic complementarity. Forward purchases act as a commitment for a firm to soften competition by charging a high spot price. Such a commitment is unilaterally profitable because the rival firms will respond by setting a high spot price as well.

total amount of forward production offered, the auction allows for substitution between horizontal and vertical forward trade. So, by purchasing from a horizontally related competitor, a flexible firm can reduce the amount of forward purchases by inflexible firms. That avoids the pro-competitive effects associated with vertical forward trade.

For that reason, the equilibrium outcome presented in Allaz and Vila (1993) is not robust to the introduction of HFT. Given that the equilibrium must differ from the one presented in Allaz and Vila (1993), the natural follow-up question is what the equilibrium looks like. The analysis finds a negative result: in the duopoly model with one round of forward trade, there exists no equilibrium in pure strategies. As we will see, that result points towards flaws in the way that the game is defined, particularly with regard to price formation in situations of bilateral monopoly.

The second approach models the forward market as an over-the-counter market. It does not specify a full game, but instead supposes that firms trade in a way that is bilaterally efficient. Bilaterally efficiency is a stability condition on the forward market that incorporates both horizontal and vertical forward trade. In particular, it requires that forward positions are such that each pair of firms cannot gain by additionally trading bilaterally.[9] A pair of firms can be horizontally related, or vertically related. An important feature of this setting is that, when two firms trade bilaterally, they take as given the other bilateral trades in the industry. So, there is no substitution between horizontal and vertical contracts; any forward contract is signed independently from other forward contracts.

Several results show that bilateral efficiency is an intuitive concept that connects the literatures on vertical and horizontal forward trade.

When forward trade is observable *ex post* (also labelled: public), all forward contracts signed become common knowledge after the forward market and before the spot market. So, when two firms trade on the forward market, outsiders to the trade can react to it on the spot market. It follows that there is a strategic role of

[9] Bilateral efficiency draws from Crémer and Riordan (1987). The concept is similar to the one used in Jeon and Lefouili (2015), and relates to Nash-in-Nash bargaining by Rey and Vergé (2016).

public contracts under bilateral efficiency that is similar to the role of public contracts in the VFT literature.

When forward trade is unobservable (also labelled: private or secret), trades are not observed by outsiders to the trade. These outsiders can therefore not react to the trade on the spot market. Any bilateral maximization problem therefore only endogenizes the behavior of insiders to the trade. So, bilaterally efficient horizontal contracts only account for the externalities that both trading partners impose on each other, as studied by Spiegel (1993). Bilaterally efficient vertical contracts achieve zero externalities by fully eliminating the inflexible firm's exposure to the spot price, a result consistent with Hughes and Kao (1997) and van Eijkel et al. (2016).

Finally, I show that the bilateral maximization problem of a pair of firms does not require an assumption about the forward price. The forward price paid serves as a sunk transfer between both firms and does not affect bilateral profits.[10] That property is not present in the VFT literature, where a firm with access to flexibility *unilaterally* chooses how much to trade forward. There, the forward price received by the flexible firm is assumed to equal the spot price, as otherwise an arbitrage opportunity would exist.

Imperfect competition on the balancing market is associated with static and dynamic inefficiencies. As forward markets determine the degree of imperfect competition on the balancing market, they directly determine the magnitude of the associated inefficiencies.

First, the model of imperfect competition is characterized by the standard allocative inefficiency. In case of an electricity surplus, firms are sellers and have excessive incentives to restrict their surplus on the balancing market in order to mitigate the price drop. In case of an electricity shortage, firms are buyers and have excessive incentives to restrict their shortage on the balancing market in order to mitigate the

[10] In fact, the forward price paid may differ depending on the counterparty, as a firm's willingness to pay depends on the counterparty. This insight provides a new rationale for over-the-counter markets where traders know the identity of their counterparty.

price rise. So, firms balance too much in-house.[11] Two results follow from the allocative inefficiency. First, the imbalance volumes on balancing markets are too small. Second, cost shocks incompletely pass-through into the equilibrium price.[12]

Second, from a dynamic efficiency perspective, market prices should reflect the true value of electricity as well. More precisely, to guarantee that entrants sufficiently invest in flexible generation or consumption assets, a surplus of electricity should result in a price drop and a shortage of electricity should result in a price rise.

However, when firms face unfavorable supply or demand shocks, because of incomplete pass-through, the price does not rise sufficiently during periods of scarcity. It follows that, for new entrants that act as price-takers on the balancing market, investing in peak units is less profitable than it should be. Moreover, incomplete pass-through also suggests under-incentives for entrants to invest in storage facilities such as batteries. Storage facilities have access to an energy inventory that allows them to profit from price differences throughout time. In particular, they can take off electricity from the grid when it is abundant and for sale at a low price, and inject the electricity later on when it is scarce and can be sold at a high price. As such, the value of a storage facility decreases when electricity prices are less variable due to incomplete pass-through. Therefore, to guarantee sufficient entry in the market for security of electricity supply services, there may be a need to complement revenues from the market with capacity subsidies (so-called capacity remuneration mechanisms).

[11] Many countries require some degree of legal responsibility for firms to balance their injections and offtakes in-house. Such legal considerations, too, can cause firms to excessively balance in-house.

[12] Both results follow immediately from a standard model of imperfect competition, so I do not prove them explicitly.

2. European electricity market institutions

This section gives background on the institutions of European balancing markets. It supports the framework developed in section 3. This section draws extensively from the European Commission regulation guideline on electricity balancing 2017/2195.[13]

I start by discussing three roles and responsibilities.

Balancing Responsible Parties (BRPs).

BRPs are financially responsible for their energy balance, meaning that the energy they inject through production or purchases should equal the energy they take off through consumption or sales. The underlying idea is that firms who sell should be responsible for delivering. Any imbalance between injections and offtakes is financially settled with a Transmission System Operator.

All firms active on the wholesale market are BRPs. The energy products they trade e.g. involve power production throughout a period of 15, 30 minutes, or one hour. The imbalance settlement period (ISP), the period over which the energy imbalance is calculated, should accordingly be sufficiently short.

Next to a financial responsibility, there can exist legal responsibilities to be balanced as well.[14] Non-asset based traders are typically inactive on the balancing market.[15]

Transmission System Operators (TSOs).

TSOs are responsible for the physical power balance and frequency on the high-voltage grid. When there is a surplus of electricity, a balanced grid requires a

[13] For more information, please refer e.g. to Nobel (2016), Neuhoff (2015), Neuhoff et al. (2015), 50Hertz Transmission GMBH et al. (2014), and the ENTSO-E's website http://bit.ly/1TyLQ3m.
[14] The legal responsibility is important in Germany, where firms should hold sufficient private reserves (see Neuhoff, 2015).
[15] For example, in Belgium, BRPs should close their position before the balancing stage starts (see BRP contract http://www.elia.be/~/media/files/Elia/Products-and-services/Balancing/201703_MasterARP_EN.pdf).

production-decrease or a consumption-increase. When there is a shortage of electricity, a balanced grid requires a production-increase or a consumption-decrease. TSOs, however, are not allowed to own or operate production facilities. They therefore call upon Balancing Service Providers.[16]

Balancing Service Providers (BSPs).

BSPs are flexible production or consumption units that provide balancing services to TSOs in return for financial settlement.

We can distinguish two types of services. The first type is balancing capacity, i.e., reserve capacity that can be used by TSOs for balancing. Balancing capacity is typically procured in advance. The second type is balancing energy. Balancing energy bids provide TSOs with the option to activate balancing energy. They either correspond to earlier contracted balancing capacity, or are `free'.[17]

Since a BSP is responsible to provide balancing services, it can be a BRP or be represented by another BRP.[18] So, a single firm can simultaneously act as a BSP and as a BRP.

Bidding on the balancing energy market can be mandatory, for example for all available units (e.g. France) and for large units (e.g. Belgium and the Netherlands).

I proceed by discussing different markets and their timing.

Forward market.

BRPs can trade energy on the forward market. Examples of trading platforms are the Over-The-Counter market (OTC), Day-Ahead Market (DAM) or Intra-Day Market (IDM). The traded product is an energy product, meaning that it involves a commitment to deliver an amount of energy during a specified timeframe. At some

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[16] The legal framework on unbundling can be found in the European Commission's directive 2009/72/EC and the proposal for regulation 2016/037 (see https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v9.pdf).

[17] Free bids are sometimes activated with priority over other bids. They often correspond to production units that were only partially called upon after the DAM auction. The remaining capacity is then available at a competitive marginal cost and can be offered as a free balancing energy bid.

[18] The guideline on electricity balancing requires that "[…] each balancing energy bid from a balancing service provider is assigned to one or more balance responsible parties […]".

point before delivery, the IDM closes, after which no more trade is possible. This end point is referred to as the IDM gate closure time. The IDM closes no more than one hour before physical delivery.

In self-dispatch systems, BRPs schedule their own production and consumption profiles. While this system is most used, there also exist central dispatch systems. In central dispatch systems, TSOs schedule and dispatch using (i) plant-level technical data, and (ii) grid security constraints. Examples of central dispatch systems are Greece, Ireland, Italy, Northern Ireland and Poland.[19] The guidelines on Electricity Balancing allow parallel existence of self and central dispatch.

Balancing energy market.

On the balancing energy market, BSPs can offer balancing energy bids for relative injection or withdrawal. The guidelines on Electricity Balancing require that the gate closure time is as close as possible to real-time, and no more than one hour before physical delivery.

Balancing services are defined differently in various countries and vary with respect to their time to respond. Frequency containment reserves are fastest and focus on power balance rather than energy delivery. Their purpose is not to deliver energy but to maintain the frequency *within* an ISP. In contrast, frequency restoration reserves and especially replacement reserves are mostly energy products. Their purpose is to deliver energy throughout an ISP. They are usually scheduled products activated at the start of an ISP, as opposed to being directly activated during an ongoing ISP. As such, their product definition is similar to the energy products traded on forward markets. Offering frequency restoration reserves or replacement reserves can substitute for offering energy on the forward market, and vice versa.

Balancing energy can be remunerated pay-as-bid or pay-as-cleared. Under pay-as-bid (also labelled: discriminatory pricing), activated balancing energy bids receive

[19] See Neuhoff and Richstein (2016), and the survey on ancillary services procurement, balancing market design 2016 (2017) at https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/WGAS_Survey_final_10.03.2017.pdf

their bid price. Under pay-as-cleared (also labelled: uniform pricing), activated bids receive a common marginal clearing price. The type of remuneration can depend on the type of balancing service.[20] Replacements reserves, which move further in the direction of an energy product, are more often remunerated pay-as-bid.[21]

An important disadvantage of a common marginal clearing price relates to so-called counteractivations. While energy delivery is aggregated over the entire ISP, an equality between energy injections and offtakes per ISP is not sufficient to guarantee a stable power grid; injections and offtakes also vary within an ISP. Counteractivations refer to situations where downward *and* upward balancing energy is activated during the same ISP. They can for example occur when there is a shortage during the first half of an ISP and a surplus during the second half of the ISP.

A common marginal clearing price raises the following issue when there are counteractivations. The common marginal clearing price is based on the net direction of the imbalance. When the *average* difference between injections and offtakes is negative during the ISP, the marginal price for downward balancing energy will apply. A balancing energy bid activated in the upward direction then receives a common marginal clearing price that does not cover its bid price. Alternatively, when the net difference between injections and offtakes is positive, a bid activated in the downward direction requires a payment larger than its bid price. Pay-as-bid pricing, or installing two marginal clearing prices, one in each direction, resolves this issue.

Reactive TSOs give incentives for BRPs to balance their portfolio independently. They exclusively activate balancing energy in response to *actual* imbalances aggregated over all firms.[22] In contrast, proactive TSOs organize all balancing via

[20] As an example, frequency restoration reserves that are manually activated are remunerated pay-as-cleared in Portugal, Spain and the Netherlands, and pay-as-bid in France and Great Britain. See survey on ancillary services procurement, balancing market design 2016 (2017) at https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/WGAS_Survey_final_10.03.2017.pdf

[21] Indeed, sourcing from the same survey, they are remunerated pay-as-cleared in Spain, and pay-as-bid in France and Great Britain.

[22] For example, the Belgian and Dutch TSO correspond closely to the reactive concept.

energy auctions. They proact to *anticipated* imbalances by activating balancing energy earlier, and discourage that firms balance their portfolio independently.[23,24] The distinction between the reactive and proactive concept is not absolute, however; even a reactive TSO may be tempted to foresee, and proact to, an emergency scenario.

Congestion market.

When the electricity grid is constrained, it may be necessary to engage in redispatch measures that substitute production on the constrained location by production on another, less constrained location.

The purpose of such redispatch measures should be distinguished from balancing energy purposes. Redispatch measures hold constant the amount of energy delivered.

Imbalance market.

Imbalances incurred by BRPs are financially settled with the TSO. Marginal pricing uses a uniform price equal to the price at which the marginal balancing energy bid was activated. It is e.g. used in Belgium. Average pricing, e.g. in Germany, settles all imbalances against the average activated bid price. Finally, dual pricing distinguishes BRPs that aggravate the system imbalance from BRPs that diminish the system imbalance.[25]

[23] For example, in Spain, production decisions are centralized. BRPs can adjust their schedule only by submitting bids on a central auction. Bilateral sales contracts are signed ex ante and are linked to physical generation schedules of production units (e.g. see Reguant, 2014).
[24] See also Neuhoff and Richstein (2016) on reactive versus proactive TSOs.
[25] Again, see survey on ancillary services procurement, balancing market design 2016 (2017) at https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/WGAS_Survey_final_10.03.2017.pdf

3. The framework

Suppose that electricity is a homogenous energy product, so that firms trade the same product on the forward market and the spot market. The framework is thus well suited to analyze strategic interactions between these markets. [26,27]

There are n firms. Each of the firms is denoted by subscript i=1,...,n. The *industry* denotes the set of all firms, N.

I distinguish flexible firms with access to a flexible portfolio from inflexible firms without access to a flexible portfolio.[28]

Flexible firms.

There are n_{flex} flexible firms and the set of flexible firms is denoted by N_{flex}. If firm i is flexible, its production from its flexible portfolio is denoted by q_i. Marginal costs $C^{'}\left(q_i\right)$ increase linearly, or

$$C\left(q_i\right) = c_i q_i + \frac{0.5}{k_i} q_i^2$$

, where parameter c_i is a firm-specific marginal cost-shifter and k_i is a measure of capacity.

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[26] As a consequence, the timeframe used to calculate energy delivery coincides for the forward market, balancing energy market, and the imbalance market. In practice, a common quarter-hourly timeframe is used for most IDMs and imbalance markets in Europe. Balancing energy products that are scheduled, rather than directly activated, also fit the quarter-hourly timeframe.

[27] The homogenous product setting narrows down the scope of the paper in two dimensions. First, fast balancing services mostly focus on power delivery and are automatically or directly activated. They do not fit the quarter-hourly timeframe and fall outside the scope of this paper. As a consequence, the framework does not incorporate counteractivations. Second, the analysis assumes that the electricity grid is a so-called “copper plate”. In particular, the analysis does not distinguish different locations where electricity is produced, and is thus not able to incorporate a congestion market.

[28] The article by Allaz and Vila (1993) refers to “speculators” for inflexible firms and “producers” for flexible firms. I choose not to adopt that labelling because it could be confusing in the context of this paper. In particular, a producer could be categorized as an inflexible firm if it does not have flexible assets. Also, flexible firms can respond to financial incentives, just as a speculator would.

The portfolio can consist of production units that can flexibly deliver energy. Increasing marginal costs then capture the merit-order; a firm dispatches its cheapest units first before using more expensive technologies. The portfolio can also consist of consumers that can flexibly reduce their energy consumption. The firm first decreases consumption from its consumption assets characterized by the lowest willingness to pay for energy, before turning to consumption assets characterized by a higher willingness to pay. Negative production ($q_i < 0$) is possible and should be interpreted as consumption.

Parameter k_i captures the *size* of firm *i*'s portfolio of controllable production or consumption. A larger portfolio corresponds to a flatter marginal cost curve. The marginal cost curve at the industry level, with slope $1 \Big/ \sum_{i \in N_{\text{flex}}} k_i$, is the horizontal summation of the firm-level marginal cost curves.[29]

Inflexible firms.

There are n_{inflex} inflexible firms and the set of inflexible firms is denoted by N_{inflex}. If firm *i* is inflexible, its production from its flexible portfolio is denoted as zero ($q_i = 0$).

Both flexible and inflexible firms may hold inflexible assets in their portfolio. The parameter $\overline{q}_i$ denotes firm *i*'s surplus from its inflexible portfolio and is firm-specific. Inflexible assets are e.g. must-run power facilities such as nuclear plants, inflexible wind farms, or consumption from households subject to pre-determined tariffs. They can also represent long-term financial positions that are considered exogenous in the short-run.

No uncertainty: all parameters of the framework are common knowledge.

An important feature in electricity markets is that some injections or offtakes originating from inflexible assets are random. For example, household demand for

[29] Note that, since firms can produce a negative quantity (increase production), the aggregate slope is constant.

heating and cooling is subject to the weather. Also, energy production facilities can be subject to unplanned outages or unfavorable weather conditions. Two reasons motivate the no-uncertainty benchmark. First, for the purpose of this paper, common knowledge is a justifiable approximation because forward trade is possible at least until one hour before delivery, so that most randomness reveals before forward markets close. Second, no-uncertainty serves as a useful benchmark that rules out hedging motives as a motivation for forward trade.[30] By excluding hedging motivations from the analysis, the analysis is biased against finding forward trades that diversify spot market price exposure. Any empirical indications that forward trades would not diversify risks should be interpreted as evidence of strategic motivations for forward trade.

The framework consists of two stages.

Forward market

Stage one is the forward trading stage where firms exchange the financial responsibility to deliver energy. If firm *i* buys from firm *j*, ceteris paribus, the increase in *i*'s balance between injections and offtakes is offset by a decrease in *j*'s balance between injections and offtakes. So, the forward market only *reallocates* commitments. Firm *i*'s net sales are denoted by $\tilde{q}_i$, where $\sum_{i \in N} \tilde{q}_i = 0$. Firm *i* receives net transfer t_i on the forward market, where $\sum_{i \in N} t_i = 0$. When firms compete on the spot market, these transfers are treated as sunk. As such, they only serve to divide the gains from trade.

Spot market

Stage two, the spot market, is modeled as Cournot competition. Each flexible firm *i* simultaneously decides how much to produce, q_i, resulting in a surplus

$$q_i + \bar{q}_i - \tilde{q}_i ,$$

[30] See e.g. van Eijkel et al. (2016) on hedging motivations for VFT versus strategic motivations for VFT.

which it sells on the spot market. Firm *i*'s surplus must represent the difference between (i) *i*'s injections, through in-house production or purchases, and (ii) *i*'s offtakes, through in-house consumption or sales. In this framework, that difference can be written as the sum of the surplus from the flexible portfolio and the inflexible portfolio, adjusting for the net sales. A negative surplus is possible and should be interpreted as a shortage. When a firm's surplus is negative, the firm acts as buyer on the spot market.

The inverse demand function is

$$P\left(\sum_{i\in N}\left(q_i+\bar{q}_i-\tilde{q}_i\right)\right)=a-b\left(\sum_{i\in N}\left(q_i+\bar{q}_i\right)\right).$$

Flexible firm i's profits equal

$$\pi_i=t_i+\left(q_i+\bar{q}_i-\tilde{q}_i\right)\left(a-b\sum_{j=1}^{n}\left(q_j+\bar{q}_j\right)\right)-c_iq_i-\frac{0.5}{k_i}q_i^2\ .$$

The first term represents the transfer that firm i receives on the forward market. The second term represents firm i's revenues from the spot market. The final terms represent firm i's production costs. There are two interpretations of this expression. The first one interprets forward sales as a financial commitment: when firm i continues to produce the same quantity q_i, any forward sales $\tilde{q}_i$ cause a one-to-one decrease in firm i's spot market surplus. The second one interprets forward sales as a physical commitment to produce: for firm i to hold constant its spot market sales, any forward sales $\tilde{q}_i$ require firm i to increase its production by $\tilde{q}_i$. The spot market analysis will investigate each flexible firm's optimal production choice.

Inflexible firm i's profits equal

$$\pi_i=t_i+\left(\bar{q}_i-\tilde{q}_i\right)\left(a-b\sum_{j=1}^{n}\left(q_j+\bar{q}_j\right)\right).$$

Any forward sales by an inflexible firm cause a one-to-one decrease in its spot market sales.

The remainder of this section details the underlying interpretations of the spot market framework. To do so, it is useful to distinguish a reactive TSO from a proactive TSO.

Reactive TSO

I argue that the Cournot framework can be interpreted as a reduced form of the following extensive game.

1. Flexible firms simultaneously
    a. choose how much to produce in-house.
    b. offer balancing energy bids to the TSO.
2. All firms' in-house production decisions result in an imbalance that is aggregated over the industry. The TSO responds to the aggregated imbalance by activating balancing energy bids to balance consumption and production.
    a. The TSO collects the balancing energy bids and ranks them in a merit order from cheap to expensive.
    b. The TSO follows the merit order to make sure that the aggregated imbalance is resolved at the lowest possible cost. The marginally activated balancing energy bid equals the uniform market-clearing price P.

The inverse demand function equals the TSO's avoided cost of activating balancing energy bids. It reflects that, the more firms produce in-house, the fewer balancing energy bids the TSO activates.

The firm simultaneously chooses how much to produce, and how to offer balancing energy bids. Therefore, its production choice should be optimal, given the balancing energy bids it offers. Since the TSO activates balancing energy bids following the merit order, more in-house production by firms leads to a cheaper marginal bid price, and hence a cheaper uniform market-clearing price. In other words, the higher the production surplus incurred by firms, the lower the marginal cost of the TSO to offset it, and therefore the lower the equilibrium price.

In the extensive version of the spot market, firms' revenues originate from the imbalance market as well as the balancing energy market. I argue, however, that offering balancing energy (1b) is a weakly dominated strategy. The reason is that, both under pay-as-bid and pay-as-cleared balancing energy remuneration, the imbalance price received for in-house production is always weakly more favorable than the balancing energy bid. Therefore, we can restrict attention to the in-house production decision (1a). Following this reasoning, balancing energy bids are only offered by a competitive fringe of flexible producers and consumers. The analysis of the extensive game reduces to a Cournot model where the inverse demand function is exogenous. The steepness of the inverse demand function, b, reflects the portfolio size of a competitive fringe that offers balancing energy bids. When the inverse demand function is steep (flat), the competitive fringe is small (large) in size.

The previous argument justifies the Cournot framework by incentives for firms to prefer in-house balancing over offering balancing energy. Rather than calling upon that "weakly dominant strategy" argument, an alternative setting could instead assume that balancing energy bids reflect marginal cost, i.e., are regulated, and are remunerated pay-as-bid. If so, a firm's profits on the balancing energy market are automatically zero and do not need to be modeled. A firm's portfolio size k_i then only reflects the portfolio available for in-house production. Demand parameter b would then capture all competitively offered balancing energy. Finally, the Cournot model can also result when firms can commit to produce in-house rather than offering balancing energy. The intuition draws from Singh and Vives (1984): firms have unilateral incentives to commit to a fixed produced quantity so as to make their rivals' residual demand functions as price-inelastic as possible. Doing so induces their rivals to compete less aggressively.

A general, and perhaps obvious, insight from the reactive TSO setting is that the task of balancing should be performed both by firms with access to in-house flexibility, as well as by TSOs with access to flexibility from balancing energy bids. If we would observe that the TSO is not called upon frequently, we should not infer that balancing occurs efficiently; firms may have undertaken large efforts to balance their portfolio on a stand-alone basis. From an efficiency point of view, the cheapest production and consumption units should be dispatched to perform the task of balancing, regardless of whether they are activated by the TSO or by other firms.

Proactive TSO

I argue that, under a proactive TSO, the Cournot outcome can result from the following supply function competition framework.

1. Firms submit balancing energy bids using supply functions.
2. The TSO activates the bids needed to balance injections and offtakes. Imbalances and balancing energy are settled at a uniform market-clearing price.

This framework represents balancing markets where all production decisions pass via auctions, as happens e.g. in Spain. When imbalances and balancing energy are settled at the same market-clearing price, imbalances do not need to be modelled explicitly, because they can be modelled as horizontal shifts of firms' supply functions. The inverse demand function parameter b reflects the portfolio size of the competitive fringe.

We know from Klemperer and Meyer (1989) that the Cournot outcome is an equilibrium under supply function competition, and that it is the preferred equilibrium by firms under no uncertainty.[31]

[31] For an analysis of forward trading and collusion in supply functions, see Wolfing (2016).

4. Analysis: substitution between vertical and horizontal contracts

This section extends the two-period setup by Allaz and Vila (1993) (henceforth AV) in the easiest possible way to allow for HFT, i.e., to allow competitors to acquire forward sales from each other.

In AV, the forward market framework assumes that there are no arbitrage opportunities: the forward market price equals the spot market price. AV show that no-arbitrage follows from a forward market auction that distinguishes two sub-stages. In the first sub-stage, each flexible firm offers a quantity on the forward market. In the second sub-stage, each inflexible firm places a bid to acquire these quantities. Competitive bidding by inflexible firms guarantees that there are no profits from arbitrage.

I extend this game by allowing flexible firms to place bids in the second sub-stage as well. This extends the analysis to allow for horizontal subcontracting: forward positions that were offered by one flexible firm in the first sub-stage can be purchased by another flexible firm in the second sub-stage.

The analysis provides a negative result: no equilibrium exists in pure strategies. This negative result motivates the approach of bilateral efficiency pursued in section 6.

The parameter values in this section follow AV. In particular, this section uses a constant, symmetric marginal costs ($c_i = c$ and $k_i = +\infty$), assumes that there is no inflexible portfolio ($\bar{q}_i = 0$ for all firms), supposes that the inverse demand function is characterized by $b = 1$, and assumes that production is non-negative ($q_i \geq 0$).As in AV (p. 13), there are two flexible firms, 1 and 2, and two inflexible firms, 3 and 4.

Forward market framework

In stage one, firms trade on the forward market. The two sub-stages are as follows.

- *Forward quantity setting.* First, flexible firm 1 and 2 simultaneously offer f_1 and f_2 forward sales. Inflexible firms 3 and 4 offer zero forward sales $f_3 = 0$ and $f_4 = 0$. This sub-stage is equivalent to AV.
- *Forward price setting.* Second, there is an auction where *all* firms compete in prices to acquire the $\sum_{i \in N} f_i$ units.
    - When $\sum_{i \in N} f_i > 0$, the winner purchases $\sum_{i \in N} f_i$ at unit price p, where p is the highest price offered.
    - When $\sum_{i \in N} f_i < 0$, the interpretation is that firms compete to sell units, in which case the winning price is the lowest price offered.[32,33]

  There is a price floor $\underline{p}$ and price cap $\bar{p}$ such that $\underline{p} \le c \le \bar{p}$.[34] In case of a tie, the winning firms equally share the market.[35]

If firm i wins the forward price setting sub-stage, its net sales are

$$\tilde{q}_i = f_i - \frac{\sum_{j=1}^{4} f_j}{\#\text{winners}} ,$$

where the denominator denotes the number of winning firms .

If firm *i* loses, its net sales are

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[32] In fact, AV (p. 13) does not specify that, when $\sum_{i \in N} f_i < 0$, the winning price should be the *lowest* price offered. However, it is needed in their setting to obtain that no arbitrage opportunities exist.

[33] In the special case where $\sum_{i \in N} f_i = 0$, the forward sales by one flexible firm exactly equal the forward purchases by the other flexible firm. Any price would equate demand and supply. In line with AV, I take the most natural assumption that trade occurs at the price that satisfies the no-arbitrage condition.

[34] AV's complete game form (p. 13) does not require that there should be a forward price cap or floor. As we will see, having finite price caps or floors becomes an important technical assumption when allowing for HFT.

[35] One exception is proposition 1b, which for simplicity restricts attention to a forward price setting sub-stage where, in case of a tie, a single winner is randomly selected.

$$\tilde{q}_i = f_i \ .$$

Spot market framework

The spot market framework is equivalent to AV. Firms fully observe the net quantities sold on the forward market. On the spot market, flexible firms compete à la Cournot by choosing how much to produce. Firm i's spot market sales equal $q_i - \tilde{q}_i$, i.e., firm i's production $q_i \geq 0$ subtracted by its net quantity sold forward.

No disposal. Firms offer at least their contracted quantity on the spot market.[36]

It follows that firm i's profit function equals

$$(p-c)\tilde{q}_i + (a - q_i - q_j - c)(q_i - \tilde{q}_i).$$

Figure 1 summarizes the framework and illustrates how firms trade products during the game.

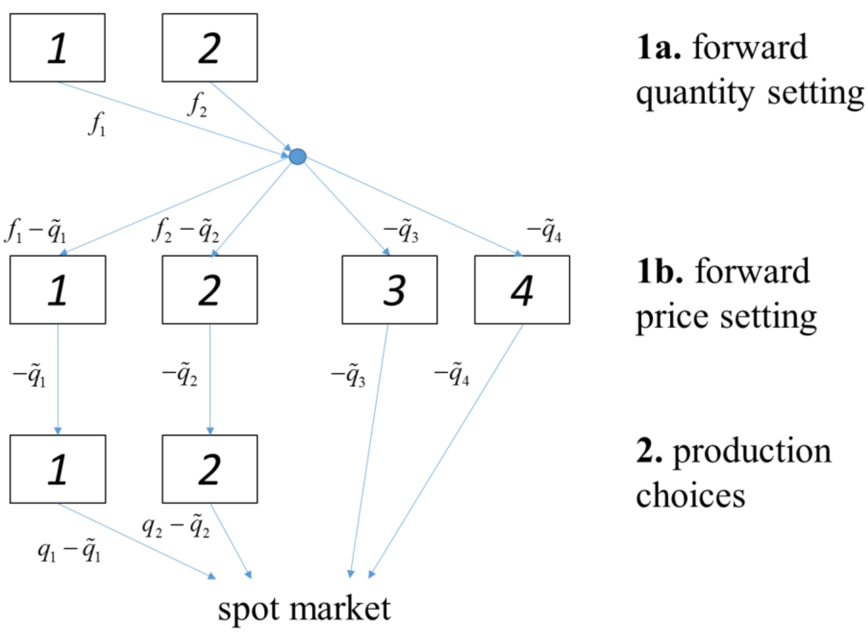

Figure 1: framework: substitution between vertical and horizontal contracts.

[36] No disposal is implicitly assumed in AV as well. Indeed, the profit functions that they display on page 7 imply that all production is offered on the market, and therefore that no production is disposed.

The upper part of the figure represents the forward quantity setting sub-stage, where firms 1 and 2 each choose a quantity to offer on the forward market. Below that, we see that all four firms participate in the forward price setting sub-stage. A flexible firm's net forward purchases, $-\tilde{q}_i$, equal the amount of production purchased in the forward price setting sub-stage, $f_i - \tilde{q}_i$, adjusted for the quantity offered in the forward quantity setting sub-stage, f_i. An inflexible firm's net purchases follow exclusively from possible purchases during the forward price setting sub-stage. Finally, the lower part of the figure represents the spot market, where flexible firms 1 and 2 choose how much to produce. Inflexible firms do not have access to flexibility, so they sell (buy) what they have purchased (sold) on the forward market, if anything.

The analysis starts backwards with the spot market.

Spot market analysis

When firm i is flexible, its optimal quantity produced, if positive, satisfies the first-order condition. Formally, we get

$$q_i^*\left(q_j, \tilde{q}_i\right) = \max(0, \frac{a - q_j + \tilde{q}_i - c}{2}).$$

The optimal production level is increasing in the quantity sold on the forward market $\tilde{q}_i$. The reason is that forward sales reduce a firm's spot market exposure, $q_i - \tilde{q}_i$, and therefore lead to higher marginal revenues of producing.

There is strategic substitution, i.e., firm i's optimal production level is decreasing in the production level by the flexible rival firm j. There is no direct effect of j's forward position on firm i's best response function.

The forward price does not affect spot market outcomes because it is sunk at the moment of competing.

There are three types of equilibria. In the interior equilibrium, both flexible firms produce a positive quantity. There can also exist equilibria where only one or zero firms produce a positive quantity. The interior solutions result in a spot market equilibrium where

$$q_1^*\left(\tilde{q}_1, \tilde{q}_2\right) = \frac{a - c + 2\tilde{q}_1 - \tilde{q}_2}{3},$$

$$q_2^*\left(\tilde{q}_1, \tilde{q}_2\right) = \frac{a - c + 2\tilde{q}_2 - \tilde{q}_1}{3},$$

and the market-clearing price equals

$$c + \frac{a - c - \left(\tilde{q}_1 + \tilde{q}_2\right)}{3}.$$

These spot market expressions are consistent with AV. The difference with AV lies in the analysis of the forward market.

Forward market analysis

In AV's two-period model, the proposed equilibrium is $f_1 = f_2 = \frac{a-c}{5}$, $q_1 = q_2 = 2\frac{a-c}{5}$ and results in profits equaling $2\frac{\left(a-c\right)^2}{25}$. By selling forward, firms commit to compete aggressively on the spot market. In AV, such a commitment is unilaterally profitable because it reduces the optimal quantity produced by the rival firm.

Proposition 1*: Consider the equilibrium proposed in AV's two-period model and suppose that all firms can bid to acquire the quantities offered on the forward market. Then, at least two profitable deviations exists. More specifically,*

a. a profitable deviation exists where the deviating firm places a large purchase order in the forward quantity setting sub-stage.

b. a profitable deviation exists where the deviating firm places a large supply order in the forward quantity setting sub-stage.

The proofs are in the appendix.

Proposition 1 highlights the importance of allowing for horizontal trade. It finds that the equilibrium traditionally investigated in the VFT literature is not robust to the introduction of HFT.

The key intuition behind the result is that the possibility of HFT allows flexible firms to withhold production that would otherwise have been offered by inflexible firms. Absent HFT, all purchases on the forward market by inflexible counterparties translate into sales on the spot market. In the AV equilibrium, these sales are quite substantial. They represent half of total production and considerably reduce the market-clearing price. The possibility of HFT provides an opportunity for firms to undo the pro-competitive effects of forward trade. By outbidding the inflexible firms, a flexible firm can avoid that the corresponding production is directly offered on the spot market. Any equilibrium analysis should thus account for the incentives for competitors to acquire production from each other. Under both deviations proposed in the proof, a) and b), firm 1 guarantees that inflexible firms do not win the forward market bidding process, so that the competitiveness of the spot market reverts back to standard Cournot.

In part a) of proposition 1, the deviating firm places a large *purchase* order in the forward quantity setting sub-stage. Doing so has two effects. First, it guarantees that the deviating firm will be substantially exposed to the spot market price. Therefore, the purchase order acts as a commitment to soften competition by withholding production. Second, as a consequence, inflexible firms are reluctant to win the forward price setting sub-stage and supply the deviating firm. The reason is that they would accordingly have to repurchase that production at a high spot market price. In this way, a horizontal contract substitutes for a vertical contract, and avoids the pro-competitive effects associated with it.

The profitability of the deviation proposed in part a) can result exclusively from reduced competition on the spot market. Indeed, the proof considers a deviation where the deviating firm bids its marginal cost in the forward price setting sub-stage. It follows that the deviating firm does not enjoy profits from trading on the forward market.

In part b) of proposition 1, the deviating firm places a large *supply* order in the forward quantity setting sub-stage. The supply order guarantees that, if inflexible firms would act as counterparties, competition would be very fierce. To avoid this pro-competitive scenario, the rival flexible firm has incentives to outbid the inflexible firms and acts as horizontally related counterparty.

I proceed by showing that the game does not have an equilibrium in pure strategies. To do so, I add three features to the model that will guarantee that each firm earns non-negative profits.[37]

(i) Bounded disposal cost: firms can dispose production on the spot market at a cost δ that ranges from zero to any bounded positive number. The interpretation is that there is an outside technology, perhaps costly, that can dispose the product at marginal cost δ.

(ii) Penalty for default: there is a default procedure for firms that do not honor their commitment to deliver. The penalty for non-delivery σ can range from the valuation of the highest-valuing consumer, to any bounded positive number. Formally, it satisfies $a \leq \sigma < \infty$. The penalty could reflect the marginal cost of a substitute product.

(iii) The industry is not too regulated: there is a sufficiently low forward price floor $\underline{p} < \delta$ and a sufficiently high forward price cap $\bar{p} > \sigma$.

Lemma 1. *When features (i), (ii), and (iii) hold, each firm earns non-negative profits in equilibrium.*

The proof is in the appendix.

Proposition 2: *Consider the equilibrium proposed in AV's two-period model and suppose that all firms can bid to acquire the quantities offered on the forward market. Then, when the forward price floor is sufficiently low and the forward price cap is sufficiently high, there is no pure strategy equilibrium.*

[37] Alternatively, I could simply assume that firms earn non-negative profits in equilibrium.

The proof is in the appendix.

Proposition 2 points towards a flaw in the way that the game is specified. The proof considers, for any pure strategy equilibrium with forward trade, the following response by a flexible firm: flexible firm i chooses a forward quantity $f_i = -(1+x) f_j$, where j is the competing flexible firm and $x > 0$. In words, firm i's forward quantity has the opposite sign and is larger in magnitude than firm j's forward quantity. As shown in the proof, this response yields two implications.

1. *Bilateral monopoly*. The forward market is a bilateral monopoly: whoever wins the forward price setting sub-stage, one flexible firm is always net purchaser on the forward market, and the other flexible firm is always net supplier on the forward market. It follows that one flexible firm, the net purchaser, benefits from the lowest forward price possible. The other firm, the net seller, benefits from the highest forward price possible.
2. *Flexible firm i's position dominates.* The flexible firm's position is larger in magnitude than the position of its rival.

The game specifies that the net production offered on the forward market is auctioned off to the most competitive bidder. Firm i's position is dominant, meaning that when firm i is net purchaser on the forward market, the bidding process seeks a supplier. Firm i, however, always benefits from a low price. It follows that firm i has incentives to push down the forward price to the price floor. Alternatively, when firm i is net supplier on the forward market, the bidding process seeks a purchaser. Firm i, since it benefits from the highest possible price, has incentives to push the forward price up to the price cap.

Under both scenarios, firm i's competitor is faced with a hold-up problem. When that competitor is insufficiently protected by price regulation, it would be subject to negative profits in equilibrium, an impossibility.

The hold-up problem follows from a flaw in the way that the situation of bilateral monopoly is modelled. Usually, situations of bilateral monopoly are modelled with a bargaining process that takes into account both firms' bids, or at least both firms' reservation values.

5. Analysis: no substitution between vertical and horizontal contracts

This section does not take a stance on what game firms play on the forward market. Instead, it introduces the concept of bilateral efficiency as a stability condition. Under bilateral efficiency, forward positions are such that each pair of firms cannot gain by engaging in additional bilateral trade, taking as given the other bilateral contracts, and taking into account unilaterally optimal behavior on the spot market. A pair of firms may be a vertically related pair, consisting of a flexible and an inflexible firm, or a horizontally related pair, consisting of two flexible firms. For completeness, I also investigate a pair consisting of two inflexible firms. Since each pair of firms treats all other bilateral contracts as given, the analysis features zero substitution between horizontal contracts and vertical contracts.

Notation. This section requires distinguishing between different pairs of firms. Whenever appropriate, I proceed by considering firm 1 and firm 2 as representative examples of flexible firms. Firm 3 and firm 4 are representative examples of inflexible firms. Firm 1 and firm 3 then form a representative vertically related pair of firms. Firm 1 and firm 2 form a representative pair of flexible firms. Finally, firm 3 and firm 4 form a representative pair of inflexible firms. For each pair of firms i and j, the sum of their net forward sales is denoted by

$$\tilde{q}_{i+j} \equiv \tilde{q}_i + \tilde{q}_j \ .$$

Importantly, that sum remains constant when firm i and j trade with each other. I will therefore fully capture bilateral trade from firm i to j with parameter $\tilde{q}_i$.

Denote the sum of firm i and firm j's net transfers by

$$t_{i+j} \equiv t_i + t_j \,,$$

which also remains constant when i and j trade with each other. In other words, the choice of transfer is a zero-sum game from a bilateral point of view.

Figure 2 displays the framework under no substitution between vertical and horizontal contracts. While the framework allows for any number of firms, the figure only represents four representative firms and their six representative bilateral links. The upper part of the figure illustrates the forward market, where all firms trade in a way that is bilaterally efficient. Each pair of firms is bilaterally linked in a way that is independent of other bilateral links. Absent production, each firm's spot market surplus is given by $\bar{q}_i - \tilde{q}_i$. The lower part of the figure represents that flexible firms can additionally choose how much to produce on the spot market.

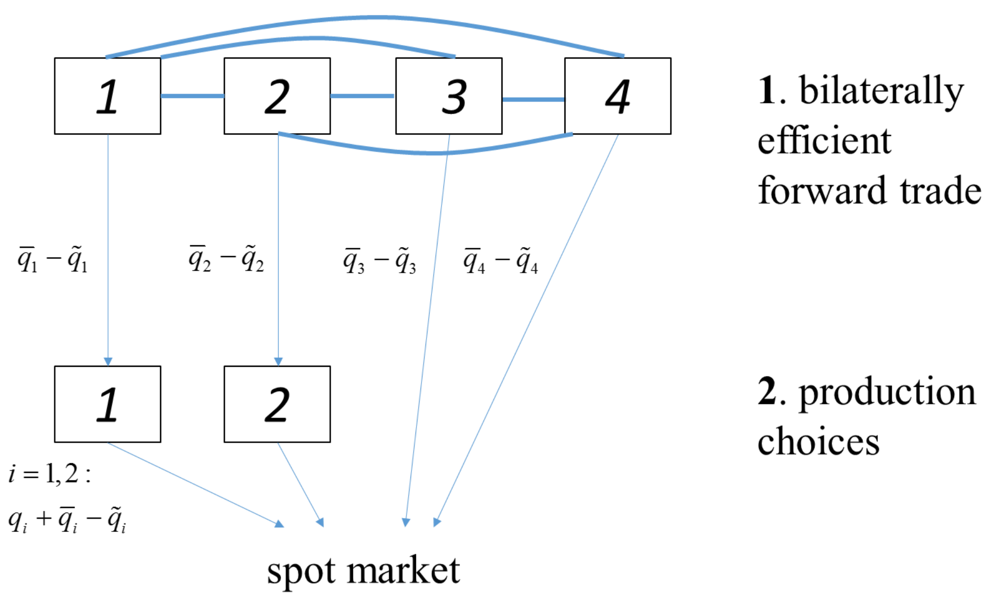

Figure 2: framework: no substitution between vertical and horizontal contracts.

The analysis proceeds backwards.

Spot market analysis

Flexible firms choose how much to produce (q_i). Recall that flexible firm i's profits equal

$$\pi_i = t_i + \left(q_i + \bar{q}_i - \tilde{q}_i\right)\underbrace{\left(a - b\sum_{j=1}^{n}\left(q_j + \bar{q}_j\right)\right)}_{P} - \underbrace{(c_i q_i - \frac{0.5}{k_i} q_i^2)}_{C_i(q_i)} \ .$$

Inflexible firms do not have a flexible portfolio and therefore produce a zero quantity ($q_i = 0$). Inflexible firm i earns a profit of

$$\pi_i = t_i + \left(\bar{q}_i - \tilde{q}_i\right)\underbrace{\left(a - b\sum_{j=1}^{n}\left(q_j + \bar{q}_j\right)\right)}_{P} \ .$$

Definition: *unilaterally optimal spot market outcome: flexible firms unilaterally decide how much they offer on the spot market.*

Firm i 's first-order condition for profit maximization can be written as

$$q_i^* = \frac{\tilde{q}_i - 2\bar{q}_i + \frac{a - c_i}{b} - \sum_{j \in N \setminus i}\left(q_j + \bar{q}_j\right)}{\frac{1}{bk_i} + 2}.$$

Forward sales ($\tilde{q}_i$) increase the optimal quantity produced (q_i^*). The intuition is that they increase the marginal revenues of producing $P - b\left(q_i + \bar{q}_i - \tilde{q}_i\right)$. Note that the first-order conditions are sufficient for an equilibrium. The reason is that profit functions are concave, and the framework always yields an interior solution because firms are allowed to produce a negative quantity (reduce consumption).

Definition: *bilaterally optimal spot market outcome of a vertically related pair: each vertically related pair jointly decides how much the flexible firm offers on the spot market.*

The vertically retailed pair consists of a flexible firm, denoted by firm 1, and an inflexible firm, denoted by firm 3. Bilateral profits on the spot market are maximized at

$$q_1^* = \frac{\tilde{q}_{1+3} - 2\bar{q}_1 + \dfrac{a - c_1}{b} - \sum_{i \in N \setminus 1} \left(q_i + \bar{q}_i \right) - \bar{q}_3}{\dfrac{1}{bk_1} + 2} .$$

As under unilateral optimality, joint forward sales ($\tilde{q}_{1+3}$) increase the bilaterally optimal quantity produced (q_1^*).

Definition: *collusive spot market outcome: all firms jointly decide how much each flexible firm offers on the spot market.*

The collusive outcome occurs when each flexible firm i takes account of the price effect of the industry. Industry profits are

$$\sum_{i \in N} \pi_i = \sum_{i \in N} \left(q_i + \bar{q}_i - \tilde{q}_i \right) \left(a - b \sum_{i \in N} \left(q_i + \bar{q}_i \right) \right) - \sum_{i \in N_{\text{flex}}} \left(c_i q_i + \frac{0.5}{k_i} q_i^2 \right) .$$

The first-order conditions, for each flexible firm i, satisfy

$$q_i^{**} = \frac{\overset{=0}{\sum_{j=1}^{n}} \tilde{q}_j - 2\bar{q}_i + \dfrac{a - c_i}{b} - \sum_{j \in N \setminus i} \left(q_j + \bar{q}_j \right) - \sum_{j \in N \setminus i} \left(q_j + \bar{q}_j \right)}{\dfrac{1}{bk_i} + 2} .$$

The collusive outcome is uniquely defined. It is independent of the allocation of forward sales. The industry surplus under collusion equals

$$\sum_{i \in N} \left(q_i^{**} + \bar{q}_i \right) .$$

Forward market analysis

There are several possibilities with respect to the forward market. I subsequently analyze a multilaterally efficient forward market, the forward market from the VFT literature, and a bilaterally efficient forward market.

Definition: *multilaterally efficient forward market: firms trade forward in a way that maximizes industry profits.*

The analysis of a multilaterally efficient forward market serves as a benchmark. It can be interpreted as collusion on the forward market. Proposition 3 establishes a relationship between collusion on the forward market and collusion on the spot market: it shows that an allocation of forward commitments exists that implements the collusive outcome on the spot market.

Proposition 3: *multilaterally efficient forward trade implements the collusive spot market outcome.*

The proof is in the appendix.

Under multilaterally efficient forward trade, each flexible firm has a unilaterally optimal surplus on the spot market, $q_i^* + \overline{q}_i - \tilde{q}_i$, that is equal to the surplus of the industry prescribed by the collusive spot market outcome, $\sum_{i \in N} \left(q_i^{**} + \overline{q}_i \right)$. That surplus is uniquely defined, see *supra*, and can always be implemented under the unilaterally optimal spot market outcome by adjusting $\tilde{q}_i$. Each flexible firm thereby internalizes the effect of producing on the price received for the aggregate industry surplus. The inflexible firms act as counterparty and take opposing positions on the spot market.

Remark that the multilaterally efficient forward allocation only depends on the *industry* surplus from the inflexible portfolios, not on the *firm-level* allocation. So, if one would assume multilaterally efficient forward trade, industry-level statistics would suffice for empirical purposes.

I next restate how the forward market is modelled in the VFT literature.

Definition: *VFT literature forward market: flexible firms unilaterally decide how much to sell forward to inflexible firms.*

This definition reflects the way that forward trade is modelled in Allaz and Vila (1993) and others[38]. Denote the flexible firm as firm 2. Under unilateral efficiency, firm 2 takes as given the other forward contracts signed, and maximizes profits with respect to $\tilde{q}_2$ only. All forward contracts signed become common knowledge before the spot market. We can write firm 2's forward market maximization problem as

$$\max_{\tilde{q}_2} \pi_2(\tilde{q}_2) = \max_{\tilde{q}_2}\left(\left(q_2^*(\tilde{q}_2)+\bar{q}_2-\tilde{q}_2\right)P\left(\sum_{i\in N} q_i^*(\tilde{q}_2)+\sum_{i\in N}\bar{q}_i\right)+\tilde{q}_2 p^f - C_2\left(q_2^*(\tilde{q}_2)\right)\right),$$

where the forward price is denoted by p^f. The profit function represents the profits from selling on the spot market (first term), the profits from selling on the forward market (second term), and accounts for 2's production costs (final term). Remark that firm 2's production choice, q_2^*, as well as its rivals' production choices depend on $\tilde{q}_2$.

This framework requires an assumption about the forward price. The commonly used assumption is that the forward price equals the (endogenous) spot market price ($p^f = P$).

Definition: *no-arbitrage assumption: the forward price equals the spot price, or* $p^f = P$.

Using the no-arbitrage assumption, the maximization problem becomes

$$\max_{\tilde{q}_2}\left(\left(q_2^*(\tilde{q}_2)+\bar{q}_2\right)P\left(\sum_{i\in N} q_i^*(\tilde{q}_2)+\sum_{i\in N}\bar{q}_i\right)-C_2\left(q_2^*(\tilde{q}_2)\right)\right).$$

Using that $P' = -b$, we can write the first-order condition as

[38] E.g. Bushnell (2007).

$$(1) \qquad \frac{dq_2^*(\tilde{q}_2)}{d\tilde{q}_2}\Big(P-b\big(q_2^*(\tilde{q}_2)+\bar{q}_2\big)-C_2'\big(q_2^*(\tilde{q}_2)\big)\Big)+\frac{d\sum_{i\neq 2} q_i^*(\tilde{q}_2)}{d\tilde{q}_2}\Big(-b\big(q_2^*(\tilde{q}_2)+\bar{q}_2\big)\Big)=0\,.$$

The forward quantity choice only affects profits via the flexible firms' equilibrium production choices. The first term represents that $\tilde{q}_2$ affects $q_2^*(\tilde{q}_2)$, and thereby affects firm 2's profits. Since firm 2 will treat forward sales as sunk on the spot market, forward sales act as a commitment to compete fiercely. The second term represents that $\tilde{q}_2$ also has a strategic effect on the rivals' production choices. Their production choices affect the price that firm 2 receives for the $q_2^*(\tilde{q}_2)+\bar{q}_2$ units it sells on the spot market. In particular, firm 2's commitment to compete fiercely reduces its rivals' equilibrium production on the spot market, and thereby raises the market-clearing price that firm 2 receives. The first-order condition on the forward market trades off these two effects. The marginal profit-loss from being aggressive on the spot market (first term) should be balanced against the marginal profit-increase from having less aggressive rivals on the spot market (second term).

I proceed by analyzing bilateral efficiency and its connections with the VFT literature.

Definition: *bilaterally efficient forward market: firms trade forward in a way that maximizes bilateral profits, while taking as given the other contracts signed.*

The analysis of bilateral efficiency is structured as follows. I subsequently analyze

1. vertically related pair
    a. public contracts
    b. private contracts
2. pair of flexible firms
    a. public contracts
    b. private contracts
3. pair of inflexible firms

1. Vertically related pair

A representative vertically related pair, again denoted by flexible firm 1 and inflexible firm 3, maximizes profits with respect to $\tilde{q}_1$. We can write the bilateral profit maximization $\max_{\tilde{q}_1}\left(\pi_1\left(\tilde{q}_1\right)+\pi_3\left(\tilde{q}_1\right)\right)$ as follows:

$$\max_{\tilde{q}_1}\left(t_{1+3}+\left(q_1^*\left(\tilde{q}_1\right)+\bar{q}_1+\bar{q}_3-\underset{\tilde{q}_1+\tilde{q}_3}{\tilde{q}_{1+3}}\right)P\left(\sum_{i\in N}q_i^*\left(\tilde{q}_1\right)+\sum_{i\in N}\bar{q}_i\right)-C_1\left(q_1^*\left(\tilde{q}_1\right)\right)\right).$$

Using again that $P^{'}=-b$, we obtain the first-order condition

$$\begin{aligned}&\frac{dq_1^*\left(\tilde{q}_1\right)}{d\tilde{q}_1}\left(P-b\left(q_1^*\left(\tilde{q}_1\right)+\bar{q}_1+\bar{q}_3-\underset{\tilde{q}_1+\tilde{q}_3}{\tilde{q}_{1+3}}\right)-C_1^{'}\left(q_1^*\left(\tilde{q}_1\right)\right)\right)\\&+\frac{d\sum_{i\in N\backslash 1}q_i^*\left(\tilde{q}_1\right)}{d\tilde{q}_1}\left(-b\left(q_1^*\left(\tilde{q}_1\right)+\bar{q}_1+\bar{q}_3-\underset{\tilde{q}_1+\tilde{q}_3}{\tilde{q}_{1+3}}\right)\right)=0\end{aligned}\quad (2)$$

Firms 1 and 3 take into account how their choice of $\tilde{q}_1$ affects production decisions. The first term represents the effect on firm 1's production choice, $q_1^*\left(\tilde{q}_1\right)$, and shows how $q_1^*\left(\tilde{q}_1\right)$ affects bilateral profits. The second term represents the effect on the rivals' production choices, $\sum_{i\in N\backslash 1}q_i^*\left(\tilde{q}_1\right)$, and shows how $\sum_{i\in N\backslash 1}q_i^*\left(\tilde{q}_1\right)$ affects bilateral profits. For both channels, bilateral profits take into account the price received for firm 1's spot sales, $q_1^*\left(\tilde{q}_1\right)+\bar{q}_1-\tilde{q}_1$, as well as the price received for firm 3's spot sales, $\bar{q}_3-\tilde{q}_3$.

a. Public contracts

For public contracts, the outsiders to the contract can observe $\tilde{q}_1$ and adjust their offered quantity accordingly. Formally, the term $\dfrac{d\sum_{i\in N\backslash 1}q_i^*\left(\tilde{q}_1\right)}{d\tilde{q}_1}$ is non-zero.

Propositions 4 and 5 relate the analysis of bilaterally efficient public forward contracts to the analysis of the VFT literature.

Proposition 4: *the assumption of bilaterally efficient VFT (public contracts) is an alternative for the no-arbitrage assumption used in the VFT literature.*

To compare both ways of modelling, it suffices to investigate the forward market. The reason is that the spot market analysis is common and uses the unilaterally optimal spot market outcome. In other words, if flexible firms sell the same net amount on the forward market (same "$\tilde{q}_i$"s), the spot market outcome is equivalent. The only difference thus lies in the way that the forward market is modelled.

Recall that the forward markets have the following features. The optimization problem under bilateral efficiency takes account of the joint spot market sales by flexible firm 1 and inflexible firm 3, $q_1^*\left(\tilde{q}_1\right)+\bar{q}_1+\bar{q}_3-\underbrace{\tilde{q}_{1+3}}_{\tilde{q}_1+\tilde{q}_3}$. The optimization problem from the VFT literature takes account of the flexible firm 2's forward and spot sales, which in sum equal $q_2^*\left(\tilde{q}_2\right)+\bar{q}_2$.

The optimality conditions under bilaterally efficiency do not consider forward sales. The forward price paid serves as a sunk transfer and does not affect joint profits. As such, bilateral efficiency provides an alternative to the no-arbitrage assumption.

Nonetheless, the bilaterally efficient vertical forward market and the VFT literature forward market generate qualitatively similar predictions. The reason is that the optimality conditions under bilaterally efficiency consider the spot sales by the inflexible counterparty, $\bar{q}_3-\tilde{q}_3$, which are not considered by the optimization problem from the VFT literature.

This section proceeds by confirming that the VFT literature can be compatible with bilateral efficiency. To do so, the following Lemma will be useful.

Lemma 2: *the bilaterally efficient vertical forward market features that all inflexible firms incur the same position on the spot market. The position incurred by each inflexible firm equals*

$$S \equiv \frac{\sum_{i \in N_{\text{inflex}}} (\bar{q}_i - \tilde{q}_i)}{n_{\text{inflex}}} .$$

Suppose now that, in the VFT literature forward market equilibrium, first-order conditions (1) are satisfied when $\tilde{q}_i$ is constant for each flexible firm *i*. Each flexible firm's forward sales can then be denoted by a constant λ. Suppose, in addition, that the number of inflexible firms is such that $\lambda = S$. Then, it follows from equilibrium conditions (1) that equilibrium conditions (2) are satisfied. In other words, the VFT literature equilibrium then coincides with bilaterally efficient VFT.

Proposition 5: *The equilibrium in Bushnell (2007)'s symmetric setting satisfies bilaterally efficient vertical forward trade (public contracts) if the number of inflexible firms is equal to the number of flexible firms.*

The proof is in the appendix.

b. Private contracts

For private contracts, the outsiders to the contract do not observe $\tilde{q}_1$. They therefore cannot respond to $\tilde{q}_1$. Formally, it follows that $\sum_{i \in N \setminus 1} q_i^*$ is independent of $\tilde{q}_1$, or

$$\frac{d \sum_{i \in N \setminus 1} q_i^* (\tilde{q}_1)}{d\tilde{q}_1} = 0 .$$

Since the behavior of outsiders to the contract is treated as constant, bilateral profit maximization on the forward market simply serves to mimic the bilaterally optimal spot market outcome. Proposition 6 states that, then, all inflexible firms are inactive on the spot market, so that the analysis reduces to an analysis of HFT.

Proposition 6: *Under bilaterally efficient forward trade with private contracts, the inflexible firms are not exposed to the spot market price.*

The proof is in the appendix.

Firm 1 poses an externality on firm 3 because its production decision affects the price that firm 3 receives on the spot market. Under bilateral efficiency, firms 1 fully internalizes the externality it imposes on firm 3. That is achieved when firm 1 is exposed to both firms' joint surplus on the spot market: $q_1+\bar{q}_1-\tilde{q}_1=\left(q_1+\bar{q}_1-\tilde{q}_1\right)+\left(\bar{q}_3-\tilde{q}_3\right)$.

2. Pair of flexible firms

This section draws from Spiegel (1993)'s duopoly analysis of ex ante horizontal subcontracting, and extends it to allow for more than two firms. The representative flexible firms under consideration are firm 1 and firm 2. Firms' bilateral profits depend on their forward sales $\tilde{q}_1$ and can be written as $\pi_1\left(\tilde{q}_1\right)+\pi_2\left(\tilde{q}_1\right)$, or

$$\begin{aligned}&t_{1+2}+\left(q_1^*\left(\tilde{q}_1\right)+\bar{q}_1+q_2^*\left(\tilde{q}_1\right)+\bar{q}_2-\tilde{q}_{1+2}\right)\left(a-b\sum_{i\in N}\left(q_i^*\left(\tilde{q}_1\right)+\bar{q}_i\right)\right)\\&-\left(c_1q_1^*\left(\tilde{q}_1\right)+\frac{0.5}{k_1}q_1^*\left(\tilde{q}_1\right)^2\right)-\left(c_2q_2^*\left(\tilde{q}_1\right)+\frac{0.5}{k_2}q_2^*\left(\tilde{q}_1\right)^2\right)\end{aligned}.$$

Bilateral profits consist of forward market profits, spot market profits, and account for the production costs incurred by both firms.

Using general notation, the first-order condition for bilateral profit maximization with respect to $\tilde{q}_1$, $\dfrac{d\pi_1\left(\tilde{q}_1\right)+d\pi_2\left(\tilde{q}_1\right)}{d\tilde{q}_1}=0$, can be written as

$$\underbrace{\frac{\partial \pi_1}{\partial \tilde{q}_1}+\frac{\partial \pi_2}{\partial \tilde{q}_1}}_{=0}+\underbrace{\frac{\partial \pi_1}{\partial q_1^*}}_{=0}\frac{dq_1^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{\partial \pi_1}{\partial q_2^*}\frac{dq_2^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{\partial \pi_1}{\partial \sum_{j=3}^{n} q_j^*(\tilde{q}_1)}\frac{d\sum_{j=3}^{n} q_j^*(\tilde{q}_1)}{d\tilde{q}_1}$$

$$+\frac{\partial \pi_2}{\partial q_1^*}\frac{dq_1^*(\tilde{q}_1)}{d\tilde{q}_1}+\underbrace{\frac{\partial \pi_2}{\partial q_2^*}}_{=0}\frac{dq_2^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{\partial \pi_2}{\partial \sum_{j=3}^{n} q_j^*(\tilde{q}_1)}\frac{d\sum_{j=3}^{n} q_j^*(\tilde{q}_1)}{d\tilde{q}_1}=0 .$$

The first two terms represent the direct effects $\frac{\partial \pi_1}{\partial \tilde{q}_1}+\frac{\partial \pi_2}{\partial \tilde{q}_1}=-P+P=0$. Also, we know from the unilaterally optimal spot market outcome that $\frac{\partial \pi_1}{\partial q_1^*}=\frac{\partial \pi_2}{\partial q_2^*}=0$ (the envelope theorem). Therefore, we obtain that bilateral efficiency requires

$$\frac{\partial \pi_1}{\partial q_2^*}\frac{dq_2^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{\partial \pi_2}{\partial q_1^*}\frac{dq_1^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{\partial \pi_1+\partial \pi_2}{\partial \sum_{j=3}^{n} q_j^*(\tilde{q}_1)}\frac{d\sum_{j=3}^{n} q_j^*(\tilde{q}_1)}{d\tilde{q}_1}=0 .$$

By trading with each other, flexible firms alter the production they offer in the spot market equilibrium. The first term represents that the change in 2's production affects firm 1's profits. The second term represents that the change in 1's production affects firm 2's profits. The final term shows that there can also be a strategic Stackelberg effect with respect to the outside firms. In particular, a commitment by firms to reduce their joint output results in the outsiders' producing more, and vice versa.

a. Public contracts

For public contracts, outsiders can observe forward trade between 1 and 2. It follows that $\frac{d\sum_{j=3}^{n} q_j^*(\tilde{q}_1)}{d\tilde{q}_1}$ can be non-zero, so that the strategic Stackelberg effect can be active.

In Bushnell (2007)'s symmetric setting, all flexible firms are characterized by marginal cost curves with a common slope, or $k_i = k$ for all flexible firms $i \in N_{\text{flex}}$. Proposition 7 shows that, then, all flexible firms sell the same surplus on the spot market, or

$$q_1^* + \bar{q}_1 - \tilde{q}_1 = q_2^* + \bar{q}_2 - \tilde{q}_2 \ ,$$

which is satisfied in the equilibrium of Bushnell (2007)'s symmetric setting.

Proposition 7: *The equilibrium in Bushnell (2007)'s symmetric setting satisfies bilaterally efficient horizontal forward trade (public contracts).*

The proof is in the appendix.

b. Private contracts.

For private contracts, outsiders cannot observe forward trade between 1 and 2. It follows that $\frac{d\sum_{j=3}^{n} q_j^*(\tilde{q}_1)}{d\tilde{q}_1}$ is always zero. There is no strategic Stackelberg effect.

3. Pair of inflexible firms

For completeness, this subsection analyzes the third type of bilateral trade: bilateral trade between two inflexible firms. Denote the two representative inflexible firms by firm 3 and firm 4. Since both firms are inflexible, they produce zero, or $q_3 = 0$ and $q_4 = 0$. We obtain that the pair of inflexible firms' bilateral profits equal

$$\pi_3 + \pi_4 = t_{3+4} + \left(\bar{q}_3 + \bar{q}_4 - \tilde{q}_{3+4}\right)\left(a - b\sum_{j\in N}\left(q_j^*\left(\tilde{q}_3\right) + \bar{q}_j\right)\right) .$$

Since bilateral trade keeps $\bar{q}_3 + \bar{q}_4 - \tilde{q}_{3+4}$ constant, it does not affect firms' joint surplus on the spot market.

For private contracts, the behavior of outsiders to the trade can be considered as given, or $q_j^*\left(\tilde{q}_3\right) = q_j$. For public contracts, whatever contract signed, there are no incentives for flexible firms to adjust their behavior, so that $q_j^*\left(\tilde{q}_3\right)=q_j$ also holds. It follows that there are no incentives for two inflexible firms to trade with each other.

6. Conclusions and discussion

Balancing markets, the institutions that balance electricity injections and offtakes, serve an important role as physical reference markets. The prices that they feature should correctly reflect whether electricity is scarce or abundant, not only to guarantee efficient dispatch decisions in the short-run (allocative efficiency), but also to guarantee efficient investment decisions in the long run (dynamic efficiency). In the context of ambitious climate targets, securing sufficient entry of flexible generation assets, storage, and demand-side response, are major areas of policy attention.

To study the efficiency of balancing markets, however, they cannot be considered in isolation. The reason is that possible supply and demand shocks can already be absorbed on forward markets, before passing through to the balancing market.

I model two types of forward trade that are relevant in short-term electricity markets. Horizontal forward trade between firms with flexible assets reallocates generation or consumption among their flexible assets. Vertical forward trade features inflexible firms as counterparty, who only have access to inflexible assets. Examples of inflexible assets are residential consumers with fixed annual tariffs or wind mills that always generate under favorable weather conditions.

To understand the efficiency of balancing markets, there is a need to understand how horizontal and vertical forward trade interact with each other. The main contribution of this paper is to show whether and how horizontal contracts interact with vertical contracts.

The first approach supposes that horizontal forward trade and vertical forward trade are full substitutes. I develop an extension of Allaz and Vila (1993)'s two-period framework that adds the possibility of horizontal forward trade. Full substitution is modelled with an auction where quantities that are offered can be purchased by competitors as well as by non-competitors.

The analysis shows that firms have incentives to avoid the pro-competitive effects of vertical forward trade by engaging in horizontal forward trade. For this reason, the approach leads to two negative results. First, the equilibrium analyzed in Allaz and Vila (1993) is not robust to the possibility of horizontal forward trade. Second, an equilibrium in pure strategies does not exist.

The second approach supposes that there is zero substitution between horizontal forward trade and vertical forward trade. I investigate bilaterally efficient forward trade between firms that are vertically related, as well as between firms that are horizontally related. Vertical and horizontal forward trade are independent from each other because, under bilateral efficiency, two trading firms treat the other forward contracts as given. Different from full substitution, zero substitution rules out the possibility for firms to un-do the pro-competitive effects of vertical forward trade. Therefore, this approach is more successful in unifying both types of forward trade. An additional advantage of bilateral efficiency is that it does not require an assumption on the forward price. Indeed, for bilateral optimization, there is no need to assume that the forward price equals the spot price, because the forward price merely acts as a transfer that shares the gains from trade.

The analysis finds that, for private contracts, the predictions of bilateral efficiency are in line with the horizontal forward trade literature. Absent a hedging motive, private forward contracting neutralizes inflexible firms on the balancing market. Forward trade between flexible firms can still occur. The standard insight on horizontal forward trade is that it can contribute to cost-efficiency, but can also reduce competition. Therefore, private forward contracting can have ambiguous effects on balancing market efficiency.

Public forward contracting is qualitatively consistent with the vertical forward trade literature. The standard insight is that forward trade can be pro- or anti-competitive, depending on the mode of competition. The policy implication for short-term electricity markets is that public forward contracting, in markets with decentral balancing, has the potential to improve efficiency, and accordingly support investments incentives. However, for auction-based balancing, forward trade can reduce efficiency, and accordingly reduce investments incentives. So, forward markets can function better under decentralized balancing than auction-based balancing. Since spot markets usually perform better under price competition (auction-based balancing) than quantity competition (decentral balancing), the overall relative performance of balancing market designs is ambiguous.

The analysis yields the following empirical predictions. Pro-competitive vertical forward trade implies that flexible and inflexible firms take positions of the same sign on the balancing market. For example, in the Allaz and Vila (1993) model, the positions of the inflexible firms *reduce* the flexible firms' exposure to the spot price. Producers and financial players are then both net sellers on the spot market. We can expect pro-competitive forward trade to occur under a reactive TSO, where we can argue that firms compete in quantities. Alternatively, risk-hedging by firms would yield the same empirical prediction. In contrast, anti-competitive forward trade implies that flexible and inflexible firms take positions of opposing signs on the balancing market. The positions of the inflexible firms then *increase* the spot price exposure for the flexible firms. Such behavior is e.g. predicted by Mahenc and Salanié (2004), who analyze a model with public forward contracts and price competition on the spot market. Depending on whether forward contracts are public as opposed to private, anti-competitive forward trade may occur under a proactive TSO with auction-based balancing.

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Appendix

Proof of proposition 1a.

The proof shows that a profitable deviation exists from the equilibrium proposed in AV.

The proof will propose a deviation where firm 1 takes an opposing long position that is larger in magnitude than firm 2's short position, or $|f_1| > f_2$. More specifically, I will consider the following deviation:

- *forward quantity setting.* firm 1 offers $f_1 = -\frac{a-c}{4}$ on the forward market. It follows that the sum of forward sales is negative and equals $f_1 + f_2 = -\frac{a-c}{20}$.
- *forward price setting.* firm 1 offers a forward price equal to marginal cost c.
- *spot market competition.* Spot market competition occurs in a way that is subgame perfect.

Remark that the proof does not require to analyze the optimal deviation. It suffices to show that, under the example deviation proposed, firm 1 can earn higher profits than in AV.[1]

The proof consists of three parts. The first part describes each firm's net forward sales under the proposed deviation, depending on whether the firm wins or loses the forward price setting sub-stage. The second part shows that, under the proposed deviation, the inflexible firms do not win the forward price setting sub-stage. The third part concludes the proof and shows that the proposed deviation is profitable for firm 1.

[1] Note that the proposed deviation in the forward quantity setting stage does not imply the proposed deviation with regard to forward price setting.

1.

In the proposed deviation, the total forward quantity offered becomes negative, or $\sum_{i \in N} f_i < 0$. It follows that firms bid to *offer* a quantity rather than to *acquire* a quantity on the forward market. The rules of the auction then dictate that the firm offering the lowest bid price wins the units.

Firm 1.

Next to possibly winning the auction and selling $\left|\sum_{i \in N} f_i\right| > 0$, firms 1 also holds a buyer position from having offered a negative quantity ($f_1 < 0$) in the forward quantity setting sub-stage. If firm 1 loses the auction, its net position equals

$$\tilde{q}_1 = f_1 < 0 .$$

If firm 1 wins the auction, its net position equals

$$\tilde{q}_1 = \underbrace{f_1}_{<0} + \frac{-\sum_{i \in N} f_i}{\underbrace{\#\,\text{winners}}_{>0}} < 0 .$$

The reason why the inequality holds takes two steps. First, remark that the inequality is hardest to satisfy when the number of winning firms is small. Second, for only one winner, we can write $f_1 - \sum_i f_i = -f_2 < 0$, so that the inequality is always satisfied.

Firm 2.

Firm 2's net position if it loses equals

$$\tilde{q}_2 = f_2 > 0 .$$

Firm 2's net position if it wins equals

$$\tilde{q}_2 = \underbrace{f_2}_{>0} + \underbrace{\frac{-\sum_{i \in N} f_i}{\#\,\text{winners}}}_{>0} > 0$$

Firms 3 and 4.

Finally, if an inflexible firm loses, it does not take any position on the forward market. If it wins, it incurs a position of

$$\frac{-\sum_{i \in N} f_i}{\underbrace{\#\,\text{winners}}_{>0}} > 0 \ .$$

Two observations crucially determine the forward price setting sub-stage. First, whatever the outcome of the auction, firm 1's buyer position dominates its potential seller position from winning the auction. Since firm 1 always acts as a net buyer, it always benefits from decreasing the forward price. Second, whatever the outcome of the auction, all other firms take a short position on the forward market, and benefit from a high price.

There are two possibilities: either a flexible firm wins, or an inflexible firm wins the forward price setting sub-stage.

2.

The second part shows that, under the proposed deviation, firm 1 guarantees that the inflexible firms do not win the forward price setting sub-stage.

Inflexible firms do not win the forward price setting sub-stage when they do not have an incentive to outbid firm 1. Under the proposed deviation, firm 1 offers c, so that outbidding firm 1 requires to charge a forward price below c. To analyze how inflexible firms choose their forward prices, we investigate their profits. Profits from losing are zero. Any profits from winning would result from arbitrage. When an inflexible firm wins, firm 1 takes long position $\tilde{q}_1 = -\frac{a-c}{4}$ and firm 2 takes short position $\tilde{q}_2 = \frac{a-c}{5}$ on the forward market. The spot market equilibrium yields a market-clearing price equal to $c + \frac{a-c+\frac{a-c}{20}}{3}$. Since $\sum_{i \in N} f_i < 0$, a winning inflexible firm would sell on the forward market and buy on the spot market. That arbitrage activity is only profitable when the forward price *exceeds* the spot price. The maximal willingness to offer of an inflexible firm on the forward market therefore equals $c + \frac{a-c+\frac{a-c}{20}}{3}$. It follows that bidding a price below $c + \frac{a-c+\frac{a-c}{20}}{3}$ is weakly dominated by bidding $c + \frac{a-c+\frac{a-c}{20}}{3}$. To undercut firm 1, an inflexible firm would need to bid at most c, which would imply that it plays a weakly dominated strategy. Therefore, it must be true that, under the proposed deviation, a flexible firm wins.

3.

The third part shows that, under the proposed deviation, firm 1's profits exceed AV profits.

Since one of the flexible firms wins the forward market in equilibrium, we have that the sum of their forward positions equals zero, or $\tilde{q}_1 + \tilde{q}_2 = 0$. The spot market equilibrium finds that both firms' sales on the spot market equal $q_i - \tilde{q}_i = \frac{a-c}{3}$. Firm 1 produces $\frac{a-c+3\tilde{q}_1}{3}$ and firm 2 produces $\frac{a-c+3\tilde{q}_2}{3}$, and they each earn a corresponding profit equaling $(p-c)\tilde{q}_i + (a - q_1 - q_2 - c)\frac{a-c}{3}$.[2] The spot price

[2] It can be checked that production is strictly positive for each flexible firm, so that there is an interior equilibrium.

equals the standard Cournot price $c+\frac{a-c}{3}$ that applies without forward trade, so that firm i 's profits can be written as $(p-c)\tilde{q}_i+\frac{(a-c)^2}{9}$.

There are two possibilities.

a. The lowest bid in the forward price setting sub-stage equals *c*. Firm 1's profits can be rewritten as $\frac{(a-c)^2}{9}$. These profits exceed firm 1's AV profits.
b. Firm 2 strictly outbids firm 1 by charging a price $p<c$. Firm 1 is net purchaser on the forward market ($\tilde{q}_1=-\frac{a-c}{4}$) and earns $(p-c)\left(-9\frac{a-c}{40}\right)+\frac{(a-c)^2}{9}$. These profits also exceed firm 1's AV profits.■

Proof of proposition 1b.

The proof will propose a deviation where firm 1 offers a quantity on the forward market equal to $f_1=\frac{a-c}{3}$. More specifically, I will consider the following deviation:

- *forward quantity setting.* Firm 1 offers $f_1=\frac{a-c}{3}$ on the forward market. It follows that the sum of forward sales equals $f_1+f_2=\frac{8}{15}(a-c)$.
- *forward price setting.* Forward price setting occurs in a way that is subgame perfect. In case of a tie, a winner is randomly chosen.
- *spot market competition.* Spot market competition occurs in a way that is subgame perfect.

Again, remark that the proof does not require to analyze the optimal deviation. It suffices to show that, under the example deviation proposed, firm 1 can earn higher profits than in AV.

The proof consists of two parts. The first part describes each firm's net forward sales under the proposed deviation, depending on whether the firm wins or loses the forward price setting sub-stage. The second part shows two possible equilibria after the deviation. The first one implies a strictly profitable deviation for firm 1. The second one implies that the deviation was not unprofitable for firm 1. If we assume that firms randomize over the two possible equilibria, the deviation is strictly profitable for firm 1 in expectation.

1.

In the proposed deviation, the total forward quantity offered becomes $\sum_{i \in N} f_i = \frac{8}{15}(a-c)$. It follows that firms bid to acquire a quantity on the forward market. The rules of the auction then dictate that the firm offering the highest bid price wins the units.

Firm 1.

If firm 1 loses the forward price setting sub-stage, its net position equals

$$\tilde{q}_1 = \frac{a-c}{3}.$$

If firm 1 wins the forward price setting sub-stage, its net position equals

$$\tilde{q}_1 = -\frac{a-c}{5}.$$

Firm 2.

Firm 2's net position if it loses equals

$$\tilde{q}_2 = \frac{a-c}{5}.$$

Firm 2's net position if it wins equals

$$\tilde{q}_2 = -\frac{a-c}{3}.$$

Firms 3 and 4.

Finally, if an inflexible firm i loses, it does not take any position on the forward market, or

$$\tilde{q}_i = 0.$$

If it wins, it incurs a position of

$$\tilde{q}_i = -\frac{8}{15}(a-c) \; .$$

2.

The first candidate equilibrium I consider is one where the inflexible firms compete away their possible arbitrage profits, firm 2 outbids the inflexible firms, and firm 1 bids less competitively than the inflexible firms.

a. Inflexible firms.

To analyze how inflexible firms choose their forward prices, we investigate their profits. Profits from losing are zero. Any profits from winning would result from arbitrage. A winning inflexible firm would buy on the forward market and sell on the spot market.

If an inflexible firm wins, firm 1 would take a short position $\tilde{q}_1 = \frac{a-c}{3}$ on the forward market and firm 2 would take a short position $\tilde{q}_2 = \frac{a-c}{5}$ on the forward market. The spot market equilibrium price would equal $c+\frac{a-c-\frac{8}{15}(a-c)}{3}$.

Inflexible firms therefore have incentives to bid up to $p=c+\frac{a-c-\frac{8}{15}(a-c)}{3}$.

b. Firm 2.

Regardless of who wins, we can use the expressions for an interior solution on the spot market.[3] Firm 2's profits can be written as

$$(p-c)\tilde{q}_2+\left(\frac{a-c-\tilde{q}_1-\tilde{q}_2}{3}\right)\left(\underbrace{\frac{a-c+2\tilde{q}_2-\tilde{q}_1}{3}}_{=q_i^*}-\tilde{q}_2\right).$$

The first term represents its profits from possibly selling on the forward market. The second term represents its profits from selling on the spot market.

If an inflexible firm wins, the forward price equals $p=c+\frac{a-c-\frac{8}{15}(a-c)}{3}$ and firm 2's profits are

$$\frac{a-c-\frac{8}{15}(a-c)}{3}\frac{a-c}{5}+\left(\frac{a-c-\frac{8}{15}(a-c)}{3}\right)\left(\underbrace{\frac{a-c+2\frac{a-c}{5}-\frac{a-c}{3}}{3}}_{=q_i^*}-\frac{a-c}{5}\right),$$

rewritten as $$\left(\frac{7}{225}+\left(\frac{7}{45}\right)^2\right)(a-c)^2\approx 0.0553(a-c)^2\ .$$

If firm 2 successfully outbids the inflexible firms, its profits are

[3] The first-order conditions apply because $q_2^*\geq\frac{a-c}{3}$.

$$-\frac{a-c-\frac{8}{15}(a-c)}{3}\frac{a-c}{3}+\frac{(a-c)^2}{9}=\left(-\frac{7}{135}+\frac{1}{9}\right)(a-c)^2\approx 0.05926(a-c)^2.$$

So, firm 2 has no incentives to deviate from the candidate equilibrium.

c. Firm 1.

Firm 1's profits are

$$(p-c)\frac{a-c}{3}+\frac{(a-c)^2}{9}>\underbrace{\frac{(a-c)^2}{9}}_{\text{standard Cournot profits}}>\underbrace{\frac{2}{25}(a-c)^2}_{\text{AV profits}}.$$

Since $p>c$, firm 1 does not have an incentive to outbid firm 2. This shows that the candidate equilibrium is indeed an equilibrium.

Since $p=c+\frac{a-c-\frac{8}{15}(a-c)}{3}$, profits exceed AV profits. This shows that the deviation is strictly profitable for firm 1.

The second candidate equilibrium I consider is one where the inflexible firms compete away their possible arbitrage profits, firm 1 outbids the inflexible firms, and firm 2 bids less competitively than the inflexible firms.

a. Inflexible firms.

The inflexible firms have equivalent incentives to possibly profit from arbitrage.

b. Firm 2.

Firm 2 earns

$$(p-c)\frac{a-c}{5}+\frac{(a-c)^2}{9}>\underbrace{\frac{(a-c)^2}{9}}_{\text{standard Cournot profits}}>\underbrace{\frac{2}{25}(a-c)^2}_{\text{AV profits}},$$

and does not have incentives to deviate from the equilibrium because $p>c$.

c. Firm 1.

If an inflexible firm wins, firm 1 gets

$$\frac{a-c-\frac{8}{15}(a-c)}{3}\frac{a-c}{3}+\left(\frac{a-c-\frac{8}{15}(a-c)}{3}\right)\left(\underbrace{\frac{a-c+2\frac{a-c}{3}-\frac{a-c}{5}}{3}}_{=q_i^*}-\frac{a-c}{3}\right),$$

which can be rewritten as

$$\frac{7}{135}(a-c)^2+\left(\frac{7}{45}\right)^2(a-c)^2\approx 0.0761(a-c)^2 \ .$$

Firm 1, by outbidding the inflexible firms, obtains

$$-\frac{a-c-\frac{8}{15}(a-c)}{3}\frac{a-c}{5}+\frac{(a-c)^2}{9}=0.8(a-c)^2=\text{AV profits} \ .$$

So, firm 1 does not have incentives to deviate from the equilibrium. In this second equilibrium, however, the deviation keeps firm 1's profits constant.■

Proof of Lemma 1.

The proof shows that each firm i can guarantee non-negative profits using the following strategy. It must therefore be true that, in any equilibrium, firm i earns non-negative profits.

- *Forward quantity setting:* If firm i is flexible, it offers $f_i=0$ (inflexible firms cannot offer a quantity on the forward market).
- *Forward price setting:* There are two possibilities.
    - When $\sum_{j=1}^{4} f_j<0$, firm i bids price cap $\overline{p}$.
    - When $\sum_{j=1}^{4} f_j>0$, firm i bids price floor $\underline{p}$.
- *Spot market:* firm i defaults on its shortage or disposes its surplus.

The proposed strategy leads to non-negative profits. Indeed, when $\sum_{j=1}^{4} f_j < 0$, firm i can go short on the forward market. When the firm loses, it earns zero profits. When the firm wins, it can default on the spot market and earn a profit of $\overline{p} - \sigma$ per unit, which is positive. If instead $\sum_{j=1}^{4} f_j > 0$, the firm can go long on the forward market. When the firm loses, it earns zero profits. When the firm wins, it can dispose on the spot market and earn a profit of $-\underline{p} - \delta$ per unit, which is positive. ■

Proof of proposition 2.

The proof is structured as follows. Part (i) establishes that when firm 2 offers $f_2 \neq 0$ as a pure strategy, firm 1 earns more than $\frac{(a-c)^2}{4}$, the collusive profits, and firm 2 earns negative profits. As that would violate non-negative profits (Lemma 1), no pure strategy equilibrium exist where $f_2 \neq 0$. From symmetry, it follows that $f_1 \neq 0$ cannot be part of a pure strategy equilibrium as well. Part (ii) completes the proof and contradicts that $f_1 = 0$ and $f_2 = 0$ is an equilibrium.

Part (i).

Suppose firm 2 chooses $f_2 \neq 0$.

I propose the following response where firm 1 offers $f_1 = -(1+x) f_2$ on the forward market, where $x > 0$. The sum of forward sales therefore equals $f_1 + f_2 = -(1+x) f_2 + f_2 = -x f_2$.

There are two possibilities: firm 1 wins the forward price setting sub-stage, or firm 1 loses the forward price setting sub-stage.

a. Firm 1 wins the forward price setting sub-stage. In case of a tie with $\#\text{winners}$ winning firms, firm 1 incurs forward sales equaling

$$\tilde{q}_1 = \underbrace{-(1+x)\, f_2}_{\text{forward quantity setting}} + \underbrace{\frac{-xf_2}{\#\,\text{winners}}}_{\text{forward price setting}} = -\left(1 + \frac{\#\,\text{winners} - 1}{\#\,\text{winners}}\, x\right) f_2 .$$

b. Firm 1 loses the forward price setting sub-stage. By losing, firm 1 incurs net forward sales

$$\tilde{q}_1 = \underbrace{-(1+x)\, f_2}_{\text{forward quantity setting}} .$$

If $f_2 < 0$, we have $f_1 + f_2 > 0$, so that firms compete to purchase in the forward price setting sub-stage. Firm 1, however, is always net seller, or $\tilde{q}_1 < 0$. Consider the following strategy by firm 1.

- *forward price setting sub-stage*: firm 1 offers the price cap $\overline{p}$.
- *spot market*: firm 1 produces the quantity it sold on the forward market so that it is not exposed to the spot price.

Using this strategy, firm 1 can guarantee to earn a profit of $(\overline{p} - c)(-f_2)$. For a sufficiently large price cap, these profits exceed the collusive profits. It follows that anther firm earns negative profits in the pure strategy equilibrium, contradicting that it is an equilibrium.

When $f_2 > 0$, we have $f_1 + f_2 < 0$, so that firms compete to sell in the forward price setting sub-stage. Firm 1, however, is always net buyer, or $\tilde{q}_1 < 0$. Consider the following strategy by firm 1.

- *forward price setting sub-stage*: firm 1 offers the price floor $\underline{p}$.
- *spot market*: firm 1 disposes the quantity it acquired so that it is not exposed to the spot price.

Using this strategy, firm 1 can guarantee to earn a profit of $(-\underline{p} - \delta)(-f_2)$. For a sufficiently low price floor, these profits exceed the collusive profits. It follows that another firm earns negative profits in the pure strategy equilibrium, contradicting that it is an equilibrium.

Part (ii).

Firm 1 and 2 choose $f_1 = f_2 = 0$. Each firm then earns standard Cournot profits $\frac{(a-c)^2}{9}$ in equilibrium.

AV already argued that the standard Cournot outcome is not an equilibrium when firms can offer production on the forward market. I show that this insight is robust when flexible firms can also place bids in the forward price setting sub-stage. Consider the Stackelberg deviation proposed by AV where firm 1 offers $f_1 = \frac{a-c}{4}$ on the forward market. The firm offering the highest price on the forward market wins the forward price setting sub-stage. There are two possibilities.

Inflexible firm wins.

When an inflexible firm wins, the spot price equals $\frac{a+3c}{4}$. Since inflexible firms compete away all arbitrage profits, it can be checked that firm 1 earns Stackelberg-leader profits $3\frac{(a-c)^2}{16}$, which exceed standard Cournot profits. Firm 2 earns Stackelberg-follower profits equaling $\frac{(a-c)^2}{16}$.

Firm 1 wins.

There is no incentive to undercut the inflexible firms because that would reduce firm 1's profits from the Stackelberg-leader profits to the standard Cournot profits.

Also, firm 1 does not have an incentive to outbid firm 2. When firm 2 wins, we have $\tilde{q}_1 + \tilde{q}_2 = 0$, so that firm 1 produces $\frac{a-c+3\tilde{q}_1}{3}$ and firm 2 produces

$\frac{a-c+3\tilde{q}_2}{3}$.[4] Both firms' sales on the spot market equal $q_i-\tilde{q}_i=\frac{a-c}{3}$, with a corresponding profit equaling $(p-c)\tilde{q}_i+(a-q_1-q_2-c)\frac{a-c}{3}$. The spot price would equal the standard Cournot price $c+\frac{a-c}{3}$, so that profits can be written as $(p-c)\tilde{q}_i+\frac{(a-c)^2}{9}$.

Hence, by outbidding firm 2, firm 1's profits would change by

$$\underbrace{\left(a-\sum_{i\in N}q_i-c\right)\frac{a-c}{3}}_{\substack{\text{profits from winning:}\\ \text{standard Cournot profits}}}-\underbrace{[(p-c)\tilde{q}_1+\left(a-\sum_{i\in N}q_i-c\right)\frac{a-c}{3}]}_{\text{profits from losing against firm 2}},$$

which can be rewritten as

$$-(p-c)\frac{a-c}{4},$$

which is negative for any forward price $p>c$. So, the only possible equilibrium where firm 1 wishes to outbid firm 2 is when $p\leq c$. However, the inflexible firms always wish to win at that price, because they could then profit from arbitrage. It follows that firm 1 never wins the forward price setting sub-stage.

Firm 2 wins.

To win, firm 2 needs to outbid the inflexible firms. To do so, it should offer a price of at most $p=\frac{a+3c}{4}$. Firm 2 can therefore earn at most $\left(\frac{a+3c}{4}-c\right)\left(-\frac{a-c}{4}\right)+\frac{(a-c)^2}{9}$, which can be rewritten as $-\frac{(a-c)^2}{16}+\frac{(a-c)^2}{9}$.

Since

[4] It can be checked that production is strictly positive for each flexible firm, so that there is an interior equilibrium.

$$\underbrace{-\frac{(a-c)^2}{16}+\frac{(a-c)^2}{9}}_{\text{maximal profits from winning}} < \underbrace{\frac{(a-c)^2}{16}}_{\substack{\text{profits from losing} \\ \text{against inflexible firm}}},$$

firm 2 does not have an incentive to outbid the inflexible firms. ■

Proof of proposition 3.

The first-order conditions of the collusive spot market outcome and the unilateral spot market outcome coincide when

$$q_i^{**} = q_i^{*},$$

which can be written as

$$\frac{a-c_i}{b} - 2\bar{q}_i - \sum_{j\in N\backslash i}\left(q_j + \bar{q}_j\right) - \sum_{j\in N\backslash i}\left(q_j + \bar{q}_j\right) = \tilde{q}_i + \frac{a-c_i}{b} - 2\bar{q}_i - \sum_{j\in N\backslash i}\left(q_j + \bar{q}_j\right),$$

or $\tilde{q}_i = -\sum_{j\in N\backslash i}\left(q_j + \bar{q}_j\right)$. Another way of rewriting the condition is that each flexible firm's surplus equals that of the industry:

$$\underbrace{q_i + \bar{q}_i - \tilde{q}_i}_{\text{flexible firm } i\text{'s surplus}} = \underbrace{\sum_{j=1}^{n}\left(q_i + \bar{q}_i - \tilde{q}_i\right)}_{\text{industry surplus}}.$$

This allocation of forward commitments can be achieved by shifting imbalances between flexible and inflexible firms. ■

Proof of Lemma 2.

The bilateral maximization problem presented *supra* applies to all firm 1's bilateral relations with inflexible firms. Firm 1's net forward sales $\tilde{q}_1$ should be optimal for all of them. This is impossible, due to a lack of degrees of freedom, unless $\bar{q}_3 - \tilde{q}_{1+3}$ is constant for each inflexible counterparty 3. In any equilibrium, each inflexible firm therefore incurs the same surplus $S \equiv \bar{q}_3 - \tilde{q}_3$. Another way of writing surplus S is as an average. In particular, it is equal to the total surplus of the inflexible portfolios, subtracted by the joint sales of the inflexible firms, divided by the number of inflexible firms, or

$$S \equiv \frac{\sum_{i \in N_{\text{inflex}}} \left(\bar{q}_i - \tilde{q}_i \right)}{n_{\text{inflex}}} . \blacksquare$$

Proof of proposition 5.

In Bushnell (2007), all flexible firms have marginal cost curves with a common intercept and slope. In formal notation, there are n_{flex} flexible firms, $k_i = k$ and $c_i = c$ are constant for all flexible firms $i \in N_{\text{flex}}$, and $\bar{q}_i = 0$ for all firms.

Then, each flexible firm's forward sales are the same, so that we can denote them by λ.[5] We can also write

$$S = \frac{\sum_{i \in N_{\text{inflex}}} \left(\bar{q}_i - \tilde{q}_i \right)}{n_{\text{inflex}}} = \frac{n_{\text{flex}} \lambda}{n_{\text{inflex}}} .$$

The last inequality follows from $\bar{q}_i = 0$ for all firms, and from $\sum_{i \in N} \tilde{q}_i = 0$ so that $\sum_{i \in N_{\text{inflex}}} -\tilde{q}_i = \sum_{i \in N_{\text{flex}}} \tilde{q}_i$. We obtain that $\lambda = S$ can be written as

$$\lambda = \frac{n_{\text{flex}}}{n_{\text{inflex}}} \lambda ,$$

which holds when the number of flexible firms is equal to the number of inflexible firms. ■

Proof of proposition 6.

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[5] From Bushnell, 2007, proposition 1, p. 232, we know that they equal $\lambda = \frac{\frac{a-c}{b}\left(n_{\text{flex}} - 1\right)}{\left(n_{\text{flex}} + \frac{0.5}{bk}\right)^2 + \left(1 + \frac{0.5}{bk}\right)}$

.

Since $\frac{d\sum_{i\in N\setminus 1} q_i^*(\tilde{q}_1)}{d\tilde{q}_1}=0$, the first-order conditions of the bilaterally efficient forward market, denoted by (1), become

$$\frac{dq_1^*(\tilde{q}_1)}{d\tilde{q}_1}\left(P-b\left(q_1^*(\tilde{q}_1)+\bar{q}_1+\bar{q}_3-\underbrace{\tilde{q}_{1+3}}_{\tilde{q}_1+\tilde{q}_3}\right)-C_1^{'}\left(q_1^*(\tilde{q}_1)\right)\right)=0.$$

The first term is non-zero, so that the condition becomes

$$P-b\left(q_1^*(\tilde{q}_1)+\bar{q}_1+\bar{q}_3-\underbrace{\tilde{q}_{1+3}}_{\tilde{q}_1+\tilde{q}_3}\right)-C_1^{'}\left(q_1^*(\tilde{q}_1)\right)=0,$$

which is equal to the first-order condition for a bilaterally optimal spot market outcome of a vertically related pair. So, forward trade serves to implement the bilaterally optimal spot market outcome.

The first-order conditions of the unilateral and the bilateral game coincide when

$$\tilde{q}_1-2\bar{q}_1+\frac{a-c_1}{b}-\sum_{j\in N\setminus 1}\left(q_j+\bar{q}_j\right)=\tilde{q}_1+\tilde{q}_3-2\bar{q}_1+\frac{a-c_1}{b}-\sum_{j\in N\setminus 1}\left(q_j+\bar{q}_j\right)-\bar{q}_3$$

, which can be written as $\bar{q}_3-\tilde{q}_3=0$: firm 3 incurs zero surplus on the spot market.

Since on the forward market, firms can increase $\tilde{q}_1$ to directly reduce $\tilde{q}_3$, holding $\tilde{q}_1+\tilde{q}_3$ constant, the bilaterally optimal spot market outcome of a vertically related pair can be achieved.

The equilibrium condition $\bar{q}_3-\tilde{q}_3=0$ shows that all inflexible firms are inactive on the spot market, so that the analysis reduces to an analysis of HFT.■

Proof of proposition 7.

Since $k_1=k_2$, it follows from the unilaterally optimal spot market analysis that, for bilateral trade, the increase in output by the seller is exactly offset by a decrease in output by the buyer. Formally,

$$\frac{dq_2^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{dq_1^*(\tilde{q}_1)}{d\tilde{q}_1}=0\,.$$

It follows that the outsiders to the trade, while they can observe the trade, do not have incentives to respond to it. Formally,

$$\frac{d\sum_{j=3}^{n} q_j^*(\tilde{q}_1)}{d\tilde{q}_1}=0\,.$$

We can therefore rewrite the first-order condition as

$$-b\left(q_1^*+\bar{q}_1-\tilde{q}_1\right)\frac{dq_2^*}{d\tilde{q}_1}-b\left(q_2^*+\bar{q}_2-\tilde{q}_{1+2}+\tilde{q}_1\right)\frac{dq_1^*}{d\tilde{q}_1}=0\,.$$

The first-order condition is sufficient for profit maximization since joint profits are concave.

Using that $\frac{dq_2^*(\tilde{q}_1)}{d\tilde{q}_1}+\frac{dq_1^*(\tilde{q}_1)}{d\tilde{q}_1}=0$, we obtain that firms sell the same surplus on the spot market, or $q_1^*+\bar{q}_1-\tilde{q}_1=q_2^*+\bar{q}_2-\tilde{q}_2$. This equilibrium condition is satisfied in Busnell (2007), where each flexible firm's forward sales are the same.[6] ■

[6] Indeed, from Bushnell, 2007, proposition 1, p. 232, we know that they equal $\lambda=\dfrac{\frac{a-c}{b}\left(n_{\text{flex}}-1\right)}{\left(n_{\text{flex}}+\frac{0.5}{bk}\right)^2+\left(1+\frac{0.5}{bk}\right)}$.

Conclusions

This thesis investigates horizontal subcontracts, i.e., outsourcing agreements between competing firms. The four chapters of my thesis each deal with different aspects of horizontal subcontracting.

The first two chapters, written with Jan Bouckaert, are related in the sense that firms sign subcontracts after competing on the main market. As a first example, consider banks that compete to provide a large loan at the best possible interest rate. After the winning bank has been selected, that bank may find it costly to carry all risk independently. The winning bank therefore benefits from setting up a syndicate with losing banks in order to share risks. As a second example, consider electricity producers that compete to serve consumers. A producer serving consumers may not have favorable generation conditions at each moment during the term of the contract. For example, some of its wind power production capacity may not be fully available. If a competing firm has access to wind mills located in a wind-abundant area, competing firms can benefit from trading with each other.

In a setting with ex post horizontal subcontracting, the consumer price can be high for two reasons. First, competing firms take into account that it may be costly to contract from rival subcontractors. Second, if firms anticipate that they can profit a lot from acting as a subcontractor, they charge a profit margin on the main market that compensates them for the foregone opportunity of acting as a subcontractor.

The first chapter of my thesis, titled "Horizontal subcontracting and investment in idle dispatchable power plants", written with Jan Bouckaert, investigates the incentives for electricity producers to invest in back-up facilities. An important feature of back-up facilities is that it provides a firm with an outside option to the subcontract. In this way, installing back-up can reduce the cost of contracting from competitors. Firms thus have strategic incentives to secure supply, even if the back-up facilities do not actually operate. This insight contributes to the debate about security of supply in a world with renewable energy sources.

The second chapter of my thesis, “Mergers and horizontal subcontracting”, written with Jan Bouckaert, investigates the effects of mergers. It finds that the merger interacts with firms’ cost of contracting, as well as with firms’ profits from subcontracting. We identify two anti-competitive effects and two pro-competitive effects. The first pro-competitive effect is that the merged firm enjoys more favorable terms of trade on the subcontracting market, which reduces its cost of contracting. The second procompetitive effect is that, as a consequence, the outsiders to the merger suffer from fewer profits from subcontracting, which increases their incentives to compete fiercely on the main market. Different from an analysis without horizontal subcontracts, we find that mergers without synergies can benefit consumers and harm outsiders to the merger.

Chapters three and four of my thesis are single-authored. They investigate subcontracting agreements that are signed before the competition stage. As a first example, consider supply contracts between producers of natural gas. Many supply contracts in this industry have a long duration. The incentives and ability of firms to offer production on the wholesale market, i.e., to compete, depends on the supply contracts that they have already committed to. As a second example, consider forward contracts between competing electricity producers that are signed a few days or hours before the moment of delivery. The forward contracts signed will affect the incentives for producers to produce, or offer, electricity in real-time.

The third chapter, “vertical integration and horizontal outsourcing”, investigates a capacity-investment stage, followed by a horizontal subcontracting stage and a competition stage. The framework finds that horizontal subcontracting, next to affecting production costs, can reduce the number of active competitors. In particular, the duopoly model shows that, in equilibrium, one firm, the subcontractor, uses its entire production capacity to supply its rival. It follows that the subcontractor does not have any residual capacity left to serve consumers. This anticompetitive motive for ex ante horizontal subcontracting has remained unreported in the literature on vertical integration, as well as the literature on price competition with capacity constraints.

The fourth chapter is titled "forward trade in short-term electricity markets: horizontal and vertical contracts". It investigates the efficiency of dispatch and investment decisions in short-term electricity markets. Both *vertical* forward trade, defined as forward trade between a competitor and a non-competitor, and *horizontal* forward trade, forward trade between competitors, are highly relevant in this industry. The paper derives conditions under which vertical forward trade is, or is not, compatible with horizontal forward trade. The insights contribute to the debate on balancing market design, and to understanding entry decisions of flexibility providers who can help secure electricity supply.

The analysis of ex post horizontal subcontracting (chapters 1 and 2) differs substantially from the analysis of ex ante horizontal subcontracting (chapters 3 and 4).

In particular, any incentives to sign subcontracts after the competition stage must follow from the possibility to reduce costs. The reason is that, ex post, the competition stage is treated as sunk. Possible cost-efficiencies can arise e.g. from decreasing returns to scale at the firm-level, as well as from ex ante uncertainty about the most efficient, constant-returns-to-scale production technology. When firms expect contracting to be costly, or when they expect to profit considerably as subcontractors, they have fewer incentives to compete for consumers.

In contrast, the incentives to sign subcontracts before the competition stage need not follow from cost-efficiencies. In other words, while cost-efficiencies can contribute to the gains from ex ante horizontal subcontracting, they are not a necessary component. The reason is that firms may anticipate that their subcontracting agreement reduces competition in the next stage. The possible anti-competitive effect of ex ante horizontal subcontracting arises because the subcontractor, by supplying the rival firm, moves up its marginal cost curve. Under decreasing returns to scale, the subcontract reduces the ability of the subcontractor to compete for consumers.

Both anti-competitive effects are distinct and can be mutually exclusive. A constant-returns-to-scale production technology can generate anti-competitive ex post horizontal subcontracting, without generating anti-competitive ex ante horizontal subcontracting. In contrast, a framework where capacity constraints are not too tight can generate anti-competitive ex ante horizontal subcontracting, without generating anti-competitive ex post horizontal subcontracting.