Mandatory electricity contracts as competitive device

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Abstract

Though the contract market is effective against market power, it has been prouved that when demand is risk-averse and retailers face increasing competition, generators do not have sufficient incentive to sign long-term agreements and thus high spot prices emerge. We argue that contractual obligations constitute a remedy to preserve the competition enhancing effect of long-term transactions. Building on Green (2003), we show that requiring mandatory contracts creates a pro-competitive effect but crowd-out private contracting. We examine the implementation of alternative regulatory designs and find that prescriptions on demand-side are better suited to preserve bilateral exchanges and to retrieve marginal cost pricing in the spot market.

Keywords: electricity markets, retail competition, regulation.

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1 Introduction

Liberalization of energy markets brought transformations into the organization and functioning of that industry around the world. Regulated vertically integrated monopolies have left room to new institutional frameworks in which natural monopolies (transmission and distribution) and potentially competitive markets (generation and supply) coexist. Albeit no standard organization of wholesale power market operations prevailed in the earliest deregulation experiences, power exchanges have been widely conducted as compulsory uniform clearing price auctions, hereafter spot markets. This market design was meant to guarantee coordination between newly separated segments of the industry and grant a merit order dispatch of energy.

However, recent international experiences indicate poor performances of power markets, especially those governed by spot market mechanisms; this draw attention to a number of unsatisfactory

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aspects of the ongoing liberalization processes and highlighted the debate on the role of new forms of regulation to prevent excessive prices (Bushnell, 2003; Newbery, 2002; Wolak, 2004; EC Commission first, second and third benchmarking reports, 2001 and 2003). Policy makers have adopted the view that to achieve welfare improving outcomes in power markets, active *pro-competitive* regulation must be accomplished through the application of *non market* or *behavioral mechanisms* with the aim to constraint firms' strategic market conducts (DOE, 2000; Newbery, 2002; Bushnell, 2003; Joskow and Tirole, 2004). However, it is important to notice that when competitive forces are weak, remedies that ignore the impact on firms' incentives, might trigger further unnecessary distortions (Viscusi, Vernon and Harrington, 2001).

In this vein, the promotion of forward contracting has been recurrently encouraged as a flexible instrument to mitigate market power [1]. From a theoretical ground, Allaz (1992) and Allaz and Vila (1993; hereafter AV) originally demonstrate that having a contract market before the production stage, i.e. the spot market, enhances competition. A vast successive literature investigate the competitive implications of the coordination between forward and spot markets in the electricity industry. Theoretical and empirical evidence confirm that when differences in the AV game formulation are introduced, an adverse effect on generators' incentives to contract might bring to controversial conclusions (e.g. von der Fehr and Harbord, 1992; Powell, 1993; Newbery, 1995 and 1998; Green, 1999a; Wolak, 2000a; Joskow, 2003). According to Green (2003), when demand for contracts arises from risk-averse retailers facing increasing competition, to little bilateral agreements will be signed at equilibrium. Spot prices will be far above competitive levels. This allows him to conclude that the mere implementation of a contract market is not well suited to prevent the exercise of market power. A monopolistic retailer regulated by yardstick competition makes consumers better off than a liberalized retail market.

Nevertheless, as worldwide the full opening to competition is a key point in the electricity market reforms, regulating monopolistic incumbent retailers does not appear to be an appropriate solution. Rather, motivated by the implementation on emerging competitive wholesale and retail electricity markets of different form of *non-market* or *behavioral mechanisms*, we draw our attention on country-specific contractual regimes that have been adopted or debated as a tool to promote the diffusion of long term contracting and to examine their potential as competitive device. As pointed out by Joskow and Tirole (2003), "*much of the economic analysis of the behavior and performance of wholesale and retail markets has either ignored these non-market mechanisms or failed to consider them in a comprehensive fashion*".

[1] Long term bilateral transactions are agreements that involve future physical delivery of energy or financial compensation underlying power exchanges; a spot market might supplement voluntary trade for physical power exchanges. An emblematic case of this approach is represented by the electricity market reform in England and Wales. In 2001, the compulsory pool has been abolished in favour to a new set of trading rules that promotes a mixed trading system (New Electricity Trading Agreements; OFGEM 1999).

The aim of our work is, thus, to contribute to this emerging debate. Building on Green's retail competition model (2003), we examine whether and under what conditions contractual obligations can be an effective instrument to restore a competitive equilibrium in the spot market. For this we introduce different regulatory designs in order to mirror country-specific solutions: contractual requirements can be imposed on generators (upstream measure), on retailers (downstream measure) or on either operators (vertical measure). We show that two effects are at stake. On one side, imposing obligations to contract increases total long-term transactions, mimicking the pro-competitive effect explained by AV. On the other, as in our model mandatory contracts represent strategic substitutes for private ones, a crowding-out effect emerges.

Although the inspiration of the work refers to practical experiences, the model is of interest in its own as it investigates the impact of one *behavioral* measure on the incentives for producers and retailers to foster private contracting. Given that we introduce a constraint on the set of strategic actions available to market participants, our main interest is to identify an optimal measure, for each regulatory environment, that maximizes the consumers' welfare subject to the generators break-even constraint. From a policy perspective, mandatory contracts imposed vertically on both generators and retailers do not solve the inefficiency pointed out by Green. Instead, contractual regimes that insist only on generators (upstream measures) or on retailers (downstream measures) do constitute an effective tool. We show that the regulator faces a trade-off between alleviating market power and affecting negatively the development of an active and voluntary-based forward market. The upstream optimal behavioral regulation proves to be too pervasive if applied on one generator, while the implementation of downstream measures attenuates the negative impact of risk-aversion, increasing demand-side responsiveness. However, the crowding-out effect as still to be controlled for.

The work proceeds as follow. Next section illustrates the pro-competitive regulation approach and screens country-specific practices to implement *contractual remedies* to market power. Section 3 presents the literature related to our work, whereas Section 4 is devoted to model setting. We explore the introduction of a long-term contracting obligation and shows how the equilibrium in the spot market is affected. The optimal policy, i.e. the level of mandatory contracts that maximize the consumer's welfare, is discussed in Section 5. Nash solutions are ranked at optimum to allow comparisons across different implementation rules. Some policy recommendations conclude our paper. Main proofs are presented in the appendix.

2 Pro-competitive policies

In order to introduce competition in the electricity industry, deregulation efforts have mainly been focused on the abolition of exclusive rights in the generation and supply of electricity. Economic regulation was eventually limited to the *natural monopoly* segments of the industry, such as the transmission networks to grant a non discriminatory access[2]. Power markets have been commonly set into operation to grant a centralized dispatch and trade of energy as in the previous vertically integrated paradigm.

Outside those very general guidelines, restructuring paths have varied considerably across countries. Regardless of the form of the liberalization architecture implemented a foremost issue within the industry has been the exercise of market power. A remedy to deal with market power is a strict enforcement of antitrust laws that prohibits anti-competitive behaviors. Indeed, antitrust legislation has a confined degree of applicability. By definition a market strategy constitute an infringement only if a firm holding a significant market power abuse of this competitive advantage to restrict, distort or prevent competition by exploiting consumers or excluding rivals. However, electricity markets have proved to be intrinsically vulnerable to the exercise of market power even by undertaking that might not fulfill the criteria of dominance. From a standard economic viewpoint, structural and industry-specific factors that account for the incomplete and imperfectly competitive nature of power markets. Deregulated industries have shown a tendency to the emergence of oligopolistic ownership; demand is low price responsive; the supply-side experience non convexity in technologies and capacity constraints (among others Borenstein, 2002). Moreover, inappropriate market design rules have exacerbate the ability of suppliers to exploit their *pivotal positions*[3] (Wolak and Patrick, 1997; Borenstein, 1999; Borenstein and Bushnell, 2000; Wolak, 2000b; Wilson, 2002). Specifically, spot markets have proved to be prone to the strategic price manipulation or capacity withholding (Le Coq, 2002; Crampes and Creti, 2003; Green, 2004)[4]. Even though there is not a widespread academic consensus on the performance and design of wholesale power exchanges, limitation to voluntary contracting as been further indicated as a key element to explain regulatory failures (Fabra, von der Fehr, and Harbord, 2004; Joskow, 2003; Wolak *et al.*, MSC Report, 2000).

The problem being to prevent the insurgence of strategic behaviors in power markers, public authorities cannot just be reliant on market processes and antitrust law (see for instance Report on Market Power, U.S. Department of Energy, 2000). In addition, as liberalisation is gradually interesting retailing markets[5], demand will be characterized by consumers with strong preferences for stable final prices as they have been exposed under regulated regimes to constant retail rates with

[2]The former EU Directive on the internal market of electricity (96/92/EC) displayed only minimum common requirements. Specifically, access to the network could have been based either under regulated third party rules or on a negotiated basis.

[3]A single firm could act as a *pivotal supplier*, that is to monopolize a portion of the market demand, with the result of periodic extreme price increases rather than smaller increases sustained continuously over longer periods of time.

[4]Generators engage in *economic withholding* when they do not offer output at a market price high enough to cover its cost but wait until the price is above the cost of generating output. *Physical withholding* implies that generators do not produce at any price.

[5]In EU Member States all customers will be free to choose their downstream retailer by July 2007 (see Directive 2003/54/EC).

contractual adjustments eventually made on annual bases. Thus an increasing attention is devoted to strengthen provisions regarding public service obligations, consumer protection and security of electricity supply. In this vein, it has been suggested that regulation does not have to be confined to natural monopoly activities "*for potentially competitive elements still need regulatory oversight to ensure that markets are not manipulated nor market power abused*" (Newbery, 2002). Moreover, "*regulation may be favoured if market designer is unable to establish a sufficiently competitive market so that prices are vastly in excess of the marginal cost*" (Wolak, 2004). Moreover, an important lesson derived from wholesale market failures is that regulatory mechanisms that worked in the former vertically-integrated monopoly regimes are inappropriate for competitive wholesale market regimes (Patrick and Wolak, 1997). Indeed, market designers must recognise the impact regulation on operators' conducts; that is to design public interventions which are compatible with the agents rationality and the participation constraints.

So far policy makers have put emphasis on the implementation of form of micro-regulation of price. Specifically, to insulate downstream markets from excessive wholesale price fluctuations price-caps or bid-caps have been set to govern firms pricing strategies in the spot power markets (Borenstein and Bushnell, 2000; Joskow and Kahn, 2002). Those interventions are not immune to critics. Wholesale price-caps implicitly determine the scarcity value of the energy; thus, if on one hand they might provide short-term protection on the other they can hinder long-term production efficiency. It is claimed that price volatility itself is desirable when it transmits the *right* signals to agents about market conditions.

Alternatively, measures can be design to foster final consumers responsiveness to prices. However, on one hand a direct final consumer participation in power exchanges remains limited; on the other, promotion of the installation and usage of time day metering technologies has not yet succeeded.

A new and interesting issue in the debate on *light hands* interventions is to analyse the effectiveness of contractual regulation.

2.1 Contract market regulation

Agreements made outside of spot power markets consist of bilateral contracts for future physical delivery of power as well as financial compensation based upon market outcomes (Borenstein et al., 1996). Contractual terms might be privately negotiated or either be relatively standardized when an official contract market is set into operation; the Nordic Pool represent a first experience (Herguera 2000). Despite the difficulties of getting precise estimated, in the first stages of liberalisation "*85% is a conservative lower boundary on the percent of final demand covered by long-term contracts for* [England and Wales, Australia and Nordic countries] *market*[s]" (Wolak, 2003). In almost all EU electricity industry, bilateral agreements represent the far most important way to transact, as the spot power liquidity do no account for more than 30% of final electricity demand in each of those markets [6]. The length of contracts varies from 1-3 to 1-5 years period. The relative importance of the spot and contract markets respectively depend upon country-specific structural conditions, as it steams from the trade-off between tight coordination of the liberalized activities and reliance on market forces (Wilson, 2002). As a general trend the inefficient performances of spot power markets has motivated policy makers to reform wholesale exchanges promoting voluntary bilateral contracting combined with residual spot power markets. In this framework, spot pricing conditions represent the relevant opportunity cost of participating in the contracts market. If markets are competitive and agents risk-neutral, the contract price should equals the expected spot price.

Bilateral contracting can accomplish several goals: hedging against the risk of spot price volatility; ensuring generation or supply adequacy for security purposes (for example to maintain reserve margins) or for promoting entry in the industry (among others Stoft *et al.*, 1998). In this respect, we believe that contractual regulation is not incompatible with a system of voluntary bilateral trade.

This regulation may take the form of contractual obligations on capacity (Wilson, 2002; Wolak, 2003). Capacity release programs are an alternative to dismission against excessive degree of concentration [7]. An example is given by the so-called *Virtual Power Plants* [8] that force incumbent generators to provide rivals or retailers with the right to dispose of a given share of their capacity. The allocation of capacity rights might be done under market mechanisms such as private or public auctions. Another regulatory option is to design capacity contracts for security purposes. Under a *Reliability Must Run* contract, one plant holding a monopoly power in a local area is run directly by the system operator to lessen transmission congestions or secure balancing or reserve margins; it is generally remunerated on audit costs (Bushnell and Wolak, 1999; Borenstein and Bushnell, 2000).

Regulation can also affect the terms of energy exchanges between generators and retailers under the form of mandatory supplying contracts. Quantities and prices can be set by the policy maker, but in a less pervasive way, undertakings can only be required to enter into minimum quantity transactions and be free to agree, under market forces, other relevant terms. It is worth mentioning that contractual requirements represent a constraint to the strategic behavior of the undertaking

[6] Based on informations provided by the Italian Single Buyer (http://www.acquirenteunico.it).

[7] For instance, Wolak and Patrick (1997) advocated that: "*There are already [in England and Wales] many independent power producers serving the market, so that simply increasing the number of competitors is not the solution [to abusive conducts]. Given the current number of firms in the market and the market rules, what is important to limiting market power is reducing the size of the largest firm relative to all the others*".

[8] The European Commission condition the approval of EDF acquisition of a joint control over the German electricity utility EnBW to a capacity realease program (M.1853, OJ L 059, 28/02/2002). The requirement tooked the form of *virtual power plants* and *power purchase agreements*. The former represents rights to nominate electricity output for delivery on the following day on the high voltage grid at a pre-defined price. There are peak-load and base-load capacity rights. The latter represents a a block of power based on the output from co-generation plants from which EDF has the obligation to purchase power at regulated tariffs under power purchase contracts.

on which it is imposed. Therefore, the effectiveness of a *contractual obligation* would depend on the impact it has on undertaking incentives as "*Market power mitigation measures that place restrictions on generator behavior without altering the their* [sic] *incentives may simply result in the exercise of the same or greater amount of market power, but in a different manner.*" (Wolak *et al.*, MSC Report, 2000).

2.2 Country-specific practices

The operation of mandatory supplying contracts is not new. Although the motivations for the introduction of contractual regimes are strictly dependent on the reform design applied in each country, theoretical and empirical evidence show that a market power mitigation intent underlies several practical experiences. As noted "*if one is concerned about market power, effective price-regulation can be imposed by forcing a large enough quantity of hedge contracts* [at a fixed quantity and price] *on the newly privatized generators*" (Wolak, 2000a). Recently, a substantial market power and an insufficient forward market hedging have been indicated as the key ingredients to explain the California electricity market crisis (Wolak *et al.*, MSC Report, 2000). On a broader view, the development of a forward market has been suggested to be a key conditions in the design and implementation of restructuring reforms to foster competitive wholesale electricity markets in Latin American Countries (see Wolak, 2003 for a complete report). One argument is based on the fact that the "*magnitude and distribution across suppliers of financial forward contracts to supply electricity to load-serving entities*" represents one of the primary mechanisms for increasing the elasticity of the residual demand curve and, thus, reduce the generators' incentive to exercise unilateral market power. As recognized, since rules have affected market outcomes, to deal with an efficient allocation of forward contracting it appears to be appropriate to "*set up periodic anonymous auctions*". Moreover, if firms are equal in size it is recommended to allocate forward contract commitments equally across them to maximize the competitive benefits. If one firm owned twice the capacity of other firms, then it should have roughly twice the forward contract commitments that the other suppliers have.

Country-specific practices have been analysed and documented, among others, by Helm and Powell (1992), Powell (1993), Newbery (1995 and 1998), Green (1999a and 1999b) and Wolfram (1998 and 1999). They all bring insights on the impact of contractual requirements in the British electricity industry. Wolak (2000a) and Wilson (2002) focus on the Australian restructuring experience; while Coutinho and Rossi de Oliveira (2002) investigate deregulation in Brazil.

We can distinguish countries that experience mandatory contracts on generators from those who implement contractual obligations on retailers.

2.2.1 Contractual obligations on generators

At the early stages of liberalisation, *England*, *Australia* and *Brazil* promote a series of mandatory agreements between incumbent generators and distributors. Those Vesting contracts or Contracts cover, were meant to provide distributors with a sufficient quantity of energy to cover non-eligible (captive) consumers for their electricity needs at stable wholesale prices. They lasted for one to five years periods and their prices were commonly subject to regulation or regulatory approval. Even though contract prices have prouved to be set at fairly generous levels, empirical studies showed that wholesale spot prices were lower compared to those absent the vesting contracts. Beside a market power mitigation concerns, the application long-term contract in England and Wales is explained by a cost-sharing motivation. Newly liberalized generators were, indeed, required to use extensively national coal to generate electricity. Thus, contract prices allowed them to recover higher input costs. In Brazil a primary objective was to encourage the development of a forward market and to entail the appearance of stand-alone dealers.

The regulatory experience in the *State of Alberta* stand for a failure of the public intervention. It is nonetheless useful to notice that the anticompetitive impact of a vast usage of hedging contracts was not due to the instrument itself but by the implementation of a contractual regime in a market structure characterized by vertically related undertakings. That is, the subscription of hedging contracts among dominant generators and their downstream affiliated allowed spot price manipulations discouraging new entry at the retailing level. Spot prices represented a transfer price within the same company group (Wilson, 2002)[9].

A very much similar case is given by the *New Zealand* electricity industry. During 2001, New Zealand registered an unexpected rise in retail prices. A key feature of the industry structure was to be highly vertically integrated with a large volume of energy already internally hedged [10]. Stand-alone retailers were not able to cover their sales efficiently and thus to promote competition at a retailing level. To reduce barriers to entry, policy makers put under scrutiny a compulsory hedging regime. The underling idea was that "*the entire industry would be more competitive if it were possible to induce generators to offer* [asymmetrically] *sufficient volumes of hedges at efficient prices* [i.e. at minimum, the amount of production that was not required for downstream affiliates]" (Small 2002). To provide a competitive allocation of those contracts, it was further suggested to implement anonymous tender administered by an independent third party [11]. It is only, in 2004, with the entering into force of the new electricity law, that the national regulator

[9] A reversed opinion is express by Mansur (2003) who estimates the performance of Pennsylvania, New Jersey, and Maryland electricity markets. He finds that vertical integration, reducing electricity producers' interest in setting high prices, constitute a key factor to explain the relative competitiveness of those markets.

[10] Another peculiar characteristic of New Zealand industry is the high dependence on hydro-generating plants that exacerbate the problem of price volatility due to seasonal and weather condition constraints.

[11] Conversely a decentralized bilateral negotiation would not have been suitable to achieve the purpose of a compulsory hedging regime, i.e. to curtail generators' market power.

has been given powers to establish and promote hedge markets. Specifically, under the new law regulator can "*require generators to offer by tender a minimum volume of contracts* [and] *require buyers of electricity from the wholesale market to maintain minimum levels of hedge and contract cover with electricity generators*".

2.2.2 Contractual obligations on retailers

In line with the most recent New Zealand electricity law, contractual obligations on retailers have been favoured by the EU Commission among the interventions that can be implemented to promote generation adequacy.

Italy provides the most significant example of the implementation of a contractual obligation on the retailing side. The stating up of a spot market, in the first trimester of 2004, reshaped the organization of the national electricity wholesale exchange system. Recent data show that spot trade accounted, during 2004, roughly for 30% of electricity exchanges. The rest is handled by private bilateral agreements (import included) or by public tenders of so called non conventional energy. The national wholesale supply structure is still dominated by the ex state-owned monopolist. Full opening of the retailing market being not yet implemented, captive consumers constituted half of the energy national demand. An independent operator (single buyer) is responsible for the supply of electricity to non-eligible market. In this framework, to overcome the concern about the exercise of potential market power, in the newly spot market, the national regulator intended to require each generator with a relevant market shares (above 20%) to subscribe legally binding financial and physical long-term contracts with the single buyer. Quantities and maximum prices would have been set by the public authority. In addition, temporary price-caps and market performances indexes would have been defined to control for spike prices and provide a series of quick tools to monitor spot market performances. The proposition encountered a strong opposition. The main objection was that the application of an asymmetric contractual obligation would have introduced a discrimination among generators. Indeed, only generators with relevant market shares would have been able to secure with yearly based contracts cover, a quota of their own generation capacity at more than fair regulated price. To fulfill the objective of controlling for market power abuses and meanwhile provide a risk hedge to captive consumers, a contractual obligation on the downstream-side has been introduced [12]. The so-called single buyer was required to promote annual or infra-annual public descending price auctions for the subscription of physical and financial long-term contracts. The auctions process end up with a total amount of energy bought under forward contracts of slightly less that 40 TWh (the maximum of energy covered with contract has been observed in November and December 2004, and amounts to 17% of the total single buyer's purchases). It is interesting to notice that, to convey the dominant generator to participate to those auctions, the regulator introduce a price condition. The initial tender purchasing price was

[12] Delibera AEEG n. 21/04 published in the official journal GU n. 66, 19 march 2004.

set higher of about 2% of the national regulated wholesale energy price (the so-called PUN). Until the entering into force of the single buyer, the PUN was meant to remunerate generators for the energy sold to distributors for non eligible consumers electricity needs. Based on former monopolist generating cost, it was recognized to be quite remunerative. Finally, the dominant operator subscribed contracts with the single buyer for 70%-75% of the total amount of energy supplied through those auctions.

3 Related literature

In the last decades, two lines of research offer a rationale explanation for the existence of markets for contracts, and, specifically, of markets for long-term financial agreements.

The first approach gives evidence of the welfare properties of long-term agreements in allocating resources and risk (see Anderson, 1984 for a review). Indeed, financial contracts operate as an insurance device. As parties agree on a fixed price of a good/asset to be paid over a fixed period of time in the future, this minimizes the variance of the profits realized on spot sales and the exposure to more volatile real-time markets. Most of the results related to this literature are driven in a framework of perfect competition and simultaneous forward and spot decisions.

One alternative approach focuses on the strategic motive for trading forward. Allaz (1992) and Allaz and Vila (1993, hereafter AV) originally show that firms have an incentive to enter into forward agreements to commit to a more aggressive behavior in the second stage spot market and thus gain a Stackelberg advantage.

The commitment mechanism goes as follow. Producers competing *à la Cournot* in a spot market know that increasing output would affect negatively rival's market position as quantities are strategic substitute (Bulow, Geneakoplos and Klemperer, 1985). An increase in production would have, however, a negative price elasticity effect on revenues. Rather, if a contract market is made available in the first stage of the game, marginal revenues would depend on the forward positions agreed. Thus each firm find it profitable to trade forward and to expand production as to gain a first mover advantage; long-term contracts represent a strategic variable yielding a new dimension of price competition into the quantity-game. Nevertheless, if both producers have access to the contract market, they are worse off. This is the *prisoners' dilemma* type of effect of the one-shot Cournot game. From the social welfare point of view, the tension between private and collective interests is resolved in favour of an improvement of market efficiency, since no generator succeeds in acquiring a leadership position while expanding its production. Furthermore, as the number of forward transactions approaches infinity the equilibrium converges to the competitive outcome. It is the inter-temporal trading that enhance the existing competition among duopolists.

3.1 Electricity Market Models

A vast, but fragmented, theoretical and empirical literature has contributed to investigate the behavior and the performances of wholesale electricity markets in the light of the contract-spot market interaction depicted by AV (for a survey see Martini, Pellegrini and Ballardi, 2002). No distinction is made between the financial or physical nature of agreements. Theoretical predictions support the idea, already pointed out by AV, that changes in the assumptions of the game formulation adversely affect generators' incentives to contract and bring to completely reverse conclusions. Thus, there is no clear consensus on the conditions upon which the implementation of a contract market could lead, by it self, to competitive outcomes in the spot market.

Specifically, Powell (1993) and lately Green (2003) show that the *pro-competitive* impact of forward contracts is weaken when the hypothesis of risk-neutrality on the demand-side, used by AV, is dropped[13].

Newbery (1995 and 1998) describes an alternative approach to sidestep AV implausible outcome when the nature of competition is not assumed to be in fixed quantity. When spot competition is modelled with a supply function equilibrium[14], AV results are preserved and only if entry is contestable (i.e. new entrants can sign base-load contracts); if the industry has enough capacity and new plants are less efficient than the incumbents, these latter have incentives to engage in forward contracting explicitly to deter entry. Green (1999a), shows that a linear supply function equilibrium in the spot market and Cournot conjectures in the contract market produce no forward contracting. Green's analysis highlights the importance of the structure of the interaction in the game theory formulations and the necessity that forward contracts affect the strategy, not only the outcomes, in the spot market.

More recent ongoing works, taking inspiration from Gul (1987) and Ausubel and Deneckere (1987), attempt to introduce some dynamic issues in the analysis of the spot/forward market interaction. Specifically, if there is multiple-period spot market competition than collusive outcomes might be sustained or entry deterred (among others Le Coq 2004; Liski and Montero, 2004).

Empirical studies have analyzed the static impact of long-term contracting positions on generators' spot market pricing behavior. Evidence of the mitigation role of contracts are mainly given for newly re-structured electricity markets where regulatory contractual regimes were applied (Helm and Powell, 1992 ; Wolfram, 1998 and 1999; Wolak, 2000a; Sweeting, 2001) [15].

[13] In the same vein are Hogan and Scott's (2000) comments on the MSC recommandation of implementing a contract market in California *"relying on buyers to engage in forward market hedging per se is not likely to have significant benefits in mitigating the market power of sellers. We find that there is little or no evidence to support the argument that the mere opportunity to arrange long-term forward market contracts would mitigate market power"*.

[14] In this model generators set profit maximizing points in correspondence to each residual demand realization. Each generator assume that competitors' supply functions are fixed.

[15] As for the England and Wales electricity industry, Helm and Powell (1992) find that the level of contracting has a significant effect on pool prices. Wolfram (1998 and 1999) explains the relative low level of spot prices with the following variables: regulatory constraints, treath of entry and financial contracts.

3.2 Retail competition and forward contracts

For the purpose of our study we will refer to Green (2003). His contribution belongs to a series of theoretical and empirical works in progress investigating the functioning of the New Electricity Trading Arrangements entered into force in England and Wales at the beginning of 2001. Above all, the goal is to verifies under what conditions this new system of voluntary bilateral agreements, replacing the mandatory pool, can truly achieved the declared objective of electricity prices reduction in the country (Green, 1999b; Evans and Green, 2003).

Departing from AV and Powell (1993), Green (2003) suggests that when contract demand comes from risk-averse retailers facing downstream competition a partial contracting equilibrium would emerges implying that the *pro-competitive* enhancing impact of a contract market is weaken. Estimates of the size of this adverse effect on the equilibrium level of spot prices is provided for the England and Wales electricity industry.

To examine the strategic choice of contracts on the demand-side, Green adds to the upstream generation Cournot game a third stage. He prouves that the nature of downstream competition affect the contracting behavior of risk-averse retailers. Specifically, when retailers face potential rivalry they are reluctant to enter into long-term contracts fearing a *lock-in* pricing effect. But this would implies a lower demand for contract and so higher spot prices. A regulated retailing regime would do better.

Before introducing Green, we will briefly recall Powell (1993), whose main innovation has been to investigate the impact of spot-forward markets interaction on buyers contractual choices. He models a renegotiation process among generators and distributors, to puts light on generators incentives to enter into new contracts at the expiration of the mandatory ones in use in the British electricity industry since 1991.

3.2.1 Powell's model (1993)

Taking inspiration by the AV forward-spot market sequential game, Powell models a contract demand in the form of non strategic risk-averse distributors with a mean-variance utility over their profits. The structure of the game goes as follow: in the first stage, generators meet in a contract market where, differing from AV, they compete in prices; since non-neutrality of demand is dropped, the equilibrium quantities of contracts would depend on distributors choices that in turn is derived by the maximisation process of the mean-variance utility function. In the second stage, generators compete in quantities in the spot market.

Given that demand for contracts is risk-averse, two forces drive distributors' contractual behav-

Wolak (2000a) illustrates the sensitivity of the generators' expected profit-maximising bidding strategies to the amounts of financial hedge contracts they held.

Finally, Sweeting (2001) tests the static Nash equilibrium assumption and finds that after 1996 the UK generators behavior was instead consistent with tacit collusion.

ior. On one hand, the equilibrium level of contracts would depend on hedging justifications. The standard optimal hedge condition states that the degree of hedging increase with risk-aversion, but this also implies that risk-averse buyer are pay a willing to pay a risk premium (demand is more inelastic). On the other, by hypothesis, the lower the expected spot price the higher the amount of energy covered by contracts. This is the *extra-benefit* in hedging, that correspond to the contract's mitigation role as in AV. Powell's main conclusion is that incentives distributors have to enter into long-term transactions are affected by the nature of the upstream competition. Generators know that signing significant long-term agreements to supply energy commits them to be very aggressive in the spot market, which can reduce average spot prices. Thus, full contracting with a forward price that equals the expected spot price is an equilibrium only when generators have Bertrand Conjectures and wholesale markets are perfectly competitive[16]. Conversely, knowing that buyers are keen to pay a risk-premium (i.e. a forward price that exceed the expected spot price), collusive generators can use the contract market to commit to non competitive levels of output in the spot market entailing a partial contracting equilibrium and higher spot prices. This implies that if generators have market power, there is little or no support for them to voluntarily surrender that market power through forward contracting at low prices.

3.2.2 Green's model (2003)

Green extends the demand-side contractual behavior analysis showing that the inefficient outcomes depend on the structural and economical characteristics of the downstream market. Explicitly, risk-aversion and increasing competition lowers the elasticity of demand, and this offsets the AV pre-commitment mechanism; such result holds irrespective of the upstream form of competition (Cournot or Bertrand conjectures); that is marginal cost pricing is not an equilibrium even when producers do not explicitly collude. In term of social welfare, Green suggests that a regulated regime would be likely to yield a more appealing solution. In the same vein, Newbery points out that a "*competently regulated domestic franchise may be preferable to a fully liberalized supply market*" (Newbery, 2002).

For the purpose of our research we will neglect Green's analysis of the regulated downstream regime, as we believe that pursuing a traditional regulatory approach in the retailing market does not represent a compatible solution with the objective of liberalization and that other form of *pro-competitive* interventions might better deal with market power issues.

Green models the supply-side as in the previous literature, but applies a conjectural variations approach to encompass the polar cases of quantity and price competition; this would ease comparisons with the earliest theoretical works, precisely of AV (Cournot competition) and Powell (Bertrand competition). A third stage is added to model retailers contractual choice.

[16] Recall that in AV there is alaways full contracting since agents are risk-neutral and the perfect foresight condition implies that the forward price equals spot price.

Two generators, indexed i and j, compete in quantities in both the forward and spot market. They have have constant marginal cost equal to c. The game is sequential; thus the equilibrium level of contracts offered in the market is derived solving the game by backward induction. Long-term conditions are agreed under uncertainty, as spot demand depend upon stochastic variables unknown at that time. In the spot market demand is $p = A - b(q_i + q_j)$ with $q_{i,j}$ the spot quantities chosen by generators. The intercept A is stochastic. This reflects the introduction of uncertainty on the demand-side or, equivalently, the effect of risk-aversion on buyers. A is assumed normally distributed with a mean equal to $A^e > c$ [17] and a variance σ_A^2. At the time where spot market competition occurs, the intercept value is known. Each producer chooses his forward position x_i to maximize the overall profit function, given the revenue in the wholesale markets. From the profit $\pi_i = (A - b(q_i + q_j))(q_i - x_i) + fx_i - cq_i$, reaction functions in the spot market ($R_i(q_j)$ and $R_j(q_i)$) are obtained. To find the contract supply (x_i and x_j), firms take into account the spot market reaction functions and maximise in a Nash setting the expected profits . Neglecting the conjectural variation coefficient for ease of explanation, the supply of contracts is given by the following symmetric reaction functions:

$$\begin{aligned} x_i &= \frac{A^e - c - bx_j + 9(f - p^e)}{4b - 9\frac{\partial}{\partial x_i}(f - p^e)}. \\ x_j &= \frac{A^e - c - bx_i + 9(f - p^e)}{4b - 9\frac{\partial}{\partial x_j}(f - p^e)}. \end{aligned} \tag{1}$$

where $f - p^e$ represent the *expected forward price premium.*

From the above reaction functions (1) it is easy to see that the supply of contracts depends on the margin between the forward and the expected spot price $(f - p^e)$, which in turn can be express endogenously as a function of the retailers inverse demand that has to be specified.

As in Powell, demand for contracts comes from non strategic retailers with a mean-variance utility over the profits. The utility function is defined under the following hypothesis. Incumbent retailers have the option to buy power either on the contract or in the spot market. However since downstream market is open to competition and new entrants are assumed to offer power at the prevailing spot price, the choice between long-term and spot positions is affected by the form of competition. Denoting by r the incumbent retailing price, V the total volume of energy for final consumption, and h an index of switching costs[18], profits in the downstream market are given by:

$$\Pi_i = (V - h(r - p))r - fx - (V - h(r - p) - x)p \tag{2}$$

[17] This condition is sufficient for that zero prices and quantities (spot and contracts) would not be observed, and that the difference between the modelled equations and the true expected value can be ignored. Another equivalent assumption would have been to define the support of A as $[\underline{a}, \overline{a}]$ but to cap the value of $\underline{a}$ such that $\underline{a} > c$, implying that it is alaways convenient for a generator to produce and trade forward.

[18] The higher is h the higher the competitive pressure, indeed, the higher the proportion of final demand that is lost by the incumbent if he offers a retailing price r grater than the prevailing spot price p of which potential entrants compete.

The profit maximising retailing price r does not depend upon contract price neither the volume of contracts signed by the incumbent but rather on the spot price and the shape of final demand.

The mean-variance utility function, when profit are maximised, takes the following form:

$$U_i = E(\Pi_i) - \frac{1}{2}\lambda Var(\Pi_i) = \\ \frac{V^2}{4h} - x(f - p^e) - \frac{1}{2}\lambda x^2 \sigma^2 \tag{3}$$

If there are n identical incumbent retailers the inverse contract demand, in terms of the expected forward margin, is:

$$\begin{aligned} f - p^e &= -(x_i + x_j)\frac{\lambda\sigma^2}{n} \\ \frac{\partial}{\partial x_i}(f - p^e) &= \frac{\partial}{\partial x_j}(f - p^e) = -\frac{\lambda\sigma^2}{n} \end{aligned} \tag{4}$$

It is straightforward to verify form equation (4) that when $f = p^e$ there will be no demand for contracts, contradicting previous theoretical results; rather, positive hedging will emerge only when the forward price is strictly lower than the expected spot price[19]. Reluctancy to fully cover retailing sales arise in Green from two reasons. On one hand, forward contracts directly increase retailers' profit variance (see equation 3); on the other, incumbent retailers do not benefit from a lower expected spot price as this would threaten new entry.

To find the decentralized equilibrium in the contract market, the inverse contract demand is plugged into the supply-side reaction functions. This gives a system with two equations and two unknowns:

$$\beta x_i + \alpha x_j = A^e - c \tag{5}$$

$$\alpha x_i + \beta x_j = A^e - c \tag{6}$$

where $\alpha = b + 9\frac{\lambda\sigma^2}{n} < \beta = 4b + 18\frac{\lambda\sigma^2}{n}$. The Nash equilibrium in the contract market is:

$$x_i^* = x_j^* = \frac{A^e - c}{\alpha + \beta}$$

The quantities produced depend on the contract market equilibrium:

$$q_k^* = \frac{A^e - c - b(x_j^* - 2x_i^*)}{3b}, with\ k = i, j \tag{7}$$

but still the expected spot prices is larger than marginal costs:

$$p^e = c + \frac{(A^e - c)(\alpha + \beta - 2b)}{3(\alpha + \beta)} \tag{8}$$

as $(\alpha + \beta - 2b) = 3b + 27\frac{\lambda\sigma^2}{n} > 0$

[19] Recall that for Powell the equality between forward and spot price is an equilibrium and implies full hedging, as in AV; conversely a negative forward expected price premium cannot be a sustainable equilibrium. If $f < p^e$, distributors demand for contracts would drive spot price down, when generators compete.

The above equations (7) and (8) provide a theoretical explanation of the inefficient outcomes (price above marginal cost and partial contracting) that would prevail in an industry characterized by a downstream market gradually opened to competition, albeit the implementation of a contract market. Numerical simulations are computed to support those findings. The model is calibrated selecting parameter values for risk-aversion and the variance of spot demand on the ground of energy market data for England and Wales along the 1990's. However, results appears to be sensitive to the value of the conjectural variation parameter and, to a less extent, on the level of risk-aversion [20].

4 Mandatory contractual regimes

The model we present builds on Green (2003). The main innovation of our work is the notion of contract obligation: we assume that the regulator or the competition agency mandates a quota of long term contracts. Our objective is to study the impact of the regulatory intervention on firms' behavior and to find the optimal measure that solves the inefficient contracting pointed out by Green, by restoring marginal cost pricing in the spot market. When the measure is optimally targeted, the total level of contracting is clearly larger than the one obtained by Green.

On a more technical ground, we neglect the conjectural variation. This is because, in Green the conjectural variation approach has proved useful to compare the sensitivity of the equilibrium outcomes to the degree of competition in the different segments of the industry. Instead, we limit our attention to Cournot competition between the two generators and to a competitive downstream scenario. As previously mentioned, we consider that liberalisation is a key element of the electricity reform and therefore we focus on the application of new forms of *light hand* regulation as a more flexible instrument of intervention.

The contractual obligation measure can be implemented in several ways, as the recent experiences of applying this kind of *light-hand* regulation in the electricity markets have also shown. The measure can be *horizontal*, that is it can be imposed on generators (upstream measure) or retailers (downstream measure), or *vertical*, when it concerns simultaneously both producers and distributors. In each of these three cases, the regulator or the competition authority has then to decide whether it is most convenient to oblige only one market player or all of them to sign long-term contracts. We will refer to the previous case as the *asymmetric measure scenario*; on the contrary, if all generators or retailers are concerned, the measure will be *symmetric*. This implies that altogether six *scenario* will be investigated.

[20]When generators compete with Betrand conjectures and the coefficient of risk-aversion takes high values (for example σ^2= 34,9 meaning a significant price volatility) than a competing downstream scenario can drive prices up to 19%, compare to a downstream regulated market. But for lower values of risk-aversion (σ^2 = 5,76), the increase in prices apper to be moderate, less than 5%. Equivalent results are obtained when generators have Cournot conjectures whatever the degree of uncertainty (or risk-aversion).

Recall that in Green, each generator chooses his forward position x_i to maximize the overall profit function, given the revenues in the wholesale markets. We set up the regulatory intervention as a minimum quantity requirement, so that the contracts of the agent i on which the measure is imposed, become a weighted sum of the mandatory share (denoted $M = \delta\overline{x_i}$) and the private one (i.e. $(1-\delta)\,x_i$), which in our framework is the only strategic variable chosen for hedging purposes. We assume that the prevailing forward market price f will remunerate both mandatory and private contracts.

In general, introducing a constraint on the set of actions available to agent i implies that, at the decentralized equilibrium, its contracts and those of the competitor will both depend on the measure (i.e. M).

If the measure is *asymmetric*, the equilibrium portfolio of total forward contracts in the market will be:

$$X^a(M) = X_i^a(M) + x_j^{*a}(M) = M + (1-\delta)\,x_i^{*a}(M) + x_j^{*a}(M),$$

where the a stands for asymmetric case. The superscript a will be equal to s, if the measure is imposed to one supplier, d, if it concerns one demand side retailer, or v, if the contractual obligation links vertically one generator to one retailer.

On the contrary, if the measure is equally extended to all generators (or retailers), the equilibrium level of forward contracts will be symmetric and thus the total portfolio of contracts in the market is as follows:

$$X^{fs}(M) = 2X_i^{fs}(M) = 2(M + (1-\delta)x_i^{*fs}(M))$$

where fs means symmetric case, and depending on the implementation scenario, fs will be denoted ss (measure imposed on the supply side), ds (on the demand side), vs (vertically).

The contractual obligation reintroduces the pro-competitive effect of forward sales as explained by AV by overcoming the insufficient incentive of oligopolistic generators to engage in long-term relationships. However, as the measure enters as a weighted share of total contracting, it can discourage generators or retailers to subscribe further bilateral private agreements in a typical Cournot setting. Indeed, contracts are strategic substitute in the terminology of Bulow *et al.* (1985). Therefore, the effectiveness of the obligation results from the trade-off between those *pro-competitive* and *crowding-out* effects.

To understanding the impact of the contractual obligation on firms' strategies we combine the different implementation possibilities, that is different Nash games, detailed in Sections 4.1 and 4.2. Stability, positivity and ranking of the solutions obtained for each scenario are studied in Appendix A.

4.1 The horizontal measure

4.1.1 Upstream contractual obligation

Asymmetric case We will first analyze the case of an asymmetric obligation on generator i. As discussed in Section 2.2, this implementation scenario corresponds to the mandatory contractual regimes that have been applied in different earliest deregulated industries. More precisely, the concrete application of an asymmetric measure has been indicated as an efficient regulatory tool when suppling companies differs in size. For instance, in the newly Italian spot market, one hypothesis suggested by the regulator to control for possible market power abuses was to require supplying companies, possessing a significant market share, to enter into long-term physical and financial agreements with the single buyer.

In the forward market, the producers sell an amount of contract equal to, respectively, $X_i^s = M + (1-\delta)\, x_i^s$ and $x_j^s = x_j$, at price f. Each generators maximize its profits, given the revenue in the spot market and the contract market. Profit are asymmetric, given the contract obligation:

$$\pi_i = (A - b(q_i + q_j))\,(q_i - M - (1-\delta)\, x_i^s) + f(M + (1-\delta)\, x_i^s) - cq_i \tag{9}$$

$$\pi_j = (A - b(q_i + q_j))\left(q_j - x_j^s\right) + f x_j^s - cq_j \tag{10}$$

Differentiating the equations (9) and (10), we obtain a system of reaction functions:

$$q_i = \frac{A - c - bq_j + bX_i^s}{2b}. \tag{11}$$

$$q_j = \frac{A - c - bq_i + bx_j^s}{2b}. \tag{12}$$

The solution of the system gives the generators' output and the spot price as a function of forward sales:

$$q_i = \frac{A - c + b(2X_i^s - x_j^s)}{3b}. \tag{13}$$

$$q_j = \frac{A - c + b(2x_j^s - X_i^s)}{3b}. \tag{14}$$

$$p = c + \frac{A - c - b(X_i^s + x_j^s)}{3}. \tag{15}$$

where $X_i^s = M + (1-\delta)\, x_i^s$. These results differ with respect to those of Green (2003) as price and quantities depends on the whole portfolio of firm i's contracts.

At the stage of forward market competition, firms do not know the value of A, which implies that also the quantity produced and the price are random. Their profits are:

$$\pi_i = \frac{A^e - c - b(X_i^s + x_j^s)}{3}\,\frac{A^e - c - bx_j^s + 2bX_i^s}{3b} + (f - p^e)X_i^s + \frac{\sigma_A^2}{(9b)^2}. \tag{16}$$

$$\pi_j = \frac{A^e - c - b(X_i^s + x_j^s)}{3}\,\frac{A^e - c - bX_i^s + 2bx_j^s}{3b} + (f - p^e)x_j^s + \frac{\sigma_A^2}{(9b)^2}. \tag{17}$$

where $X_i^s = M + (1-\delta)\, x_i^s$.

Generators choose strategically their supply of contracts, hence for firm i :
$\frac{\partial \pi_i}{\partial x_i^s} =$
$2(1-\delta)\frac{A^e-c-b(X_i^s+x_j^s)}{9} - (1-\delta)\frac{A^e-c-bx_j^s+2bX_i^s}{9} + (1-\delta)(f-p^e) + (M+(1-\delta)\,x_i^s)\,\frac{\partial}{\partial x_i^s}(f-p^e) = 0,$
whereas for firm j, we have:

$$\frac{\partial \pi_j}{\partial x_j} = 2\frac{A^e-c-b(X_i^s+x_j^s)}{9} - \frac{A^e-c-bX_i^s+2bx_j^s}{9} + (f-p^e) + x_j^s\frac{\partial}{\partial x_j^s}(f-p^e) = 0.$$

Solving the system of equations given by the derivatives of the profit functions, we obtain the supply of contracts:

$$\begin{aligned} x_i^s &= \frac{A^e-c-bx_j^s+9(f-p^e)}{4b(1-\delta)-9\frac{\partial}{\partial x_i^s}(f-p^e)} - \frac{M}{1-\delta} \\ x_j^s &= \frac{A^e-c-b(1-\delta)x_i^s+9(f-p^e)-bM}{4b-9\frac{\partial}{\partial x_j^s}(f-p^e)} \end{aligned}$$

Combining the competitive retail demand (see equation 4) with the above contract supply, the system of reaction function reads as follows:

$$x_i^s = \frac{A^e-c-(b+9\frac{\lambda\sigma^2}{n})x_j^s-\frac{M}{1-\delta}\left(4b(1-\delta)+9\frac{\lambda\sigma^2}{n}\right)}{4b(1-\delta)+18\frac{\lambda\sigma^2}{n}} \quad (18)$$

$$x_j^s = \frac{A^e-c-x_i^s(b(1-\delta)+9\frac{\lambda\sigma^2}{n})-bM}{4b+18\frac{\lambda\sigma^2}{n}} \quad (19)$$

or, with a more synthetic writing:

$$\beta^s x_i^s + \alpha x_j^s = A^e - c - m_i^s M \quad (20)$$

$$\alpha^s x_i^s + \beta x_j^s = A^e - c - m_j^s M \quad (21)$$

where:
$\beta^s = 4b(1-\delta)+18\frac{\lambda\sigma^2}{n} > \quad \alpha^s = b(1-\delta)+9\frac{\lambda\sigma^2}{n}, \quad m_i^s = 4b+\frac{9\frac{\lambda\sigma^2}{n}}{(1-\delta)} > \quad m_j^s = b$
In terms of reaction functions:

$$R_i\left(x_j^s\right) = \frac{A^e-c-m_i^s M}{\alpha} - \frac{\beta^s}{\alpha}x_i^s \quad (22)$$

$$R_j\left(x_i^s\right) = \frac{A^e-c-m_j^s M}{\beta} - \frac{\alpha^s}{\beta}x_i^s \quad (23)$$

Recall that the Green's system (see equations 5 and 6) obtains by setting $m_i^s = m_j^s = 0$, with a slope $-\frac{\beta}{\alpha}$ and $-\frac{\alpha}{\beta}$ for, respectively, the reaction function of firm i and j. Also notice that $\beta > \beta^s, \alpha > \alpha^s$.

In the plane (x_i^s, x_j^s), equations (22) and (23) show the trade-off between the pro-competitive and the crowding-out effects of the measure. On one side, with respect to the case where no measure is imposed, the sensitivity of firm i to firm j in terms of private forward sales increases ($-\frac{\beta}{\alpha} < -\frac{\beta^s}{\alpha}$); the larger the share of public contract δ, the smaller β^s,the flatter the reaction function (22). Firm i tends to be more aggressive in the contract market, relying on the mandatory contract as source of revenue. On the other, this incentive is restrained by the quantitative effect of M : the share of private contracting is substituted away by the mandatory one, and this shifts inwards the reaction function. The picture is similar for firm j : its sensitivity to the strategic variable of the rival increases $(-\frac{\alpha}{\beta} < -\frac{\alpha^s}{\beta})$, as it knows that firm i is obliged to sign the mandatory contracts, and the quantitative or Cournot effect of M discourages it from contracting. However, as the measure is asymmetric, its overall impact is stronger on firm i : this can be seen both in terms of the shift of its reaction function compared to firm j $(-\frac{\beta^s}{\alpha} < -\frac{\alpha^s}{\beta})$, and of its sensitivity to M $(\frac{m_i^s}{\alpha} > \frac{m_j^s}{\beta})$.

We solve the system given by equations (22) and (23) to calculate the Nash equilibrium in the contract market:

$$\begin{aligned} x_i^{*s} &= \frac{(\beta-\alpha)(A^e-c) - M(m_i^s\beta - m_j^s\alpha)}{(\beta^s\beta - \alpha^s\alpha)} \\ x_j^{*s} &= \frac{(\beta^s-\alpha^s)(A^e-c) - M(m_j^s\beta^s - m_i^s\alpha^s)}{(\beta^s\beta - \alpha^s\alpha)}. \end{aligned}$$

Notice that (see Corollary A.1 in the Appendix A) x_j^{*s} is always positive; therefore $M < (A^e-c)\frac{\beta-\alpha}{m_i^s\beta - m_j^s\alpha}$ is the necessary and sufficient condition that guarantees $x_i^{*s} > 0$. This is the consequence of the larger crowding out effect on i.

The solutions are asymmetric, but it is not necessarily the case that the equilibrium private contracts sold by i are larger that those supplied by j, as the pro-competitive affects mostly firm i.

In the Appendix A we show that in the range of positive solutions, there exists a threshold value of $M = M_i^s$ such that if and only if $M < M_i^s$, $x_i^{*s} > x_j^{*s}$. Simple calculations show that this effect is similar to introducing a marginal production cost advantage to firm i in Green setup. If appropriately targeted, a contractual obligation could make generator i more aggressive in the contract market, as it has an efficiency gain. In the context where one firm possesses a dominant share of the generation capacity, the pro-competitive effect of the asymmetric measure can induce the large generator to increase its contract cover and output, succeeding in spot market price reduction. This shows the potential benefit of a behavioral regulation, as an alternative to structural remedies.

Symmetric case If the measure is imposed on both the producers, that is $X_i^{ss} = M + (1-\delta)\,x_i^{ss}$ and $X_j^{ss} = M + (1-\delta)\,x_j^{ss}$), reaction functions become symmetric:

$$\begin{aligned} x_i^{ss} &= \frac{A^e - c - bx_j^{ss} + 9(f-p^e)}{4b(1-\delta) - 9\frac{\partial}{\partial x_i^{ss}}(f-p^e)} - \frac{M}{1-\delta} \\ x_j^{ss} &= \frac{A^e - c - bx_i^{ss} + 9(f-p^e)}{4b(1-\delta) - 9\frac{\partial}{\partial x_j^{ss}}(f-p^e)} - \frac{M}{1-\delta} \end{aligned} \tag{24}$$

Integrating in the above system the retail competition behavior (see equation 4), Nash equilibrium in contracting solves:

$$\beta^{ss} x_i + \alpha^{ss} x_j = A^e - c - m^{ss} M \quad (25)$$

$$\alpha^{ss} x_i + \beta^{ss} x_j = A^e - c - m^{ss} M \quad (26)$$

where:

$\beta^{ss} = 4b(1-\delta) + 18\frac{\lambda\sigma^2}{n} = \beta^s, \quad \alpha^{ss} = b(1-\delta) + 9\frac{\lambda\sigma^2}{n} = \alpha^s, \quad m^{ss} = 5b + \frac{9\lambda\sigma^2}{(1-\delta)n} = m_i^s + m_j^s.$

In the system given by equations (25) and (26) all the coefficient in the matrix of x_i^{ss} and x_j^{ss} are now affected by the measure; moreover, the coefficient that multiply M is the sum of those that enter in the reaction functions (22) and (23), as imposing a contractual obligation to both firms is simply a linear combination of the asymmetric measure. The pro-competitive effect compensates each other: the slope of firm j's reaction function is as steeper as the slope of firm i. The crowding-out effect is the same for both firms, and stronger than in the asymmetric case. Therefore at the Nash equilibrium both firms sign the same amount of private contracts, $x_i^{*ss} = x_j^{*ss}$, therefore:

$$x^{*ss} = \frac{A^e - c - m^{ss} M}{\alpha^{ss} + \beta^{ss}}$$

To have positive contracts, M must lie below a given threshold ($M < (A^e - c)/m^{ss}$, see corollary A.1 in the Appendix).

4.1.2 Downstream contractual obligation

Asymmetric case Assume now that there is only one retailer that is obliged to sign a mandatory share of long term contract. This is actually the case for the single buyer in the Italian electricity system, as explained in Section 2.2.

The measure will entail a change in the demand of contracts and an increase of retailer's i elasticity to the forward-spot margin. The inverse demand for contracts becomes

$$f - p^e = -(X_i^d + x_j^d)\frac{\lambda\sigma^2}{n} = -(M + (1-\delta)\, x_i^d + x_j^d)\frac{\lambda\sigma^2}{n} \quad (27)$$

$$\frac{\partial}{\partial x_i^d}(f - p^e) = -(1-\delta)\frac{\lambda\sigma^2}{n}$$

$$\frac{\partial}{\partial x_j^d}(f - p^e) = -\frac{\lambda\sigma^2}{n}$$

Replacing the set of equations (27) into the generators' reaction functions given by the Green's equations (1), we obtain:

$$\beta^d x_i^d + \alpha x_j^d = A^e - c - m^d M. \quad (28)$$

$$\alpha^d x_i^d + \beta x_j^d = A^e - c - m^d M.$$

where:

$\beta^d = 4b + 18(1-\delta)\frac{\lambda\sigma^2}{n} > \quad \alpha^d = b + 9(1-\delta)\frac{\lambda\sigma^2}{n}, \quad m^d = 9\frac{\lambda\sigma^2}{n}.$

Equilibrium contracts are:

$$\begin{aligned} x_i^{*d} &= (\beta - \alpha)\frac{(A^e - c) - m^d M}{\beta^d \beta - \alpha^d \alpha} \\ x_j^{*d} &= (\beta^d - \alpha^d)\frac{(A^e - c) - m^d M}{\beta^d \beta - \alpha^d \alpha} \end{aligned}$$

Positivity of the solutions depends on M that must lie below a given threshold (see A.1). The pro-competitive effects at stake have the same nature as those discussed in the asymmetric upstream measure, as in the system 28, only the coefficients for x_i^d change. However, now the measure modifies the slope of the firms' reaction functions by smoothing the impact of the retailers' risk-aversion. The crowding-out effect has the same intensity for both firms. At equilibrium firm i is more aggressive ($\beta - \alpha > \beta^d - \alpha^d$), regardless of M. The asymmetric downstream measure can thus be seen as an attractive alternative to the regulation of an incumbent retailer proposed by Green.

Symmetric case If all retailers sign a share of mandatory long term contracts (as for instance suggested in the New Zealand energy law or as a measure to ensure security of supply or to fulfil universal service and public service obligations), downstream competition is modified as follows:

$$\begin{aligned} f - p^e &= -(2M + (1-\delta)\,(x_i^{ds} + x_j^{ds}))\frac{\lambda\sigma^2}{n}. \qquad (29) \\ \frac{\partial}{\partial x_i^{ds}}(f - p^e) &= \frac{\partial}{\partial x_j^{ds}}(f - p^e) = -(1-\delta)\frac{\lambda\sigma^2}{n}. \end{aligned}$$

Replacing equations (29) into the reaction functions (1) gives:

$$\begin{aligned} \beta^{ds} x_i^{ds} + \alpha^{ds} x_j^{ds} &= A - c - m^{ds} M \\ \alpha^{ds} x_i^{ds} + \beta^{ds} x_j^{ds} &= A - c - m^{ds} M \end{aligned}$$

where:

$$\beta^{ds} = 4b + 18(1-\delta)\tfrac{\lambda\sigma^2}{n} = \beta^d > \quad \alpha^{ds} = b + 9(1-\delta)\tfrac{\lambda\sigma^2}{n} = \alpha^d, \quad m^{ds} = 18\tfrac{\lambda\sigma^2}{n} = 2m^d$$

The pro-competitive effects of a symmetric downstream measure are qualitatively similar to those discussed in the symmetric upstream case. The crowding-out effect is the same for both generators and stronger than in the asymmetric downstream measure. At equilibrium $x_i^{*ds} = x_j^{*ds}$, thus:

$$x^{*ds} = \frac{A - c - m^{ds} M}{\alpha^{ds} + \beta^{ds}}$$

Positivity of the solutions requires $M < (A^e - c)/m^{ds}$ (see corollary A.1 in the Appendix).

4.2 The vertical measure

An alternative implementation scenario is represented by imposing the contractual obligation to one retailer and one generator, if the measure is asymmetric, or to generalize this practice to all the market participants. Such an hypothesis reflects the vertical integrated structures as experienced in Alberta or New Zealand before the electricity reform.

If retailer and generator i are linked through long-term contracts, the contract offer of i is given by (18), while the retailer behave as specified by the set of equations (27). Finally the Nash equilibrium solves the following system:

$$\begin{aligned}(1-\delta)\beta x_i^v + \alpha x_j^v &= A^e - c - \beta M \\ (1-\delta)\alpha x_i^v + \beta x_j^v &= A^e - c - \alpha M\end{aligned}$$

which can be rewritten as

$$\begin{aligned}\beta\left[M + (1-\delta)x_i^v\right] + \alpha x_j^v &= A^e - c \\ \alpha\left[M + (1-\delta)x_i^v\right] + \beta x_j^v &= A^e - c\end{aligned} \tag{30}$$

implying the equilibrium contracts:

$$\begin{aligned}x_i^{*v} &= \frac{A^e - c - M(\beta+\alpha)}{(1-\delta)(\beta+\alpha)} \\ x_j^{*v} &= \frac{A^e - c}{\beta+\alpha}\end{aligned}$$

Notice that x_i^{*v} is positive if and only if $M < (A^e - c)/(\beta+\alpha)$. Similarly to the case of the asymmetric obligation imposed on one generator, in the Appendix A we show that for M lower than a given value firm i signs more contracts than j, who sells as many contracts as in the Green's model.

If the obligation is generalized, we combine the set of equations (24) with (29), which gives

$$\begin{aligned}\beta\left[M + (1-\delta)x_i^{vs}\right] + \alpha\left[M + (1-\delta)x_j^{vs}\right] &= A^e - c \\ \alpha\left[M + (1-\delta)x_i^{vs}\right] + \beta\left[M + (1-\delta)x_j^{vs}\right] &= A^e - c\end{aligned} \tag{31}$$

The Nash solutions are:

$$x_i^{*vs} = \frac{A^e - c - M(\beta+\alpha)}{(1-\delta)(\beta+\alpha)} = x_j^{*vs} = x_i^{*v}$$

Positivity requires $M < (A^e - c)/m^{vs}$.

Equations (30) and (31) show that the measure is totally internalized not only on those on which it is imposed, but also on the other market participants. Generators obliged to enter into mandatory agreements with retailers just reduce their private contracting to exactly compensate the level of the mandatory ones, thus neutralizing the *pro-competitive* effect of the measure. When the obligation is only imposed on firm i, firm j, knowing that at equilibrium the competitor will contract as the measure were absent, is left with the Green's outcome. If both generators are vertically integrated with retailers through a system of symmetric mandatory contracts, they internalize reciprocally the measure.

It results that locking one or all generators to the retailing sector does not allow to solve forward market inefficiency. At the equilibrium, total contracting is the same as in Green (2003), both in the asymmetric and the symmetric case:

$$X^{vs}(M) = X^{v}(M) = 2\frac{A-c}{\beta+\alpha}$$

The vertical measure is such that retailers are obliged to buy exactly the mandatory share of contracts. This reproduces, in some sense, the AV hypothesis that risk-neutral speculators are assumed to equal forward positions taken by producers, on the basis of arbitrage considerations. The ineffectiveness of the measure is therefore due to the complete matching of the demand and supply in the contract market, perfectly anticipated by the agents' strategies. In fact, if in the AV model we impose a contract obligation on one or all firms, we observe the same effect of substitution between private and mandatory contracts, so that spot market price and quantity are not affected.

5 Optimal policy

In all but the vertical measure cases, the contractual obligation can be targeted to solve the forward market inefficiency by calculating the optimal measure that maximizes the consumer surplus[21] subject to the generators' break-even constraint.

Given the interaction between the spot and the forward markets, at the decentralized equilibrium the expected spot price and quantities will in turn depend on M. In fact, we have:

$$q_i^{*e}(M) = \frac{A^e - c - b(x_j^{*a}(M) + 2X_i^{*a}(M))}{3b}. \tag{32}$$

$$q_j^{*e}(M) = \frac{A^e - c - b(X_i^{*a}(M) + 2x_j^{*a}(M))}{3b}. \tag{33}$$

$$p^{*e} = c + \frac{A^e - c - b(X_i^{*a}(M) + x_j^{*a}(M))}{3}. \tag{34}$$

where $X_i^{*a}(M) = M + (1-\delta)x_i^{*a}(M)$. The optimal policy solves:

$$\begin{aligned} & Max \;\; CS_M = (A^e - p^{*e}(M))(q_i^*(M) + q_j^*(M)) \\ = \; & \frac{1}{9}\frac{\left(2(A^e - c) + 2b(X_i^{*a}(M) + x_j^{*a}(M)\right)^2}{b} \\ & s.t. \; p^{*e}(M) \geq c \end{aligned} \tag{35}$$

[21] There are several reasons to be in favour of a consumer welfare objective instead of a more general approach to maximize social welfare. First of all, given that the aim of the regulatory intervention is to mitigate market power, it seems reasonable to pursue allocative efficiency which directly benefit consumers as it implies prices at marginal cost. Anyway, absent any price discrimination among consumers categories, from a policy perspective maximizing consumer welfare give the same results of maximizing total surplus. Moreover, EC competition law appears to give more emphasis on consumer welfare . By the principle of the "primacy" of the community law, EC competition law enforcement prevails on national law and, therefore, on regulation. This offers a further argument for the application of the above mentioned analysis.

where $a = s, d$.

Given that $x_i^{*a}(M), x_j^{*a}(M)$ are linear functions of M, straightforward calculations show that the consumer surplus (see equation 35) is convex in M; therefore its maximum is reached at the value of M where the constraint is binding. The amount of the asymmetric contractual obligations such that $p^e = c$ will be denoted by M_{mc}^a :

$$M_{mc}^a \equiv Arg\{p^{*e}(M) = c\}$$

Therefore, by setting in an appropriate way the amount of mandatory contracts, we retrieve the limit AV's result obtained by infinitely repeating the contract game.[22]

In the Appendix B we compute the optimal contractual asymmetric obligation:

$$M_{mc}^a = (A^e - c)\,\frac{b\left((1-\delta)(\beta-\alpha) + (\beta^a - \alpha^a)\right) - (\beta^a\beta - \alpha^a\alpha)}{b\left((1-\delta)(m_i^a\beta - m_j\alpha) + (m_j^a\beta^a - m_i\alpha^a) - (\beta^a\beta - \alpha^a\alpha)\right)}.$$

The specific coefficients vary depending whether the measure concerns one generator ($a = s$) or one retailer only ($a = d$). In the Appendix B (lemma 6), we also check that M_{mc}^a is positive.

If the measure is applied to all market participants, the consumer surplus is slightly different, but still convex in M :

$$\begin{aligned} & Max\;\; CS_M = (A^e - p^{*e}(M))(q_i^*(M) + q_j^*(M)) \\ = \;\; & \frac{1}{9}\frac{\left(2(A^e - c) + b(X_i^{*fs}(M) + X_j^{*fs}(M)\right)^2}{b} \\ & s.t.\; p^{*e}(M) \geq c \end{aligned} \tag{36}$$

where $fs = ss, ds$.

The optimal measure is (lemma 7 in appendix B):

$$M_{mc}^{fs} = (A^e - c)\,\frac{\alpha^{fs} + \beta^{fs} - 2b(1-\delta)}{2b\left(\alpha^{fs} + \beta^{fs} - m^{fs}(1-\delta)\right)}.$$

In both the downstream and the upstream cases, M_{mc}^{fs} is positive (see appendix B).

5.1 Marginal cost pricing and private contracting

Marginal cost pricing implies that at equilibrium the total portfolio of contracts is equal to $(A^e - c)/b$, both in the symmetric and the asymmetric case. The question that now arises is whether the contract level that curb generators' market power leaves room for private contracting; as we know from Section 4 that to guarantee interior Nash solutions, we have to restrict the value of M to limit the crowding-out effect.

We show that:

[22] More realistically, an optimal contractual measure can be targetes on long run marginal cost to take into account investment issues.

Proposition 1 *In the case of an horizontal upstream measure, when the obligation is asymmetric, marginal cost pricing crowds out generator i; when the measure is symmetric, there is no private contracting at all.*

Proof. See Appendix C. ■

The negative effect on private contracting is weaker when one generator only is constrained to sign a mandatory share of long-term contracts, as the competitor always engage in forward contracting, regardless the level of M. When the measure is symmetric, each generator is sensitive to the level of M and marginal cost pricing would require a too high M to preserve private contracting; thus the implementation of a contractual obligation might end-up, in this case, to be too pervasive.

For horizontal downstream measure, both in the symmetric and asymmetric cases, the following holds:

Proposition 2 *In the case of a downstream measure, positive private contracting by both generators is guaranteed if and only if $b > \frac{9\lambda\sigma^2}{n}$*

Proof. See Appendix D. ■

Therefore, with a downstream measure, whether the market can bear a contractual obligation with positive private contracting depends on structural parameters such as risk aversion and numbers of competitors at the retail level, and demand uncertainty and slope at the spot market level.

Assuming that the variance of the price is σ^2, which gives $\sigma_A^2 = 9\sigma^2$, and using the data provided by Green ($b = 2/3$, $\lambda = 0.178$, $\sigma^2 = 5.76$ or alternatively $\sigma^2 = 34.9$, $n = 12$), the optimal downstream measure would eliminate private contracting, that is the condition of proposition 2 does not hold. However, when $\sigma^2 = 5.76$, two more retailers will be enough to ensure an active forward market. Clearly, if the variance is larger, an optimal downstream measure that constrains generator to marginal cost pricing would require a very large number of retailers (at least 83) to have positive private contracting[23]. In this case, but also whenever estimation of structural parameters proves to be difficult, it is preferable to implement an asymmetric upstream measure that ensures private contracting, though at the equilibrium the generator which is not obliged to sign contracts is the only one who freely trades bilateral contracts.

At the optimum, it is possible to rank Nash solutions across different regulatory scenarios and to compare private to mandatory contracting. From a policy perspective, it is useful to recognize what kind of distortions might be triggered by the application of each regulatory scheme. Denoting by mc the subscript for firms' contracts at optimal measure, we have:

[23] For example, in 2002, the Italian dowstream liberalized market accounted for almost 100 active retailers. This despite the fact that 60% of final sales to eligible consumers were supplied by the first four retailers (see case N. A333 - Enel Trade-Clienti Idonei, violation of art. 82 of the EC treaty; http://www.agcm.it)

Proposition 3 *When* $b > \frac{9\lambda\sigma^2}{n}$*, marginal cost pricing implies the following ranking:*
1) in terms of firms' private contracting: $x^{*s}_{j_{mc}} > x^{*d}_{i_{mc}} > x^{*ds}_{_{mc}} > x^{*d}_{j_{mc}}$;
2) in terms of total private contracting: $(1-\delta)x^{*d}_{i_{mc}} + x^{*d}_{j_{mc}} > 2(1-\delta)x^{*ds}_{_{mc}} > x^{*s}_{j_{mc}}$;
3) in terms of mandatory contracting: $M^d_{_{mc}} < 2M^{ds}_{mc} < M^s_{mc}$;
4) in terms of private versus mandatory contracting:
4a) $x^{*s}_{j_{mc}} > M^s_{mc}$
4b) $(1-\delta)x^{*d}_{i_{mc}} + x^{*d}_{j_{mc}} < M^d_{_{mc}}$
4c) $2(1-\delta)x^{*ds}_{i_{mc}} < 2M^{ds}_{mc}$

Proof. See Appendix D. ■

We see that in term of individual bilateral trade, when the measure is implemented upstream and asymmetrically, as private contracting is a positive function of M, generator j will increase his forward position to the point that $x^{*s}_{j_{mc}}$ turns out to be the largest amount of private contracts ever signed at the optimum. Instead, regarding downstream regulation, the asymmetric mandatory obligation enhances a stronger pro-competitive effect on generator i compared to the rival ($x^{*d}_{i_{mc}} > x^{*d}_{j_{mc}}$) and to the symmetric case ($x^{*d}_{i_{mc}} > x^{*ds}_{_{mc}}$). Notice that, if generator i was dominant, since the optimal measure is already such that $p^e = c$, larger forward sales would only benefit him in terms of higher market shares.

As for total private contracting, downstream measures induce all generators to engage in more bilateral contracting compared to the upstream regulation. Furthermore, we find that imposing symmetrically a mandatory share on all retailers leads to a thinner forward market as the pro-competitive effect compensate between agents ($2(1-\delta)x^{*ds}_{_{mc}} < (1-\delta)x^{*d}_{i_{mc}} + x^{*d}_{j_{mc}}$). As the forward-spot margin is a negative function of contracts (see 4), with marginal cost pricing, the asymmetric downstream measure grants the lowest forward price.

Recall that by definition, as the optimal measure is such that total contracting equals $(A^e - c)/b$, the larger the mandatory contracts the smaller the private ones. Therefore, given the above discussed ranking of firms' contracting, the larger share of mandatory long-term agreements corresponds to the asymmetric upstream case ($M^d_{_{mc}} < 2M^{ds}_{mc} < M^s_{mc}$). However, notice that in the downstream measures the crowding-out effect is controlled for but not eliminated; therefore the level of private contracting in those scenario appears to be lower than the mandatory one. This is not the case for the upstream regulation where for firm j, $x^{*s}_{j_{mc}} > M^s_{mc}$, but here firm i contracting is reduced to the public obligation. The shortcoming is that it reintroduces a pervasive regulation on markets.

6 Conclusions

The model proposed here attempted to depict various regulatory scenarios as a useful tool for the implementation of a contractual pro-competitive regulation. For this scope, we have investigated the conditions under which optimal contractual obligations could mitigate generators market power, when those latter face a demand for contracts from competing risk averse retailers. We show that imposing a mandatory share of contracts produces two opposite effects on generators incentives to further trade privately: a pro-competitive and a crowding-out effect.

Results show that the balance between those two effects is not easy to achieve, thought the measures can be targeted to obtain a marginal cost pricing in the spot market. Asymmetric upstream optimal requirements might appear to be a too pervasive regulatory tool for the generator on which it is imposed since it crowds out all his private contracting. However, it proves to have the advantage of making rivals always keen to subscribe bilateral contracts. This is the pro-competitive effect explained by AV.

Conversely, measures on the contract demand-side preserve an active bilateral trade for all generators. However, the crowing-out effect remains a limiting force that constraints the size of the private bilateral contracting with respect to the share of the mandatory one. Moreover, the measure has to be targeted on the overall electricity market performance. We find that binding conditions for the optimal downstream obligations to be compatible with private contracting are determined by the relative magnitude of structural parameters (intensity of downstream competition, retailers' risk aversion, slope and variance of the spot market demand). Nevertheless, this intervention goes in the direction to solve the inefficiency highlighted by Green, that is too little demand side responsiveness, by smoothing risk-aversion. Clearly, those findings can contribute to address the debate on regulatory efforts to stimulate demand elasticity.

Our model can be adapted to study upstream capacity release programmes, as this will allow to compare the relative efficiency of different behavioral pro-competitive measure with respect to structural ones. Furthermore, extending our framework to a Stackelberg game could provide insights on the functioning of spot and contract electricity markets with dominant players, an issue still experienced in the European countries.

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A Properties of the Nash solutions

For ease of calculations, we will study the case of a symmetric measure (Section A.1) with respect to the case of a symmetric one (Section A.2).

A.1 Asymmetric measure

We study the properties of the Nash solutions given by the following system:

$$\beta^a x_i + \alpha x_j = A^e - c - m_i^a M$$
$$\alpha^a x_i + \beta x_j = A^e - c - m_j^a M$$

$a = s$ (supply only), d (demand only), v (vertical)

Nash solutions can be written as:

$$x_i^{a*} = \frac{(\beta-\alpha)(A^e-c) - M(m_i^a\beta - m_j^a\alpha)}{\beta^a\beta - \alpha^a\alpha}. \tag{37}$$
$$x_j^{a*} = \frac{(\beta^a-\alpha^a)(A^e-c) - M(m_j^a\beta^a - m_i^a\alpha^a)}{\beta^a\beta - \alpha^a\alpha}.$$

Recall the case-specific coefficients:

$\beta^s = 4b(1-\delta) + 18\frac{\lambda\sigma^2}{n}$, $\alpha^s = b(1-\delta) + 9\frac{\lambda\sigma^2}{n}$, $m_i^s = 4b + \frac{9\frac{\lambda\sigma^2}{n}}{(1-\delta)}$, $m_j^s = b$.
$\beta^d = 4b + 18(1-\delta)\frac{\lambda\sigma^2}{n}$, $\alpha^d = b + 9(1-\delta)\frac{\lambda\sigma^2}{n}$, $m_i^d = m_j^d = 9\frac{\lambda\sigma^2}{n}$.
$\beta^v = (1-\delta)\beta$, $\alpha^v = (1-\delta)\alpha$, $m_i^v = \beta$, $m_j^v = \alpha$.

Lemma 1 *(Stability) The Nash solutions given by (37) are stable, that is*

$$\left|\frac{\beta^a}{\alpha^a}\right| > \left|\frac{\alpha}{\beta}\right|$$

for $a = s, d, v$.

Proof. This is immediate, given that
$(\beta^s\beta) - (\alpha^s\alpha) = 3\frac{5b^2n^2(1-\delta)+21bn\lambda\sigma^2(2-\delta)+81\lambda^2\sigma^4}{n^2} > 0$
$(\beta^d\beta) - (\alpha^d\alpha) = 3\frac{5b^2n^2+21bn\lambda\sigma^2(2-\delta)+81\lambda^2\sigma^4(1-\delta)}{n^2} > 0$
$(\beta^v\beta) - (\alpha^v\alpha) = (1-\delta)\beta^2 - (1-\delta)\alpha^2 = 3\frac{bn+3\lambda\sigma^2}{n^2}\left(5bn + 27\lambda\sigma^2\right) > 0$ ■

Lemma 2 *(Positivity) NSC for interior solutions given by (37) are as follows:*
1) if $\min\left\{m_i^a\beta - m_j^a\alpha, m_j^a\beta^a - m_i^a\alpha^a\right\} \geq 0$, $x_i,x_j > 0 \Leftrightarrow$
$M < \min\left\{(A^e-c)\frac{\beta-\alpha}{m_i^a\beta - m_j^a\alpha}, (A^e-c)\frac{\beta^a-\alpha^a}{m_j^a\beta^a - m_i^a\alpha^a}\right\}$
2a) if $\min\left\{m_i^a\beta - m_j^a\alpha, m_j^a\beta^a - m_i^a\alpha^a\right\} = m_i^a\beta - m_j^a\alpha < 0$, *then* $x_i > 0$; $x_j > 0 \Leftrightarrow M < (A^e-c)\frac{\beta^a-\alpha^a}{m_j^a\beta^a - m_i^a\alpha^a}$
2b) if $\min\left\{m_i^a\beta - m_j^a\alpha, m_j^a\beta^a - m_i^a\alpha^a\right\} = m_j^a\beta^a - m_i^a\alpha^a < 0$, *then* $x_j > 0$; $x_i > 0 \Leftrightarrow M < (A^e-c)\frac{\beta-\alpha}{m_i^a\beta - m_j^a\alpha}$.

Proof. Stability (Lemma 1) ensures $(\beta^a\beta - \alpha^a\alpha) > 0$; straightforward calculations show that $\beta > \alpha, \beta^a > \alpha^a \ \forall\ a = s, d, v$; moreover, by assumption $(A^e - c) > 0$. The positivity of the solutions given by equations (37) solely depends on their denominator. ■

Corollary 1 *Measure on supply:*
$\min\left\{m_i^s\beta - m_j^s\alpha, m_j^s\beta^s - m_i^s\alpha^s\right\} = m_j^s\beta^s - m_i^s\alpha^s < 0$, *hence* $x_j^{*s} > 0\ \forall M$;
$m_i^s\beta - m_j^s\alpha > 0$, *hence* $x_i^{*s} > 0 \Leftrightarrow M < (A^e - c)\frac{\beta-\alpha}{m_i^s\beta - m_j^s\alpha} = M^s$.

Corollary 2 *Measure on demand:*
$\min\left\{m^d\beta - m^d\alpha, m\beta^d - m\alpha^d\right\} = m^d\beta^d - m^d\alpha^d > 0$, *hence* $x_i^{*d}, x_j^{*d} > 0 \Leftrightarrow$
$M < (A^e - c)\frac{1}{m^d} = M^d$

Corollary 3 *Vertical measure:*
$\min\left\{m_i^v\beta - m_j^v\alpha, m_j^v\beta^v - m_i^v\alpha^v\right\} = m_j^v\beta^v - m_i^v\alpha^v = 0$; *hence* $x_j^{*v} > 0\ \forall M$; $x_i^{*v} > 0 \Leftrightarrow M < (A^e - c)\frac{1}{\beta+\alpha} = M^v$.

Lemma 3 *(Ranking of the solutions). There exists an* $M_i^a = M_i^a(A^e, c, b, \delta, \lambda, \sigma^2, n) > 0$, *for* $a = s, d, v$, *such that*

$$x_i^{*a} \geq x_j^{*a} \quad iif \quad M \leq M_i^a$$

where $M_i^a = \frac{(A^e-c)[\beta-\alpha-(\beta^a-\alpha^a a)]}{(m_i^a\beta - m_j^a\alpha)-(m_j^a\beta^a - m_i^a\alpha^a)}$.

Proof. The calculation of M_i^a immediately obtains by comparing the Nash solutions given by equations (37). ■

Corollary 4 *Measure on supply. For* $M < M_i^s$, $x_i^{*s} > x_j^{*s}$, *whereas for* $M_i^s < M < M^s$, $x_j^{*s} > x_i^{*s} = 0$.

Proof. Simple calculations show that

$$M_i^s - M^s = (A^e - c)\frac{(\beta-\alpha-(\beta^s-\alpha^s))\left(m_i^s\beta - m_j^s\alpha\right) - (\beta-\alpha)\left[(m_i^s\beta - m_j^s\alpha) - (m_j^s\beta^s - m_i^s\alpha^s)\right]}{\left((m_i^s\beta - m_j^s\alpha) - (m_j^s\beta^s - m_i^s\alpha^s)\right)\left(m_i^s\beta - m_j^s\alpha\right)}$$

The denominator is positive as:

by corollary A.1, $-(m_j^s\beta^s - m_i^s\alpha^s) > 0$, and $(m_i^s\beta - m_j^s\alpha) > 0$; then $\left((m_i^s\beta - m_j^s\alpha) - (m_j^s\beta^s - m_i^s\alpha^s)\right) > 0$;

the numerator is negative:

$$(\beta - \alpha - (\beta^s - \alpha^s))\left(m_i^s\beta - m_j^s\alpha\right) - (\beta - \alpha)\left[(m_i^s\beta - m_j^s\alpha) - (m_j^s\beta^s - m_i^s\alpha^s)\right] =$$
$$-9\left(5b^2n^2(1-\delta) + 21bn\lambda\sigma^2(2-\delta) + 81\lambda^2\sigma^4\right)\frac{bn(1-\delta)+3\lambda\sigma^2}{n^3(1-\delta)} < 0.$$

We conclude that $M_i^s - M^s < 0$, that gives the result. ■

Corollary 5 *Measure on demand.* $M_i^d = M^d \Leftrightarrow x_i^{*d} > x_j^{*d} > 0 \;\forall M < M^d$.

Corollary 6 *Vertical measure. For* $M < M_i^v$, $x_i^{*v} > x_j^{*v}$, *whereas for* $M_i^v < M < M^v$, $x_j^{*v} > x_i^{*v} = 0$.

Proof. $M_i^v - M^v = -(A^e - c)\frac{1-\delta}{\beta+\alpha} < 0$. The proof is similar to those of A.1. ■

A.2 Symmetric measure

We study the properties of the Nash solutions given by the following system

$$\begin{aligned} \beta^{fs}x_i + \alpha^{fs}x_j &= A^e - c - m^{fs}M \\ \alpha^{fs}x_i + \beta^{fs}x_j &= A^e - c - m^{fs}M \end{aligned} \tag{38}$$

where fs=ss (supply symmetric), ds (demand symmetric), vs (vertical symmetric).

The Nash solutions are:

$$x_i^{*fs} = x_j^{*fs} = \frac{(A^e - c) - m^{fs}M}{\beta^{fs} + \alpha^{fs}} \tag{39}$$

Recall that the coefficient take specific values, depending on the implementation scenario:

$\beta^{ss} = 4b(1-\delta) + 18\frac{\lambda\sigma^2}{n}$, $\alpha^{ss} = b(1-\delta) + 9\frac{\lambda\sigma^2}{n}$, $m^{ss} = 5b + \frac{9\lambda\sigma^2}{(1-\delta)n}$.
$\beta^{ds} = 4b + 18(1-\delta)\frac{\lambda\sigma^2}{n}$, $\alpha^{ds} = b + 9(1-\delta)\frac{\lambda\sigma^2}{n}$, $m^{ds} = 18\frac{\lambda\sigma^2}{n}$.
$\beta^{vs} = (1-\delta)\beta$, $\alpha^{vs} = (1-\delta)\alpha$, $m^{vs} = (5b + 27\frac{\lambda\sigma^2}{n}) = \alpha + \beta$.

Lemma 4 *The Nash solutions given by (39) are stable, that is*

$$\left|\frac{\beta^{fs}}{\alpha^{fs}}\right| > \left|\frac{\alpha^{fs}}{\beta^{fs}}\right|$$

for $fs = ss, ds, vs$.

Proof. This is immediate, given that:
$(\beta^{ss})^2 - (\alpha^{ss})^2 = 3\left(3\lambda\sigma^2 + bn(1-\delta)\right)\frac{27\lambda\sigma^2 + 5bn(1-\delta)}{n^2} > 0$.
$(\beta^{ds})^2 - (\alpha^{ds})^2 = 3\left(5bn + 27\lambda\sigma^2(1-\delta)\right)\frac{bn + 3\lambda\sigma^2(1-\delta)}{n^2} > 0$.
$(\beta^{vs})^2 - (\alpha^{vs})^2 = 3\frac{bn+3\lambda\sigma^2}{n^2}\left(5bn + 27\lambda\sigma^2\right)(1-\delta)^2 > 0$. ■

Lemma 5 *There exists an* $M^{fs} = M^{fs}\left(A^e, c, b, \delta, \lambda, \sigma^2, n\right)$, *for* $fs = ss, ds, vs$, *such that the Nash solutions given by (39) are positive.*

Proof. Given that $\beta^{fs} + \alpha^{fs} > 0$, $(A^e - c) > 0$, the Nash solutions are positive iff $M < \frac{A^e - c}{m^{fs}}$, for $s = ss, ds, vs$. ■

B Optimal policy

Lemma 6 *It exists a unique* $M^a_{mc} = M^s_{mc}(A^e, c, b, \delta, \lambda, \sigma^2, n) > 0$ *such that* $M^s_{mc} = Arg\left\{p^e(M^s) = c\right\}$ *for* $a = s, d$.

Measure on supply. $M^s_{mc} = Arg\left\{p^e(M^s) = c\right\}$ gives:

$$M^s_{mc} = (A^e - c)\frac{b\left((1-\delta)(\beta-\alpha) + (\beta^s - \alpha^s)\right) - (\beta^s\beta - \alpha^s\alpha)}{b\left((1-\delta)(m^s_i\beta - m^s_j\alpha) + (m^s_j\beta^s - m^s_i\alpha^s) - (\beta^s\beta - \alpha^s\alpha)\right)}.$$

Given that the equation $p^e(M^s) - c = 0$ is linear in M, M^s_{mc} is unique.

$M^s_{mc} > 0$, as

$b(1-\delta)(\beta-\alpha) + b(\beta^s - \alpha^s) - (\beta^s\beta - \alpha^s\alpha) =$
$9\frac{-b^2n^2(1-\delta)-6bn\lambda\sigma^2(2-\delta)-27\lambda^2\sigma^4}{n^2} < 0$

$(1-\delta)(m^s_i\beta - m^s_j\alpha) + (m^s_j\beta^s - m^s_i\alpha^s) - (\beta^s\beta - \alpha^s\alpha) =$
$-27\lambda\sigma^2\frac{2bn(1-\delta)+3\lambda\sigma^2(2-\delta)}{n^2(1-\delta)} < 0.$

Measure on demand. By equating $p^e(M^d) - c = 0$, we obtain:

$$M^d_{mc} = (A^e - c)\frac{b\left((\beta-\alpha)(1-\delta) + (\beta^d - \alpha^d)\right) - (\beta^d\beta - \alpha^d\alpha)}{b\left(m^d\left((1-\delta)(\beta-\alpha) + (\beta^d - \alpha^d)\right) - (\beta^d\beta - \alpha^d\alpha)\right)}.$$

Uniqueness is proved similarly to the previous case. Positivity of M^d_{mc} is also straightforward, as

$b\left((\beta-\alpha)(1-\delta) + (\beta^d - \alpha^d)\right) - (\beta^d\beta - \alpha^d\alpha) =$
$-3\frac{3b^2n^2(1+\delta)+3bn\lambda\sigma^2(12-5\delta)+81\lambda^2\sigma^4(1-\delta)}{n^2} < 0.$

$\left(m^d(1-\delta)(\beta-\alpha) + m^d(\beta^d - \alpha^d) - (\beta^d\beta - \alpha^d\alpha\right) =$
$-3\frac{5b^2n^2+12bn\lambda\sigma^2(2-\delta)+27\lambda^2\sigma^4(1-\delta)}{n^2} < 0.$

Lemma 7 *It exists a unique* $M^{fs}_{mc} = M^s_{mc}(A^e, c, b, \delta, \lambda, \sigma^2, n) > 0$ *such that* $M^s_{mc} = Arg\left\{p^e(M^s) = c\right\}$ *for* $fs = ss, ds$.

Measure on supply. Similarly to the previous cases, M^{ss}_{mc} is unique.

$$M^{ss}_{mc} = (A^e - c)\,\frac{2b(1-\delta) - (\alpha^{ss} + \beta^{ss})}{2b\left(m^{ss}(1-\delta) - (\alpha^{ss} + \beta^{ss})\right)}.$$

$M^{ss}_{mc} > 0$, as

$2b(1-\delta) - \alpha^{ss} - \beta^{ss} = -\frac{3bn+27\lambda\sigma^2-18\lambda\sigma^2\delta+bn\delta}{n} < 0.$

$m^{ss}(1-\delta) - (\alpha^{ss} + \beta^{ss}) = -2\frac{9\lambda\sigma^2-9\lambda\sigma^2\delta+2bn\delta}{n} < 0.$

Measure on demand. The equation $p^e(M^{ds}) - c = 0$ gives M^{ds}_{mc}:

$$M^{ds}_{mc} = (A^e - c)\,\frac{2b(1-\delta) - \left(\alpha^{ds} + \beta^{ds}\right)}{2b\left(m^{ds}\,(1-\delta) - \left(\alpha^{ds} + \beta^{ds}\right)\right)}.$$

$M^{ds}_{mc} > 0$, as
$2b(1-\delta) - \left(\alpha^{ds} + \beta^{ds}\right) = -\frac{bn(3+2\delta)+27\lambda\sigma^2(1-\delta)}{n} < 0.$
$m^{ds}\,(1-\delta) - \left(\alpha^{ds} + \beta^{ds}\right) = -5b - 9\frac{\lambda\sigma^2}{n}(1-\delta) < 0.$

C Proof of Proposition 1

Asymmetric case.

Partial crowding out: the positivity constraint on x_i^{*s} is violated (see Corollary A.1).
$M^s_{mc} - M^s =$
$-\left(A^e - c\right)\left(\beta^s\beta - \alpha^s\alpha\right)\frac{\beta(b-m_i^s)-b(m_j^s-m_i^s)+\alpha(m_j^s-b)}{b\left((1-\delta)(m_i^s\beta-m_j^s\alpha)+(m_j^s\beta^s-m_i^s\alpha^s)-(\beta^s\beta-\alpha^s\alpha)\right)\left(m_i^s\beta-m_j^s\alpha\right)}.$
Corollary 1 ensures $(\beta^s\beta - \alpha^s\alpha) > 0$ and positivity of M^s_{mc} (see Appendix B) that $b\left((1-\delta)(m_i^s\beta - m_j^s\alpha) + (m_j^s\beta^s - m_i^s\alpha^s) - (\beta^s\beta - \alpha^s\alpha)\right)\left(m_i^s\beta - m_j^s\alpha\right) < 0$.Therefore, as

$$\beta(b - m_i^s) - b(m_j^s - m_i^s) + \alpha(m_j^s - b) = -9\left(6\lambda\sigma^2 + bn\right)\frac{-bn + bn\delta - 3\lambda\sigma^2}{n^2\,(-1+\delta)} < 0,$$

we conclude that $M^s_{mc} - M^s > 0$,which gives the result.

Symmetric case.

Total crowding out: the positivity constraint (see Lemma 5) is violated.

$$M^{ss}_{mc} - M^{ss} = (A^e - c)\left(\alpha^{ss} + \beta^{ss}\right)\frac{2b - m^{ss}}{bm^{ss}\left(m^{ss}\,(1-\delta) - (\alpha^{ss} + \beta^{ss})\right)} > 0.$$

as (see Appendix B) $\left(m^{ss}\,(1-\delta) - (\alpha^{ss} + \beta^{ss})\right) < 0$ and $2b - m^{ss} = -3\frac{bn(1-\delta)+3\lambda\sigma^2}{(1-\delta)n} < 0$.

D Proof of Proposition 2

Asymmetric case.

Positivity of contracting obtains if and only if the optimal measure is compatible with the conditions given by Corollary A.1; we check the sign of $M^d_{mc} - M^d$.

$$M^d_{mc} - M^d = -\left(m^d - b\right)\frac{(\beta^d\beta - \alpha^d\alpha)}{bm^d\left(m^d(1-\delta)(\beta-\alpha) + m^d(\beta^d - \alpha^d) - (\beta^d\beta - \alpha^d\alpha)\right)}.$$

As $\beta^d\beta - \alpha^d\alpha > 0$ and $\Big(m^d(1-\delta)(\beta-\alpha) + m^d(\beta^d - \alpha^d) - (\beta^d\beta - \alpha^d\alpha\Big) < 0$ (see Appendix B), we have:

$$M^d_{mc} - M^d < 0 \Leftrightarrow b > m^d.$$

Symmetric case.

Similarly to the previous case:

$$M^{ds}_{mc} - M^{ds} = -\frac{1}{2}\left(2b - m^{ds}\right)\frac{\alpha^{ds} + \beta^{ds}}{bm^{ds}\Big(\alpha^{ds} + \beta^{ds} - m^{ds}\left(1-\delta\right)\Big)}.$$

Since $\Big(\alpha^{ds} + \beta^{ds} - m^{ds}\left(1-\delta\right)\Big) > 0$ (see Appendix B) and $\alpha^{ds} + \beta^{ds} > 0$, the condition on the sign is as follows:

$$M^{ds}_{mc} - M^{ds} < 0 \Leftrightarrow 2b > m^{ds}.$$

As $m^{ds} = 2m^d$, we finally have:

$$M^{ds}_{mc} - M^{ds} < 0 \Leftrightarrow b > m^d.$$

D.1 Proof of Proposition 3

We denote by the subscript mc firms contracts at the optimum. Recall that by Proposition 1, $x^{*s}_{i_{mc}} = 0$ in the upstream asymmetric scenario and that $x^{ss}_{i_{mc}} = x^{ss}_{j_{mc}} = 0$ in the upstream symmetric case. Moreover, by Proposition 2 that $bn - 9\sigma^2\lambda > 0$ to have positive contracting in the downstream cases.

1) Ranking of firms' contracting

Tedious calculations show that:

1a. $x^{*s}_{j_{mc}} - x^{*d}_{i_{mc}} =$

$$\frac{3(A^e-c)\Big(b^3n^3(1-\delta)+\sigma^6\lambda^3(81-54\delta)+bn\sigma^4\lambda^2(63-54\delta)+15b^2n^2\sigma^2\lambda(1-\delta)+9bn\sigma^4\lambda^2\delta^2+4b^2n^2\sigma^2\lambda\delta^2\Big)}{(2bn(1-\delta)+3\sigma^2\lambda(2-\delta))(12bn\sigma^2\lambda(2-\delta)+5b^2n^2+27\sigma^4\lambda^2(1-\delta))} > 0$$

1b. $x^{*d}_{i_{mc}} - x^{*ds}_{mc} =$

$$\frac{3\Big(bn-9\sigma^2\lambda\Big)(A^e-c)n\sigma^2\lambda\delta}{(9\sigma^2\lambda\delta-9\sigma^2\lambda-5bn)(12bn\sigma^2\lambda\delta-24bn\sigma^2\lambda-5b^2n^2-27\sigma^4\lambda^2+27\sigma^4\lambda^2\delta)} > 0$$

1c. $x^{*d}_{j_{mc}} - x^{*ds}_{mc} =$

$$\frac{-3(A^e-c)\Big(4bn+9\sigma^2\lambda-9\sigma^2\lambda\delta\Big)\Big(bn-9\sigma^2\lambda\Big)\sigma^2\lambda\delta}{b(9\sigma^2\lambda\delta-9\sigma^2\lambda-5bn)(12bn\sigma^2\lambda\delta-24bn\sigma^2\lambda-5b^2n^2-27\sigma^4\lambda^2+27\sigma^4\lambda^2\delta)} < 0$$

Hence $x^{*s}_{j_{mc}} > x^{*d}_{i_{mc}} > x^{*ds}_{mc} > x^{*d}_{j_{mc}}$.

2) Ranking of total private contracting We calculate $2x^{*ds}_{mc}(1-\delta)-\left((1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}\right)$:

$$2x^{*ds}_{mc}(1-\delta)-\left((1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}\right)= \frac{(A^e-c)\left(-3\sigma^2\lambda(1-\delta)-bn\right)5n\delta}{(9\sigma^2\lambda(\delta-1)-5bn)(12bn\sigma^2\lambda(\delta-2)-5b^2n^2-27\sigma^4\lambda^2(\delta-1))}<0$$

Hence $2x^{*ds}_{mc}(1-\delta)<\left((1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}\right)$.

We then calculate $2x^{*ds}_{mc}(1-\delta)-x^{*d}_{j_{mc}}$:

$$2x^{*ds}_{mc}(1-\delta)-x^{*d}_{j_{mc}}= \frac{\left(48bn\sigma^2\lambda(1-\delta)+b^2n^2(1-\delta)+\sigma^4\lambda^2(135-81\delta)+9bn\sigma^2\lambda\delta^2\right)}{b\left(5bn+9\sigma^2\lambda(1-\delta)\right)\left(2bn(1-\delta)+3\sigma^2\lambda(2-\delta)\right)}>0$$

It follows that

$$(1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}>2x^{*ds}_{mc}(1-\delta)>x^{*d}_{j_{mc}}. \tag{40}$$

3) Ranking of the contracting obligation Recall that at optimum, total contracting must be equal to $\frac{A^e-c}{b}$; therefore

$$M^s_{mc}+x^{s*}_{j_{mc}}=M^d_{mc}+(1-\delta)\,x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}=2\,(1-\delta)\,x^{*d}_{i_{mc}}+2M^{ds}_{mc}=\frac{A^e-c}{b} \tag{41}$$

Therefore, by equation (40), we conclude

$$M^d_{mc}<2M^{ds}_{mc}<M^s_{mc}. \tag{42}$$

4) Public versus private contracting

4a. For ease of calculation, as total contracting must be equal to $\frac{A^e-c}{b}$, we compute M^s_{mc} as follows:

$$\tfrac{A^e-c}{b}-x^{*s}_{j_{mc}}=\frac{(A^e-c)\,(1-\delta)\left(bn+3\sigma^2\lambda\right)}{(2bn(1-\delta)+3\sigma^2\lambda(2-\delta))b}=M^s_{mc}.$$

By computing firm j contracts at the optimal measure ($x^{*s}_{j_{mc}}$),we have $x^{*s}_{j_{mc}}-M^s_{mc}=(A^e-c)\,\frac{3\sigma^2\lambda\delta}{(2bn(1-\delta)+3\sigma^2\lambda(2-\delta)}>0$, hence

$$x^{*s}_{j_{mc}}>M^s_{mc}. \tag{43}$$

4b. $(1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}-M^d_{mc}=$

$$-\left(A^e-c\right)\frac{\left(bn\sigma^2\lambda(48-18\delta)+b^2n^2(1-\delta)+135\sigma^4\lambda^2(1-\delta)\right)}{b(5b^2n^2+12bn\lambda\sigma^2(2-\delta)+27\lambda^2\sigma^4(1-\delta))}<0.$$

Hence

$$(1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}<M^d_{mc}. \tag{44}$$

4c. From equations (40) and (44) we know that $M^d_{mc}>(1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}>2x^{*ds}_{mc}(1-\delta)$; moreover $M^d_{mc}<2M^{ds}_{mc}$ (equation 42). It follows that $2M^{ds}_{mc}>M^d_{mc}>(1-\delta)x^{*d}_{i_{mc}}+x^{*d}_{j_{mc}}>2x^{*ds}_{mc}(1-\delta)$, or

$$2M^{ds}_{mc}>2x^{*ds}_{mc}(1-\delta). \tag{45}$$