Strategic Forward Overbuying as a Counterstrategy against Raising Rivals' Costs

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Abstract

Anticompetitive overbuying has received increased attention from US and EU authorities, but little is known about its possible benefits. These can arise when overbuying is used by vertically separated downstream firms in imperfectly competitive vertical industries (e.g. natural gas, electricity, gasoline) to counter against anticompetitive practices of vertically integrated rivals, such as raising rivals' costs (RRC). Forward markets often feature prominently in such industries. We show that when a separated downstream firm can strategically buy an intermediate good on a forward upstream market when the good is also traded on a later upstream market, there are conditions under which that firm optimally overbuys forward and then sells its excess on that later market. We call this strategic forward overbuying (SFO). By becoming a de facto supplier on the later upstream market the downstream firm benefits from RRC – which is more intensively pursued by the integrated firm because it assumes an additional defensive purpose – and also improves its downstream position. We show there are conditions under which this benefits consumers, comparing welfare under both RRC and SFO with a situation in which SFO is prohibited. Conversely, prohibiting just RRC by compulsorily foreclosing the integrated firm from the later upstream market also eliminates SFO. We show there are conditions under which doing so maximizes welfare. Our findings suggest that fresh attention should be paid to the competitive effects of forward markets, and to the welfare implications of RRC, SFO and foreclosure.

Keywords: Imperfect Competition, Anticompetitive Practice, Regulation, Strategic Overbuying, Forward Contracts

1. Introduction

In May 2007 the European Commission initiated proceedings against the vertically integrated German natural gas importer and retailer, RWE Group (European Commission (2007)). The Commission's concerns included that RWE had engaged in "raising rivals' costs" (RRC), a form of strategic overbuying regarded as anticompetitive. RRC can involve an integrated firm buying rather than selling an intermediate good on an upstream market in order to raise its price. That in turn raises the input cost of the firm's vertically separated downstream rivals. The integrated firm benefits from this overbuying strategy – even if its internal supply costs are lower than the upstream price – provided its competitive gains from weakening its downstream rivals are sufficient to offset its additional purchase costs.[1]

When might an apparently anticompetitive practice such as strategic overbuying be welfare-enhancing? One possibility is when it is adopted by firms as a counterstrategy against anticompetitive practices of their suppliers, with benefits to consumers as well as the adopting firms. We examine a particular combination of such strategies – when vertically separated firms in the downstream part of an imperfectly competitive vertical industry overbuy in a forward upstream market, to counter an existing RRC strategy pursued in a later upstream market by vertically integrated rivals. We call this overbuying by separated downstream firms "strategic forward overbuying" (SFO).[2] While individually each strategy may be anticompetitive, the question remains as to whether one being adopted to counter the other either further reduces welfare, or improves it.

Vertical industries often involve the upstream supply of an intermediate good to downstream firms, with imperfect competition at each industry level, as in the supply of natural gas, electricity and gasoline.[3] Such industries

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[1] For discussions of the RRC strategy, see Salop and Scheffman (1983), Gaudet and Van Long (1996) and Normann (2010). A background to the development of RRC analysis and its application in antitrust policy is provided in Scheffman and Higgins (2003).

[2] Both strategies fall within the Salop (2005, p. 669) definition of anticompetitive overbuying, since they involve "increasing the purchases of a particular input with the purpose and effect of gaining (or maintaining) either monopsony power in the input market or market power in the output market, or both." Similarly, they meet the Blair and Lopatka (2008, p. 452) test for predatory buying, since they are "cases in which a firm incurs losses by increasing input purchases with the expectation that the losses will be more than offset by gains resulting from a likely reduction in competition."

[3] We exclude discussion of vertical integration between production and natural monopoly transportation activities such as transmission, instead considering just integration between intermediate and final good production stages.

often involve asymmetric ownership structures, with vertically integrated firms competing against vertically separated firms in upstream and/or downstream markets. Such "asymmetric vertical integration" (AVI) raises the possibility of anticompetitive strategies like RRC. In addition to the RWE case cited above, RRC has been a policy concern in UK electricity and gas markets (Ofgem (2008)), and in the US cable television industry (Chen and Waterman (2007)). Evidence of firms pursuing a RRC strategy has been documented in the US in both the gasoline industry (Hastings and Gilbert (2005)), and cable television industry (Waterman and Weiss (1996)). Experimental evidence in support of RRC arising in the context of repeated firm interactions is provided in Normann (2010). Hence it is instructive to examine whether downstream firms in such industries have opportunities to counter anticompetitive upstream strategies of their integrated rivals, such as those offered by strategic forward purchases.

Forward markets are often an important feature of vertical industries.[4] Indeed, forward contracting is often used as a policy instrument to enhance competition in electricity and gas sectors. For example, Ausubel and Cramton (2010) report that dominant electricity or gas firms in many European states and parts of the US have been obliged by regulation to forward sell part of their capacity via "virtual power plant" (VPP) auctions, or via their gas-industry equivalent "gas release programme" auctions.[5] Likewise, "vesting contracts" have often been imposed on dominant suppliers when liberalizing electricity sectors – either to constrain market power, or to offload legacy supply contracts with industrial customers (e.g. aluminium producers). Finally, forward contracting has been imposed as a political reaction to liberalization failures, such as in the California and Ontario electricity systems.[6] Hence, upstream firms in such industries often must participate in forward markets even if they prefer not to do so, raising the possibility that downstream firms might use such markets strategically to the detriment of upstream firms.

Conversely, limits are sometimes placed on the ability of downstream firms to acquire forward supply in excess of their downstream commitments – i.e. on their ability to engage in SFO – such as the NOME law in France (Lévêque (2010)). Regulatory limits like these could hamper strategic forward trading, with unclear welfare implications.

It is well-known that forward trading can induce firms to compete harder in subsequent trade and thus be pro-competitive, with the seminal contribution being Allaz and Vila (1993).[7] However, little is known about the implications of separated downstream firms strategically overbuying on forward upstream markets to counter against strategies such as RRC in later later upstream trading. Certainly the issues of buyer power and anticompetitive overbuying have received attention from antitrust authorities in the US and Europe.[8] In particular, increasing concentration in retail supply industries (e.g. supermarkets in Europe, Wal-Mart in the US) has raised concerns that less concentrated upstream suppliers will suffer competitive harm. However, in antitrust circles there is not yet consensus on the implications of buyers exercising countervailing buyer power against market power held by upstream suppliers. For example, Scheelings and Wright (2006) state that there is debate in US merger analysis as to whether countervailing buyer power should be accepted as a defence in mergers that otherwise raise market power concerns. Conversely, they argue that in the EU it is recognized that buyer power can neutralize supplier market power when examining supply-side mergers. Hence, work remains to be done to identify when and if buyer power – such as SFO being used to counter RRC – should raise or alleviate antitrust concerns.

Our contribution is to directly address a question first posed but left unanswered by Salop and Scheffman (1987) – namely, what are the implications of imperfectly competitive firms that are the target of anticompetitive overbuying strategies being able to engage in counterstrategies? To do so, we model an asymmetrically integrated and imperfectly competitive vertical industry, in which RRC endogenously arises. Like other studies, we allow for the possibility of forward trading in the intermediate good, which enables downstream firms to combat this upstream firm strategy. However, unlike other studies, in our setup we find conditions under which downstream firms *strategically overbuy* on a forward upstream market as a means of enhancing their *downstream* market position. This is despite them paying a "strategic premium" in that forward market (i.e. paying a higher price for the good in forward upstream trade than that arising in later upstream trade). In particular, we find that when downstream firms can strategically forward overbuy upstream, this enables them to improve their downstream market position relative to that of their integrated rivals, and that this results in increased downstream output at a reduced downstream price (increasing consumer welfare).

While the forward trading literature following Allaz and Vila (1993) generally finds that forward contracting causes firms to compete harder in subsequent trading, this is in the context of a single-level industry. Here we find

[4]For example, Anderson et al. (2007) report that electricity generators forward contract between 70-80% of output in the US PJM and New England markets, in the Australian National Electricity Market, and in New Zealand, while the figure is as high as 95% in the UK.

[5]The first and longest-running VPP auctions commenced in 2001 with France's EDF, and have since been adopted across Europe, in Belgium, the Netherlands, Denmark, Spain and Germany. Gas auctions have been used in Germany, Austria, France, Hungary and Denmark. Similar regulations have been imposed in the New Zealand electricity sector.

[6]For a survey of forward contracting examples in liberalized electricity systems, see Meade and O'Connor (2011).

[7]This literature is further discussed in Section 2.

[8]For surveys, see Scheelings and Wright (2006) and Blair and Lopatka (2008), as well as the 2005 Antitrust Law Journal (volume 72) symposium on buyer power and antitrust including Salop (2005).

that forward upstream trade improves downstream as well as later upstream competition, which extends this earlier finding by shedding light on an additional channel through which forward contracting is pro-competitive. Furthermore, by pursuing a SFO strategy, separated downstream firms become de facto competitors of integrated firms on the later upstream market, and thus "throw a spanner in the works" of integrated firms' RRC strategy on that market. This forces integrated firms to pursue that strategy more intensively, since it now includes an additional defensive motive over and above the conventional offensive motive. This finding extends the standard rationale for RRC. Finally, by selling rather than buying in later upstream trade, separated downstream firms not only undermine the integrated firms' RRC strategy, but in fact benefit from the price inflation on the later upstream market caused by that strategy.

We show there are conditions under which consumer surplus increases when SFO is permitted to counter endogenous RRC. In other words, regulating against SFO in the presence of RRC can be welfare-reducing, and in particular consumer-welfare reducing. Hence, in a sense permitting SFO as a counterstrategy against RRC is an example of "two wrongs making a right". However, in asymmetric industry structures in which RRC and hence SFO endogenously arise, we show that welfare can be improved even further if RRC is eliminated, e.g. by compulsorily foreclosing integrated firms from the later upstream market. In that case the incentive for SFO is removed, and neither strategy then arises (i.e. compulsory foreclosure of the integrated firm on the later upstream market "kills two birds with one stone", and can maximize welfare under our industry structure).

These findings shed light on how industry features such as forward trading can give rise to countervailing anti-competitive strategies, with resulting welfare gains. This adds further rationale for integrated firms to be required to forward contract at least part of their upstream capacity, and sheds further light on whether apparently anti-competitive buyer power is a legitimate means of combating supplier market power. It also raises questions about the desirability of rules limiting the ability of downstream firms to strategically forward overbuy. Finally, it suggests that compulsory foreclosing integrated firms from upstream markets may in some instances be pro-competitive.

Our paper is organized as follows. In Section 2 we summarize related literatures, emphasizing how our treatment of forward demand differs from that in previous studies. In particular, we derive forward demand from the profit-maximizing choice of downstream firms, rather than assuming (as in Allaz and Vila (1993) and others) that all forward supply is consumed by non-strategic speculators. Section 3 describes our setup in detail. In Section 4 we derive and explain our results, identifying how forward trading changes the tradeoffs confronting both integrated firms engaging in RRC, and separated downstream firms engaging in SFO. We also identify conditions under which both strategies arise in equilibrium. In Section 5 we show there are conditions under which allowing SFO on the one hand, and prohibiting RRC on the other, each improves consumer welfare. For clarity of exposition we focus on the case of successive upstream and downstream duopolies, but in Section 6 we show how our results extend to an oligopoly setting. Finally, Section 7 discusses our results and their policy implications, and concludes.

2. Related Literature

Salop and Scheffman (1987) provide the first detailed analysis of overbuying, but they do not model strategic interactions between their dominant overbuying firm and its fringe rivals. They thus exclude the possibility of overbuying counterstrategies by the fringe, but suggest that further work be done on the possibility of such counterstrategies in oligopolistic industries. Since then, further research has analyzed endogenous overbuying (e.g. Salop (2005), Avenel and Christin (2011)), but not as a means of combating upstream market power per se. While Avenel and Christin (2011) find endogenous overbuying by a downstream firm that faces an upstream monopolist, the target of such overbuying is not the upstream firm, but rather a downstream entrant rival. Furthermore, neither study examines the role of forward markets in enabling downstream firms to combat upstream market power.

As mentioned above, the literature on the pro-competitive effects of forward trading is well-known. Allaz and Vila (1993) provided the seminal contribution, showing that when two firms compete in quantities for a homogeneous good on successive markets, they face a prisoner's dilemma. If they do not compete on the initial (i.e. forward) market, then they risk their rival being able to act as a Stackelberg leader and thereby undermine their position on the later market. However, if they both supply the forward market, then they both suffer worse outcomes on the later market. By trading forward they commit themselves to being more aggressive competitors on the later market.

This analysis has been applied and extended in the case of electricity markets, with theoretical contributions by Powell (1993), Newbery (1998), Green (1999, 2004), Anderson and Hu (2005, 2008), Bushnell (2007), Bonacina et al. (2008), Aïd et al. (2009) and Holmberg (2010). Empirical electricity-related discussions are provided by Wolak (2000), Anderson et al. (2007) and Bushnell et al. (2008). Experimental evidence that is also in favour of forward trading being pro-competitive is provided in Le Coq and Orzen (2006), Brandts et al. (2008), and Ferreira et al. (2010). However, Mahenc and Salanie (2004) show the contrary - i.e. that forward contracting can be anti-competitive - in a differentiated-good Bertrand setup. Finally, Hughes and Kao (1997) show that the competitive effects of forward contracting also depend on the observability of firms' forward positions.

The studies on forward trading closest to ours explore the incentives for downstream firms to forward contract for either hedging or strategic reasons, such as Powell (1993), Anderson and Hu (2005, 2008), and Aïd et al. (2009). While Aïd et al. (2009) consider forward contracting in a vertical industry, they set aside strategic considerations and assume price-taking behaviour by all agents. Powell (1993) finds that even absent a hedging motive, downstream firms have an incentive to forward contract upstream so as to constrain upstream market power. However, he does not find SFO by downstream firms even in that case. Finally, Anderson and Hu (2005, 2008) explore the incentives for downstream firms to forward contract when they condition their offers on ensuring that upstream firms find it profitable to accept them. While downstream firms can forward contract strategically in their setup, they do not model downstream competition per se, and nor do they find SFO by downstream firms. Hence, none of these studies examines how SFO might be used by downstream firms to combat anticompetitive upstream strategies, such as RRC.

Our forward trading setup differs from that assumed in most other studies of the strategic aspects of forward markets (i.e. those following Allaz and Vila (1993)). In such studies it is typically suppliers that are assumed to determine the level of forward contracts to be sold, not separated downstream firms (indeed, in many cases these models do not include explicit downstream competition, and none of them considers vertical integration). Moreover, forward contracts are usually assumed to be sold to speculators with perfect foresight at a forward price equaling the anticipated later upstream price in equilibrium - what Anderson and Hu (2005, 2008) call "contract-spot price equivalence", a form of no-arbitrage condition. In contrast, Anderson and Hu observe that there is evidence of persistent price differences between wholesale and forward electricity markets in practice. Also, even absent a hedging-related risk-premium in forward prices, they argue that there may still be a "strategic premium" in forward prices if downstream firms can use forward purchases to constrain real-time later upstream market power (as in their model, and in Powell (1993), Wolak (2000), Anderson et al. (2007), Bushnell (2007)). They thus assume downstream firms are active, rather than passive, actors in forward contracting decisions. In contrast, studies based on contract-spot price equivalence do not provide for the interaction between upstream and separated downstream firms that is the focus of our study.

As in Anderson and Hu (2005, 2008), we allow separated downstream firms to actively determine their preferred level of forward contracting, thus introducing direct strategic motives for forward trading. However, under their approach downstream firms offer inducements to upstream firms to accept their contract offers, and allow upstream firms to accept or reject those offers. By contrast, we assume that separated downstream firms formulate their profit-maximizing forward demand as a function of forward price, thus defining a forward market (derived) inverse demand function. Integrated and separated upstream firms anticipate this derived inverse demand – just as firms in the downstream market anticipate downstream demand from the utility maximization problem of final consumers – and compete in quantities to supply it.

Anderson and Hu (2005, 2008) seek to address why upstream firms should choose to enter into forward contracts when their profits fall as a consequence.[9] For example, they discuss the possibility of firms colluding, in the context of repeated interactions, to not enter into forward contracts, thus avoiding the prisoner's dilemma often cited as the reason why upstream firms forward contract despite suffering lower profits when collectively they do (e.g. Allaz and Vila (1993)). Instead, they model downstream firms as choosing their optimal forward contract offers subject to participation constraints requiring that upstream firms enjoy profits from accepting those offers that are at least as great as their profits without contracts. This both guarantees contract acceptance by upstream firms in equilibrium, and is sufficient to guarantee the uniqueness of that equilibrium in their supply function equilibrium setup.

Anderson and Hu motivate their decision to have downstream, rather than upstream, firms proposing contracts based on Australian electricity market evidence that this is commonly the case, reflecting the fact that the risk of price increases facing downstream firms is far greater than the risk of price reductions facing upstream firms. By contrast, our setup is motivated by the fact that forward contracting is commonly imposed on producers (particularly in gas and electricity sectors, as discussed in Section 1), giving rise to the possibility of strategic forward trading by downstream firms even when upstream firms would prefer not to forward trade. In any case, under our setup, when an integrated firm that would prefer not to trade forward competes with a vertically separated upstream firm that maximizes its profits by trading in that market, forward selling remains a profit-maximizing strategy for both firms. This is because the integrated firm is adversely affected by strategic forward purchases of its separated downstream rival whether or not the integrated firm supplies those purchases, and if it does not supply them then its vertically separated upstream rival will.

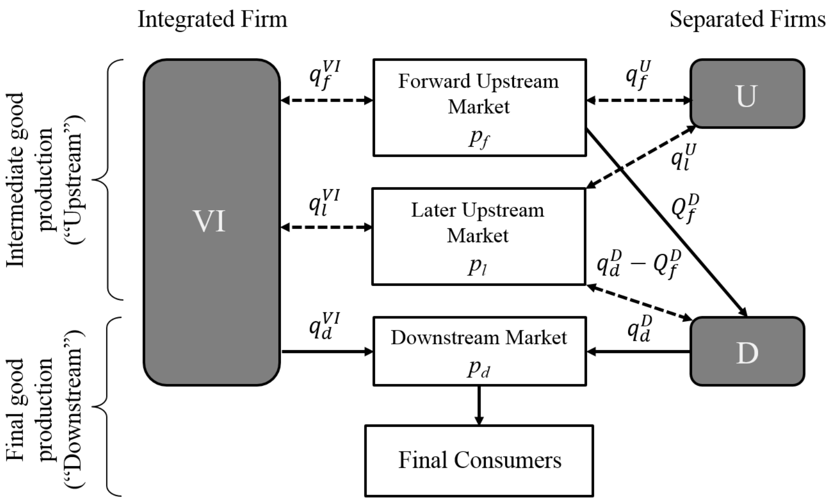
3. Model

3.1. Vertical Industry with Asymmetric Vertical Integration (AVI) and Forward Trading

3.1.1. Industry Structure

[9] Newbery (1998) and Green (1999) similarly model upstream firms' forward contracting incentives, finding that the nature of assumed conjectures between such firms in the forward market determines whether they either fully contract (Bertrand) or not at all (Cournot). However, neither of these studies involves strategic forward purchases by downstream firms.

Figure 1: Industry Structure (Duopolies Case)



Our industry structure is as illustrated in Figure 1 (dashed lines indicate that the relevant firm can either buy or sell on the associated market). A homogeneous intermediate good such as natural gas, electricity or gasoline can be produced by two firms, potentially with each firm having different marginal production costs.[10] This good is traded on either or both of two, time-differentiated "upstream" markets – an initial intermediate good market, and a subsequent intermediate good market which trades after the initial market has closed. Since the initial upstream market trades first, we refer to it as the "forward upstream market", while we refer to the subsequent upstream market as the "later upstream market" (together, the "forward and later upstream markets", or just "upstream markets").

One of these two firms (denoted VI) is vertically integrated into the industry's "downstream" market on which a final good that incorporates the intermediate good is traded. VI can either produce the intermediate good it requires to supply the downstream market (using the same technology as for its supply of the two upstream markets), or acquire intermediate good on the upstream markets. The other firm (denoted U) that can produce the intermediate good is vertically separated and serves only the two upstream markets. Alternatively, it can acquire the intermediate good on the forward upstream market in order to supply the later upstream market.

VI transforms the intermediate good into the final good using a 1-1 fixed proportions technology. It competes to supply the final good on the downstream market against a vertically separated rival (denoted D) which has no capacity to produce the intermediate good. D can acquire the intermediate good on the forward upstream market, and either buy or sell (using its forward purchases) the intermediate good on the later upstream market. Finally, D transforms the intermediate good into the final good using the same fixed proportions technology as VI.

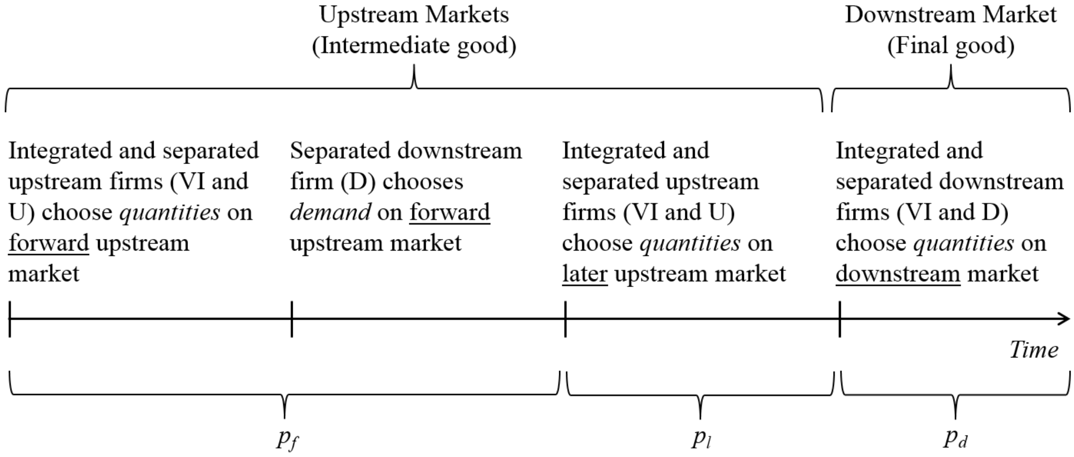
With two vertically separated firms – one with upstream production capacity, and the other without – and each competing with an integrated firm that trades both upstream and downstream, our industry features AVI. This case is of particular interest, because we show that it endogenously gives rise to both RRC and SFO.

In terms of notation, we denote the forward and later upstream markets, on which the intermediate good is traded, by subscripts f and l respectively. Likewise, the downstream market is denoted by subscript d. So the price on each market is p_f, p_l and p_d respectively. Quantities are denoted by q, with superscripts denoting the firm associated with that quantity. Thus q_f^{VI}, q_l^{VI} and q_d^{VI} represent the integrated (VI) firm's quantities on each of the three markets. Conversely, q_f^U and q_l^U are the vertically separated upstream (U) firm's quantities on the forward and later upstream markets respectively. Likewise q_d^D is the separated downstream (D) firm's output of the final good on the downstream market. A notational exception is that we use Q_f^D to denote D's *demand* on the forward upstream market, which is restricted to be non-negative since D has no intermediate good production capacity.

We further restrict both q_d^{VI} and q_d^D to be non-negative (i.e. outputs). Thus there is no inter-firm trade of the final good. However, as mentioned above we allow D to be either a net buyer or seller on the later upstream market. So $q_d^D - Q_f^D$ (the difference between D's downstream market output and its purchases of the intermediate good on the forward upstream market) denotes that firm's demand, if positive, or supply, if negative, on the later upstream market. We also allow q_l^{VI} and q_l^U – and one of q_f^{VI} or q_f^U – to be negative (i.e. demands). Thus VI and U are each permitted to be net buyers on the later upstream market, but at least one of them must supply the forward upstream

[10] In Section 6 we extend the analysis to the oligopolies case with symmetric marginal costs.

Figure 2: Timing



market if there is demand on that market. Per-unit production costs for the intermediate good are c^{VI} and c^U for VI and U respectively, while the costs of transforming that good into the final good are normalized to zero for both VI and D.

3.1.2. Timing

Our timing is as illustrated in Figure 2. We stress that the key distinction between the two intermediate good markets is that trade on the forward upstream market closes before trade on the later upstream market. One possibility is that the later market is a spot or day-ahead market, while the forward market trades either weeks, months or years ahead. Alternatively, the later upstream market might trade one or more months ahead, while the forward upstream market trades many months or years ahead.[11] We emphasize the latter interpretation, since it allows for trade on the downstream market to occur after the two upstream markets have closed.[12] Under this interpretation, both upstream markets could properly be described as "forward" markets. However, to avoid cumbersome terminology (e.g. "long maturity forward upstream market" and "short maturity forward upstream market"), and without loss of generality, we persist with calling just the initial upstream market the forward upstream market.

[11] Such a timing is consistent, for example, with a separated downstream firm securing a portfolio of forward supply commitments before contracting to supply final demand.

[12] In some industries, such as gas and electricity, customer switching costs can mean that final good competition occurs over relatively long time-frames, and in particular before spot or short-term forward markets have closed. On the other hand, electricity and gas industries in some countries feature price comparison and switching websites that enable customers to find their cheapest supplier and switch to them "in minutes" (e.g. www.energyhelpline.com in the UK). Either way, our setup allows for both the forward and later upstream markets to close before trade occurs on the downstream market.

3.1.3. Competition

All firms producing the intermediate good for sale on each of the forward or later upstream markets, or producing the final good for sale on the downstream market, are assumed to simultaneously compete in quantities. This Cournot assumption is made because there is evidence that pricing in relevant markets, such as for electricity, is consistent with Cournot behaviour (Bushnell et al. (2008)). Also, using more sophisticated approaches such as supply function equilibria does not discernibly improve price predictions over the simpler Cournot approach in such markets (Willems et al. (2009)). Our Cournot assumption treats demand as passive, and concentrates market power on the supply-side. This is at odds with relevant industries such as electricity systems in which there can be active demand-side bidding, and hence in which market power can also be expressed on the demand side. However, it is consistent with industries in which the demand-side remains passive, such as gas or gasoline industries, or electricity industries in which market rules do not allow for demand-side bidding.[13] Furthermore, it is instructive that despite concentrating market power on the supply-side, in our analysis we still find countervailing buyer power.

We assume no spatial separation between producers and customers, so transportation and congestion issues do not arise. We ignore capacity considerations, though this is of less consequence for quantity competition as it is for price competition. Our setting is static, so entry and exit do not arise, and investment considerations are ignored. To focus on strategic rather than hedging motives, we assume no uncertainty.[14] Finally, we assume all

[13] While using a supply function instead of Cournot setup, Anderson and Hu (2005, 2008) also assume passive upstream demand, and explicitly model strategic forward demand.

[14] If we had allowed for uncertainty in our setup, a more natural timing might have been to start with either downstream or forward upstream trading, allow (demand and/or supply) uncertainty to be

agents enjoy symmetric and full information (including as to forward positions, thus avoiding the issues identified by Hughes and Kao (1997) when forward positions are not observable).

3.1.4. Defining RRC and SFO

We define RRC and SFO as follows:

Definition 1. Raising rivals' costs (RRC) and strategic forward overbuying (SFO):

1. RRC arises if VI is a purchaser on the later upstream market, i.e. if $q_l^{VI} < 0$.
2. SFO arises if D is a seller on the later upstream market, i.e. if $q_d^D - Q_f^D < 0$.

By buying on the later upstream market VI exerts upward pressure (in our imperfectly competitive setup) on p_l. All other things being equal, if D purchases the intermediate good on this market then such upward pressure raises D's input cost for supplying the final good on the downstream market, and thus advantages VI when competing against D on that market. This we describe as RRC.

Conversely, we say that SFO arises if D purchases more quantity on the forward upstream market than it needs to supply its downstream output, meaning that it has a net quantity to sell on the later upstream market (rather than being a net buyer on that market). By selling on the later upstream market D exerts downward pressure on p_l.

3.2. Downstream Demand, and Profit Functions

3.2.1. Downstream Market Demand

In the downstream market, VI and D compete in quantities q_d^{VI} and q_d^D, facing a linear inverse demand function:

$$p_d = a - b\left[q_d^{VI} + q_d^D\right] \tag{1}$$

with $a > max[c^{VI}, c^U]$ and $b > 0$. Later we impose further conditions on b to ensure that second order conditions are satisfied, and that equilibrium results are well-defined.

3.2.2. Vertically Separated Downstream Firm (D)

D sells amount $q_d^D \geq 0$ on the downstream market. It purchases amount $Q_f^D \geq 0$ of its required intermediate good on the forward upstream market at unit cost p_f, and thus $q_d^D - Q_f^D$ of that good from the later upstream market at unit price p_l. Downstream production costs aside from intermediate good purchases are assumed to be zero.[15] Thus D has profit function:

$$\Pi^D = p_d q_d^D - p_l\left[q_d^D - Q_f^D\right] - p_f Q_f^D \tag{2}$$

i.e. the separated downstream firm earns revenue from its downstream sales, and incurs costs from its forward and later upstream purchases of the intermediate good. Importantly, it generates *revenue* by *supplying* the later upstream market if it forward purchases more of the intermediate good than it requires for its downstream sales, in which case $q_d^D - Q_f^D < 0$. This possibility provides the basis for a SFO strategy.

3.2.3. Integrated Firm (VI)

VI can self-supply its downstream output q_d^{VI} by incurring unit production cost c^{VI}. Alternatively it can purchase amount $q_l^{VI} < 0$ of intermediate good on the later upstream market, from U and/or D (if $q_d^D - Q_f^D < 0$), at the later upstream price p_l to supply that downstream output. As for D, additional downstream production costs are assumed to be zero. Conversely, VI can sell amount $q_l^{VI} \geq 0$ of the intermediate good on the later upstream market at p_l (to U, if $q_l^U < 0$, and/or D, if $q_d^D - Q_f^D > 0$). Finally, VI can supply output $q_f^{VI} \geq 0$ on the forward upstream market (to D and/or U; but if U is supplying that market then VI can instead purchase $q_f^{VI} < 0$ on that market).

Thus, and assuming further that $p_l \geq max[c^{VI}, c^U]$ and $p_f \geq max[c^{VI}, c^U]$, VI has profit function:[16]

$$\Pi^{VI} = \left[p_d - c^{VI}\right] q_d^{VI} + \left[p_l - c^{VI}\right] q_l^{VI} + \left[p_f - c^{VI}\right] q_f^{VI} \tag{3}$$

i.e. the integrated firm generates profits from its downstream sales, and profits (losses) from its forward and later upstream sales (purchases). Allowing $q_l^{VI} < 0$ (or $q_f^{VI} < 0$) provides the basis for a RRC strategy, which we will show is modified (i.e. intensified) in the presence of SFO.[17]

resolved, and then treat the later upstream market as a balancing market. This would be a better reflection of many electricity systems, for example. However, since we ignore uncertainty to focus just on strategic motives, our setup is appropriate, as there is no role for a balancing market as such.

[15]For the industries we have in mind, production costs tend to be large upstream, and relatively much smaller downstream.

[16]In principle VI could also be simultaneously purchasing the intermediate good on the later upstream market to supply its downstream output, while supplying the later upstream market. Furthermore VI could also be purchasing the intermediate good on the forward upstream market in order to supply its downstream and later upstream market outputs, while simultaneously supplying the forward later upstream market. Likewise, U could simultaneously be purchasing the intermediate good on the forward upstream market to supply its later upstream output, while supplying the forward upstream market. For clarity of exposition we preclude these possibilities by assuming that $p_l \geq max[c^{VI}, c^U]$ and $p_f \geq max[c^{VI}, c^U]$. In that case it can easily be shown using amended profit functions with additional quantity demand variables that it is never profit maximizing for VI or U to make such simultaneous purchases.

[17]If we had assumed nil production costs for the intermediate good that might seem to preclude the possibility of either $q_l^{VI} < 0$ or $q_f^{VI} < 0$, as VI would be buying that good at a positive price when it can produce itself at no cost. As we will see, however, purchases of the intermediate good can arise despite nil production costs provided doing so generates sufficient offsetting profits, which is the basis of RRC. This highlights that the more important determinant of whether either $q_l^{VI} < 0$ or $q_f^{VI} < 0$ is the extent to which the associated prices p_l and p_f constitute input costs of VI's downstream rival D.

3.2.4. Vertically Separated Upstream Firm (U)

Finally, U sells quantity $q_l^U \geq 0$ on the later upstream market to D and/or VI at later upstream price p_l (or buys that amount, from VI and/or D, if $q_l^U < 0$), incurring per-unit production cost c^U. It also sells quantity $q_f^U \geq 0$ to D and/or VI at price p_f on the forward upstream market (or buys that amount, from VI, if $q_f^U < 0$) at unit cost c^U. Thus U has profit function:

$$\Pi^U = \left[p_l - c^U\right] q_l^U + \left[p_f - c^U\right] q_f^U \tag{4}$$

i.e. the separated upstream firm generates profits (losses) from its forward and later upstream sales (purchases).

3.3. Solution

We solve our game using backward induction, with subgame perfect equilibrium the relevant equilibrium concept. Equilibrium comprises output quantities that maximize profits for all agents, with market-clearing equilibrium prices then given from the relevant (derived) indirect demand functions. Second order conditions are easily verified in all profit maximizations given our linear-Cournot setup.

4. Results

In this section we first solve for subgame equilibrium prices and quantities, using these to demonstrate the incidence of both RRC and SFO. Then in Section 5 we assess the welfare implications of suppressing either or both of these strategies, to determine whether allowing SFO to counter existing RRC raises or reduces welfare. In Section 6 we extend these duopoly analyses to an oligopoly case.

4.1. Downstream Market Subgame – Source of SFO Welfare Benefits

Given the timing in Figure 2, in the downstream market D takes as given all prices and quantities from the forward and later markets, as well as the downstream market output q_d^{VI} of its downstream rival VI. Thus, substituting for p_d in (2) using (1), and taking the first order condition with respect to q_d^D, results in a best response function for D of the following form:

$$q_d^D\left(q_d^{VI}, p_l\right) = \frac{1}{2b}\left(a - p_l\right) - \frac{1}{2}q_d^{VI} \tag{5}$$

Proceeding likewise for VI, which maximizes profit function (3) with respect to q_d^{VI} taking as given all prices and quantities from the forward and later markets, as well as the downstream market output q_d^D of its separated rival D, we obtain best response function:[18]

$$q_d^{VI}\left(q_d^D\right) = \frac{1}{2b}\left(a - c^{VI}\right) - \frac{1}{2}q_d^U \tag{6}$$

[18]It is easily verified that each firm's second order condition for a maximum is satisfied for all $b > 0$.

Observe that while D's optimal output choice directly depends on later upstream price (via the cost of its later upstream purchases), VI's choice does not. In the subgame equilibrium for this stage, however, after simultaneously solving (5) and (6) for q_d^D and q_d^{VI}, and substituting these quantities into (1), we find:

Lemma 1. *In the downstream market subgame equilibrium, downstream outputs and price depend on later upstream price as follows:*

$$q_d^D\left(p_l\right) = \frac{1}{3b}\left(a + c^{VI}\right) - \frac{2}{3b}p_l \tag{7}$$

$$q_d^{VI}\left(p_l\right) = \frac{1}{3b}\left(a - 2c^{VI}\right) + \frac{1}{3b}p_l \tag{8}$$

$$p_d\left(p_l\right) = \frac{1}{3}\left(a + c^{VI}\right) + \frac{1}{3}p_l \tag{9}$$

Thus, in the downstream subgame equilibrium, VI's optimal output q_d^{VI} depends on p_l because of the dependence of D's best response on p_l. The later upstream price p_l has a positive effect on VI's downstream output, since it has a negative effect on that of D. Notice also that forward upstream quantities play no role in this subgame equilibrium, except to the extent that they affect p_l, to which we return below.

From (7) and (8) we can see that q_d^D is more responsive to p_l in absolute terms than is q_d^{VI}, i.e.:

$$\left| \frac{\partial q_d^D}{\partial p_l} \right| > \frac{\partial q_d^{VI}}{\partial p_l} \tag{10}$$

As a consequence, total downstream output is decreasing in p_l – i.e. $\frac{\partial\left(q_d^D + q_d^{VI}\right)}{\partial p_l} < 0$. Furthermore, from (9) we see that p_d is increasing in p_l. These features prove to be critical to the welfare implications of SFO, and to how the pro-competitive effects of forward contracting modify those of Allaz and Vila (1993) and other authors in our setup. As we next show, p_l is decreasing in D's choice variable, forward upstream demand Q_f^D. This offers a way for D to reduce p_l, and as a consequence to expand its downstream market output by more than VI's downstream output contracts, while also reducing p_d. In other words, D has a strategic tool with which it can affect forward and later upstream market outcomes, and which can simultaneously increase downstream consumer welfare.

4.2. Later Upstream Market Subgame

Demand on the later upstream market comes from the difference between D's output choice in the downstream market, and its forward purchases of the intermediate good, i.e. from $q_d^D\left(p_l\right) - Q_f^D$. This demand is supplied by the aggregate of later upstream market quantity choices of VI and separated upstream firm U, namely $q_l^{VI} + q_l^U$. Setting $q_d^D\left(p_l\right) - Q_f^D = q_l^{VI} + q_l^U$, substituting for $q_d^D\left(p_l\right)$ using (7), and solving for p_l yields the later upstream market derived inverse demand function faced by VI and U:

$$p_l\left(q_l^{VI},q_l^U,Q_f^D\right)=\frac{1}{2}\left(a+c^{VI}\right)$$
$$-\frac{3b}{2}\left(q_l^{VI}+q_l^U+Q_f^D\right) \qquad (11)$$

As expected, p_l is decreasing in the later upstream market outputs of both VI and U. Notably, however, it is also decreasing in D's choice of forward upstream demand, Q_f^D, holding q_l^U and q_l^{VI} constant. That choice shifts demand from the later upstream market to the forward upstream market, and is thus equivalent to expanding later upstream output, relieving pressure on p_l. Indeed, a key insight is that to the extent that D makes forward upstream purchases (i.e. $Q_f^D>0$) it becomes a de facto producer on the later upstream market, having procured "capacity" in the forward market which it can then use to supply the later market – in competition with VI and U. While this later upstream competition between D and U is confined to the later upstream market, between D and VI it will clearly also have implications for their competition on the downstream market. We explore this further below, after determining VI's and U's optimal quantity choices on the later upstream market, and deriving conditions under which RRC arises in equilibrium.

Given the above derived inverse demand (11), but taking as given both the forward upstream market price and quantities, as well as VI's later upstream market quantity choice q_l^{VI}, U chooses its later upstream market quantity q_l^U to maximise profit function (4), yielding the following best response function:

$$q_l^U\left(q_l^{VI},Q_f^D\right)=\frac{1}{6b}\left(a+c^{VI}-2c^U\right)$$
$$-\frac{1}{2}\left(q_l^{VI}+Q_f^D\right) \qquad (12)$$

Likewise, but also anticipating the downstream market subgame equilibrium $q_d^{VI}\left(p_l\right)$ and $p_d\left(p_l\right)$ from (8) and (9) respectively, VI chooses its later upstream market quantity q_l^{VI} to maximize profit function (3), using (11) for p_l, and taking q_l^U and forward upstream market prices and quantities as given. This yields VI's later upstream market best response function:[19]

$$q_l^{VI}\left(q_l^U,Q_f^D\right)=-\frac{2}{5}\left(q_l^U+Q_f^D\right) \qquad (13)$$

VI's and U's best response functions are therefore decreasing in their rival's later upstream market quantity choice. They are also decreasing in D's forward upstream demand choice. Furthermore, provided the sum of U's later upstream market output and D's forward upstream demand (i.e. $q_l^U+Q_f^D$) is positive, VI's best response function (13) is always negative, unlike U's best response (12). To see why, it is useful to compare the profit functions of VI and U, namely (3) and (4). Substituting for p_l using (11), it can be shown that Π^U is concave in q_l^U via the term $p_lq_l^U$. For VI, however, Π^{VI}combines the analogous term $p_lq_l^{VI}$ which is also concave in q_l^{VI}, but also the extra term $p_dq_d^{VI}$ which is convex (after substituting (8) and (9), using (11) for p_l).

Thus, for a given Q_f^D, VI and U each trade off later upstream market quantity and price when maximizing their profits on that market. For VI, however, there is an additional consideration, namely that a fall in p_l due to an increase in q_l^{VI} lowers the input cost of its downstream rival D. This causes D's downstream output to expand, and p_d to fall – at the expense of VI's downstream profits. Here this additional influence causes VI to prefer raising p_l by buying rather than selling on the later upstream market, trading off the cost of purchases on the later upstream market against the extra downstream profits that arise from raising D's input cost. This is the familiar rationale for RRC.

Below we show how D's forward upstream demand choice modifies this rationale. Before doing so, we simultaneously solve (12) and (13), and substitute their solutions into (11) for p_l, obtaining the following subgame equilibrium on the later upstream market:

Lemma 2. *In the later upstream market subgame equilibrium, later upstream quantities and price depend on D's forward upstream demand choice as follows:*

$$q_l^U(Q_f^D)=\frac{1}{24b}\left[5\left(a+c^{VI}-2c^U\right)-9bQ_f^D\right] \qquad (14)$$

$$q_l^{VI}(Q_f^D)=-\frac{1}{12b}\left[a+c^{VI}-2c^U+3bQ_f^D\right] \qquad (15)$$

$$p_l(Q_f^D)=\frac{1}{16}\left[5\left(a+c^{VI}\right)+6c^U-9bQ_f^D\right] \qquad (16)$$

Thus, consistent with interpreting D's forward upstream demand choice Q_f^D as de facto later upstream output, we see that VI's and U's equilibrium later upstream quantities, and also later upstream price, are all decreasing in Q_f^D. Indeed, by adding (14) and (15) we see that the total later upstream quantity of U and VI, $q_l^U+q_l^{VI}$, is decreasing in Q_f^D. However, the de facto later upstream output for the purposes of determining p_l (in (11)) adds Q_f^D to this total, with the result that de facto total output is increasing in Q_f^D. In this sense D's forward demand "toughens competition" on the later upstream market, lowering p_l despite a decline in U and VI's total later upstream output, and with D's de facto later upstream output taking market share from each of VI and U. With p_l as well as both q_l^{VI} and q_l^U falling, VI and U both suffer unambiguous falls in later upstream profits as Q_f^D rises.

It is helpful to revisit how downstream market equilibrium outcomes relate to D's forward upstream demand.

[19] Once again, each firm's second order condition for a maximum is assured for any $b>0$.

We summarize these in the following corollary, after substituting (16) for $p_l\left(Q_f^D\right)$ into the downstream market subgame equilibrium expressions in Lemma 1:

Corollary 1. *Downstream market subgame equilibrium in terms of D's forward upstream demand*

$$q_d^D(Q_f^D) = \frac{1}{8b}\left(a + c^{VI} - 2c^U\right) + \frac{3}{8}Q_f^D \tag{17}$$

$$q_d^{VI}(Q_f^D) = \frac{1}{16b}\left(7a - 9c^{VI} + 2c^U\right) - \frac{3}{16}Q_f^D \tag{18}$$

$$p_d(Q_f^D) = \frac{1}{16}\left[7\left(a + c^{VI}\right) + 2c^U\right] - \frac{3b}{16}Q_f^D \tag{19}$$

Thus we confirm the predictions made after Lemma 1. Specifically, we see from the corollary that both q_d^{VI} and p_d are decreasing in D's forward upstream demand choice Q_f^D, while q_d^D is increasing in that choice. In effect, by causing a reduction in p_l, D's forward upstream demand shifts its downstream market reaction function (5) outwards. Since VI's downstream reaction function (6) is independent of p_l, it is invariant to D's forward upstream demand choice. Thus the overall impact of Q_f^D – via p_l – is to cause D's downstream output to expand and VI's to contract. Furthermore, by inspection we have from the corollary that:

$$\left|\frac{\partial q_d^{VI}}{\partial Q_f^D}\right| < \frac{\partial q_d^D}{\partial Q_f^D} \tag{20}$$

and hence that $\frac{\partial\left(q_d^D + q_d^{VI}\right)}{\partial Q_f^D} > 0$. In other words, by forward purchasing the intermediate good, D reduces VI's downstream output by less than it expands its own. This results in an expansion in total downstream output, and hence a reduction in downstream price. Finally, with both q_d^{VI} and p_d falling, VI's downstream profits unambiguously fall as Q_f^D rises (in addition to the fall in its later upstream profits noted above).

Thus, aside from "toughening competition" in the later upstream market, D's forward upstream demand choice unambiguously improves consumer welfare on the downstream market. These later upstream market effects modify the commonly understood pro-competitive effects of forward contracting in Allaz and Vila (1993) and related studies. The downstream market effects represent a novel extra channel via which forward contracting can be pro-competitive.

Finally, before proceeding to the forward upstream market subgame, we state the following lemma:

Lemma 3. *Impact of D's forward upstream demand on VI's later upstream quantity choice:*

VI's later upstream output choice, q_l^{VI}, whether negative or positive, is decreasing in D's forward upstream demand choice, Q_f^D.

Proof. Direct differentiation of (15) yields $\frac{dq_l^{VI}(Q_f^D)}{dQ_f^D} < 0$. □

Thus if it transpires that VI pursues RRC in equilibrium – i.e. $q_l^{VI} < 0$ – then by Lemma 3 we know that D's forward upstream demand causes VI to do so more intensively. With Q_f^D rising, VI confronts increasing downward pressure on p_l, improving D's downstream position at VI's expense. This induces VI to purchase even more on the later upstream market so as to reduce this downward pressure on p_l. In a sense, by choosing positive forward upstream demand, D forces VI to engage in a profit-preserving (i.e. loss-in-profit reducing) "tug-of-war" over p_l.

Thus RRC, if it arises, takes on a *defensive* purpose, and does so in two ways. First, its extent hinges on D's choice of forward upstream purchases, unlike the apparently more offensive purpose absent any forward demand. Second, VI's pursuit of RRC in the face of positive forward upstream demand by D is to minimize the fall in its downstream profits, rather than to increase them. Since VI's later upstream profits also suffer as Q_f^D rises, the integrated firm's challenge is to determine the level of later upstream market purchases that minimizes its combined profit reduction.

We now determine D's profit-maximizing choice of Q_f^D, and VI's and U's profit-maximizing choices of forward upstream quantities, q_f^{VI} and q_f^U.

4.3. Forward Upstream Market Subgame

4.3.1. Forward Upstream Demand

As discussed in Section 2, in our setup D chooses its profit-maximizing forward upstream demand Q_f^D, anticipating the subgame equilibria of the downstream and later upstream markets, and taking p_f as given (i.e. determined by VI and U when competing to supply anticipated forward demand). Using (19) for $p_d\left(Q_f^D\right)$, (17) for $q_d^D\left(Q_f^D\right)$, and (16) for $p_l\left(Q_f^D\right)$, D's profit function (2) can be written:

$$\Pi^D\left(Q_f^D, p_f\right) = p_d\left(Q_f^D\right) q_d^D\left(Q_f^D\right)$$

$$-p_l\left(Q_f^D\right)\left[q_d^D\left(Q_f^D\right) - Q_f^D\right] - p_f Q_f^D \tag{21}$$

Differentiating this expression with respect to Q_f^D yields D's optimal forward upstream demand, with the usual negative relationship between price and quantity:[20]

$$Q_f^D(p_f) = \frac{1}{27b}\left[13\left(a + c^{VI}\right) + 6c^U\right] - \frac{32}{27b}p_f \tag{22}$$

In choosing this optimal forward demand, D balances the following three effects on its profits:

[20] This requires that $b > 0$, which is also sufficient to satisfy D's second order condition for this problem.

1. Revenues $p_d\left(Q_f^D\right) q_d^D\left(Q_f^D\right)$ are concave in Q_f^D, giving rise to a "downstream business-stealing/expansion effect". Increases in Q_f^D cause q_d^D to rise and p_d to fall, with the former effect initially dominating.
2. Purchase "costs" on the later upstream market, namely $p_l\left(Q_f^D\right)\left[q_d^D\left(Q_f^D\right)-Q_f^D\right]$, are convex in Q_f^D, but negative for some values of Q_f^D (implying revenues rather than costs on the later upstream market), giving rise to a "later upstream market cost/revenue effect". Increases in Q_f^D cause p_l to fall and q_d^D to rise, with the former effect initially dominating.
3. Finally, given p_f, D's forward cost $p_f Q_f^D$ is proportional to Q_f^D, giving rise to a "forward upstream market cost effect".

Thus for sufficiently low forward upstream demand D chooses that demand to trade off increased downstream revenues and decreased purchase costs on the later upstream market against increased forward upstream market purchase costs. Conversely, when forward upstream demand is sufficiently high, D's tradeoff is between increased downstream revenues on the one hand, and increased purchase costs on the later upstream market (or reduced revenues if $q_d^D - Q_f^D < 0$), and increased forward market purchase costs, on the other.

4.3.2. Forward Upstream Supply

As before, the derived forward upstream market inverse demand function facing VI and U is found by solving $Q_f^D(p_f) = q_f^{VI} + q_f^U$ for p_f, using (22) for $Q_f^D(p_f)$, where q_f^{VI} and q_f^U are the forward quantity choices of VI and U respectively. This yields:

$$p_f\left(q_f^{VI}, q_f^U\right) = \frac{1}{32}\left[13\left(a + c^{VI}\right) + 6c^U\right] - \frac{27b}{32}\left(q_f^{VI} + q_f^U\right) \tag{23}$$

Facing this derived inverse forward upstream demand, and anticipating D's forward upstream demand choice and the subgame equilibrium outcomes in the later upstream and downstream markets, U's profits can be written as a function of its and VI's forward quantity choices, using (22) for $Q_f^D(p_f)$, (16) for $p_l\left(Q_f^D\right)$, and (14) for $q_l^U\left(Q_f^D\right)$:

$$\Pi^U\left(q_f^{VI}, q_f^U\right) = \left[p_l\left(q_f^{VI}, q_f^U\right) - c^U\right] q_l^U\left(q_f^{VI}, q_f^U\right) + \left[p_f\left(q_f^{VI}, q_f^U\right) - c^U\right] q_f^U \tag{24}$$

where:

$$p_l\left(q_f^{VI}, q_f^U\right) = p_l\left(Q_f^D\left(p_f\left(q_f^{VI}, q_f^U\right)\right)\right)$$
$$q_l^U\left(q_f^{VI}, q_f^U\right) = q_l^U\left(Q_f^D\left(p_f\left(q_f^{VI}, q_f^U\right)\right)\right)$$

Taking VI's forward upstream quantity as given, U's profit-maximizing forward quantity choice is found by differentiating (24) with respect to q_f^U, yielding U's forward upstream market best response function:

$$q_f^U\left(q_f^{VI}\right) = \frac{1}{81b}\left[11\left(a + c^{VI}\right) - 22c^U\right] - \frac{1}{3}q_f^{VI} \tag{25}$$

Similarly, VI's profit function can be written as follows, additionally using (19) for $p_d\left(Q_f^D\right)$, (18) for $q_d^{VI}\left(Q_f^D\right)$, and (15) for $q_l^{VI}\left(Q_f^D\right)$:

$$\Pi^{VI}\left(q_f^{VI}, q_f^U\right) = \left[p_d\left(q_f^{VI}, q_f^U\right) - c^{VI}\right] q_d^{VI}\left(q_f^{VI}, q_f^U\right) + \left[p_l\left(q_f^{VI}, q_f^U\right) - c^{VI}\right] q_l^{VI}\left(q_f^{VI}, q_f^U\right) + \left[p_f\left(q_f^{VI}, q_f^U\right) - c^{VI}\right] q_f^{VI} \tag{26}$$

where $p_l\left(q_f^{VI}, q_f^U\right)$ is as above, $q_l^{VI}\left(q_f^{VI}, q_f^U\right)$ is defined analogously to $q_l^U\left(q_f^{VI}, q_f^U\right)$, and:

$$p_d\left(q_f^{VI}, q_f^U\right) = p_d\left(Q_f^D\left(p_f\left(q_f^{VI}, q_f^U\right)\right)\right)$$
$$q_d^{VI}\left(q_f^{VI}, q_f^U\right) = q_d^{VI}\left(Q_f^D\left(p_f\left(q_f^{VI}, q_f^U\right)\right)\right)$$

Differentiating this expression with respect to q_f^{VI} yields VI's forward upstream market best response function:[21]

$$q_f^{VI}\left(q_f^U\right) = \frac{1}{57b}\left(9a - 7c^{VI} - 2c^U\right) - \frac{7}{19}q_f^U \tag{27}$$

Finally, the forward upstream market subgame equilibrium is summarized in the following lemma.

4.3.3. Forward Upstream Market Equilibrium

Lemma 4. *In equilibrium, the forward upstream quantities of U and VI, forward upstream price, and forward upstream demand of D, are respectively:*

$$q_f^U = \frac{1}{675b}\left(64a + 136c^{VI} - 200c^U\right) \tag{28}$$

$$q_f^{VI} = \frac{1}{675b}\left(83a - 133c^{VI} + 50c^U\right) \tag{29}$$

$$p_f = \frac{1}{400}\left(89a + 161c^{VI} + 150c^U\right) \tag{30}$$

$$Q_f^D = \frac{1}{225b}\left(49a + c^{VI} - 50c^U\right) \tag{31}$$

Proof. q_f^U and q_f^{VI} are computed directly by simultaneously solving (25) and (27), while p_f is found by substituting (28) and (29) into (23). Q_f^D is found by substituting (30) into (22). □

[21] Note that both VI's and U's second order conditions for these profit maximizations are satisfied if $b > 0$. Thus these, and all preceding second order conditions, are satisfied for $b > 0$.

In choosing its optimal forward upstream quantity, U recognizes that higher forward output decreases forward price, and hence affects its forward profits. Additionally, reducing forward price raises D's forward upstream demand and thus lowers both later upstream price and U's later upstream output (thus reducing its later upstream profits). By contrast, VI faces the same tradeoff in the forward upstream market, but a different impact in the later upstream market. Specifically, a decrease in forward price from increased forward output stimulates D's forward upstream demand, with the resulting falls in both later upstream price and VI's later upstream quantity – if it is pursuing RRC – lowering the cost of VI's later upstream purchases. At the same time, however, VI faces the additional consideration that stimulating D's forward upstream demand will also lower both the downstream price and VI's downstream output (and hence its downstream profits).

In the following subsection we identify if and when RRC and/or SFO arise in equilibrium. To do so, conditions are first identified under which all relevant quantities are non-negative in equilibrium, all prices exceed relevant minima, and each of RRC and SFO arise. We will show that there is one equilibrium involving symmetric costs, and two equilibrium ranges involving asymmetric costs. The equilibrium incidence of RRC and SFO will be shown to depend on which of these equilibria is applicable.

4.4. Equilibrium Incidence of RRC and SFO

Appendix A sets out later upstream market equilibrium values q_l^U and p_l, as well as downstream market equilibrium values q_d^{VI}, q_d^D and p_d. Since they are of particular interest, we summarize the equilibrium values of VI's and D's later upstream quantities in the following lemma:

Lemma 5. *Equilibrium later upstream quantities of VI and D:*

$$q_l^{VI} = \frac{1}{225b}\left(-31a - 19c^{VI} + 50c^U\right) \tag{32}$$

$$q_d^D - Q_f^D = \frac{1}{90b}\left(-a + 11c^{VI} - 10c^U\right) \tag{33}$$

Proof. q_l^{VI} is found by substituting (31) for Q_f^D into (15), while q_d^D is found by substituting (31) into (17). $q_d^D - Q_f^D$ is then computed directly. □

In order to determine whether RRC (i.e. $q_l^{VI} < 0$) and/or SFO (i.e. $q_d^D - Q_f^D < 0$) arises in equilibrium, it is first necessary to identify conditions under which equilibrium arises. In particular, clearing on the forward and later upstream markets is assured by virtue of how inverse demand functions were derived in each case (i.e. since market clearing was imposed when deriving inverse demands). However, since we allow quantities to be negative in certain cases, in equilibrium we further require that:

1. Total forward upstream output is non-negative, even if either VI or U makes purchases on the forward market – i.e. $q_f^{VI}+q_f^U \geq 0$. Since the forward market clears this also ensures that $Q_f^D \geq 0$, i.e. D's forward upstream demand is non-negative, since D has no production capacity of its own;
2. Total forward and later upstream output is non-negative, even if VI or U makes purchases on the forward or later upstream markets – i.e. $q_f^{VI}+q_f^U+q_l^{VI}+q_l^U \geq 0$;
3. Both VI's and D's downstream output is non-negative, since we do not allow either to be purchasers on that market – i.e. $q_d^{VI} \geq 0$ and $q_d^D \geq 0$;
4. Forward and later upstream market prices are no less than maximum upstream production costs, to ensure that neither VI nor U simultaneously buy and sell on either or both of those markets – i.e. $p_f \geq max\left[c^{VI}, c^U\right]$ and $p_l \geq max\left[c^{VI}, c^U\right]$; and
5. Downstream price is non-negative – i.e. $p_d \geq 0$.

Simultaneous satisfaction of these conditions – after denoting $c^U = \delta c^{VI}$ for $\delta \lesseqgtr 1$ without loss of generality – leads to our first proposition:

Proposition 1. *Equilibria*

Denoting $c^U = \delta c^{VI}$, there is one symmetric equilibrium, and two asymmetric equilibria ranges, satisfying all relevant quantity- and price-related constraints:

1. Equilibrium 1 – with $\delta = 1$, at which $c^{VI} = c^U$, requiring that:
$$c^{VI} \leq a \tag{34}$$
2. Equilibrium Range 2 – with $\frac{1}{50} < \delta < \frac{19}{50}$, at which $c^U \ll c^{VI}$, requiring that:
$$0 \leq c^{VI} \leq \frac{19a}{69 - 50\delta} \tag{35}$$
3. Equilibrium Range 3 – with $\delta > \frac{169}{50}$, at which $c^U \gg c^{VI}$, requiring that:
$$0 \leq c^{VI} \leq \frac{89a}{250\delta - 161} \tag{36}$$

Proof. See Appendix B. We begin by finding conditions on cost relativity parameter δ ensuring that quantity-related non-negativity constraints are satisfied. These identify one candidate equilibrium and two candidate equilibrium ranges. We show that all relevant constraints are either assured since they require c^{VI} to exceed some negative minimum value, or can be reduced to a single, non-negative, most binding constraint on the upper value of c^{VI}. Such singular constraints are then necessary conditions for equilibrium. To find necessary and sufficient conditions for equilibrium, we then identify conditions for c^{VI} ensuring that price-related constraints are satisfied. We show that the most binding of these conditions are more binding than the most binding quantity-related constraints, and hence constitute the relevant equilibrium conditions. □

Having determined conditions under which either point or range equilibria arise in our setup, we can now determine the equilibrium incidence of RRC and SFO. By Lemma 5 it is easily verified that $q_l^{VI} < 0$ and $q_d^D - Q_f^D < 0$ if the following two conditions are respectively satisfied:

$$c^{VI} > \frac{1}{19}\left(50c^U - 31a\right) \qquad \text{(RRC)}$$

$$c^U < \frac{1}{11}\left(10c^U + a\right) \qquad \text{(SFO)}$$

Substituting $c^U = \delta c^{VI}$ as in Proposition 1, and solving for c^{VI}, results in the following lemma:

Lemma 6. *RRC and SFO arise under the following conditions:*

$$RRC: \begin{cases} RRC1\text{: } c^{VI} > \frac{31a}{50\delta - 19} & \delta < \frac{19}{50} \\ RRC2\text{: } c^{VI} < \frac{31a}{50\delta - 19} & \delta > \frac{19}{50} \end{cases}$$

$$SFO: \begin{cases} SFO1\text{: } c^{VI} < \frac{a}{11 - 10\delta} & \delta < \frac{11}{10} \\ SFO2\text{: } c^{VI} > \frac{a}{11 - 10\delta} & \delta > \frac{11}{10} \end{cases}$$

Observe that in RRC1 and SFO2, in which the relevant thresholds represent lower bounds on c^{VI}, the thresholds are negative. Hence their satisfaction is assured by assumption, since $c^{VI} \geq 0$. Conversely, in RRC2 and SFO1, in which the thresholds are upper bounds on c^{VI}, those thresholds are positive, meaning that there may be some $c^{VI} \geq 0$ in equilibrium less than either or both of those thresholds. The question is whether either or both of these constraints – or neither – is satisfied in the equilibria identified in Proposition 1.

By comparing the equilibrium constraints in Proposition 1 with those for RRC and SFO in Lemma 6 we arrive at the following proposition:

Proposition 2. *With $c^U = \delta c^{VI}$, RRC and SFO arise in equilibrium as follows:*

1. Both RRC and SFO arise:
   (a) If $\delta = 1$ (Equilibrium 1, $c^{VI} = c^U$);
   (b) For all $\delta > \frac{169}{50}$ (Equilibrium Range 3, $c^U \gg c^{VI}$); and
   (c) For $\frac{1}{50} < \delta < \frac{19}{50}$ (Equilibrium Range 2, $c^{VI} \gg c^U$) if:
   $$0 \leq c^{VI} < \frac{a}{11 - 10\delta}$$
2. For $\frac{1}{50} < \delta < \frac{19}{50}$ (Equilibrium Range 2, $c^{VI} \gg c^U$), RRC but not SFO arises if:

$$\frac{a}{11 - 10\delta} \leq c^{VI} \leq \frac{19a}{69 - 50\delta}$$

Proof. When $\delta = 1$ the relevant constraints in Lemma 6 are RRC2 and SFO1, each of which reduces to $c^{VI} < a$ in this case. While this condition is more restrictive than equilibrium condition (34), with $a > max\left[c^{VI}, c^U\right]$ by assumption all three conditions are satisfied. Thus both RRC and SFO arise in this equilibrium.

For $\delta > \frac{169}{50}$ the relevant constraints are RRC2 and SFO2. Since the right-hand side of SFO2 is negative, its satisfaction is assured for all $c^{VI} \geq 0$. Furthermore, it is easily verified that the difference between RRC2 and equilibrium condition (36) is positive for all $\delta > \frac{169}{50}$ and arbitrary $a > 0$. This means that the equilibrium upper bound on c^{VI} is more binding than that given by RRC2, ensuring satisfaction of the latter in this case. Thus, once again, both RRC and RRC are assured in this equilibrium range.

Finally, for $\frac{1}{50} < \delta < \frac{19}{50}$ the relevant constraints are RRC1 and SFO1. Since the right-hand side of RRC1 is negative, its satisfaction is assured for all $c^{VI} \geq 0$. Furthermore, it is easily verified that the difference between SFO1 and equilibrium condition (35) is *negative* for $\frac{1}{50} < \delta < \frac{19}{50}$ and arbitrary $a > 0$. This means that the upper bound on c^{VI} given by SFO1 is more binding than the equilibrium condition, meaning that only some equilibrium values of c^{VI} will also satisfy SFO1. Thus, RRC is assured in this equilibrium range, while SFO also arises in this case only if the tighter SFO1 condition is satisfied. This completes the proof of the proposition. □

Thus with AVI in our successive duopolies setup we find that RRC is a feature of both our symmetric and asymmetric equilibria. Conversely, SFO also features in all three possible equilibria cases, though conditionally when $c^{VI} \gg c^U$. Of additional interest is the fact that when SFO arises, D may be prepared to pay a "strategic premium" in the forward upstream market, with $p_f > p_l$ in equilibrium (as in Anderson and Hu (2005, 2008)). Furthermore, despite having an interest in D not buying forward, VI can in fact supply more on the forward upstream market than does U in equilibrium. This is summarized the following corollary:

Corollary 2. *In equilibrium D pays a "strategic premium" in the forward upstream market (i.e. $p_f - p_l > 0$), and VI's forward upstream supply exceeds that of U (i.e. $q_f^{VI} > q_f^U$), if:*

1. $\delta = 1$;
2. $\frac{1}{50} < \delta < \frac{19}{50}$ and $0 \leq c^{VI} < \frac{19a}{269 - 250\delta}$; or
3. $\delta > \frac{169}{50}$ and $0 \leq c^{VI} < \frac{13a}{50\delta - 17}$

Proof. Omitted, since it follows the same procedure as the proofs to Propositions 1 and 2. Using the equilibrium expressions for $p_f - p_l$ and $q_f^{VI} - q_f^U$ and substituting $c^U = \delta c^{VI}$ it is possible to derive conditions on c^{VI} in terms of $a > 0$ and δ for which each expression is positive. When $\delta = 1$ these conditions reduce to requiring $c^{VI} < a$, which is assumed. In the other cases one of the two constraints requires c^{VI} to exceed some negative threshold, which is also assured by assumption. Thus only the remaining constraint need be compared with the relevant equilibrium ($\delta > \frac{169}{50}$) or SFO ($\frac{1}{50} < \delta < \frac{19}{50}$) upper bound on c^{VI} from Proposition 1. In each case it is easily verified that these additional constraints are more binding than the relevant Proposition 1 constraints. Hence, while one of $p_f - p_l > 0$ or $q_f^{VI} - q_f^U > 0$ is assured for each of the two asymmetric equilibrium ranges, the other arises only if c^{VI} is less than the relevant binding constraint (which is positive), as stated above. □

Hence, even though D in effect "buys high" on the forward upstream market and then "sells low" on the later upstream market, this still represents D's profit-maximizing strategy. By purchasing $Q_f^D > q_d^D$ on the forward upstream market D is able to sell $q_d^D - Q_f^D$ on the later upstream market, depressing p_l and improving its downstream market position. Thus D can afford to "overpay" when buying intermediate good on the forward rather than later upstream market.

For its part VI suffers decreased profits on both later upstream and downstream markets due to D's forward overbuying. However, if it does not supply on the forward upstream market then it fails to take advantage of any strategic premium paid by D. Moreover, even if VI should not supply on the forward market, it is profit-maximizing for U to do so, particularly given any strategic premium. Hence VI's best strategy is to profit from that market rather than leave it entirely to its upstream rival, since D will secure forward upstream supply in either case. Moreover, by selling on the later upstream market D depresses p_l in a situation where it is VI and not itself that is buying on that market. This reduces D's own profits on the later upstream market, but "softens the blow" of VI supplying the forward upstream market, thus inducing it to supply more on that market than it would otherwise. However, it is profitable for D to do so because of the greater downstream profits it enjoys as a consequence of inducing VI to sell forward, which justifies D paying this strategic premium.

We have thus demonstrated that RRC and SFO are profit-maximizing strategies in our duopolies setup. In Section 6 we summarize the equilibrium incidence of each strategy in a successive oligopolies framework, demonstrating that the strategies can and do arise in that context as well. Before doing so, however, we consider the welfare consequences of these strategies.

5. Welfare Consequences of RRC and SFO

To examine the welfare implications of RRC and SFO we consider two, assumed "perfect"/"costless", stylized regulatory interventions. The first involves regulating against SFO but allowing RRC, while the second involves regulating against RRC but allowing SFO. We measure welfare using consumer surplus, which for equilibrium downstream price p_d and associated total downstream market output $q_d \equiv q_d^{VI} + q_d^D$ is:

$$CS = \int_0^{q_d} (a - bq)dq - p_d q_d \tag{37}$$

The welfare impact of *allowing* SFO is measured as the consumer surplus arising when both RRC and SFO are permitted (denoted CS) less that arising when SFO is prohibited (denoted CS_{SFO}). Conversely, the welfare impact of *prohibiting* RRC is measured as the consumer surplus arising when RRC is prohibited (denoted CS_{RRC}) less that arising when both RRC and SFO are permitted (i.e. CS). Thus our two welfare measures are:

$$W_{SFO} = CS - CS_{SFO}$$

$$W_{RRC} = CS_{RRC} - CS$$

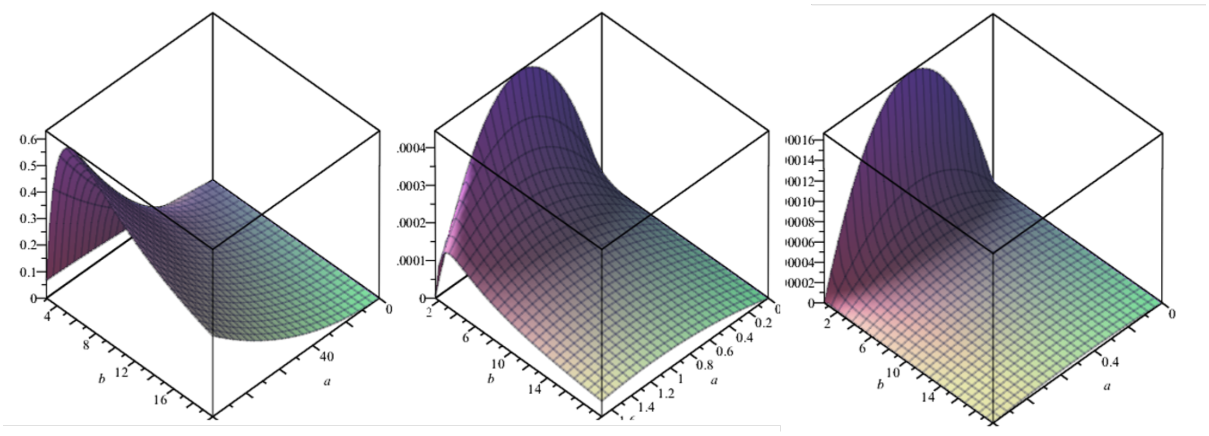
We restrict attention to the symmetric equilibrium identified in Section 4, in which $c^U = \delta c^{VI}$ and $\delta = 1$. By Proposition 2 we know that both RRC and SFO arise endogenously in that case. Furthermore, without loss of generality we write $c^{VI} = c^U = \gamma a$ where $0 \leq \gamma < 1$.[22] With the model's relevant parameters now being (a, b, γ), we show that there are conditions under which $W_{SFO}(a, b, \gamma) > 0$, implying that allowing SFO in the presence of RRC is beneficial for consumers. Since RRC arises in this case whether or not SFO is prohibited, we can interpret the increase in welfare from allowing SFO as indicating that SFO is a welfare-enhancing counterstrategy to RRC. We further show that there are conditions under which $W_{RRC}(a, b, \gamma) > 0$, meaning that prohibiting RRC is welfare-enhancing. Indeed, we show that SFO vanishes endogenously in this case, thus the welfare benefits of SFO relate to whether or not that strategy arises in the presence of RRC.

5.1. Regulating against SFO – Quantity Cap or Corrective Tax, with Rationed Forward Upstream Supply

Regulating against SFO involves ensuring $q_d^D \geq Q_f^D$. We know from Proposition 2 with $\delta = 1$ that D wishes to pursue SFO (i.e. $q_d^D < Q_f^D$) in equilibrium. Thus we assume that the regulatory goal is to ensure that $q_d^D = Q_f^D$. However, from (17) we know that D's profit-maximizing downstream output choice increases in its profit-maximizing forward upstream demand Q_f^D. Hence the first step in implementing this stylized intervention is to substitute Q_f^D for q_d^D in (17), and to solve for the required level of Q_f^D, which we denote Q_f^{SFO}. Thus this intervention could be thought of as imposing a forward buying cap on the separated downstream firm, or equivalently as a corrective "tax" that notionally increases p_f just enough to ensure that $q_d^D \geq Q_f^D$. Furthermore, since Q_f^D is now given, VI and U cannot rely on changes in p_f to ensure that $q_f^{VI} + q_f^U = Q_f^{SFO}$. Instead we require a rationing rule

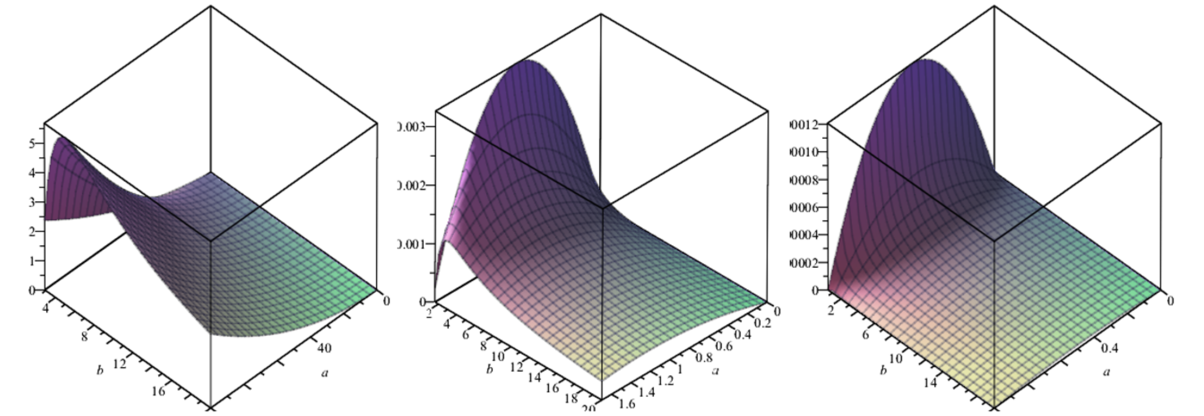
[22] Recall that $a > max\left[c^{VI}, c^U\right]$ has been assumed.

Figure 3: Illustrating Conditions under which Allowing SFO to Rival RRC Enhances Consumer Welfare ($W_{SFO} > 0$)



(a) $\gamma = 0$, $\hat{a} = 100$, $\hat{b} = 2.9$ (b) $\gamma = 0.5$, $\hat{a} = 1.7$, $\hat{b} = 1.6$ (c) $\gamma = 0.99$, $\hat{a} = 1$, $\hat{b} = 0.5$

Figure 4: Illustrating Conditions under which Eliminating RRC (and hence SFO) Enhances Consumer Welfare ($W_{RRC} > 0$)



(a) $\gamma = 0$, $\tilde{a} = 100$, $\tilde{b} = 2.9$ (b) $\gamma = 0.5$, $\tilde{a} = 1.7$, $\tilde{b} = 1.6$ (c) $\gamma = 0.99$, $\tilde{a} = 1$, $\tilde{b} = 0.5$

that reduces both q_f^{VI} and q_f^U below their equilibrium values so that in aggregate they equal $Q_f^{SFO} < Q_f^D$. To do this we simply assume that both q_f^{VI} and q_f^U are scaled proportionately by Q_f^{SFO}/Q_f^D.

After imposing these restrictions the balance of the model is solved as in Section 4. Both CS and CS_{SFO} are then computed directly using the respective downstream market price and total quantities, thus allowing computation of $W_{SFO}(a, b, \gamma)$. Note that in this scenario VI's later upstream output can be written:

$$q_l^{VI} = \frac{2a(\gamma - 1)}{15b} < 0$$

where the inequality arises due to $0 \le \gamma < 1$. Thus RRC arises endogenously, with or without SFO, if it is not explicitly prohibited. With this in mind, we make the following claim:

Claim 1. There are conditions under which allowing SFO, in the presence of RRC, increases consumer surplus. More specifically, for any $0 \le \gamma < 1$ there exists a maximum downstream market size $\hat{a}(\gamma)$ and a minimum downstream demand-price sensitivity $\hat{b}(\gamma)$ such that $W_{SFO}(a, b, \gamma) > 0$ for all $0 < a < \hat{a}(\gamma)$ and $b > \hat{b}(\gamma)$.

The claim is illustrated in Figure 3, which shows – for three candidate values of γ – values of (a, b) yielding $W_{SFO}(a, b, \gamma) > 0$. In each case $W_{SFO}(a, b, \gamma)$ becomes negative at high a and low b whenever a exceeds the stated maximum or b falls short of the stated minimum.

Thus there are conditions under which one apparently anti-competitive overbuying strategy – SFO – actually increases consumer welfare when pursued by a separated downstream firm whose vertically integrated rival is engaging in another apparently anti-competitive overbuying strategy – RRC. Under such conditions we have an apparent case of "two wrongs make a right" (or rather that two wrongs can prove to be less undesirable than just one wrong). D's strategy harms the profits of both VI and U. However, as discussed in Section 4, consumers benefit from SFO because D's downstream output – as a consequence of SFO – expands by more than VI's downstream output contracts. With total downstream output increased, and price decreased, consumer surplus – under the identified conditions – increases as a consequence of allowing SFO to counter against RRC.

5.2. Regulating against RRC – Compulsory Foreclosure from the Later Upstream Market

Regulating against RRC is simpler to implement. Once again, we know from Proposition 2 with $\delta = 1$ that VI wishes to pursue RRC with $q_l^{VI} < 0$ in equilibrium. Hence in this stylized intervention we can eliminate RRC by imposing $q_l^{VI}\left(q_l^U, Q_f^D\right) \equiv q_l^{RRC} = 0$ – i.e. we assume that VI is *compulsorily foreclosed* from the later upstream market.[23] We substitute this value for (13), and solve the balance of the model as in Section 4. Doing so reveals that, when we force $q_l^{RRC} = 0$:

$$q_d^D - Q_f^D = \frac{4a\left(1-\gamma\right)}{51b} > 0$$

where the inequality arises because $0 \leq \gamma < 1$. Notably, with RRC prohibited, SFO no longer endogenously arises – the incentive for SFO having been eliminated. The welfare consequences of this are summarized in the following claim:

Claim 2. There are conditions under which prohibiting RRC (which also eliminates SFO) increases consumer surplus. More specifically, for any $0 \leq \gamma < 1$ there exists a maximum downstream market size $\tilde{a}\left(\gamma\right)$ and a minimum downstream demand-price sensitivity $\tilde{b}\left(\gamma\right)$ such that $W_{RRC}\left(a, b, \gamma\right) > 0$ for all $0 < a < \tilde{a}\left(\gamma\right)$ and $b > \tilde{b}\left(\gamma\right)$.

The claim is illustrated in Figure 4, which shows – for the same three candidate values of γ as in Figure 3 – values of (a, b) yielding $W_{RRC}\left(a, b, \gamma\right) > 0$. Once again, in each case $W_{RRC}\left(a, b, \gamma\right)$ becomes negative at high a and low b whenever a exceeds the stated maximum or b is less than the stated minimum.

Notably, we are able to show that there are conditions under which foreclosing VI – another apparently anticompetitive practice – from the later (though not forward) upstream market enhances consumer welfare. In this case the mechanism is that precluding VI from engaging in RRC means that the later upstream market price p_l is lower than when both RRC and SFO are permitted to arise simultaneously. This causes D's downstream output to expand by more than VI's downstream market contracts, and thus increases consumer surplus, relative to the case in which both RRC and SFO arise. Thus this intervention "kills two birds with one stone" – eliminating RRC also eliminates SFO – to the benefit of consumers. While allowing D and VI to engage in a "tug of war" over p_l serves to reduce that price relative to what it would be if only VI pursued RRC, there are conditions under which it is better for consumers if there was no need for that tug of war in the first place.

In conclusion, we have shown that there are conditions – in Figures 3 and 4 the same conditions – under which it is welfare enhancing to permit SFO if RRC is also permitted. However, we have also shown that under those conditions consumer surplus is even further enhanced if RRC is eliminated, in which case SFO is also eliminated. Having established in the duopolies case conditions under which both RRC and SFO are equilibrium strategies – and in which allowing SFO to counter RRC or eliminating RRC (and hence SFO) can increase consumer welfare – we now examine how these results carry over to a successive oligopolies context.

6. Oligopoly Extension

While the preceding analysis establishes that RRC and SFO arise in equilibrium under a duopoly structure, and that SFO can be welfare-enhancing, this section explores whether these findings extend to more general asymmetric oligopoly structures in which we have a total of $n_u \geq 2$ upstream firms and a total of $n_d \geq n_u$ downstream firms, m of which are vertically integrated upstream-downstream pairs $(0 \leq m \leq n_u)$.[24] All VI firms are denoted as VI, i and are assumed symmetric. Likewise, all D firms are denoted D, j and assumed symmetric, as are all U firms (denoted U, j). Note that under symmetric integration ($m = n_u = n_d$) only downstream trading occurs, given symmetric firms, in which case both RRC and SFO are precluded (i.e. $q_l^{VI,i} = q_d^{D,j} - Q_f^{D,j} = 0$).

We restrict attention to the symmetric case in which $c^{VI,i} = c^{U,j} = 0$, and further rationalize notation by fixing downstream demand parameters to be $a = b = 1$. Thus our only free parameters are now n_u, n_d and m.

The derivation of the generalized oligopoly case is a straightforward extension of Section 4. Details are summarized in Appendix C, including equilibrium expressions for $q_l^{VI,i}$ and $q_d^{D,j} - Q_f^{D,j}$.[25] Here we graphically summarize the key results. Firstly, Figure 5 comprises six panels, each showing the equilibrium level of an integrated firm's later upstream market output, $q_l^{VI,i}$, for a different total number of upstream firms. For illustration purposes we consider values of n_u from two to seven, which should adequately characterize imperfectly competitive industries of the sort we consider.[26] Each numbered line (or point) in each panel shows the value of $q_l^{VI,i}$ for the indicated value of n_d, which for illustration purposes we take to be from n_u to nine (which, once again, should adequately characterize

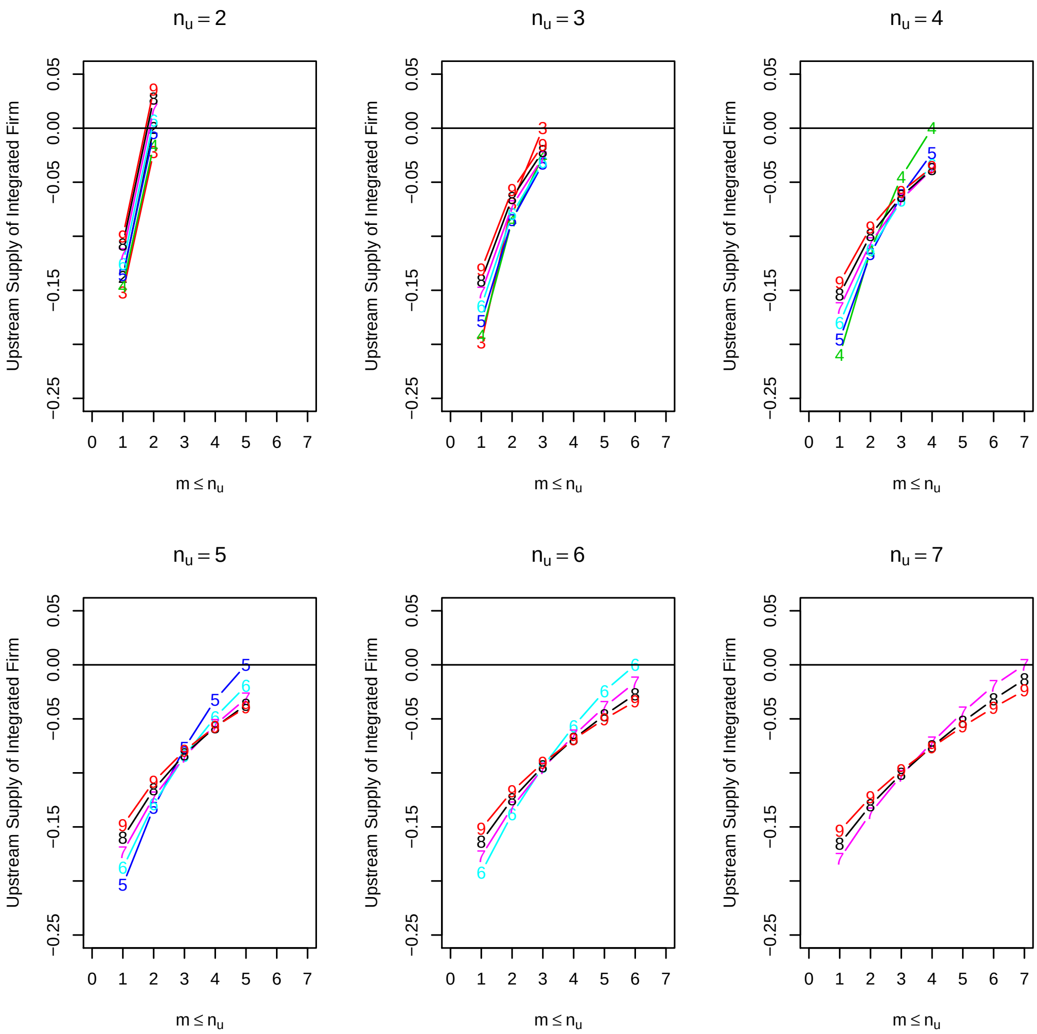
[23] As for our stylized SFO intervention, clearly such an intervention is sufficient to achieve this, but may not be necessary.

[24] We restrict attention to the case in which there are always at least as many downstream as upstream firms to eliminate the possibility of being left with redundant upstream firms.

[25] Full details are available from the author on request. Note that the equilibrium conditions set out in Section 4.4 (generalized to the oligopolies case) are all satisfied for the parameter values we consider.

[26] The US Department of Justice considers that market concentration issues begin to arise for a Herfindahl-Hirschman Index of 1500 or more. Assuming symmetric firms this corresponds to industries with seven firms or less.

Figure 5: Later Upstream Market Supply of Each Vertically Integrated Firm – Oligopoly Case

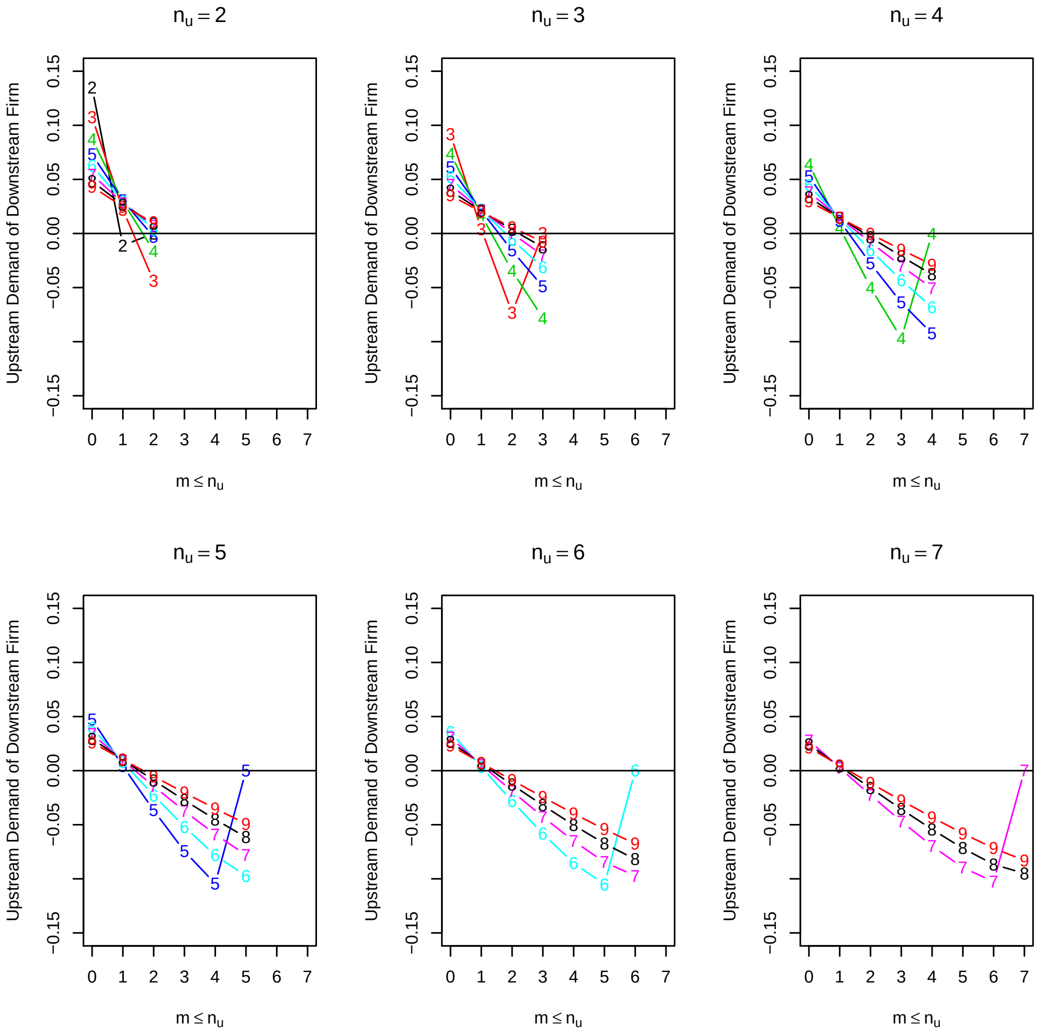


the sorts of industries in question). Finally, the horizontal scale of each graph shows the number m of integrated upstream-downstream pairs of firms (with $m \le n_u$). In Figure 5 no values are plotted for $m = 0$ since there are no integrated firms in that case.

The key feature is that in all panels $q_l^{VI,i}$ almost always plots below zero, confirming that for the representative total numbers of upstream and downstream firms considered, and for the degrees of integration considered, each integrated firm pursues a RRC strategy. While the number of downstream firms or the degree of vertical integration affects the intensity to which the strategy is pursued, in only exceptional cases does an integrated firm choose to supply the later upstream market. Thus the fact that an integrated firm pursues a RRC strategy is not fundamentally changed by shifting from successive duopolies to a more general oligopoly setting.

Figure 6 repeats the six panels used in Figure 5, but this time plots a separated downstream firm's later upstream market demand $q_d^{D,j} - Q_f^{D,j}$ for different total numbers of upstream and downstream firms, and different degrees of vertical integration. The picture that emerges is more nuanced than in the successive duopolies case. To begin, the first panel of Figure 6 illustrates the case of $n_u = 2$. We see that in this case SFO (i.e. $q_d^{D,j} - Q_f^{D,j} < 0$) arises only exceptionally, including when there are also $n_d = 2$ downstream firms, with one integrated upstream-downstream pair (i.e. $m = 1$), as was analyzed in Section 4. Unsurprisingly each separated downstream firm's later upstream market demand is positive in the absence of vertical integration (i.e. when $m = 0$), since RRC does not arise in that case. However, we see that when $m = 1$ this demand is positive for values of $n_d > 2$ in the range considered. Glancing across the remaining panels of Figure 6 we see that later upstream demand remains positive for $m \in \{0, 1\}$, and it is only at higher levels of vertical integration that SFO emerges as a clear strategy for a greater total number of upstream firms, or lower total number of

Figure 6: Later Upstream Market Demand of Each Separated Downstream Firm – Oligopoly Case



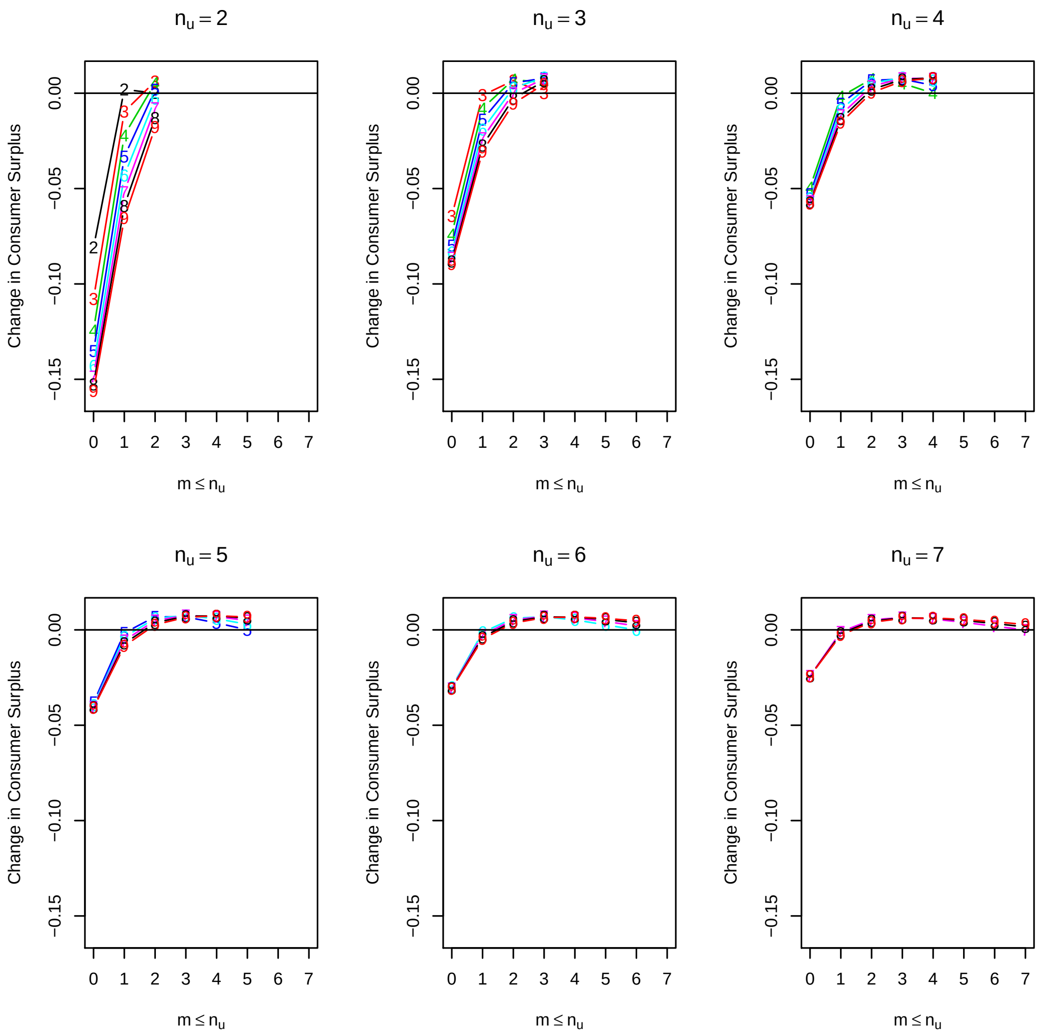
downstream firms for $m > 1$.[27] Indeed, numerical simulation of $q_d^{D,j} - Q_f^{D,j}$ confirms this finding for much higher maximum values of n_u and n_d: demand is non-negative for $m \in \{0,1\}$, but negative otherwise. Thus while the successive duopolies analysis presented earlier may be regarded as one of a few special cases when there are just two upstream firms, the basic finding that SFO endogenously arises in the presence of asymmetric vertical integration is more typical for higher values of n_u.

Finally, we consider whether allowing (versus precluding) SFO as a counterstrategy against an existing RRC strategy of integrated firms improves or harms welfare – again measured by consumer surplus. As in Section 5, we model a prohibition on SFO as involving the imposition of a stylized regulation requiring $q_d^{D,j} - Q_f^{D,j} = 0$ in equilibrium, either through quantity regulation or an equivalent corrective tax on forward upstream prices (and non-price rationing of forward upstream supply). This is not identical to the scenario analyzed in Section 5, however, as we have just seen that $q_d^{D,j} - Q_f^{D,j} > 0$ (i.e. an absence of SFO) is now an equilibrium outcome in certain cases. Hence while the successive duopolies case allows us to impose $q_d^{D,j} - Q_f^{D,j} = 0$ to represent the elimination of SFO, that is now unnecessary in certain cases. Thus the analysis here instead examines the welfare consequences of forcing separated downstream firms to fully contract their downstream market input requirements, rather than allowing them to freely choose their forward upstream purchases. Unlike in Section 5, this is not the same as comparing the prohibition with the toleration of SFO.

Given this caveat, on examining the first panel of Figure 7 we see that with just two upstream firms, "allowing SFO" enhances welfare in only a handful of cases. With the number of downstream firms high enough, "allowing SFO" results in a decline in consumer surplus (i.e.

[27] Note that a separated downstream firm's equilibrium demand on the later upstream market is nil whenever $n_u = m$. All upstream firms are integrated in that case, and their optimal strategy is to foreclose the upstream markets from separated downstream rivals.

Figure 7: Change in Consumer Surplus from Allowing SFO versus Forcing Full Forward Contracting – Oligopoly Case



$W_{SFO} < 0$), in contrast to our earlier finding. However, from the remaining panels we see that allowing separated downstream firms to optimally choose their level of forward upstream purchases (and hence their later upstream market demand) remains welfare-enhancing (i.e. $W_{SFO} > 0$) when there are at least three upstream firms, and with two or more upstream-downstream pairs of firms being integrated. For the borderline case in which $n_u = 3$, we see that this finding depends also on the number of downstream firms, with the change in consumer surplus from "allowing SFO" being positive for lower numbers of downstream firms, but negative otherwise.

Thus, whether or not allowing SFO is welfare-enhancing depends on whether the separated downstream firms pursuing the strategy can capture a sufficient share of the resulting benefits (as opposed to sharing them with their downstream rivals), and whether they face a sufficient threat of RRC from integrated firms. With the number of upstream firms and degree of integration high enough, or number of downstream firms low enough, "allowing SFO" emerges as a welfare-enhancing strategy. Indeed, comparing Figures 6 and 7 we see that the situations in which "allowing SFO" enhances welfare correspond to those in which it arises as an equilibrium strategy. Conversely, forcing separated firms to fully forward contract when they optimally choose to under-contract enhances welfare.

This is consistent with Powell (1993), who argues that forward contracting has public good characteristics. This is because the social (e.g. consumer) benefits generated by pro-competitive forward contracting are not fully internalized by downstream firms. In such circumstances, imposing full forward contracting can resolve the coordination problem that otherwise leads to socially sub-optimal contracting levels.

Thus our findings in Section 5 for successive duopolies do not translate identically into the oligopoly context, but tend only to fail in circumstances in which the social benefits of increased forward contracting may be higher than the associated private benefits to separated downstream firms. We summarize the above findings in the following proposition:

Proposition 3. *With a total of $n_u \geq 2$ upstream firms and $n_d \geq n_u$ downstream firms, m of which are vertically integrated $(0 \leq m \leq n_u)$:*

1. RRC is typically an equilibrium strategy of integrated firms (for the representative maximum total numbers of upstream and downstream firms considered).
2. For such cases SFO emerges as a clear equilibrium strategy when the total number of integrated firms is sufficiently large, or the total number of downstream firms is sufficiently small.
3. Allowing SFO, as opposed to forcing separated downstream firms to fully fully contract just their downstream market input requirements, enhances consumer surplus in the same situations in which SFO emerges as an endogenous equilibrium strategy.
4. Conversely, forcing separated downstream firms to fully forward contract their downstream market input requirements, in situations in which they would optimally choose to under-contract those requirements (i.e. versus pursuing a SFO strategy), enhances consumer surplus.

7. Conclusions

Using a simple model of vertical oligopolies within a rich institutional framework we have identified conditions under which apparently anticompetitive overbuying – in this case by separated downstream firms on a forward market for an intermediate good – arises in equilibrium, and is welfare-enhancing. In particular, SFO serves as an effective counterstrategy against anticompetitive overbuying on an upstream market for that intermediate good (i.e. a RRC strategy) by those firms' vertically integrated rivals. Whilst our principal findings were derived for the case of successive duopolies under asymmetric vertical integration, we have shown that they remain typical under more general asymmetric oligopoly structures.

Our analysis reveals three key tradeoffs. First, when determining their optimal later upstream market output, integrated firms trade off the fact that by buying on the later upstream market they increase their own average production cost, but improve their downstream market position by also increasing their separated downstream rivals' input costs. When those rivals can make strategic forward purchases, however, they become de facto producers on the later upstream market, having acquired "capacity" on the forward upstream market. As a consequence an integrated firm's tradeoff becomes more nuanced, in that the integrated firm must now intensify its RRC strategy on the later upstream market to limit the decrease in later upstream price resulting when forward upstream sales result in such additional later upstream supply. Thus the tradeoff becomes between increasing average production costs and limiting profit losses, with the RRC strategy now taking on an additional defensive motive in addition to the standard offensive motive. By engaging in SFO, a separated downstream firm forces an integrated firm to engage in a defensive "tug of war" over the later upstream market price.

The second key tradeoff confronts separated downstream firms when choosing their forward upstream demand. For sufficiently low forward demand the separated downstream firm trades off increased downstream revenues and decreased later upstream purchase costs against increased forward purchase costs. Conversely, when forward upstream demand is sufficiently high, the tradeoff is between increased downstream revenues on the one hand, and increased purchase costs (or reduced revenues) in the later upstream market and increased forward purchase costs on the other.

This tradeoff modifies the pro-competitive effects of forward contracting – not only does such contracting induce greater competition in later upstream markets, but it also improves competition on related downstream markets. Finally, when choosing their forward supply, separated upstream firms trade off the impact of this choice on their forward upstream market profits against its impact on the later upstream market price and hence their later upstream market profits. Conversely, for an integrated firm the tradeoff is between forward upstream and downstream market profits on the one hand, and later upstream market purchase costs on the other.

Our analysis of the welfare impacts of strategic forward overbuying by separated downstream firms results in three policy prescriptions. First, in the presence of anticompetitive overbuying by integrated firms (i.e. RRC), there are conditions under which it is preferable from the consumer's perspective to tolerate anticompetitive overbuying by separated downstream firms (i.e. SFO). The target of strategic forward overbuying is not consumers, but rather integrated rivals, and its consequence can be to lower downstream prices while increasing downstream output. In a sense this amounts to "two wrongs make a right". Conversely, in instances where strategic forward overbuying does not endogenously arise to combat raising rivals' costs, regulations which would otherwise eliminate such overbuying (such as full forward contracting obligations on separated downstream firms) might improve consumer welfare. In this case separated downstream firms effectively under-purchase on forward upstream markets from the consumer's perspective, because they internalize only their own pro-competitive benefits from forward contracting, and not those of other separated downstream firms or consumers.

Second, and related to the first point, regulations affecting the level of forward contracting undertaken by separated downstream firms may have unintended consequences. Indeed, France's 2010 NOME law in effect (if not intent) precludes separated downstream firms in that country's electricity sector from engaging in strategic forward overbuying (at least at historical nuclear tariffs). Given France's asymmetric and imperfectly competitive electricity industry structure, this law may have the unintended consequence of limiting the use of forward contracting in countervailing against upstream market power.

Third, and to conclude, while we have identified conditions under which tolerating the coexistence of both forms of strategic overbuying is preferable to regulating against just SFO, eliminating RRC "kills two birds with one stone", by also eliminating SFO. For our industry structure we have found conditions under which this maximizes welfare, suggesting that in some cases compulsory foreclosure of integrated firms from the later upstream market – so as to eliminate RRC (and hence SFO too) – is desirable. This provides further grounds to question whether foreclosure in vertical industries is anticompetitive.

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AppendixA. Equilibrium Values

Equilibrium values are presented here using the forward upstream market equilibrium values presented in Lemma 4 (which are repeated here for convenience). All other equilibrium values can be derived from expressions stated in the main text using Q_f^D to compute any intermediate expressions.

Forward Upstream Market

$$q_f^U = \frac{1}{675b}\left(64a + 136c^{VI} - 200c^U\right)$$
$$q_f^{VI} = \frac{1}{675b}\left(83a - 133c^{VI} + 50c^U\right)$$
$$p_f = \frac{1}{400}\left(89a + 161c^{VI} + 150c^U\right)$$
$$Q_f^D = \frac{1}{225b}\left(49a + c^{VI} - 50c^U\right)$$

Later Upstream Market

$$q_l^U = \frac{1}{150b}\left(19a + 31c^{VI} - 50c^U\right)$$
$$q_l^{VI} = -\frac{1}{225b}\left(31a + 19c^{VI} - 50c^U\right)$$
$$p_l = \frac{1}{100}\left(19a + 31c^{VI} + 50c^U\right)$$

Downstream Market

$$q_d^D = \frac{1}{150b}\left(31a + 19c^{VI} - 50c^U\right)$$
$$q_d^{VI} = \frac{1}{300b}\left(119a - 169c^{VI} + 50c^U\right)$$
$$p_d = \frac{1}{300}\left(119a + 131c^{VI} + 50c^U\right)$$

AppendixB. Proof of Proposition 1

Conditions for Non-Negative Equilibrium Quantities

After substituting $c_j = \delta c_i$ in the equilibrium expressions set out in Section 4 or Appendix A for q_d^{VI}, q_d^D, total forward upstream output $q_f^{VI} + q_f^U$, and combined total forward and later upstream output $q_f^{VI} + q_f^U + q_l^{VI} + q_l^U$, it is easily verified that:

1. $q_f^{VI} + q_f^U \geq 0$, (and hence $Q_f^D \geq 0$ by forward upstream market balance in equilibrium) iff:

$$\text{Constraint A} \begin{cases} \text{A1: } c_i \leq \frac{49a}{50\delta - 1} & \delta > \frac{1}{50} \\ \text{A2: } c_i \geq \frac{49a}{50\delta - 1} & \delta < \frac{1}{50} \end{cases}$$

2. $q_f^{VI} + q_f^U + q_l^{VI} + q_l^U \geq 0$, and $q_d^D \geq 0$, iff:

$$\text{Constraint B} \begin{cases} \text{B1: } c_i \leq \frac{31a}{50\delta - 19} & \text{if } \delta > \frac{19}{50} \\ \text{B2: } c_i \geq \frac{31a}{50\delta - 19} & \text{if } \delta < \frac{19}{50} \end{cases}$$

3. $q_d^{VI} \geq 0$ iff:

$$\text{Constraint C} \begin{cases} \text{C1: } c_i \geq \frac{119a}{169 - 50\delta} & \text{if } \delta > \frac{169}{50} \\ \text{C2: } c_i \leq \frac{119a}{169 - 50\delta} & \text{if } \delta < \frac{169}{50} \end{cases}$$

Figure B.1 highlights the three possible sets of equilibria satisfying these quantity-related constraints. It plots the differences between the thresholds in constraints B and A, and in constraints C and A, over the relevant ranges for δ.[28] Since $a > 0$ simply scales these differences without changing their signs, we restrict attention to the case $a = 1$ with no loss of generality. Note that the $C - A$ curve is negative for all $\delta > 1$. We summarize the figure's implications in the following lemma:

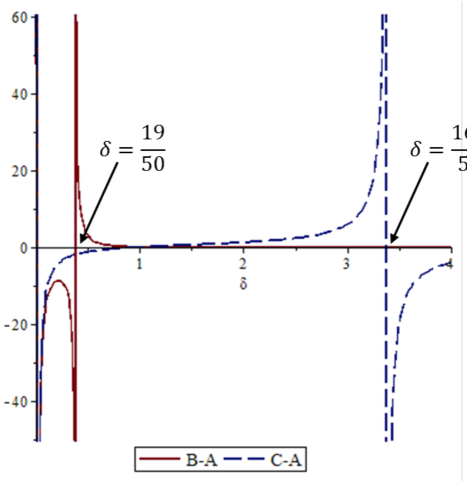
Lemma 7. *Candidate Equilibria satisfying Quantity-Related Constraints:*

There is one symmetric candidate equilibrium, and two asymmetric candidate equilibria ranges, satisfying all relevant quantity-related constraints:

1. Candidate 1 – with $\delta = 1$, at which $c^{VI} = c^U$, requiring that $c^{VI} \leq a$;
2. Candidate Range 2 – with $\frac{1}{50} < \delta < \frac{19}{50}$, at which $c^U \ll c^{VI}$, requiring that $0 \leq c^{VI} \leq \frac{119a}{169 - 50\delta}$; and

[28] Note that since we allow $c^{VI} \lesseqgtr c^U$, we have $\delta \lesseqgtr 1$.

Figure B.1: Candidate Equilibria (Ranges) with $c^U = \delta c^{VI}$



3. Candidate Range 3 – with $\delta > \frac{169}{50}$, at which $c^U \gg c^{VI}$, requiring that $0 \leq c^{VI} \leq \frac{31a}{50\delta - 19}$.

Proof. For $\frac{19}{50} < \delta < \frac{169}{50}$, the relevant conditions are A1, B1 and C2, which each requires c^{VI} to be below a given, positive threshold. Equilibrium requires the simultaneous satisfaction of all three conditions, which over this δ range is satisfied only at $\delta = 1$, in which case $c^{VI} = c^U$.[29] At this value of δ each condition collapses to requiring simply that $c^{VI} \leq a$, which is assured since $a > max\left[c^{VI}, c^U\right]$ by assumption.

For $\frac{1}{50} < \delta < \frac{19}{50}$, the relevant quantity-related conditions are A1, B2 and C2. Satisfaction of B2 is assured, since its right-hand side is negative, and by assumption $c^{VI} \geq 0$. Simultaneous satisfaction of A1 and C2 simply requires that one lies above or below the other throughout the relevant δ range. It is easily verified that the difference between the A1 and C2 thresholds is positive for all relevant δ, given an arbitrary positive value of a. Since each constraint represents an upper bound on c^{VI}, and C2 is both the more binding constraint and positive for the relevant δ, this means that both conditions are satisfied provided:

$$0 \leq c^{VI} \leq \frac{119a}{169 - 50\delta} \qquad \text{(B.1)}$$

Finally, for $\delta > \frac{169}{50}$, the relevant conditions are A1, B1 and C1. Since the right-hand side of C1 is negative in this case, and $c^{VI} \geq 0$ by assumption, its satisfaction is assured. Constraints A1 and B1 are simultaneously satisfied if one lies above or below the other for the relevant values of δ. It is easily verified that the difference between the A1 and B1 thresholds is positive for all relevant δ, given an arbitrary positive value of a. Since each constraint represents an upper bound on c^{VI}, and B1 is both the more binding constraint and positive for the relevant δ, this means that both conditions are satisfied provided:

$$0 \leq c^{VI} \leq \frac{31a}{50\delta - 19} \qquad \text{(B.2)}$$

This completes the proof of the lemma. □

These necessary conditions must be satisfied, along with any relevant price-related conditions, for the above candidates to be equilibria, to which we now turn.

Price-Related Conditions, and Equilibria

By inspection (see Appendix A), it can be seen that $p_d \geq 0$ for all $a > max\left[c^{VI}, c^U\right]$ and c^{VI}, $c^U \geq 0$. Conversely, we have two cases for the p_f and p_l constraints, depending on which of the quantity-related candidate equilibria are being considered:

1. For $\delta = 1$ ($c^{VI} = c^U$) and $\frac{1}{50} < \delta < \frac{19}{50}$ ($c^{VI} \gg c^U$), we require that p_f, $p_l \geq c^{VI}$; and
2. For $\delta > \frac{169}{50}$ ($c^U \gg c^{VI}$), we require that $p_f, p_l \geq c^U$.

Below we show that when $\delta = 1$ (Candidate 1), these price-related constraints are identical to the quantity-related constraints for that case – i.e. $c^{VI} \leq a$ – which is true by assumption. When $\frac{1}{50} < \delta < \frac{19}{50}$ (Candidate Range 2), we show that $p_l \geq c^{VI}$ is the more binding of the two price constraints, and is more binding than the quantity-related constraint (B.1). Conversely, when $\delta > \frac{169}{50}$ (Candidate Range 3), we show that $p_f \geq c^U$ is the more binding of the two price constraints, and is more binding than the quantity-related constraint (B.2).

Specifically, by (30), $p_f \geq c^{VI}$ implies that:

$$\frac{1}{400}\left(89a + 161c^{VI} + 150c^U\right) \geq c^{VI}$$

Substituting $c^U = \delta c^{VI}$, with $\delta = 1$, and solving for c^{VI}, yields $c^{VI} \leq a$, which is true by assumption. Doing likewise using the equilibrium expression for p_l in Appendix A yields the condition:

$$\frac{1}{100}\left(19a + 31c^{VI} + 50c^U\right) \geq c^{VI}$$

Substituting $c^U = c^{VI}$ and solving for c^{VI} also yields $c^{VI} \leq a$, which is assumed. This proves the first part of the proposition.

Repeating the above for $c^U = \delta c^{VI}$, with $\frac{1}{50} < \delta < \frac{19}{50}$, yields the following two conditions:

$$c^{VI} \leq \frac{89a}{239 - 150\delta} \qquad (p_f \geq c^{VI})$$

$$c^{VI} \leq \frac{19a}{69 - 50\delta} \qquad (p_l \geq c^{VI})$$

It is easily verified that the difference between these two thresholds is positive for all relevant δ, and arbitrary

[29] For values of delta either side of $\delta = 1$ the two curves are of opposite sign. This means there is no uniformly lowest upper bound for c^{VI}, the satisfaction of which assures satisfaction of the remaining two constraints, for the relevant δ range.

positive a. This implies that the second is the more binding upper bound on c^{VI}. Furthermore, it is easily verified that the difference between that constraint and the relevant quantity-related constraint in Lemma 7 (i.e. C2, as in (B.1)) is *negative* for all relevant δ, and arbitrary positive a, indicating that $p_l \geq c^{VI}$ is the most binding upper bound on c^{VI} of all the relevant constraints in this case. It is also easily verified that this condition is positive for all relevant δ and $a > 0$. Thus equilibrium in this case requires that:

$$0 \leq c^{VI} \leq \frac{19a}{69 - 50\delta}$$

Finally, repeating the above with $\delta > \frac{169}{50}$, and noting that now we require $p_f,\ p_l \geq c^U = \delta c^{VI}$, yields the following two conditions:

$$c^{VI} \leq \frac{89a}{250\delta - 161} \qquad (p_f \geq c^U)$$

$$c^{VI} \leq \frac{19a}{50\delta - 31} \qquad (p_l \geq c^U)$$

It is easily verified that the difference between these two thresholds is *negative* for all relevant δ, and arbitrary positive a. This implies that the first is the more binding upper bound on c^{VI}. Furthermore, it is easily verified that the difference between this constraint and the relevant quantity-related constraint in Lemma 6 (i.e. B1, as in (B.2)) is also negative for all relevant δ, and arbitrary positive a, indicating that $p_f \geq c^U$ is the most binding upper bound on c^{VI} of all the relevant constraints in this case. It is also easily verified that this condition is positive for all relevant δ and $a > 0$. Thus equilibrium in this case requires that:

$$0 \leq c^{VI} \leq \frac{89a}{250\delta - 161}$$

This completes the proof of Proposition 1.

AppendixC. Oligopoly Case Derivation

In this appendix we summarize the derivation for our model assuming oligopoly structures comprising a total of $n_u \geq 2$ upstream firms and a total of $n_d \geq n_u$ downstream firms, m of which are vertically integrated ($0 \leq m < n_u$). Since the basic approach is as in Section 4, we simply describe the key steps and present only the main results. As noted in Section 6, vertically integrated firms are denoted VI, i, while separated downstream and upstream firms are denoted D, j and U, j respectively. We consider the case of asymmetric vertical integration ($0 < m < n_u$), with $c^{VI,i} = c^{U,j} = 0$ and $a = b = 1$.

Downstream Market Subgame

Downstream market inverse demand now takes the assumed form:

$$p_d = 1 - mq_d^{VI,i} - (n_d - m)q_d^{D,j} \tag{C.1}$$

where we have m symmetric vertically integrated firms each producing output $q_d^{VI,i}$, and $n_d - m$ symmetric separated downstream firms each producing output $q_d^{D,j}$. Separated downstream and integrated firms each have profit functions as in (2) and (3) respectively.

Given the assumed symmetry, each integrated firm in this subgame chooses $q_d^{VI,i}$ to maximize its profit function (3) taking the output of its $n_d - m$ separated and $m - 1$ integrated rivals as given (as well as all forward and later upstream market prices and quantities). This can be achieved by substituting $p_d = 1 - q_d^{VI,i} - A_i$ into (3), maximizing the resulting expression with respect to $q_d^{VI,i}$, and then substituting $A_i = (m-1)q_d^{VI,i} + (n_d - m)q_d^{D,j}$ before solving for $q_d^{VI,i}$ to obtain that integrated firm's best response function in terms of $q_d^{D,j}$. Likewise, $p_d = 1 - q_d^{D,j} - A_j$ can be substituted into (2), which is then maximized with respect to $q_d^{D,j}$, before substituting $A_j = mq_d^{VI,i} + (n_d - m - 1)q_d^{D,j}$ and solving for $q_d^{D,j}$ to obtain each separated downstream firm's best response function in terms of $q_d^{VI,i}$. This recognizes that each separated downstream firm chooses its profit-maximizing output taking the output of its m integrated and $n_d - m - 1$ separated rivals as given. Simultaneously solving these reaction functions, and substituting the results into (C.1) for p_d, results in the following downstream market subgame equilibrium:

$$q_d^{VI,i}(p_l) = p_d(p_l) = \frac{1}{n_d + 1}\left[1 + (n_d - m)p_l\right] \tag{C.2}$$

$$q_d^{D,j}(p_l) = \frac{1}{n_d + 1}\left[1 - (m+1)p_l\right] \tag{C.3}$$

Later Upstream Market Subgame

The later upstream market demand of each of the $n_d - m$ separated downstream firms is $q_d^{D,j}(p_l) - Q_f^{D,j}$, which is supplied by the combined later upstream market output of the integrated and separated upstream firms. Thus the derived inverse demand function for the later upstream market is obtained by solving $(n_d - m)q_d^{D,j}(p_l) = q_l^{VI,tot} + q_l^{U,tot} + Q_f^{D,tot}$ for p_l, where by symmetry $q_l^{VI,tot} = mq_l^{VI,i}$, $q_l^{U,tot} = (n_u - m)q_l^{U,j}$ and $Q_f^{D,tot} = (n_d - m)Q_f^{D,j}$. Doing so yields a derived inverse demand function of the form:

$$p_l\left(q_l^{VI,tot}, q_l^{U,tot}, Q_f^{D,tot}\right) = \frac{1}{m+1} - \frac{(n_d+1)\left(q_l^{VI,tot} + q_l^{U,tot} + Q_f^{D,tot}\right)}{(m+1)(n_d - m)} \tag{C.4}$$

Given symmetry, each integrated firm in this subgame chooses $q_l^{VI,i}$ to maximize its profit function (3) evaluated using $q_d^{VI,i}(p_l)$ and $p_d(p_l)$ from (C.2), and substituting $q_l^{VI,tot} + q_l^{U,tot} + Q_f^{D,tot} = q_l^{VI,i} + B_i$ in (C.4) where

$B_i = (m-1)q_l^{VI,i} + (n_u - m)q_l^{U,j} + Q_f^{D,tot}$. It does so taking as given all forward upstream market quantities and prices, as well as the later upstream output choices of its $m-1$ integrated and $n_u - m$ separated upstream rivals. As above, after taking the required first order condition we then substitute for B_i, and solve for $q_l^{VI,i}$ to obtain each integrated firm's later upstream market best response function $q_l^{VI,i}\left(q_l^{U,j}, Q_f^{D,tot}\right)$. Likewise, each separated upstream firm chooses $q_l^{U,j}$ to maximize its profit function (4), substituting $q_l^{VI,tot} + q_l^{U,tot} + Q_f^{D,tot} = q_l^{U,j} + B_j$ in (C.4) with $B_j = mq_l^{VI,i} + (n_u - m - 1)q_l^{U,j} + Q_f^{D,tot}$. It does so taking as given all forward upstream market quantities and prices, as well as the later upstream output choices of its m integrated and $n_u - m - 1$ separated upstream rivals. Once again, after taking the first order condition we substitute for B_j, and solve for $q_l^{U,j}$ to obtain each separated upstream firm's later upstream market best response function $q_l^{U,j}\left(q_l^{VI,i}, Q_f^{D,tot}\right)$. Simultaneously solving these best response functions, and substituting the results into (C.4) yields the following form of later upstream market subgame equilibrium:[30]

$$q_l^{VI,i}\left(Q_f^{D,tot}\right) = -\alpha - \beta Q_f^{D,tot} \tag{C.5}$$

$$q_l^{U,j}\left(Q_f^{D,tot}\right) = \gamma - \delta Q_f^{D,tot} \tag{C.6}$$

$$p_l\left(Q_f^{D,tot}\right) = \eta - \kappa Q_f^{D,tot} \tag{C.7}$$

It is easily verified that $\alpha \gtreqless 0$, while $(\beta, \gamma, \delta, \eta, \kappa) > 0$.

Forward Upstream Market Subgame

Forward Upstream Demand

Each of the $n_d - m$ separated downstream firms chooses $Q_f^{D,j}$ to maximize its profit function (2), taking as given p_f, the forward upstream demand choices of its $n_d - m - 1$ separated downstream rivals, and the forward upstream output choices of the integrated and separated upstream firms. They do so anticipating the downstream market subgame equilibrium, thus substituting $q_d^{D,j}(p_l)$ and $p_d(p_l)$ from (C.3) and (C.2) respectively into (2), after substituting for $p_l\left(Q_f^{D,tot}\right)$ in both (C.3) and (C.2) using (C.7). The first order condition for each separated downstream firm is taken after substituting $Q_f^{D,tot} = Q_f^{D,j} + C_j$ in the resulting profit function. Given symmetry, we then substitute $C_j = (n_d - m - 1)Q_f^{D,j}$, and solve for $Q_f^{D,j}$ to obtain separated downstream firm j's optimal forward upstream demand $Q_f^{D,j}(p_f)$. Summing over all $n_d - m$ symmetric separated downstream firms yields aggregate forward demand $Q_f^{D,tot}(p_f)$.

Since $Q_f^{D,tot}$ is supplied by the aggregate forward upstream output $q_f^{VI,tot} + q_f^{U,tot} = mq_f^{VI,i} + (n_u - m)q_f^{U,j}$ of the integrated and separated upstream firms, the derived inverse demand function $p_f\left(q_f^{VI,tot} + q_f^{U,tot}\right)$ for the forward upstream market is found by solving $Q_f^{D,tot}(p_f) = q_f^{VI,tot} + q_f^{U,tot}$ for p_f.

Forward Upstream Supply

Facing the forward market derived inverse demand function $p_f\left(q_f^{VI,tot} + q_f^{U,tot}\right)$ described above, each integrated firm chooses $q_f^{VI,i}$ to maximize its profit function (3), anticipating the downstream and later upstream subgame equilibria (i.e. substituting for $q_d^{VI,i}(p_l)$ and $p_d(p_l)$ from (C.2), for $q_l^{VI,i}\left(Q_f^{D,tot}\right)$ and $p_l\left(Q_f^{D,tot}\right)$ using the full expressions for (C.5) and (C.7), for $Q_f^{D,tot}(p_f)$ derived as above, and for $p_f\left(q_f^{VI,tot} + q_f^{U,tot}\right)$ using the forward upstream market derived inverse demand function). This expresses $\Pi^{VI,i}$ in terms of $q_f^{VI,tot} + q_f^{U,tot}$. Taking the forward upstream output choice of its $m-1$ integrated and $n_u - m$ separated upstream rivals as given, the profit-maximizing forward output of each integrated firm is found by substituting $q_f^{VI,tot} + q_f^{U,tot} = q_f^{VI,i} + D_i$ into $p_f\left(q_f^{VI,tot} + q_f^{U,tot}\right)$, taking the first order condition with respect to $q_f^{VI,i}$, substituting for D_i, and then solving for $q_f^{VI,i}$ to obtain each integrated firm's forward upstream market best response function in terms of $q_f^{U,j}$, namely $q_f^{VI,i}\left(q_f^{U,j}\right)$.

Similarly, each separated upstream firm faces the same forward upstream inverse demand, and chooses $q_f^{U,j}$ to maximize its profit function (4), anticipating the later upstream market subgame equilibrium values of $q_l^{U,j}\left(Q_f^{D,tot}\right)$ and $p_l\left(Q_f^{D,tot}\right)$, and taking as given the forward output choices of its m integrated and $n_u - m - 1$ separated upstream rivals. This profit-maximizing forward upstream output is found by substituting $q_f^{VI,tot} + q_f^{U,tot} = q_f^{U,j} + D_j$ into $p_f\left(q_f^{VI,tot} + q_f^{U,tot}\right)$, taking the first order condition with respect to $q_f^{U,j}$, substituting for D_j, and then solving for $q_f^{U,j}$ to obtain each separated upstream firm's forward upstream market best response function in terms of $q_f^{VI,i}$, namely $q_f^{U,j}\left(q_f^{VI,i}\right)$.

Equilibrium

Simultaneously solving these forward upstream market reaction functions of the integrated and separated upstream firms yields our equilibrium values of forward output $q_f^{VI,i}$ and $q_f^{U,j}$, from which we obtain total forward upstream output $q_f^{VI,tot} + q_f^{U,tot} = mq_f^{VI,i} + (n_u - m)q_f^{U,j}$. Since $Q_f^{D,tot} = q_f^{VI,tot} + q_f^{U,tot}$ in equilibrium, we can use this value in (C.5), (C.6) and (C.7) to obtain equilibrium $q_l^{VI,i}$, $q_l^{U,j}$ and p_l respectively. Furthermore, we can use

[30] Recall that α, β and $q_l^{VI,i}$ are defined only for $m > 0$, since there are no integrated firms when $m = 0$.

$q_f^{VI,tot} + q_f^{U,tot}$ to obtain equilibrium p_f, from which we obtain equilibrium $Q_f^{D,j}$. In turn equilibrium p_l allows us to obtain equilibrium $q_d^{VI,i}$, $q_d^{D,j}$ and p_d from (C.2) and (C.3). With these equilibrium values we can then also compute consumer surplus.

Of particular interest for our purposes are the later upstream market output of each integrated firm $q_l^{VI,i}$ (indicating the pursuit of a RRC strategy if negative), and the later upstream market demand of each separated downstream firm $q_d^{D,j} - Q_f^{D,j}$ (indicating the pursuit of a SFO strategy if negative). We also wish to know whether consumer surplus increases if SFO is allowed in the face of RRC, and thus in comparing consumer surplus in the above model with that obtained when SFO is eliminated by imposing $q_d^{D,j} - Q_f^{D,j} = 0$ for all separated downstream firms (as in Section 5.1, and discussed further in Section 6). Graphical summaries of these three items were provided in Section 6 for selected parameter values, while the equilibrium values of $q_l^{VI,i}$ and $q_d^{D,j} - Q_f^{D,j}$, which involve high-order polynomial expressions in n_u, n_d and m, can be written as follows:[31]

$$q_l^{VI,i} = -\frac{\sum_{k=1}^{4} n_u^{k-1}(i \times N_d \times M_k \times M)}{\sum_{k=1}^{4} n_u^{k-1}(i \times N_d \times O_k \times M)} \tag{C.8}$$

$$q_d^{D,j} - Q_f^{D,j} = -\frac{\sum_{k=1}^{4} n_u^{k-1}(i \times N_d \times N_k \times M)}{\sum_{k=1}^{4} n_u^{k-1}(i \times N_d \times O_k \times M)} \tag{C.9}$$

where:

$$i^T = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \qquad M = \begin{bmatrix} m^6 \\ m^5 \\ m^4 \\ m^3 \\ m^2 \\ m \\ 1 \end{bmatrix}$$

$$N_d = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & n_d & 0 & 0 & 0 & 0 \\ 0 & 0 & n_d^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & n_d^3 & 0 & 0 \\ 0 & 0 & 0 & 0 & n_d^4 & 0 \\ 0 & 0 & 0 & 0 & 0 & n_d^5 \end{bmatrix}$$

$$M_1 = \begin{bmatrix} 12 & 12 & 13 & 13 & -1 & -1 & 0 \\ 4 & -28 & -15 & -3 & -24 & 1 & 1 \\ 0 & -8 & 23 & 9 & -23 & 15 & 0 \\ 0 & 0 & 3 & -5 & -11 & 17 & -4 \\ 0 & 0 & 0 & 2 & -4 & 6 & -4 \\ 0 & 0 & 0 & 0 & -1 & 2 & -1 \end{bmatrix}$$

$$M_2 = \begin{bmatrix} -8 & 2 & -3 & -14 & -15 & -2 & 0 \\ 0 & 36 & -5 & -18 & -9 & 18 & 2 \\ 0 & 2 & -53 & -10 & 8 & 32 & -3 \\ 0 & 0 & -3 & 26 & 8 & 18 & -9 \\ 0 & 0 & 0 & 0 & -1 & 6 & -5 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$

$$M_3 = \begin{bmatrix} 0 & -8 & -6 & 1 & 2 & 3 & 0 \\ 0 & -8 & 16 & 17 & 3 & 7 & -3 \\ 0 & 0 & 22 & -5 & -13 & 5 & -9 \\ 0 & 0 & 0 & -21 & -7 & 5 & -9 \\ 0 & 0 & 0 & 0 & 7 & 4 & -3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$M_4 = \begin{bmatrix} 0 & 0 & -2 & -2 & 2 & 2 & 0 \\ 0 & 0 & -4 & 0 & 10 & 4 & -2 \\ 0 & 0 & -2 & 6 & 12 & -2 & -6 \\ 0 & 0 & 0 & 4 & 2 & -8 & -6 \\ 0 & 0 & 0 & 0 & -2 & -4 & -2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$N_1 = \begin{bmatrix} -8 & -4 & 0 & 2 & 8 & 2 & 0 \\ 0 & 20 & 12 & 6 & 18 & 0 & 0 \\ 0 & 0 & -12 & -6 & 10 & -8 & 0 \\ 0 & 0 & 0 & -2 & 2 & -8 & 0 \\ 0 & 0 & 0 & 0 & 2 & -2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$N_2 = \begin{bmatrix} 8 & -4 & 0 & 3 & -1 & -5 & -1 \\ 0 & -28 & 4 & 5 & -4 & -13 & 0 \\ 0 & 0 & 28 & 5 & -4 & -13 & 4 \\ 0 & 0 & 0 & -5 & -4 & -7 & 4 \\ 0 & 0 & 0 & 0 & -3 & -2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$N_3 = \begin{bmatrix} 0 & 8 & 4 & -5 & -2 & -1 & 0 \\ 0 & 8 & -12 & -15 & 5 & 3 & 3 \\ 0 & 0 & -16 & -3 & 13 & 7 & 7 \\ 0 & 0 & 0 & 7 & 7 & 5 & 5 \\ 0 & 0 & 0 & 0 & 1 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$N_4 = \begin{bmatrix} 0 & 0 & 2 & 2 & -3 & -4 & -1 \\ 0 & 0 & 4 & 2 & -9 & -8 & -1 \\ 0 & 0 & 2 & -2 & -9 & -4 & 1 \\ 0 & 0 & 0 & -2 & -3 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

[31] The equilibrium expression for change in consumer surplus is sufficiently more involved than that for $q_l^{VI,i}$ and $q_d^{D,j} - Q_f^{D,j}$, so details are available on request. The above expressions hold for $m \leq n_u$ provided $m \neq n_d$. In the special case of symmetric integration ($m = n_u = n_d$) only downstream trading occurs, in which case $q_l^{VI,i} = q_d^{D,j} - Q_f^{D,j} = 0$, and neither RRC nor SFO arises. Thus in that case the change in consumer surplus from prohibiting SFO is also zero.

$$O_1 = \begin{bmatrix} 0 & 0 & 2 & 9 & 7 & 5 & 1 \\ 0 & 0 & 6 & 20 & 9 & 12 & 1 \\ 0 & 0 & 6 & 10 & -6 & 10 & -4 \\ 0 & 0 & 2 & -4 & -10 & 4 & -8 \\ 0 & 0 & 0 & -3 & -1 & 1 & -5 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 \end{bmatrix}$$

$$O_2 = \begin{bmatrix} 0 & 4 & 2 & 7 & 7 & 7 & 1 \\ 0 & 8 & -6 & 14 & 11 & 18 & -1 \\ 0 & 4 & -18 & 16 & 0 & 16 & -10 \\ 0 & 0 & -10 & 18 & -8 & 6 & -14 \\ 0 & 0 & 0 & 9 & -7 & 1 & -7 \\ 0 & 0 & 0 & 0 & -3 & 0 & -1 \end{bmatrix}$$

$$O_3 = \begin{bmatrix} 0 & 0 & 4 & 3 & 1 & 1 & -1 \\ 0 & 0 & 12 & 2 & -3 & 0 & -7 \\ 0 & 0 & 12 & -12 & -12 & -4 & -16 \\ 0 & 0 & 4 & -18 & -8 & -2 & -16 \\ 0 & 0 & 0 & -7 & 3 & 3 & -7 \\ 0 & 0 & 0 & 0 & 3 & 2 & -1 \end{bmatrix}$$

$$O_4 = \begin{bmatrix} 0 & 0 & 0 & 1 & 1 & -1 & -1 \\ 0 & 0 & 0 & 4 & 3 & -6 & -5 \\ 0 & 0 & 0 & 6 & 2 & -14 & -10 \\ 0 & 0 & 0 & 4 & -2 & -16 & -10 \\ 0 & 0 & 0 & 1 & -3 & -9 & -5 \\ 0 & 0 & 0 & 0 & -1 & -2 & -1 \end{bmatrix}$$

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