Vertical Integration vs Vertical Separation in an Imperfectly Competitive Industry, such as Electricity, with Retail, Wholesale and Forward Markets[†]

Richard Meade

Toulouse School of Economics, New Zealand Institute for the Study of Competition and Regulation, Cognitus Advisory Services Limited

richard.meade@cognitus.co.nz

5 July 2010 (Revised 12 October 2012)

Abstract

In an imperfectly competitive industry for a homogeneous good, like electricity – with forward, wholesale and retail markets – should upstream firms (generators) be vertically integrated with, or separated from, downstream firms (retailers)? Left to their own devices, will firms integrate or separate, and how does this contribute to welfare? Vertical integration is often viewed by competition authorities, regulators and policy-makers with suspicion, but are these suspicions misplaced? We address these questions by developing a static and deterministic multi-stage game with oligopolies in both generation and retailing, and endogenous choice by generators over the degree of vertical integration. Firms simultaneously compete in quantities in successive forward, wholesale and retail markets, with retailers able to purchase forward energy from generators. We find that total surplus, consumer surplus and other welfare measures are unambiguously better under higher levels of vertical integration. According to many measures, we find that "four is enough", i.e. that once a sector has four generators, there are diminishing returns, in terms of welfare, from adding more generators. Moreover, full integration is akin to "synthetic" generation – equivalent in welfare terms to adding an additional generator in an otherwise separated sector. Our analysis supports earlier research that shows integrated firms pursue a "raising rivals' costs" strategy – buying wholesale energy to increase the input cost of separated downstream rivals. However, by adding forward contracting we also find that separated retailers pursue a countervailing "over-buy and recycle" strategy – buying more energy forward than they need to meet their retail supply commitments, and selling their surplus energy on the wholesale market. This not only protects them against the integrated firms' strategy, but in the case of duopoly generation, at least, ensures that full integration is the generators' only equilibrium choice.

[†] This paper is based on a Mémoire submitted in partial satisfaction of the requirements of a Masters 2 degree in economics at the Toulouse School of Economics. Special thanks to the author's supervisor, Professor Claude Crampes, and his co-jurors Professors Thomas-Olivier Leautier and Norbert Ladoux, for their comments and suggestions. Thanks too to Luc Bridet for introducing the author to Maple, and to participants at a Toulouse School of Economics Mémoire workshop for their feedback on an earlier version of this work. As usual, any errors or omissions are entirely the responsibility of the author.

1. Introduction

In liberalised electricity systems it is reasonably settled that potentially competitive activities such as generation and energy retailing (i.e. supply) should be separated from "natural monopoly" activities such as high voltage transmission and low voltage distribution. There is little consensus, however, regarding whether electricity generators should be vertically integrated with energy retailers – the form of vertical integration considered in this paper – or vertically separated from such concerns.

Indeed, while vertical arrangements such as vertical integration or long-term contracting have been found to be associated with better outcomes in some electricity systems (Bushnell et al. (2008)), there is sometimes suspicion among regulators, competition authorities and reformers that vertical integration between generators and retailers is undesirable (European Commission (2007)), for example strengthening generator market power and reducing retail entry. In the vertically integrated New Zealand electricity system, for example, complaints about possible abuse of generator market power in the wholesale market resulted in the competition authority commissioning a major study which found that such abuse had occurred (Wolak (2009)). This undertaking was despite existing research suggesting that such an inquiry was misplaced in the context of vertically integrated firms, since wholesale prices are essentially an internal transfer price for integrated firms (Hogan and Meade (2007)).

Also behind the suspicions of regulators, competition authorities and reformers lies a concern that vertical arrangements undermine the efficient operation of key markets often seen as critical to the successful functioning liberalised electricity systems, namely forward contract and wholesale markets (European Commission (2007)). Indeed, long-standing concerns about the relatively illiquid forward market in New Zealand (Hansen (2004)) lead to the promulgation of regulations in 2010 requiring generators to make available a certain level of energy via forward contracts (Electricity Technical Advisory Group (2009)), in effect partially unwinding the existing high level of vertical integration in New Zealand. And where vertical arrangements such as vertical integration arise endogenously rather than as a matter of policy, it is natural to question whether this is an undesirable expression of the inevitable market power enjoyed by electricity generators arising from the scale economies dictated by current technology.

In Section 2 we highlight existing literatures relevant to modelling the strategic aspects of these questions. While there is existing literature examining the impact of vertical integration on demand and price risk management in the context of forward, wholesale and retail electricity markets, this literature does not focus on strategic interactions between markets, or allow for imperfect competition. Conversely, there is existing research on the separate issues of the strategic implications of vertical integration between upstream and downstream firms in a generalised setting, and of the impacts of forward contracting on wholesale and retail electricity market interactions. However, to our knowledge there is no existing research addressing both sets of issues simultaneously, from a strategic perspective, and with imperfect competition. Furthermore, for our purposes there are shortcomings in the way that the existing literature approaches the questions, and there is presently no research that formally assesses the welfare implications of different degrees of vertical integration in electricity systems having the desired institutional features.

The contribution of this paper is to formally shed light on the question of whether partial or complete vertical integration between imperfectly competitive electricity generators on the one hand, and potentially imperfectly competitive energy retailers on the other, results in better outcomes than vertical separation between such concerns. Setting aside hedging considerations and uncertainty, it does so in the context of an electricity system comprising markets for forward contracting, wholesale trading, and energy retailing. It examines the strategic interplay between such markets and the degree of vertical integration, for differing numbers of upstream (i.e. generation) and downstream (i.e. retailing) firms. By "outcomes" we mean measures such as total surplus or consumer surplus, industry profits, prices, and market concentration indices. The analysis presented below highlights that some of these measures can give potentially misleading impressions as to which market configurations – i.e. partial or complete vertical integration or separation – are best in welfare terms (i.e. total or consumer surplus). Finally, we also examine the incentives of generators and retailers to integrate, and whether in equilibrium such firms benefit or lose from doing so.

Among our key findings are the following. Considering a fixed maximum number of generators and retailers, both total surplus and consumer surplus are maximised when firms are fully integrated. The equivalence between the predictions of these two performance measures reflects the fact that both retail prices and industry profits are decreasing in the level of integration. Indeed, close to first best levels of total surplus are achievable with just four generators, provided there are sufficient retailers. This *"four is enough" result* – suggesting that there are decreasing returns, in welfare terms, from adding extra generators, recurs with respect to a number of performance measures. Another result is "*synthetic generation*" – i.e. that full integration is comparable in welfare terms to having a separated industry with one extra generator. Furthermore, especially with monopoly or duopoly generation, some performance measures (such as retail market concentration and total industry profits) mistakenly suggest integration is socially harmful when in fact the reverse is the case. Considering the case of duopolistic generation with multiple retailers, we show that full integration is the only equilibrium outcome of firms endogenously choosing whether to integrate or separate, despite the fact that integration results in lower industry profits. This result contrasts with earlier research, and highlights how the addition of forward contracting fundamentally alters firms' strategies and incentives – in our model, of both retailers and generators.

Our other key findings relate to the strategic interactions between forward, spot wholesale and retail markets. As in others' research, our model finds that retailers can use the purchase of forward contracts strategically to reduce generator market power in the spot wholesale market, thereby reducing wholesale price. We also find, as have others, that integrated firms prefer to purchase rather than sell energy in the wholesale market, as a means to put upward pressure on wholesale price and hence on the input cost of their non-integrated rival retailers (i.e. a "raising rivals' costs" strategy). We show, however, that this is not associated with welfare losses all the same, in terms of either total or consumer surplus.

Our main original finding is that with both vertical integration and forward contracting, non-integrated retailers can actively undermine the raising rivals' costs strategy of integrated firms. They do so by forward purchasing more energy than they require to meet their retail supply commitments, and by selling back their surplus energy into the wholesale market – what we call an *"over-buy and recycle" strategy*. In effect the wholesale energy bought by integrated firms as a means to increase wholesale price is sold to them by the very non-integrated retailers they seek to harm. Not only do such forward purchases by separated retailers cause separated generators to compete more aggressively in the wholesale market, but their subsequent resale on the wholesale market undermines attempts by integrated firms to compete less aggressively. It is because of this strategic use of forwards by separated retailers that both integrated firms and separated generators face incentives to remain integrated or to integrate. This remains true even when the number of separated retailers rises relative to the number of integrated firms – in contrast to the findings of earlier research.

Within the limitations of this paper's assumptions, these results should find application in a number of contexts. They should assist competition authorities when assessing whether horizontal or vertical mergers should be permitted, highlighting how partial measures such as likely merger impacts on wholesale prices are not adequate for assessing merger gains or detriments. They should assist regulators in considering the impacts of measures such as forcing generators to sell a fixed proportion of their output via contracts. Finally, they should assist reformers in determining whether electricity systems are better reformed along vertically separated or vertically integrated lines, and also the extent to which horizontal separation is required under different degrees of vertical integration or separation to achieve effective competition and satisfactory levels of welfare. While the motivating questions for this study naturally arise in relation to liberalised electricity sectors, our study's predictions will equally apply in any other homogeneous good industry with the same institutional features.

This paper is organised as follows. In Section 2 we discuss related literatures, highlighting where this paper combines, extends or diverges from existing approaches. Section 3 sets out and solves our model, and includes details of the institutional setting, agents' decision timing and information sets, and our other assumptions. A general case model is presented, along with a special case model of balanced full integration (which cannot be solved using the general model). Performance measures are defined, and a derivation of the first best welfare benchmark is provided, to enable comparisons with other scenarios. Section 4 presents our propositions and other findings based on the model's results, highlighting total and consumer surplus as the relevant measures of different industry arrangements. Other performance measures are also discussed, with a focus on whether these other measures agree with the industry arrangements found to be best according to total or consumer surplus. Strategic interactions between forward, wholesale and retail markets are identified and explained. Section 5 sets out possibly fruitful extensions to the model, while Section 6 concludes.

2. Related Literature

There are two main streams of existing research relevant to modeling the strategic questions of interest in this paper. The first relates to modeling vertical integration between upstream and downstream firms operating in general, imperfectly competitive markets for homogeneous goods, absent forward trading. Prominent among this stream are the works of Gaudet and Van Long (1996) and Salinger (1988). The other stream relates to the modeling of forward contracting choices in electricity systems that have forward, wholesale and retail markets. One part of this stream ignores consideration of vertical integration, with prominent papers including Powell (1993) and Green (2004). The other part – Aïd et al. (2009) – considers the impact of vertical integration on prices and utility in the context of all three electricity markets, but focuses on hedging considerations under perfect competition and uncertainty, rather than strategic considerations. Also related is Allaz and Vila (1993), which was the first research to study how forward contracting affects firms' strategies in downstream markets.[1] We now elaborate on these streams highlighting their key findings, and how they differ from our research.

As to the literature on vertical integration absent forward contracting, both Gaudet and Van Long (1996) and Salinger (1988) model an arbitrary number of symmetric upstream firms, and another arbitrary number of symmetric downstream firms, all competing simultaneously in quantities (i.e. Cournot). While Salinger treats the number of integrating firms as exogenous, and assumes integrated firms withdraw completely from the upstream market, Gaudet and Van Long formally model firms' integration choices, and allow integrated firms to both buy and sell upstream. Both papers are set in a static, deterministic setting, highlighting strategic interactions. While Gaudet and Van Long assume zero marginal costs of upstream production, and of downstream production (other than the upstream good price), Salinger allows for non-zero marginal costs at both production stages.

Gaudet and Van Long identify a "raising rivals' costs" strategy that will be employed by integrated firms in some cases. Under this strategy, integrated firms purchase output from the upstream industry (in which they could equally have been sellers) in order to raise the input costs of

[1] A related work is by Mahenc and Salanie (2004), showing that the Allaz and Vila (1993) predictions rest on their assumption that upstream firms compete in quantity rather than price. Since the Mahenc and Salanie model assumes a differentiated product, this is of less relevance in our case, given the homogeneity of electricity. Bushnell (2007) extends Allaz and Vila's duopoly analysis, in an electricity context, assuming a general oligopoly in generation.

their separated downstream rivals (whose input cost is the upstream good's price). They do so provided the number of separated firms is small relative to the number of integrated firms, since the gains from doing so become too diffuse otherwise. They also derive conditions under which vertical integration is a dominant strategy, and also when there exist equilibria in which there is full separation. While Gaudet and Van Long provide no welfare analysis – which is a key focus of our work – Salinger considers the impact of (exogenous) integration on downstream price, concluding that the impact is in general indeterminate.

While Gaudet and Van Long (1996) and Salinger (1988) analyse vertical integration – without forward contracting – in a general context, Powell (1993) and Green (2004) analyse forward contracting – absent vertical integration – in an electricity context. Both papers assume symmetric duopolistic generation, but in some cases with a potentially arbitrary number of symmetric non-integrated retailers. They assume a static setting, with demand uncertainty and risk-averse retailers (and hence both hedging and strategic rationales for forward contracting). Generation costs are constant, while retailing costs (over and above wholesale purchase costs) are assumed to be zero. While Powell assumes fixed retail prices and quantities, Green allows for a more general setup, but assumes retailers are incumbent monopolies, and focuses on retailers' forward contracting interactions with generators rather than on retail market competition *per se*. Both Powell and Green assume Cournot competition in the spot wholesale market, and a variety of quantity- and price-based forward competition.

Powell (1993) finds that retailers' optimal forward positions relate positively to the sensitivity of expected wholesale prices to the level of forward contracting. Indeed, even without uncertainty retailers have a strategic reason to contract forward, as doing so commits generators to wholesale supply and eases wholesale prices, though retailers fail to fully internalise the benefits to other retailers from their own contracting choices. Green (2004) finds that retailers' contract demand is positively related to the premium in expected wholesale prices over forward prices, which can be positive in equilibrium due to demand uncertainty. He also finds that generators sell less electricity forward if retailers face competition, compared with the case in which retailers are regulated monopolies.

Aïd et al. (2009) compare and contrast forward contracting and vertical integration as alternative devices for managing demand and price risks in an electricity sector comprising forward, wholesale and retail markets. They model retailers and integrated firms as committing to retail supply and forward positions before demand is realised, while generators and integrated firms compete on the wholesale market once demand is known. While they consider the impacts of vertical integration on prices and agents' utilities, they do not consider the range of welfare measures used in this paper. Their model allows for uncertainty, but sets aside strategic considerations, and assumes price-taking behaviour by all agents rather than imperfect competition. Moreover, like Salinger (1988), they treat the degree of vertical integration as exogenous. They find that both forward contracting and vertical integration reduce risks and thus encourage greater retail supply, leading to lower retail prices and greater retail quantities. They find, however, that integration and contracting are imperfect substitutes. Separated retailers are exposed to greater risk than integrated firms, as they must take decisions under full uncertainty, whereas integrated firms have the advantage of taking some decisions once demand uncertainty is resolved.

Given the influence of Allaz and Vila (1993), it is worth briefly mentioning their work. In a static and deterministic setting they model the impact of forward contracting on wholesale prices with duopolists competing in quantities, but without consideration of either retail competition or vertical integration. They model forward contracting by assuming firms choose their desired level of forward sales based on the impact they expect this to have on later wholesale market outcomes. Specifically, they effectively assume that firms offer financial contracts to financial speculators, which fixes the price they receive on some fraction (i.e. the contracted portion) of their output. With perfect foresight such speculators anticipate that the forward price will equal the price derived in the wholesale game in equilibrium, thus earning zero profits.[2] Allaz and Vila find that firms seek to contract forward in order to gain a strategic advantage over their rival producer, but when each does so it results in lower industry profits (i.e. presents a prisoner's dilemma).

To the author's knowledge, and based on this discussion, there is currently a lack of research that simultaneously considers the role of vertical integration in an imperfectly competitive electricity sector and the strategic interaction of competition in forward, wholesale and retail markets. This paper seeks to fill that gap, extending the works of Gaudet and Van Long (1996) and Salinger (1988) by considering the incentives for, and consequences of, vertical integration in oligopolistic forward, wholesale and retail electricity markets. It also seeks to extend Powell (1993) and Green (2004), not just by considering the role of forward contracting in a possibly vertically integrated electricity sector, but by allowing for an arbitrary number of generators, and also by more clearly modelling both retail competition and the interaction between retailers and generators in all three electricity markets. It complements Aïd et al. (2009) by modeling strategic considerations under certainty and with imperfect competition. This paper also seeks to extend these streams of research by providing a formal and comprehensive welfare analysis, in order to assess the desirability or otherwise of vertical integration between generators and retailers. Finally, we seek to both extend and modify the research of Allaz and Vila (1993). We do this by not just allowing for a more general institutional environment, but also by tailoring the treatment of forward contracting to the electricity context. This means explicitly modeling the forward contract demand of electricity retailers, instead of assuming generators are free to choose contract quantities and to sell those quantities to financial speculators at zero expected profit.

---

2 This feature is discussed more fully by Bonacina et al. (2008), who consider forward contracting in a static and deterministic electricity sector context. They allow for forward and wholesale markets, but do not model retail competition.

3. Model and Solution

In this section we set out the institutional setting, assumptions, and details of agent's information sets and decision timing, underlying our analysis. We then derive the general case model, working backwards through each sub-stage of the five stage game by which the model is represented. This is followed by a derivation of the simple special case model in which balanced full integration is assumed. Finally, performance measures and first best benchmark welfare are stated or derived for comparison purposes.

3.1 Institutional Setting

A homogeneous good, electricity, is produced by n_g "upstream" electricity generators using identical generation technologies, and resold by n_r "downstream" electricity retailers. Ultimately this electricity is bought by customers served by these electricity retailers, any one of which might also be thought of as an industrial customer rather than as an aggregator of retail demand. A number m of these generators and retailers is pair-wise vertically integrated (i.e. one is owned by the other). Retailers compete to supply retail demand, represented by an inverse demand curve, at an equilibrium price P_r. Both integrated and separated generators trade with non-integrated (i.e. separated) retailers, and potentially with each other, on a wholesale market at equilibrium price P_w. Retailers are permitted to be net sellers to the wholesale market, just as generators are permitted to be net buyers on that market. Retailers also buy electricity from generators via physical contracts sold on a forward market at equilibrium forward price P_f.

It should be noted that this set-up differs from that assumed in Allaz and Vila (1993), which is applied in a general context, and also in Bushnell (2007) and Bonacina et al. (2009), which are applied in an electricity market context. In these papers it is generators that are assumed to determine the level of forward contracts that are to be sold, not retailers. Moreover, forward contracts are financial rather than physical, being sold to speculators at a forward price that equates to the anticipated wholesale price in equilibrium. The forward trading set-up assumed here, in which retailers determine their preferred level of forward contracting and generators then compete to supply total contract demand, is offered as a more natural assumption. While electricity systems can involve both physical and financial forward contracts, and both retailers and speculators purchase such contracts, the approach taken in these other papers removes an important interaction between retailers and generators. While the current setting is static and deterministic, thus removing any hedging rationale for forward trading, our approach reveals important strategic interactions between markets and different (in terms of integration) types of firms.

Forward contracting occurs immediately prior to real-time wholesale trading, which in turn occurs immediately prior to retail trading. Thus the forward market differs from the wholesale market both in terms of its timing (forward occurs before wholesale trading) and its duration (in principle contracting is for multiple period, while wholesale trading is assumed real-time only). In the special case that all generator-retailer pairs are vertically integrated – what we shall call *balanced full integration* (with $n_g = n_r = m$) – trade occurs only through the retail market, and not through either the wholesale or forward markets. There is no spatial separation between generators and customers, so issues of transmission and distribution pricing, and of transmission congestion, do not arise.

3.2 Assumptions

Our model is placed in a static, deterministic setting with symmetric information. It is assumed that there is at least one generator ($n_g > 0$), and that there are at least as many retailers as there are generators ($n_r \geq n_g$).[3] The number of vertically integrated pairs of generators and retailers is limited to the number of available generators ($0 < m \leq n_g$), with the case $m = 0$ representing complete vertical separation and $m = n_g$ representing complete vertical integration (as above, balanced complete integration is the special case $n_g = n_r = m$). Thus we have m integrated firms, $n_r - m$ separated retailers, and $n_g - m$ separated generators. All integrated firms are assumed to be symmetric, as are all separated retailers, and all separated generators. Throughout we use indexes i to represent integrated firms, and indexes j to represent separated firms. As in Salinger (1988), we assume vertical integration between a generator and retailer occurs (or not) irrespective of their relative sizes.

As in Gaudet and Van Long (1996), electricity retailers compete in quantities (i.e. Cournot), facing a linear inverse demand curve of the form:

$$P_r(y_{tot}) = 1 - \left(\sum_{i=1}^{m} y_i\right) - \left(\sum_{j=m+1}^{n_r} y_j\right) \tag{1}$$

where P_r is the retail price, y_i is the retail output of integrated firm i ($i = 1, \ldots, m$), y_j is the retail output of separated retailer j ($j = m+1, \ldots, n_r$), and $y_{tot} = \sum_{i=1}^{m} y_i + \sum_{j=m+1}^{n_r} y_j$.

Separated retailers face input costs comprising P_w for any energy they acquire from the spot wholesale market, and P_f for the amount Q_j of energy they purchase on the forward contracts market. Additional costs of retailing are assumed to be zero, which is unlikely to be restrictive in practise given the homogeneous nature of electricity (i.e. it is not physically transformed by retailers). Thus symmetric separated retailer j ($j = m+1, \ldots, n_r$) has a profit function of the form:

$$\Pi_j^r = P_r . y_j - P_w(y_j - Q_j) - P_f . Q_j \tag{2}$$

In the retail market an integrated firm can either self-supply its retail demand, or purchase amount S_i of energy on the wholesale market ($S_i < 0$) at the wholesale price P_w to meet retail demand.

[3] This assumption can be defended on the basis that the fixed costs of retail entry are likely to be far lower than those of entering into generation.

Conversely an integrated firm can sell S_i amount of energy ($S_i > 0$) at the wholesale price P_w, competing in quantities with other integrated firms and separated generators. Following Gaudet and Van Long (1996), generation costs are assumed zero, and generators face no capacity constraints. While these assumptions significantly simplify the analysis, they appear to come at the expense of realism. However, even with zero generation costs wholesale price is positive in equilibrium (a standard consequence of assuming Cournot competition among a finite number of firms), meaning that the scale effects of allowing non-zero generation costs should not fundamentally alter the nature of the equilibrium in our analysis.[4]

Since an integrated firm would not *simultaneously*, at forward price P_f, buy energy forward to meet its retail demand, and sell it forward energy, we assume that its demand for forward contracts is nil ($Q_i \equiv 0$) while allowing it to sell amount Z_i forward.[5] Since we allow Z_i to be negative, however, an integrated firm is permitted to buy energy forward (we simply impose that it does not buy and sell forward at the same time). Since all integrated firms are symmetric, $Z_i < 0$ would require the symmetric non-integrated generators to sell energy forward. The profit function of symmetric vertically integrated firm i ($i = 1, \ldots, m$) is thus:

$$\Pi_i^{vi} = P_r . y_i + P_w . S_i + P_f . Z_i \tag{3}$$

A separated generator competing in quantities on the wholesale market sells X_j amount of energy at P_w (or buys that amount if $X_j < 0$), and also sells Z_j amount of energy at P_f on the forward market (or buys that amount if $Z_j < 0$). As for integrated firms, generation costs are assumed to be zero, hence the profit function for symmetric separated generator j ($j = m+1, \ldots, n_g$) writes as:

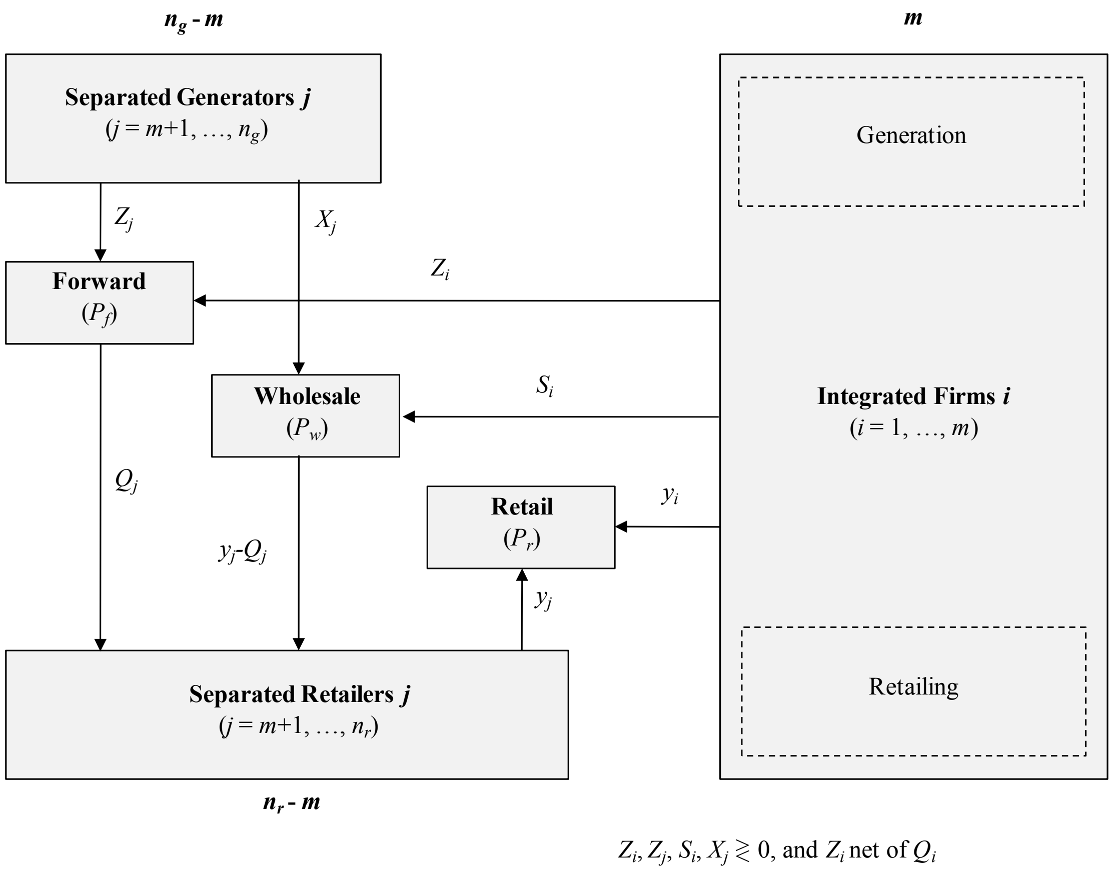
$$\Pi_j^{g} = P_w . X_j + P_f . Z_j \tag{4}$$

Figure 3.1 summarises the assumed interactions between integrated firms, separated retailers and separated generators in the forward, wholesale and retail markets (a full description of model timing is given in the next subsection).

[4] Indeed, examining the equilibrium expressions for firms' outputs and wholesale price in Salinger (1988) confirm that for n_g large enough any quantity distortion from assuming zero generation costs will vanish, and wholesale price will differ only by a constant. For lower values of n_g the effect of assuming zero costs is to understate price and overstate quantities for all levels of integration (m), so the assumption should not fundamentally distort our conclusions regarding the optimal level of integration.

[5] Earlier modeling suggested this assumption was of no consequence, as in equilibrium integrated firms sold energy forward as generators, rather than bought it forward as retailers. Our current analysis bears this out, with $Z_i > 0$ in equilibrium in all cases considered.

Figure 3.1 – Interactions between Firms and Markets

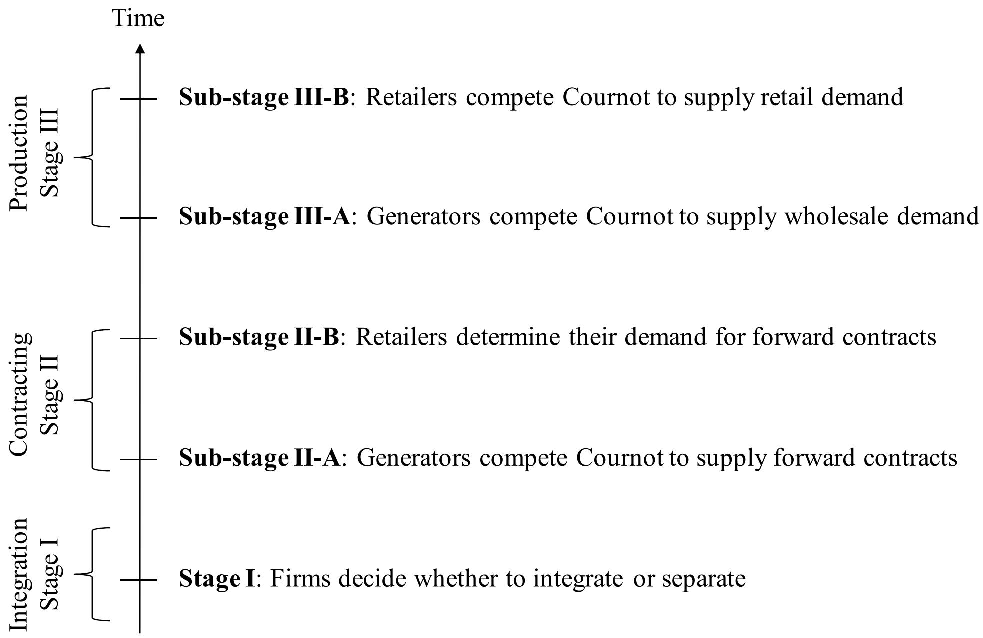


3.3 Timing and Information

Figure 3.2 illustrates the timing assumed in our model. In Stage I, before markets open for trade, simultaneously integrated firms decide whether to stay integrated or to separate, and separated generators decide whether to stay separated or to integrate. They do so based on the equilibrium profits they anticipate receiving from the later game stages, given the integration or separation decisions of their rivals. In other words, in this stage firms endogenously determine m, the equilibrium level of integration.

Stage II is the forward contracting stage, which takes place after integration or separation decisions have been taken in Stage I. This stage comprises Sub-stages II-A and II-B. In Sub-stage II-B separated retailers simultaneously determine their demand for forward contracts, given the integration/separation decisions taken at Stage 1 and the forward price, P_f, determined in Sub-stage II-A, and based on the equilibrium outcomes anticipated from Stage III. In Sub-stage II-A generators simultaneously compete in quantities to supply retailers' forward inverse demand derived in Sub-stage II-B, given the integration/separation decisions taken at Stage 1, and based on the equilibrium outcomes they anticipate from Stage III.

Figure 3.2 – Model Timing



After integration/separation and forward trading decisions have been taken in Stages I and II, production decisions are then taken by firms in Stage III. This stage also comprises two sub-stages, with Sub-stage III-B involving integrated firms and separated retailers simultaneously competing in quantities to supply the assumed retail inverse demand, given the outcomes of all earlier stages and sub-stages (in particular, P_w, Q_j and P_f). Sub-stage III-A involves integrated firms and separated generators simultaneously competing in quantities to supply the wholesale inverse demand derived from the equilibrium outcome of Sub-stage III-B, given the integration/separation decisions taken at Stage I, and outcomes of the forward trading decisions taken in Stage II.

3.4 General Case

As usual, the model is solved by backward induction. Below we step through the main details of the model's derivation for each stage and sub-stage.[6] Note that in all optimisations below, second order conditions have been confirmed but are not reported. Given the dimensionality involved in solving this model, use has been made of the symbolic algebra software package Maple.

3.4.1 Sub-Stage III-B – Retail Supply

Consider first the problem of integrated firm *i*. Since all integrated firms are symmetric, and all separated retailers are also symmetric, we can rewrite equation (1) as $P_r = 1 - (y_i + A_i)$ where, in equilibrium:

6 Longer equilibrium expressions have been omitted in the interest of space, but are available on request.

$$A_i = (m-1)\,y_i + \left(n_r - m\right) y_j \tag{5}$$

Making this substitution for P_r in equation (3), and taking P_w, S_i, P_f and Z_i as given, integrated firm i chooses y_i to maximise its profit, Π_i^{vi}. Taking the first order condition with respect to y_i, substituting for A_i, and solving for y_i, yields the following integrated firm's reaction function:

$$y_i(y_j) = \frac{1-(n_r-m).y_j}{m+1} \tag{6}$$

Likewise, for a separated retailer j, equation (1) can be rewritten as $P_r = 1 - \left(y_j + A_j\right)$ with:

$$A_j = m\,y_i + \left(n_r - m - 1\right) y_j \tag{7}$$

Making this substitution for P_r in equation (2), choosing y_j to maximise Π_j^r, and following the procedure as above, yields the following separated retailer's reaction function:

$$y_j(y_i) = \frac{1-m.y_i-P_w}{n_r-m+1} \tag{8}$$

Simultaneously solving these two reaction functions for the Nash equilibrium of the Sub-stage III-B retail game yields the following equilibrium functions for y_i, y_j and P_r:

$$y_i(P_w) = \frac{1+(n_r-m).P_w}{n_r+1}$$

$$y_j(P_w) = \frac{1-(m+1).P_w}{n_r+1} \tag{9}$$

$$P_r(P_w) = \frac{1+(n_r-m).P_w}{n_r+1}$$

Notice that y_i and P_r are increasing in P_w whereas y_j is decreasing in P_w. Also, none of these expressions depends on forward price P_f (this dependence enters in Sub-stage II-B).

3.4.2 Sub-Stage III-A – Wholesale Supply

The retail demand to be supplied from the wholesale and forward markets derives from the $n_r - m$ symmetric separated retailers supplying y_j each. Their wholesale demand, net of forward market demand, is thus $(n_r - m).y_j - Q_{tot}$ where $Q_{tot} = \sum_{j=m+1}^{n_r} Q_j$. This net wholesale demand is supplied by $S_{tot} + X_{tot}$ where $S_{tot} = \sum_{i=1}^{m} S_i$ and $X_{tot} = \sum_{j=m+1}^{n_g} X_j$. Equating wholesale demand and wholesale supply, substituting for equilibrium y_j from Sub-stage III-B, and solving for P_w, yields the *derived* wholesale inverse demand curve faced by generators in the wholesale market:[7]

$$P_w(S_{tot}, X_{tot}, Q_{tot}) = \frac{1}{m+1}\left[1 - \frac{n_r+1}{n_r-m}\,(S_{tot} + X_{tot} + Q_{tot})\right] \quad (10)$$

Considering first the integrated firm's problem in the wholesale market sub-stage, each such firm chooses S_i to maximise Π_i^{vi} as in equation (3), where P_r and y_i now take their equilibrium values from Sub-stage III-B, P_w is as given by equation (10), and P_f and Z_i are taken as given. To do so we rely on the symmetry of all integrated firms, and of all separated generators, to rewrite equation (10) by substituting $S_i + B_i$ for $S_{tot} + X_{tot} + Q_{tot}$ in P_w, with $B_i = (m-1)\,S_i + (n_g - m)\,X_j + Q_{tot}$ in equilibrium. Following the same procedure as in Sub-stage III-B yields the following wholesale market reaction function for integrated firm *i*:

$$S_i(X_j, Q_{tot}) = T + U.X_j + V.Q_{tot} \quad (11)$$

where:

$$T = -\frac{(-1+m)\,(-n_r+m)}{n_r + m^2 n_r + 2m + 1 + 3m^2}$$

$$U = \frac{(3m + 1 + m n_r - n_r)\,(m - n_g)}{n_r + m^2 n_r + 2m + 1 + 3m^2}$$

$$V = -\frac{3m + 1 + m n_r - n_r}{n_r + m^2 n_r + 2m + 1 + 3m^2}$$

For example, with $m = 1$ and $n_g = n_r = 2$ (i.e. with duopolies in both generation and retailing, and one integrated generator-retailer pair), the integrated firm's reaction function is:

$$S_i(X_j, Q_{tot}) = -\frac{2}{5}X_j - \frac{2}{5}Q_{tot} \quad (12)$$

Similarly, for separated generator *j* we can rewrite equation (10) by substituting $X_j + B_j$ for $S_{tot} + X_{tot} + Q_{tot}$ in P_w, with $B_j = m\,S_i + (n_g - m - 1)\,X_j + Q_{tot}$ in equilibrium. Taking P_f and Z_j as given, and substituting for P_w as discussed, separated generator *j* then chooses X_j to maximise Π_j^g

[7] Examination of the denominator in equation (10) makes it clear why complete balanced integration, in which $n_r = m$, cannot be analysed using this general model, and instead must be treated as a special case. This expression is equivalent to that in Salinger (1988) save for our introduction of Q_{tot} and assumed zero costs.

from equation (4). Following the procedure as above yields the following wholesale market reaction function for separated generator *j*:

$$X_j(S_i, Q_{tot}) = \frac{(n_r - m) - m.(n_r + 1).S_i - (n_r - 1).Q_{tot}}{(n_r + 1)(n_g - m + 1)} \tag{13}$$

For example, with $m = 1$ and $n_g = n_r = 2$, the separated generator's reaction function is:

$$X_j(S_i, Q_{tot}) = \frac{1}{6} - \frac{1}{2} S_i - \frac{1}{2} Q_{tot} \tag{14}$$

Simultaneously solving equations (11) and (13) yields the Nash equilibrium of the Sub-stage III-A wholesale game with the following equilibrium functions for S_i, X_j and P_w:

$$\begin{aligned}
S_i(Q_{tot}) = {} & -\left(\left(m n_r^2 + 1 - n_r^2 + 4 m n_r + 3 m\right) Q_{tot}\right) \Big/ \left(\left(n_r + 1\right) \left(m n_r n_g + m n_g + 2 m^2 + n_r n_g + n_g - m n_r + m + n_r + 1\right)\right) \\
& - \left(-m + 3 m^2 - 2 m^2 n_g + 2 m n_r n_g + n_r^2 - m^2 n_r + n_r - 4 m n_r + 2 m^3 - 2 m n_g + 2 n_r n_g - m n_r^2\right) \Big/ \\
& \left(\left(n_r + 1\right) \left(m n_r n_g + m n_g + 2 m^2 + n_r n_g + n_g - m n_r + m + n_r + 1\right)\right) \\[1em]
X_j(Q_{tot}) = {} & -\left(\left(m + 2 m n_r + m n_r^2 + n_r^2 + 1 + 2 n_r\right) Q_{tot}\right) \Big/ \left(\left(n_r + 1\right) \left(m n_r n_g + m n_g + 2 m^2 + n_r n_g + n_g - m n_r + m + n_r + 1\right)\right) \\
& - \left(2 m^3 - m^2 n_r + 3 m^2 - 2 m n_r - m n_r^2 + m - n_r - n_r^2\right) \Big/ \\
& \left(\left(n_r + 1\right) \left(m n_r n_g + m n_g + 2 m^2 + n_r n_g + n_g - m n_r + m + n_r + 1\right)\right) \\[1em]
P_w(Q_{tot}) = {} & \frac{2 m + n_r + 1}{m n_r n_g + m n_g + 2 m^2 + n_r n_g + n_g - m n_r + m + n_r + 1} \\
& + \left(\left(n_r + 1\right)^2 Q_{tot}\right) \Big/ \left(\left(-n_r + m\right) \left(m n_r n_g + m n_g + 2 m^2 + n_r n_g + n_g - m n_r + m + n_r + 1\right)\right)
\end{aligned} \tag{15}$$

For example, with $m = 1$ and $n_g = n_r = 2$ we have:

$$\begin{aligned}
S_i(Q_{tot}) &= -\frac{1}{12} - \frac{1}{4} Q_{tot} \\
X_j(Q_{tot}) &= \frac{5}{24} - \frac{3}{8} Q_{tot} \\
P_w(Q_{tot}) &= \frac{5}{16} - \frac{9}{16} Q_{tot}
\end{aligned} \tag{16}$$

Observe that here S_i is unambiguously negative (i.e. integrated firm *i* chooses to purchase energy on the wholesale market) for $Q_{tot} \geq 0$, a feature to which we return in Section 4. Conversely, for some positive values of Q_{tot} we have that X_j is positive (i.e. separated generators sell energy on the wholesale market), as is P_w.

Notice also that the equilibrium wholesale price function above appears to be analogous to that derived by Allaz and Vila (1993). In their production (i.e. wholesale) sub-game they too find wholesale price is decreasing in forward quantity, since producers who have already contracted forward are less price-sensitive in subsequent wholesale trading. The key difference is that in their model the level of forward contracting is chosen by the wholesale producers themselves, whereas in our model it is determined by the *customers* of the wholesale producers – i.e. by the separated retailers who might otherwise be fully exposed to any upstream market power possessed by integrated or separated generators. In Allaz and Vila (1993) generators face a prisoner's dilemma in that they individually face incentives to sell output forward so as to pre-empt their rival's supply, but when they simultaneously do so they reduce wholesale price and their own profits. By contrast, in our model forward contracting is used strategically by retailers to reduce generator market power, without reliance on generators' incentives to sell forward. We return to this point in Section 4.

3.4.3 Sub-Stage II-B – Forward Demand

Since only separated retailers demand forward supply in equilibrium, we can rewrite Q_{tot} as $Q_{tot} = Q_j + C_j$ where $C_j = \left(n_r - m - 1\right) Q_j$ in equilibrium. Separated retailer *j* now chooses Q_j to maximise Π_j^r from equation (2), using the equilibrium functions for P_r and y_j from Sub-stage III-B, and for P_w (including in P_r and y_j) from Sub-stage III-A after substituting for Q_{tot} as above, and taking P_f as given. Solving for the profit-maximising level of forward demand for each separated retailer *j* yields the following equilibrium function $Q_j(P_f)$, relating forward demand to forward price:

$$Q_j(P_f) = L + M.P_f \qquad (17)$$

where:

$$\begin{aligned} L = -\Big(& -5m + 5m n_r n_g - 7m^2 + n_r + 2n_g - 3m n_r + 3m n_g + 3n_r n_g \\ & + 3m n_g n_r^2 - 2m^3 n_r n_g - 4m^3 + 2n_r^2 + n_r^3 - 4m^4 - m^2 n_g + m \\ & n_r^2 + 2n_g n_r^2 - 2m^2 n_r - m n_r^3 + m^2 n_r^2 + 4m^3 n_r + m^2 n_r^2 n_g \\ & + n_g m n_r^3 + n_g n_r^3 - 2n_g m^3\Big) \Big/ \Big(\left(n_r + 1\right)^2 \Big(2m^3 + n_r n_g m^2 \\ & - 3m^2 n_r + m^2 + m^2 n_g - m n_g n_r^2 + m n_r^2 - m n_r n_g + m n_r + 4m \\ & - n_r^2 - n_g n_r^2 - 2n_r n_g - 2n_r - n_g + 1\Big)\Big) \end{aligned}$$

$$
\begin{aligned}
M = -\Big(& m + 2m^2 - n_r + 2\,m\,n_g - 2\,n_r n_g - 2\,m\,n_g n_r^2 - 2\,n_r n_g m^2 \\
&+ 5m^3 - 2n_r^2 - n_r^3 + 4m^4 + 4m^2 n_g + m\,n_r^2 - 4\,n_g n_r^2 - 5m^2 n_r \\
&+ 2\,m\,n_r^3 - 4m^2 n_r^2 - 2m^3 n_r - 4m^2 n_r^2 n_g - 2\,n_g n_r^3 + 6\,n_g m^3 \\
&+ 2m^2 n_g n_r^3 + 2m^2 n_g^2 - 2n_r^2 n_g^2 - m^2 n_r^3 + m\,n_g^2 - n_r n_g^2 - n_r^3 n_g^2 \\
&+ m^3 n_g^2 - 8m^4 n_r + 5m^3 n_r^2 + 4m^5 - 6m^3 n_r^2 n_g + 4m^4 n_r n_g \\
&+ 3m^2 n_r n_g^2 - 3\,m\,n_r^2 n_g^2 - m^2 n_r^3 n_g^2 - 2\,m\,n_r^3 n_g^2 + m^3 n_r^2 n_g^2 \\
&+ 2m^3 n_r n_g^2 + 4\,n_g m^4\Big) \Big/ \Big((n_r+1)^2 \big(2m^3 + n_r n_g m^2 - 3m^2 n_r \\
&+ m^2 + m^2 n_g - m\,n_g n_r^2 + m\,n_r^2 - m\,n_r n_g + m\,n_r + 4m - n_r^2 \\
&- n_g n_r^2 - 2\,n_r n_g - 2\,n_r - n_g + 1\big)\Big)
\end{aligned}
$$

For example, with $m = 1$ and $n_g = n_r = 2$ we have:

$$
Q_j(P_f) = \frac{13}{27} - \frac{32}{27}P_f \tag{18}
$$

By the symmetry of the separated retailers, Q_{tot} is therefore $(n_r - m).Q_j$.

3.4.4 Sub-Stage II-A – Forward Supply

Total retailer demand for forward contracts is $(n_r - m).Q_j$ as just derived in Sub-stage II-B, which is supplied by $Z_{tot} = \sum_{i=1}^{m} Z_i + \sum_{j=m+1}^{n_g} Z_j$. Solving for P_f yields the *derived* forward inverse demand curve faced by generators in the forward market, $P_f(Z_{tot})$, as follows:

$$
P_f(Z_{tot}) = N + O.Z_{tot} \tag{19}
$$

where:

$$
\begin{aligned}
N = \Big(& 5m - n_r + 2m^3 n_r n_g - 2n_g - 2n_r^2 + 7m^2 - 5\,m\,n_r n_g + 4m^3 \\
&+ 3\,m\,n_r - 3\,m\,n_g - 3\,n_r n_g - m\,n_r^2 + 2m^2 n_r + m^2 n_g - n_r^3 + m\,n_r^3 \\
&- m^2 n_r^2 + 4m^4 - 3\,n_g m\,n_r^2 - 2\,n_g n_r^2 - n_g n_r^3 - 4m^3 n_r + 2\,n_g m^3 \\
&- m^2 n_r^2 n_g - n_g m\,n_r^3\Big) \Big/ \Big((-n_r + m)\big(m\,n_r n_g + m\,n_g + 2m^2 \\
&+ n_r n_g + n_g - m\,n_r + m + n_r + 1\big)^2\Big)
\end{aligned}
$$

$$
\begin{aligned}
O = \Big(&(n_r+1)^2 \big(2m^3 + n_g n_r m^2 - 3m^2 n_r + m^2 + m^2 n_g - n_g m\,n_r^2 \\
&+ m\,n_r^2 - m\,n_r n_g + m\,n_r + 4m - n_r^2 - n_g n_r^2 - 2\,n_r n_g - 2\,n_r - n_g \\
&+ 1\big)\Big) \Big/ \Big((-n_r + m)^2 \big(m\,n_r n_g + m\,n_g + 2m^2 + n_r n_g + n_g \\
&- m\,n_r + m + n_r + 1\big)^2\Big)
\end{aligned}
$$

For example, with $m = 1$ and $n_g = n_r = 2$ we have:

$$P_f(Z_{tot}) = \frac{13}{32} - \frac{27}{32} Z_{tot} \tag{20}$$

Solution of this sub-stage proceeds as above. An integrated firm chooses Z_i to maximise Π_i^{vi} from equation (3), substituting for $P_f(Z_{tot})$ using equation (19) in both equation (3) as well as in equation (18) for $Q_j(P_f)$, and thus in $S_i(Q_{tot})$ and $P_w(Q_{tot})$, and hence in both $P_r(P_w)$ and $y_i(P_w)$. This expression would then be maximised with respect to Z_i, resulting in an integrated firm's forward market reaction function in terms of other integrated or separated firms' forward output. Similarly, a separated generator chooses Z_j to maximise Π_j^g from equation (4), also substituting for $P_f(Z_{tot})$ using equation (19) in both equation (4) as well as in equation (18) for $Q_j(P_f)$, and thus in $X_j(Q_{tot})$ and $P_w(Q_{tot})$, and hence in both $P_r(P_w)$ and $y_j(P_w)$. This expression is then maximised with respect to Z_j, resulting in a separated generator's forward market reaction function in terms of other firms' forward output.

When determining an integrated firm's optimal choice of forward supply, Z_i, we substitute $Z_{tot} = Z_i + D_i$ in $P_f(Z_{tot})$, where $D_i = (m-1)Z_i + (n_g - m) Z_j$ in equilibrium, and derive integrated firm i's forward market reaction function in terms D_i. Similarly, when determining a separated generator's optimal choice of Z_j, we substitute $Z_{tot} = Z_j + D_j$ where $D_j = m Z_i + (n_g - m - 1) Z_j$ in equilibrium, from which we derive separated generator j's forward market reaction function in terms of D_j. Simultaneously solving these reaction functions after substituting for D_i and D_j yields equilibrium values of Z_i and Z_j in terms of the model's parameters, thus enabling calculation of the equilibrium value of all the model's variables in terms of the model's parameters.

For expositional purposes (i.e. for output tables and graphs) we have generated model outputs for all integer combinations of n_g, n_r and m for $1 \le n_g \le 6$, $n_g \le n_r \le 6$ and $0 \le m \le n_g$. To analytically prove the propositions in Section 4, however, we use $1 \le n_g \le 10$ and $n_g \le n_r \le 10$ instead. The choice of having a maximum of six (or 10) generators and retailers is of course arbitrary, but aside from convenience reasons it is also supported by the fact that in most countries with liberalised electricity systems the vast bulk of total output is usually accounted for by a handful of generators, so our results should be relevant to most liberalised electricity systems.[8] Numerical outputs for the model are tabulated in Appendix A.

By way of example, with $m = 1$ and $n_g = n_r = 2$ we obtain the following equilibrium values:

Retail market:	$P_r = 0.397$	$y_i = 0.397$	$y_j = 0.207$	
Wholesale market:	$P_w = 0.190$	$S_i = -0.138$	$X_j = 0.127$	(21)

[8] For example, see O'Donnell (2004) for a comparison of the market share of the largest and top three generators in European electricity systems.

Forward market:	$P_f = 0.223$	$Q_i = 0$	$Q_j = 0.218$	(21)
		$Z_i = 0.123$	$Z_j = 0.095$	
Firm profits:	$\Pi_j^r = 0.036$	$\Pi_i^{vi} = 0.159$	$\Pi_j^g = 0.045$	

3.4.5 Stage I – Integration or Separation

Given the anticipated equilibrium profits from Sub-stage II-A, in Stage I integrated firms decide whether or not to stay integrated, and separated firms decide whether to stay separated or to integrate (i.e. to endogenously choose the level of integration, *m*). For expositional purposes we focus on the case of duopolistic generation ($n_g = 2$), as this simply requires examination of two-by-two payoff matrices containing pairs of equilibrium profits – those of integrated firms, and those of pairs of separated generators and retailers. We also assume that integration and separation decisions are taken by generators. In Section 4.4 we present the solution of this stage for n_r ranging between two and six, exploring the equilibrium level of *m*, where equilibrium possibly includes $m = 0$ (full separation), $m = 2$ (full integration) or $m = 1$ (an asymmetric equilibrium with partial integration).

3.5 Special Case – Balanced Full Integration

In this special case $n_g = n_r = m$, and hence equation (10) in the general case derivation is undefined, as its denominator is zero. Since all firms are vertically integrated and are symmetric, it is not possible that in equilibrium some are buying from any given market while others are selling into that market. As such, the wholesale and forward markets are assumed foreclosed, with integrated firms simply competing in quantities to supply retail demand using their own generation.

Specifically, we now have m integrated firms each supplying y_i retail output from self-generation, so $y_{tot} = y_i + A_i$ where $A_i = (m-1)\,y_i$ in equilibrium. Retail inverse demand is now a simplified version of equation (1), which can be substituted into the integrated firm's profit function from equation (3) and maximised with respect to y_i in order to derive integrated firm *i*'s retail market reaction function in terms of the other integrated firms' output. Substituting for A_i and solving for y_i yields the equilibrium level of output of each integrated firm, with total output being *m* times this amount. The corresponding equilibrium values are:

$$y_i = \frac{1}{1+m} \qquad P_r = \frac{1}{1+m} \qquad \Pi_i^{vi} = \frac{1}{(1+m)^2} \tag{22}$$

3.6 Performance Measures and First Best Benchmark for Welfare Comparisons

Our main performance measures for welfare comparisons are the usual measures of total surplus and consumer surplus, as either or both of these are commonly the criteria used by competition authorities in assessing the benefits or detriments of vertical mergers. They are also relevant measures for regulators and policy-makers when considering interventions or reforms in electricity sectors.

Given equilibrium retail market total output equal to $y_{tot} = m.y_i + (n_r - m).y_j$, consumer surplus ($CS$) is computed as the area beneath the retail inverse demand curve given in equation (1), for retail output ranging between zero and y_{tot}, and from which must be subtracted total equilibrium expenditure on retail output. That is:

$$CS = \int_0^{y_{tot}} (1 - Y)\, \mathrm{d}Y - P_r y_{tot} \qquad (23)$$

Related to consumer surplus is the level of retail price, P_r, hence we also consider how this measure fares under different industry structures.

As usual, total surplus (TS) is defined to be consumer surplus plus equilibrium industry profits, which gives:

$$TS = CS + m.\Pi_i^{vi} + (n_r - m).\Pi_j^{r} + (n_g - m).\Pi_j^{g} \qquad (24)$$

Industry profits are themselves a measure of sector performance, with competition authorities, regulators and policy-makers concerned when imperfectly competitive generators (or retailers) appear to be earning undue profits. This might manifest itself, for example, if integration or separation decisions by firms should lead to increased industry profits. Hence we examine industry profits to see how they correlate with our main performance measures (TS and CS).

Finally, common market concentration measures such as the Herfindahl-Hirschman Index (HHI) can also be examined to see if vertical integration changes market concentration in ways that correlate with welfare changes. Our focus will be on how vertical integration affects concentration in the retail market, as the HHI for the wholesale and forward markets is sometimes undefined, or distorted by negative output levels for some firms. Given retail price is common to all firms, and with y_{tot} defined as above, the retail market HHI is defined as:

$$HHI_r = \frac{10000\, m\, y_i^2}{y_{tot}^2} + \frac{10000\, (n_r - m)\, y_j^2}{y_{tot}^2} \qquad (25)$$

Finally, to provide a benchmark against which total surplus can be compared, we compute the surplus generated by a benevolent and fully informed social planner facing retail inverse demand as in equation (1), and zero production costs. Specifically, the social planner chooses $y*$ to maximise the area beneath the retail inverse demand curve for all output levels between zero and $y*$:

$$\underset{y^*}{Max} \int_0^{y*} 1 - Y \; dY \tag{26}$$

This yields $y* = 1$, and hence optimal total surplus is $TS* = 0.5$.

4. Predictions and Analysis

Since the solution of Sub-stage II-A in the general case model of Section 3.4 involves lengthy equilibrium expressions (see footnote 6), the results presented in this section are mainly graphical, though analytical results have also been possible. Full numerical outputs are contained as tables in Appendix A. When reviewing the output tables and graphs produced by this approach it should be noted that rounding errors of around $\pm 1/1000$ may have arisen. As discussed in Section 3.4.4, for graphical and numerical outputs we restrict attention to all integer combinations of n_g, n_r and m for $1 \leq n_g \leq 6$, $n_g \leq n_r \leq 6$ and $0 \leq m \leq n_g$, though where we state that we have proved our propositions analytically we use $1 \leq n_g \leq 10$, $n_g \leq n_r \leq 10$. The results below should be understood accordingly.

4.1 Total Surplus and Consumer Surplus

Figure 4.1 illustrates how, for varying numbers of generators (n_g), total surplus varies as a function of the degree of vertical integration (m). Each separate graph in the figure plots TS versus m for varying levels of n_r, given n_g. The numbers in the plots refer to the number of retailers (n_r). Recall from Section 3.6 that the first best level of total surplus is 0.5. We now present our main proposition:

Proposition 1 – Total Surplus

1.1) Total surplus is strictly increasing in the degree of integration. Furthermore, for $m > 0$ and given n_r, total surplus does not appreciably change with m for $n_g \geq 5$.

1.2) Total surplus is unambiguously higher as n_g increases, given n_r and m, and attains almost first best levels for $n_g \geq 4$.

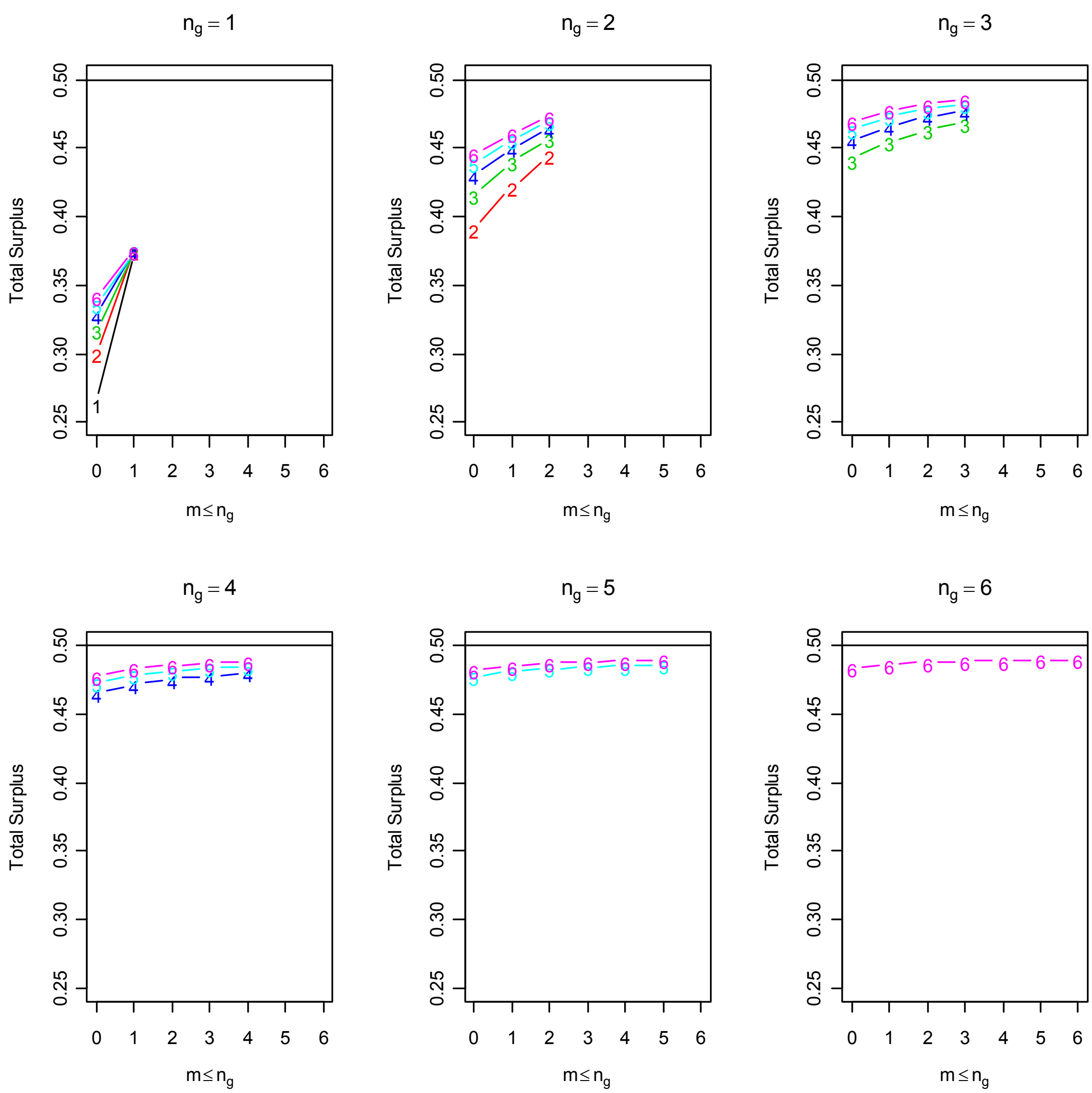
1.3) Except for the case of monopoly generation, total surplus is strictly increasing in n_r, given n_g and m.

1.4) Except for the case of monopoly generation, total surplus under full integration is comparable to that under full separation with one more generator, given the number of retailers. That is, given $n_g > 1$ and n_r, total surplus with $m = n_g$ is comparable to (though not uniformly higher than) that achieved with $n_g + 1$ generators and $m = 0$.

1.5) Total surplus is lowest across all scenarios for separated monopolies in generation and retailing (i.e. when $n_g = n_r = 1$ with $m = 0$). Conversely, the highest total surplus under monopoly generation ($n_g = 1$) occurs with full integration ($m = 1$) for all values of n_r (all non-integrated retailers are foreclosed in this case).

Proof: For 1.4 – 1.5, see Figure 4.1 and its associated tables in Appendix A. For 1.1 – 1.3, we partially differentiated the equilibrium expression for total surplus with respect to the relevant parameter, and then checked the resulting sign for $1 \leq n_g \leq 10$, $n_g \leq n_r \leq 10$ and $0 \leq m \leq n_g$. These results are also apparent from Figure 4.1 and its associated tables.

Figure 4.1 – Total Surplus as a function of Integration (*m*)



Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

This is our key proposition. Not only does it state that full integration maximises total surplus, it also shows that partial integration is superior to no integration. In the monopoly case, this remains true even though full integration results in total foreclosure in the retail market.[9] Furthermore, under our model's assumptions, almost first best levels of total surplus are achieved with just four or more generators, when $m > 0$ and in the presence of $n_r \geq n_g$ retailers. As we shall see, this "four is enough" characteristic, suggesting rapidly diminishing returns in welfare terms from extra competition in generation, also arises for various other performance measures.

Analogous to Figure 4.1, Figure 4.2 illustrates consumer surplus, as a function of the degree of integration, for varying numbers of generators and retailers. Since consumer surplus ignores industry profits, it is unsurprising that consumer surplus is not as close to first best total surplus as was total surplus (for $n_g \geq 4$). Examination of Figure 4.2 and the associated tables in Appendix A leads to the following proposition:

Proposition 2 – Consumer Surplus

2.1) Consumer surplus is strictly increasing in the degree of integration, given n_g and n_r.[10]

2.2) Consumer surplus is unambiguously higher as n_g increases, given n_r and m, and attains almost maximal levels for $n_g \geq 4$.

2.3) Except for the case of monopoly generation, consumer surplus is strictly increasing in n_r, given n_g and m.

2.4) Except for the case of monopoly generation, consumer surplus under full integration is comparable to that under full separation with one more generator, given the number of retailers. That is, given $n_g > 1$ and n_r, consumer surplus with $m = n_g$ is comparable to (though not uniformly higher than) that achieved with $n_g + 1$ generators and $m = 0$.

2.5) Consumer surplus is lowest across all scenarios for separated monopolies in generation and retailing (i.e. when $n_g = n_r = 1$ with $m = 0$). Conversely, the highest consumer surplus under monopoly generation ($n_g = 1$) occurs with full integration ($m = 1$) for all values of n_r (all non-integrated retailers are foreclosed in this case).

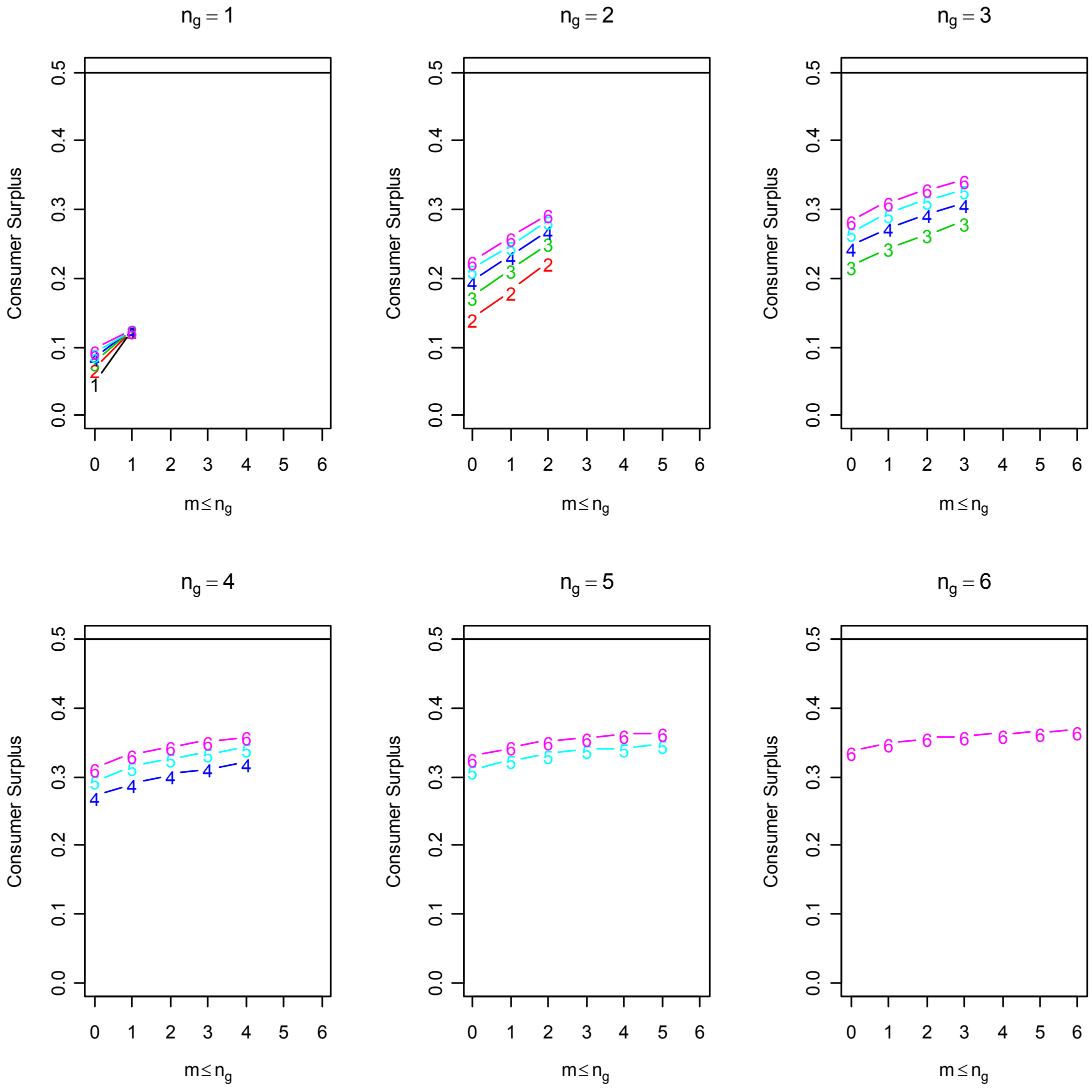
Proof: As for Proposition 1, the result is demonstrated by Figure 4.2 and its associated tables in Appendix A. Also, 2.1 – 2.3 were established by partially differentiating the equilibrium expression for consumer surplus and examining the resulting signs for $1 \leq n_g \leq 10$, $n_g \leq n_r \leq 10$ and $0 \leq m \leq n_g$.

---

9 Note that such full foreclosure of non-integrated retailers arises only in the monopoly generation case. As shown in Appendix A, for $n_g > 1$ and $n_r > n_g$ we find that separated retailers coexist with integrated firms even under full integration.

10 Given the very small (i.e. no more than 3/1000) decrease in consumer surplus observed for four or more generators as m increases, it is unclear whether this decrease is a genuine result of the analysis or merely rounding error.

Figure 4.2 – Consumer Surplus as a function of Integration (*m*)



Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

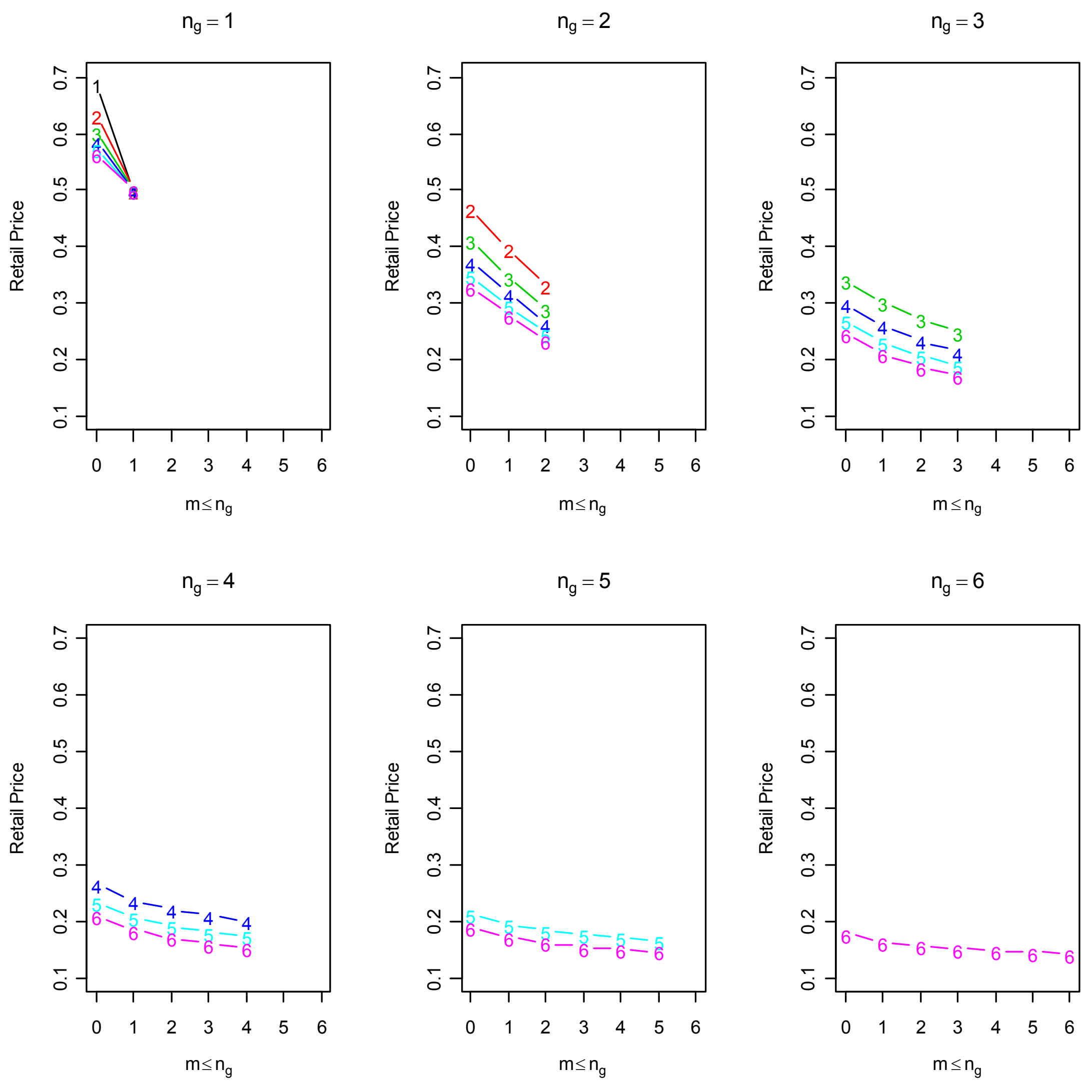
Proposition 2 is at least as significant as Proposition 1. It states that even if firm profits are ignored and only the more restrictive measure of consumer welfare is considered, integration remains the welfare-maximising form of industry organisation. Moreover, in the case of monopoly generation, this remains true even though non-integrated retailers are completely foreclosed. The next sub-section sheds light on why these two measures of welfare support the same conclusions regarding the benefits on integration.

4.2 Other Measures of Sector Performance

Here we consider five other measures of industry performance as functions of the degree of integration, exploring whether they align with our main welfare measures (i.e. total surplus and consumer surplus). We focus first on variables of keen interest to competition authorities, regulators and policy-makers, namely retail prices, industry profits and retail market concentration.[11] We also briefly discuss wholesale and forward market prices.

Figure 4.3 illustrates retail price, as a function of the degree of integration, for varying numbers of generators and retailers.

Figure 4.3 – Retail Price as a function of Integration (*m*)



Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

[11] As mentioned in Section 3.6, wholesale and forward market concentration indices are distorted by negative output in some cases, so they are not presented here.

Associated with these graphs is the following proposition:

Proposition 3 – Retail Price

3.1) Retail price is strictly decreasing in the degree of integration, given n_g and n_r.

3.2) Retail price is unambiguously lower as n_g increases, given n_r and m, and attains almost minimal levels for $n_g \geq 4$.

3.3) Except for the case of monopoly generation, retail price is strictly decreasing in the number of retailers, given n_g and m.

3.4) Except for the case of monopoly generation, retail price under full integration is comparable to that under full separation with one more generator, given the number of retailers. That is, given $n_g > 1$ and n_r, retail price with $m = n_g$ is comparable to (though not uniformly lower than) that achieved with $n_g + 1$ generators and $m = 0$.

Proof: The proposition follows from examination of Figure 4.3 and its associated tables in Appendix A, and for 3.1 – 3.3 by checking the sign of the partial derivative, with respect to the relevant parameters, of the equilibrium expression for retail price, for our chosen values of n_g, n_r and m.

Proposition 3 helps to explain the congruence between Propositions 1 and 2. The reason that consumer surplus, like total surplus, indicates that integration is to be preferred – even in the monopoly generation case in which integration also means full foreclosure of separated retailers – is that integration is associated with lower retail prices.

Turning now to industry profits, Figure 4.4 illustrates the combined profits of integrated and separated firms, as a function of the degree of integration, for varying numbers of generators and retailers. Examination of Figure 4.4 leads us to the following proposition:

Proposition 4 – Industry Profits

4.1) Except for the case of monopoly generation (i.e. for $n_g > 1$):

a) Industry profits are strictly decreasing in the level of integration, given n_g and n_r, with the rate of decrease most pronounced for three or less generators (i.e. the rate of decrease slows or vanishes, given n_r, for $n_g \geq 4$).

b) Industry profits are strictly decreasing in the number of generators, given n_r and m.

c) Industry profits are strictly decreasing in the number of retailers, given n_g and m, with the rate of decrease slowing or vanishing for $n_g \geq 4$.

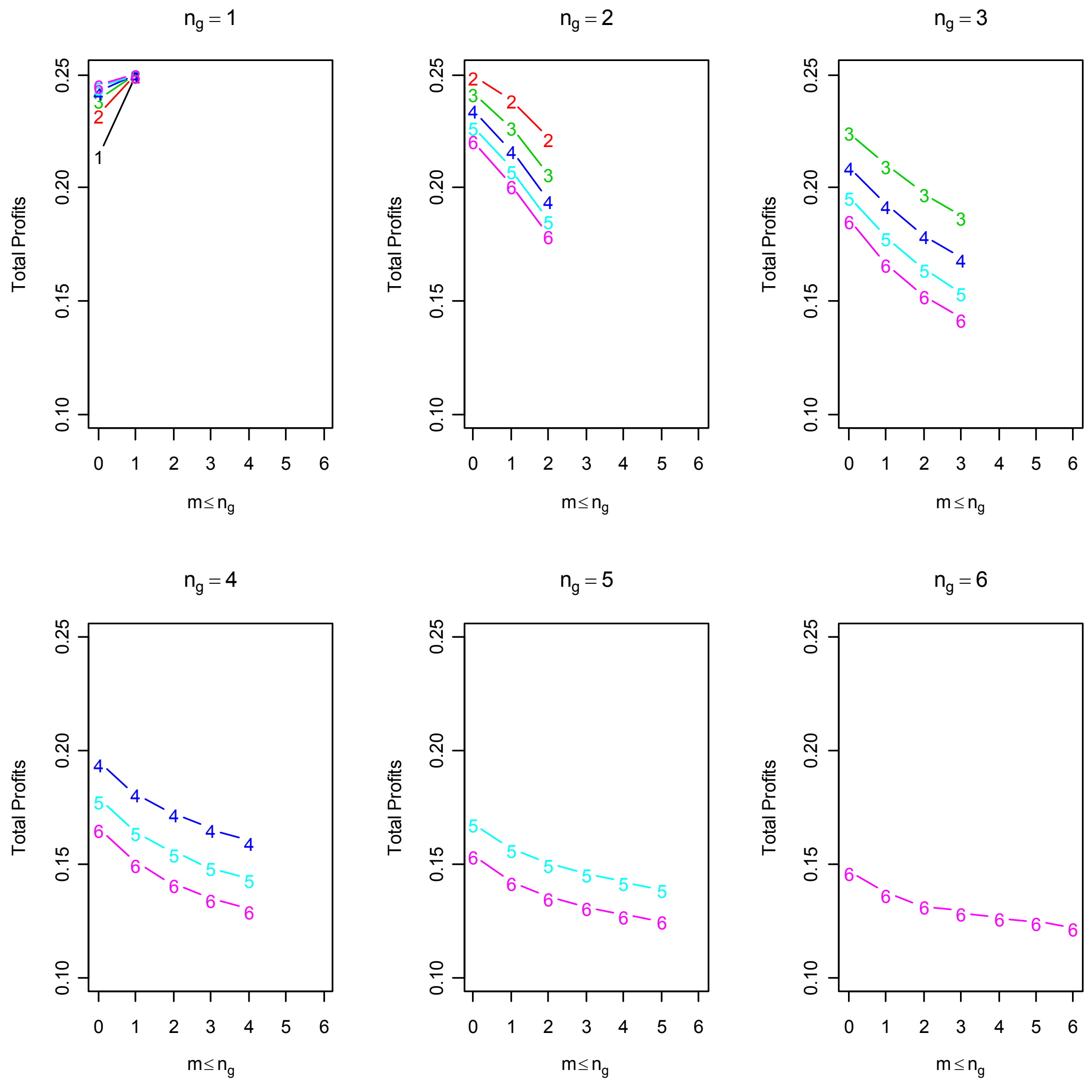
4.2) In the case of monopoly generation (i.e. for $n_g = 1$):

a) Industry profits are higher under full integration than under full separation.

b) Industry profits under full integration are comparable to those arising under duopoly with full separation.

Proof: The proposition follows from examination of Figure 4.4 and its associated tables in Appendix A, and for 4.1(a) – (c) by checking the sign of the partial derivative, with respect to the relevant parameters, of the equilibrium expression for industry profits.

Figure 4.4 – Industry Profits as a function of Integration (*m*)

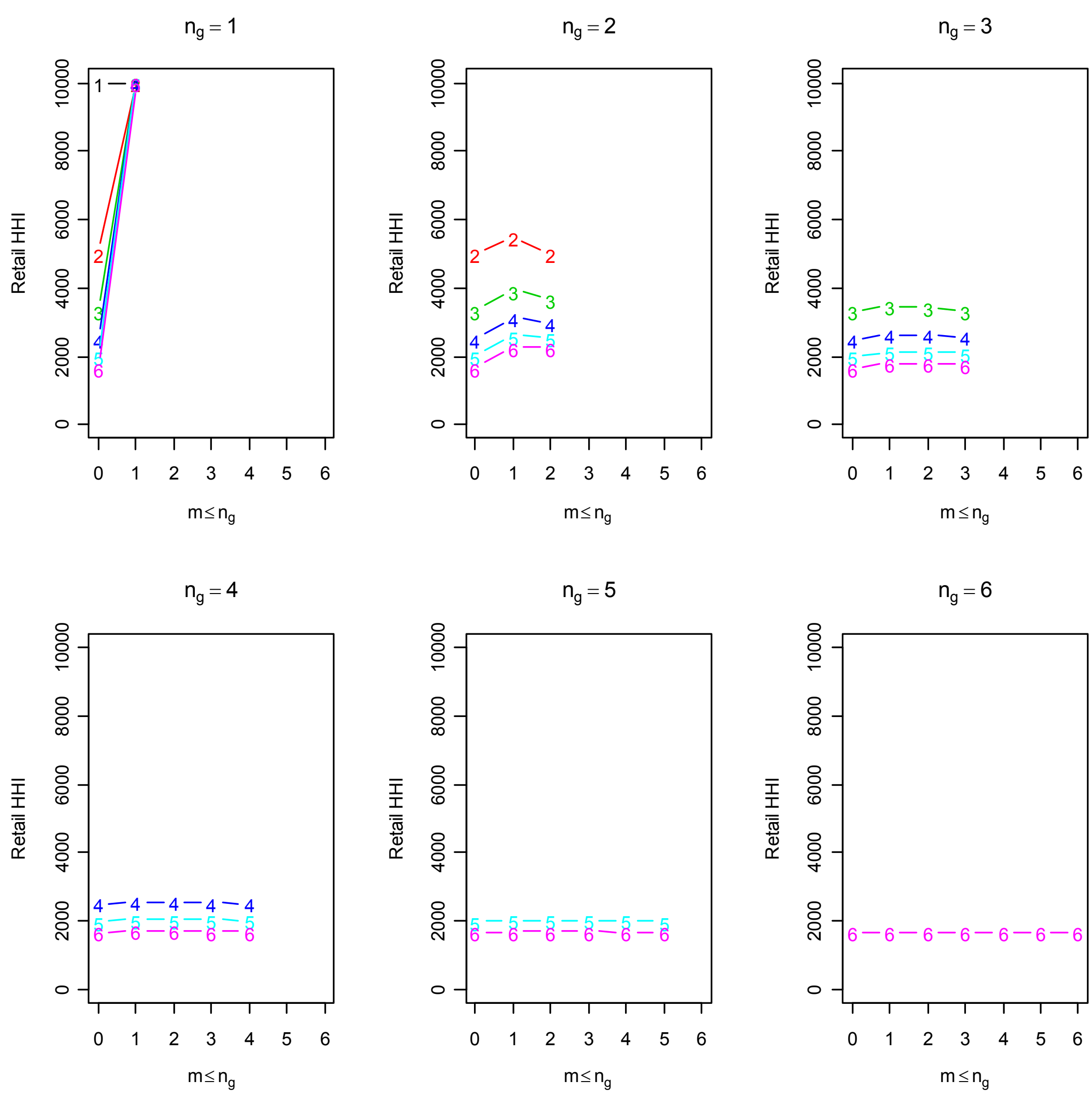


Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

Proposition 4.1 further strengthens the conclusions of Propositions 2 and 3. Except in the case of monopoly generation, total profits are declining in integration, meaning that rising consumer surplus more than offsets declining industry profits to yield increasing total surplus as integration rises. Conversely, Proposition 4.2 highlights how competition authorities, regulators or policy-makers confronting monopolistic generation might draw incorrect inferences regarding the desirability of integration. While industry profits rise when a monopolist generator integrates with a retailer and forecloses all other retailers, we know from Propositions 1 and 2 that total surplus and consumer surplus are both higher under such full integration, while retail prices are lower. This reflects the recognised benefits of removing double marginalisation (i.e. sequential monopolies are worse than an integrated monopoly, which enjoys higher profits at lower prices). While integrating firms with $n_g > 1$ is also associated with lower prices and higher total and consumer surpluses, unlike in the monopoly case industry profits do not rise.

Figure 4.5 illustrates retail HHI, as a function of the degree of integration, for varying numbers of generators and retailers.

Figure 4.5 – Retail HHI as a function of Integration (*m*)



Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

Examination of Figure 4.5 leads us to the following proposition:

Proposition 5 – Retail HHI

5.1) Retail HHI is either insensitive to the level of integration ($n_g \geq 4$), increasing in the level of integration ($n_g = 1$), or otherwise not systematically related to the level of integration.

5.2) Retail HHI is non-increasing in the number of generators, given n_r and m.

5.3) Except for the case of monopoly generation, retail HHI is non-increasing in the number of retailers, given n_g and m.

Proof: The proposition follows from examination of Figure 4.5 and its associated tables in Appendix A, and for 5.2 – 5.3 by checking the sign of the partial derivative, with respect to the relevant parameters, of the equilibrium equation for retail HHI.

The first two panels of Figure 4.5 highlight how competition authorities, regulators or policy-makers might be misled about the benefits or disadvantages of integration if they should rely on retail market concentration as their performance measure. In the monopoly case the increase in retail HHI resulting from integration (and the associated foreclosure of separated retailers) seems to clearly indicate that such integration is undesirable. Similarly, when confronted with rising concentration ratios in an integrating sector with duopolistic generation, it might be concluded that integration is undesirable. However, our earlier propositions clearly reveal that total and consumer surpluses are higher, and retail price is lower, with increasing integration in both cases.

Finally, in terms of wholesale and forward prices, less clear relationships with the level of integration emerge. In the case of monopoly generation, a separated generator charges a lower forward price as the number of retailers rises, with the opposite being the case for wholesale prices. In all other cases both forward and wholesale prices tend to be lower with a greater level of integration. They are also lower with a higher number of retailers, regardless of the level of integration. As was the case for retail prices, forward and wholesale prices tend to fall as the number of generators rises, given the number of retailers and level of integration, with the rate of decrease stabilising for around four or more generators.[12]

Since these measures broadly move in the same direction as our main welfare measures discussed above – i.e. indicating higher welfare as integration increases – these two performance measures appear to give broadly accurate impressions of the benefits or disadvantages of integration.

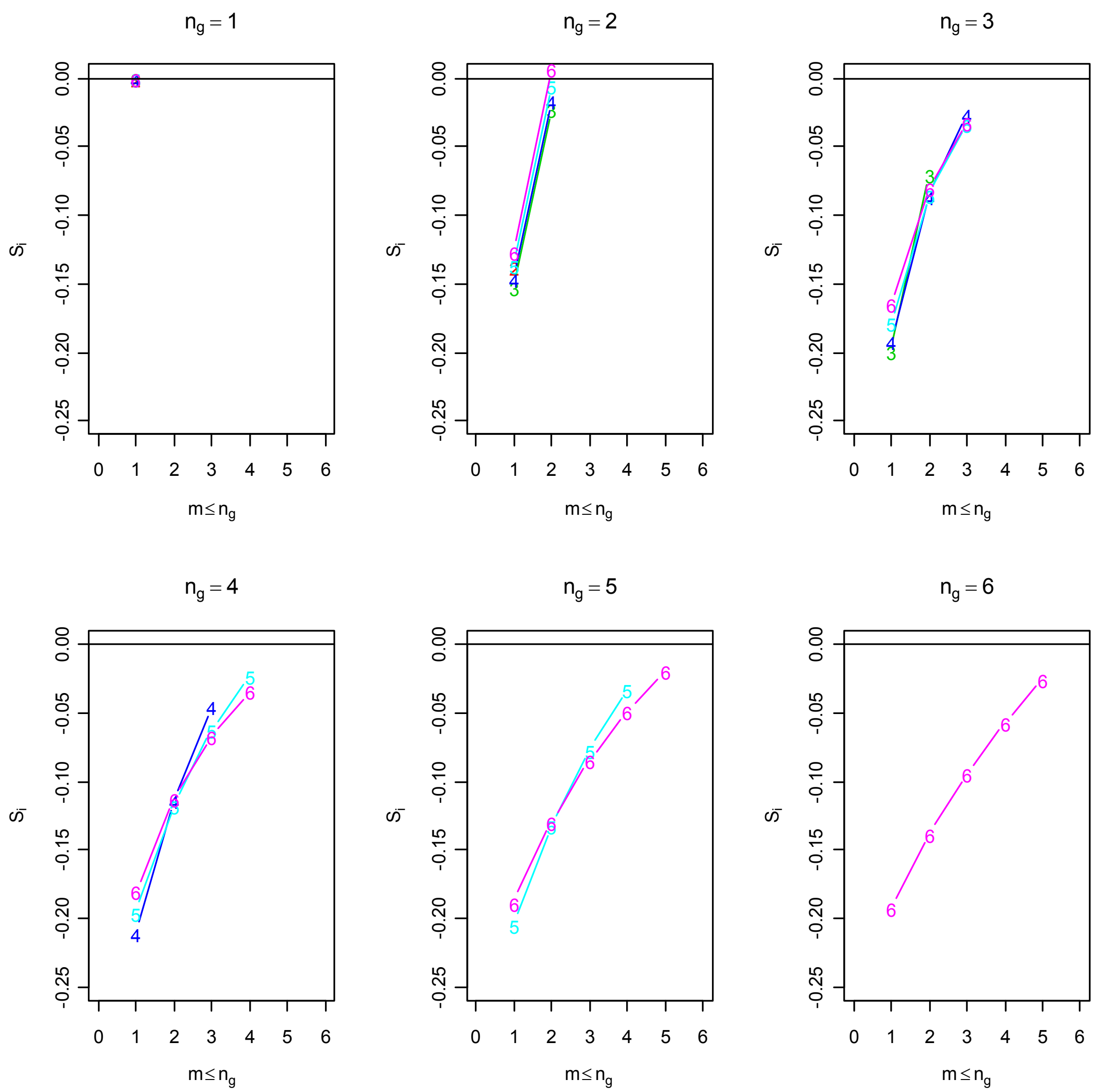
[12] In general we find that equilibrium forward and wholesale are positive. However, for higher values of n_g and some values of n_r and m, either can be marginally negative (see Appendix A). This is an artifact of our assumption that retail inverse demand takes the simple form as in equation (1). With a more general specification – i.e. with $P_r = a - b.y_{tot}$ instead of forcing $a = b = 1$ as in (1) – it should be possible to place restrictions on a and b ensuring all prices are always positive.

4.3 Strategic Interactions across Markets

Our model produces two interesting examples of strategic interactions across markets. The first, consistent with the findings in Gaudet and Van Long (1996), relates to the incentive of integrated firms to buy rather than sell wholesale energy. The second – which to our knowledge has only been partly revealed in earlier research – relates to the incentive of retailers to use forward energy purchases as a means to constrain generator market power. (In fact, this gives rise to a third result (also new), in terms of firms' incentives to integrate or remain integrated, as discussed in Section 4.4.)

As to the former, Figure 4.6 illustrates an integrated firm's wholesale output, as a function of the degree of integration, for varying numbers of generators and retailers.

Figure 4.6 – Integrated Firm Wholesale Output as a function of Integration (*m*)



Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

Under monopoly either there is no integrated generator (m = 0), or if there is (m = 1) all separated retailers are foreclosed and so there is no wholesale market. In all other cases excepting $n_g = m = 2$ with $n_r = 6$, integrated firms optimally purchase energy from the wholesale market, though to a lesser degree as the level of integration rises, irrespective of the number of retailers.

Gaudet and Van Long (1996) reveal a similar phenomenon in their model of vertical integration with only wholesale and retail markets, which they describe as a strategy of "raising rivals' costs". Under this strategy an integrated firm will make purchases, at higher than its own production cost, on the wholesale market as a means to increase wholesale (i.e. input) prices for their separated rival retailers. This incentive decreases when the number of separated retailers is small relative to the number of integrated firms, consistent with our finding that such purchases decrease as m rises.

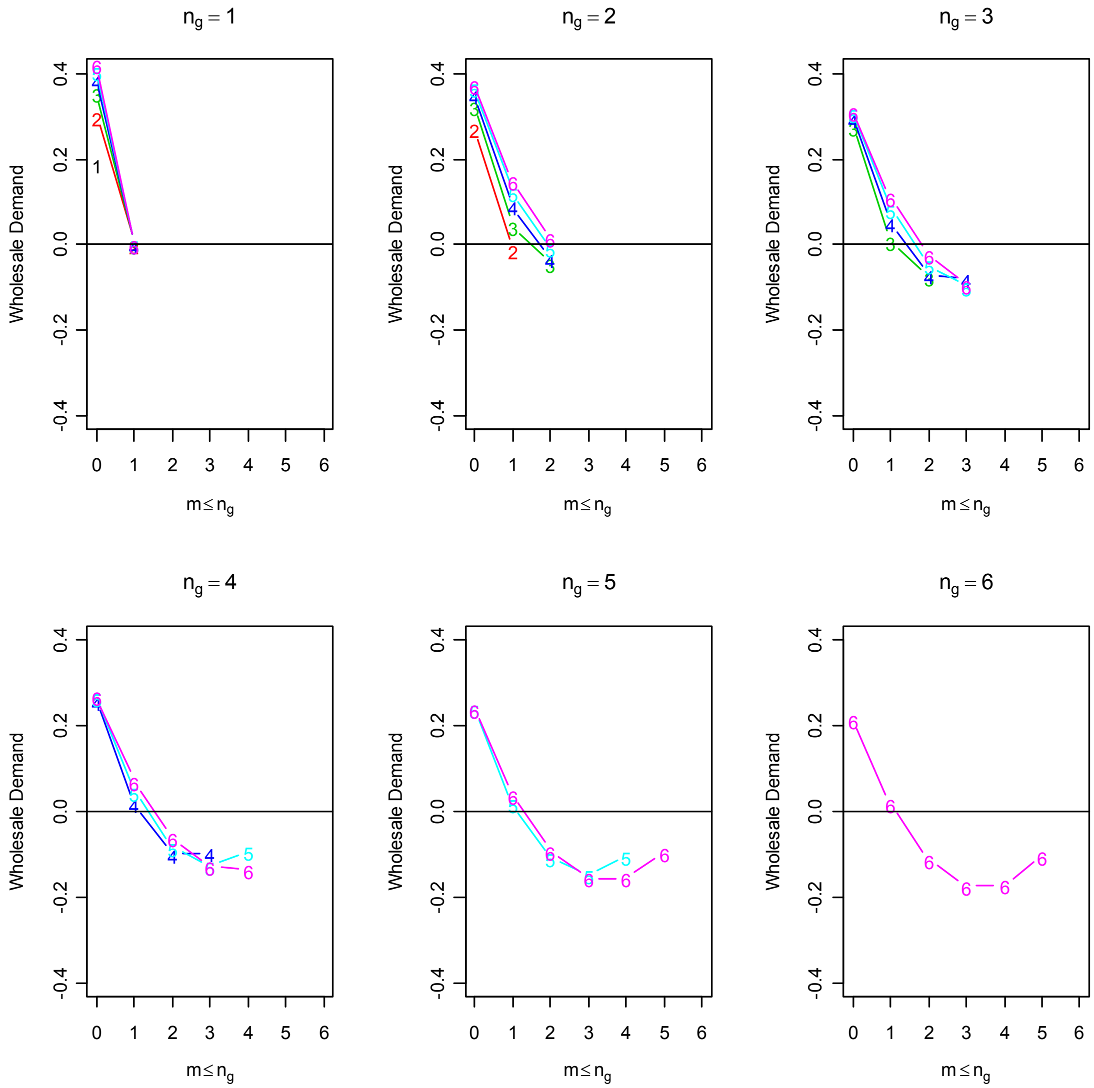
A less studied phenomenon is revealed in Figure 4.7 (overleaf), which illustrates total wholesale demand – in equilibrium equalling $S_{tot} + X_{tot}$, using our notation from Section 3.4.2 – as a function of the degree of integration, for varying numbers of generators and retailers.

Regardless of the number of generators or retailers, this demand is positive whenever there is full separation (m = 0). It remains positive for all $n_g > 1$ if only one generator is integrated (except for the case where $n_g = n_r = 2$). In all other cases, total wholesale demand is negative, indicating that retailers are net sellers to the wholesale market while generators are net buyers.

This is made possible through separated retailers' purchase of forward energy. In effect these retailers engage in an "over-buy and recycle" strategy, buying more energy forward than they require to meet their own retail supply commitments, and selling their excess back to the wholesale market. Indeed, such sales potentially meet the demand of integrated firms for wholesale energy discussed just above. Why a separated retailer should wish to do so is clear from our comparison in Section 3.4.2 of the forward market set-up in Allaz and Vila (1993) and in our model. Whereas in Allaz and Vila wholesale price is declining in the level of financial forward contracts *offered* by generators to financial speculators, in our model it is declining in the level of separated retailers' *demand* for physical forward contracts. Hence, rather than relying on generators' own incentives to reduce their wholesale market power through forward sales, in our set-up retailers can proactively purchase forward energy to ensure generator market power is reduced.

Interestingly, this means that in our model separated retailers have a tool that is not available under the set-up of Gaudet and Van Long (1996) to neutralise the raising rivals' costs strategy involving integrated firms purchasing wholesale energy. This goes some way towards explaining why wholesale prices tend to decrease in the number of generators (given the number of retailers and level of integration) and in the level of integration (given the number of generators and retailers) in our model. While integrated firms purchase wholesale energy to raise their separated retailer rivals' input costs, those retailers have already undermined the strategy by purchasing energy forward – indeed they purchase so much forward energy that they are able to sell it back to those very generators.

Figure 4.7 – Total Wholesale Demand as a function of Integration (*m*)



Note: the digits plotted above refer to the number of retailer firms ($n_r \geq n_g$), some or all of which may be vertically integrated (depending on the level of $m \leq n_g$).

Powell (1993) similarly shows – in a model absent vertical integration – that retailers should wish to purchase forward energy, even without a hedging motive, as a means to reduce generator market power. However, our paper is the first to show that this involves retailers purchasing more than their retail supply requirements in order to sell energy back to the integrated generators that are attempting to raise their input costs through wholesale market purchases.

4.4 Solution to Integration or Separation Stage for Duopoly Generation Case

Given the equilibrium profits derived in Section 3 for integrated firms and pairs of separated generator-retailers for different combinations of integration, we can solve for the equilibrium level of vertical integration or separation. A separated generator-retailer pair is assumed to wish to integrate if, given the other firm's (or firms') strategies, this results in higher anticipated equilibrium profits. Conversely, an integrated firm will separate if, given the other firm's (or firms') strategies, this too results in higher anticipated profits.

For expositional purposes we consider the case of duopolistic generation, and with between two and six retailers (i.e. n_g = 2, 2 ≤ n_r ≤ 6). We assume it is the generators that take integration or separation decisions. This decision structure constitutes a simple two-player game which can be represented by two-by-two decision payoff matrices as in Table 4.1

Table 4.1 – Integration or Separation Stage Payoff Matrices (n_g = 2)

Case 1 – Both Firms Initially Separated

		Second Separated Generator-Retailer Pair	
		Stay Separated	*Integrate*
First Separated Generator-Retailer Pair	*Stay Separated*	$\Pi^{g+r}(2, n_r, 0)$ $\Pi^{g+r}(2, n_r, 0)$	$\Pi^{g+r}(2, n_r, 1)$ $\Pi^{vi}(2, n_r, 1)$
	Integrate	$\Pi^{vi}(2, n_r, 1)$ $\Pi^{g+r}(2, n_r, 1)$	$\Pi^{vi}(2, n_r, 2)$ $\Pi^{vi}(2, n_r, 2)$

Case 2 – Both Firms Initially Integrated

		Second Integrated Firm	
		Stay Integrated	*Separate*
First Integrated Firm	*Stay Integrated*	$\Pi^{vi}(2, n_r, 2)$ $\Pi^{vi}(2, n_r, 2)$	$\Pi^{vi}(2, n_r, 1)$ $\Pi^{g+r}(2, n_r, 1)$
	Separate	$\Pi^{g+r}(2, n_r, 1)$ $\Pi^{vi}(2, n_r, 1)$	$\Pi^{g+r}(2, n_r, 0)$ $\Pi^{g+r}(2, n_r, 0)$

Case 3 – Only One Firm Initially Integrated

		Separated Generator-Retailer Pair	
		Stay Separated	*Integrate*
Integrated Firm	*Stay Integrated*	$\Pi^{vi}(2, n_r, 1)$ $\Pi^{g+r}(2, n_r, 1)$	$\Pi^{vi}(2, n_r, 2)$ $\Pi^{vi}(2, n_r, 2)$
	Separate	$\Pi^{g+r}(2, n_r, 0)$ $\Pi^{g+r}(2, n_r, 0)$	$\Pi^{g+r}(2, n_r, 1)$ $\Pi^{vi}(2, n_r, 1)$

We write the first (i.e. left) player's payoff in the top left of each matrix cell. $\Pi^{g+r}(2, n_r, m)$ represents the combined equilibrium profits of a separated generator-retailer pair, assuming a sector with two generators (m is either zero or one). Conversely, $\Pi^{vi}(2, n_r, 2)$ represents the equilibrium profits of an integrated firm, assuming a sector with two generators (m is either one or two). Full payoff matrices for $2 \leq n_r \leq 6$ can be obtained using the profit figures in Appendix A.

Three cases are relevant in determining the equilibrium level of integration arising in response to the profits anticipated in Stages II and III for either integrated firms, or pairs of separated generators and retailers. They are the cases in which all firms are initially separated, both firms are initially integrated, or only one firm is initially integrated. Each is examined in turn below.

Considering first the case in which all firms are initially separated (i.e. initially $\underline{m} = 0$), we find that the firms face a prisoner's dilemma for all the values of n_r considered. If the firms remained separated they would enjoy higher profits, but instead they face an incentive to unilaterally deviate (i.e. to integrate), resulting in lower profits for all firms. The only equilibrium of the integration stage in this case is for both firms to integrate (i.e. $m = 2$). Conversely, with both firms initially integrated we find the opposite driver of integration. While both firms would enjoy higher profits if they both separated, neither has an incentive to unilaterally do so, hence remaining integrated is the only equilibrium of the integration stage in this case. Finally, in the case that only one firm is initially integrated (i.e. initially $m = 1$), the separated pair of firms' dominant strategy is to integrate, while for the integrated firm it is to remain integrated. Hence, once again, full integration is the only equilibrium outcome of the integration stage, for all values of n_r considered.

In summary, analysis of the integration or separation stage with $n_g = 2$ and $2 \leq n_r \leq 6$ predicts that the natural industry structure to emerge from this model is full integration ($m = 2$), regardless of the initial industry configuration (and setting aside the costs of firm reorganisations, and a myriad of other relevant considerations). This result is to be contrasted with Proposition 6 in Gaudet and Van Long (1996). In that proposition integration is either a dominant strategy and full equilibrium is the only outcome ($n_r = 3$), only one generator integrates in equilibrium ($n_r = 4$), or in equilibrium no firm integrates ($n_r \geq 5$). Since our model has identical retailing and wholesale sub-stages to those in Gaudet and Van Long, aside from our introduction of forward contracting, we attribute our alternative result to the impact of forward contracting, and relate this to retailers' "over-buy and recycle" strategy.

In Gaudet and Van Long, integrated firms can pursue a "raising rivals' costs" strategy to the detriment of separated retailers, though only when the number of separated retailers is large relative to the number of integrated firms. In our model, by contrast, forward contracting does not only provide retailers with a means to neutralise the harm they otherwise face from integrated firms attempting to raise their input cost (i.e. wholesale price). The ability of retailers to purchase energy forward and recycle their excess to the wholesale market (i.e. to "over-buy and recycle") also enables them to harm both integrated firms and separated generators. Consequently integrated firms have an incentive to remain integrated even with a rising number of retailers, while separated generators face an incentive to integrate in order to allow them to countervail against the separated retailers' strategies to reduce wholesale price. Hence in our model full integration emerges as the only equilibrium. For a relatively low number of retailers generators have incentives to integrate (or remain integrated) to enable them to raise rivals' costs. However, as the relative number of retailers (and hence, given n_g, separated retailers) rises, this gives way to a different incentive for all generators to integrate or remain integrated, so as to protect themselves against separated retailers' "over-buy and recycle" strategy.

We note that these results have been derived assuming duopolistic generation, so naturally they may not extend to industries with more than two generators. However, they give cause to reflect when policymakers consider the optimal initial industry configuration while undertaking electricity sector reform, or when considering policy responses to mergers that give rise to integrated firms. Similarly, the model's prediction that full integration is the only equilibrium outcome of endogenous integration decisions by firms – with lower industry profits being the consequence – should be relevant to competition authorities considering mergers that result in greater integration.

5. Limitations and Extensions

The potentially more significant limitations of this model relate to its assumptions of zero generation costs, a specific rather than general form of inverse retail demand, and the absence of generation capacity constraints. Making these simplifying assumptions – as did Gaudet and Van Long (1996) – significantly reduces the complexity of a model that already involves a significant computational burden, at the cost of a loss in realism. While, as discussed in Section 3.2, the assumption of zero generation costs may not be restrictive in practise, for greater generality it would be desirable to relax that and these other assumptions in any future work. One possibility is to introduce linear generation costs (or even piecewise linear costs as in Bushnell et al. (2008)) to both approximate capacity constraints and to allow for increasing returns in generation. Either a parameterised form of linear inverse demand, or a more general specification such as that in Salinger (1989), could be assumed.

Other desirable refinements include the introduction of uncertainty, allowing for multiple technologies, providing for asymmetric information, and modeling multi-period features such as entry and investment. Uncertainty could be introduced in generation (e.g. fuel costs), demand, or both. Assuming multiple technologies, which enables consideration of strategic interactions between fuel types, would provide a much richer environment for analysis, as would the introduction of asymmetric information (e.g. as between generators and contract buyers regarding fuel stocks or costs). Making these refinements would not only add a significant degree of realism, but would also enable comparison of the respective hedging benefits of forward contracting and vertical integration.

They would (in a multi-period model) also facilitate an analysis of real options over investment timing and fuel choice, and a comparison of how firms respond to carbon pricing under separated and integrated structures. Additionally, the impact of assuming price rather than quantity competition might be explored, and a more general analysis of the integration or separation game (i.e. with $n_g > 2$) would be desirable.

More significantly, at the expense of adding yet even more game stages, allowing for entry, multi-period contracting, and investment, opens up a wide area of future inquiry. Meade and O'Connor (2010) identify a current lack of research modeling the question of whether there can be too much retail level competition in industries such as electricity, in which there are large sunk investments upstream (i.e. in generation) but only low entry barriers downstream (i.e. in retailing). They hypothesise that there is an interior optimum level of retail competition beyond which "hit and run" retail entry introduces hold-up risks for retailers who purchase forward contracts (if there are subsequent, unexpected falls in wholesale price). If, in the face of such entry, retailers renege on their contracts with generators, this then creates upstream hold-up risks for generation investments, and possibly also for investments further upstream (e.g. in fuel exploration, extraction/processing or transportation). Anticipating such hold-up, generators will both offer lower levels of contracts, and make lower levels of investment (at the expense of supply security).

Meade and O'Connor (2010) argue that vertical integration is a more natural and self-sustaining industry structure in the face of such contracting problems – being able to sustain a higher level of retail competition, and enable higher levels of investment (and supply security), than a non-integrated industry. These are claims that could be more deeply explored by extending our current model, endogenising n_g and/or n_r. Doing so would address topical questions arising in industrial organisation, institutional economics, contract theory, and competition policy. These questions include the demarcation of the limits of contracting and the boundary between ownership and contracting, the tradeoffs between static and dynamic efficiency, and the determination of optimal industry structure. Our present analysis could be extended to fruitfully examine some or all of these questions.

6. Summary and Conclusions

Our model's contribution has been to explore and offer new answers to some open questions in industrial organisation, institutional economics and competition policy. Namely, what are the welfare consequences of vertical integration in an industry combining forward, wholesale and retail markets, and what are the drivers of integration in such an industry? While our study was motivated by the particular institutional features of liberalised electricity systems, its results extend to other, comparable homogeneous good industries.

As to the welfare consequences of integration, we have been able to demonstrate that within the confines of our model, vertical integration is (second best) welfare-maximising under a range of criteria, including the maximisation of total or consumer surplus. At the same time we have identified diminishing returns – in a welfare sense – to increasing the number of generators in an electricity sector: our "four is enough" result, based on a number of performance measures. Also, we have identified circumstances in which vertical integration can substitute for, and in welfare terms is equivalent to, adding an extra generator in an otherwise separated sector (i.e. is akin to "*synthetic generation*"). Finally, we have also highlighted how some performance measures, if considered in isolation, can give a misleading impression regarding the harms of vertical integration.

As to the drivers of integration, our analysis extends the work of Gaudet and Van Long (1996). In their model the absence of forward trading means full vertical integration is not assured to be the equilibrium outcome of the integration game, with the number of retailers (relative to the number of generators) influencing the equilibrium outcome. Behind this effect is the "raising rivals' costs strategy" available to integrated firms, which becomes less important as the relative number of retailers increases.

By contrast, also allowing for forward trading, as we do, introduces a further influence favouring integration even with a relatively high number of retailers. This relates to the ability of separated retailers to use an "over-buy and recycle" strategy to not only countervail against the integrated firms' "raising rivals' costs" strategy, but also to harm separated generators by restraining wholesale prices. If such retailers can forward buy more energy than they require to meet their retail supply commitments, and later re-sell their excess on the wholesale market, this affords them with a tool to both protect themselves, and to harm generators. Accordingly, even with a relatively high number of retailers, separated firms have an incentive to integrate, and integrated firms have an incentive to remain integrated.

Finally, by modeling vertical integration in an institutional context with forward, wholesale and retail markets, our work provides a tool for deeper inquiry, including into dynamic questions such as retail entry and investment. Such inquiry could shed light on the optimal degree of retail competition under either integrated or separated (i.e. contracts based) industry structures, for industries with large, sunk upstream investments, but with low downstream entry barriers. Doing so offers the potential of shedding light on ongoing debates and open questions in industrial organisation, institutional economics, contract theory and competition policy.

References

Aïd, R., Chemla, G., Porchet, A. and N. Touzi, 2009, *Hedging and Vertical Integration in Electricity Markets*.

Allaz, B., and J.-L. Vila, 1993, "Cournot Competition, Forward Markets and Efficiency", *Journal of Economic Theory*, 59, 1-16.

Bonacina, M., Creti, A., and F. Manca, 2008, *Im-Perfectly Competitive Contract Markets for Electricity*, IEFE Working Paper Series, Working Paper No. 8, January.

Bushnell, J., 2007, "Oligopoly Equilibria in Electricity Contract Markets", *Journal of Regulatory Economics*, 32, 225-245.

Bushnell, J. B., Mansur, E. T. and C. Saravia, 2008, "Vertical Arrangements, Market Structure, and Competition: An Analysis of Restructured US Electricity Markets", *American Economic Review*, Vol. 98, No. 1, 237-266.

Electricity Technical Advisory Group, 2009, *Improving Electricity Market Performance*, preliminary report to the Ministerial review of electricity market performance, August.

European Commission (2007), *Inquiry pursuant to Article 17 of Regulation (EC) No 1/2003 into the European gas and electricity sectors—Final Report*, COM(2006) 851 final.

Gaudet, G., and N. Van Long, 1996, "Vertical Integration, Foreclosure, and Profits in the Presence of Double Marginalization", *Journal of Economics & Management Strategy*, Vol. 5, No. 3, 409-432).

Green, R., 2004, *Retail Competition and Electricity Contracts*, Cambridge Working Papers in Economics, CWPE 0406.

Hansen, C. (2004), *Improving Hedge Market Arrangements in New Zealand,* Paper for the 6th Annual National Power New Zealand Conference.

Hogan, S. and R. Meade, 2007, *Vertical Integration and Market Power in Electricity Markets*, New Zealand Institute for the Study of Competition and Regulation working paper, February.

Mahenc, P. and F. Salanie, 2004, "Softening Competition through Forward Trading", *Journal of Economic Theory*, 116, 282-293.

Meade, R. and S. O'Connor, 2010, "Comparison of Long-term Contracts and Vertical Integration in Decentralised Electricity Markets", in *Long Term Contracts in Electricity Markets: New Track for Competition Development*, Glachant, J.-M. and D. Finon (eds.), Edward Elgar, forthcoming.

O'Donnell, A. J., 2004, "Europe Rewired: A Giant Awakens", *Public Utilities Fortnightly*, February.

Powell, A., 1993, "Trading Forward in an Imperfect Market: The Case of Electricity in Britain", *Economic Journal*, Vol. 103, No. 417, March, 444-453.

Salinger, M. A., 1988, "Vertical Mergers and Market Foreclosure", *Quarterly Journal of Economics*, May, 345-356.

Salinger, M. A., 1989, "The Meaning of 'Upstream' and 'Downstream' and the Implications for Modeling Vertical Mergers", *Journal of Industrial Economics*, Vol. XXXVII, No. 4, June, 373-387.

Wolak, F., 2009, *An Assessment of the Performance of the New Zealand Electricity Market*, study commissioned by the New Zealand Commerce Commission, May.

Appendix A – Model Outputs

n_g	n_r	m	y_i	y_j	P_r	S_i	X_j	P_w	Q_j	Z_i	Z_j	P_f	$\Pi_{i,vi}$	$\Pi_{j,r}$	$\Pi_{j,g}$	HHI_r	CS	TS
1	1	0	n.a.	0.313	0.688	n.a.	0.188	0.375	0.125	n.a.	0.125	0.563	n.a.	0.074	0.141	10,000	0.049	0.264
1	1	1	0.500	n.a.	0.500	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.250	n.a.	n.a.	10,000	0.125	0.375
1	2	0	n.a.	0.183	0.633	n.a.	0.300	0.450	0.033	n.a.	0.067	0.517	n.a.	0.031	0.169	5,000	0.067	0.299
1	2	1	0.500	0.000	0.500	0.000	0.333	0.500	0.000	0.000	-0.093	0.500	0.250	0.000	0.120	10,000	0.125	0.375
1	3	0	n.a.	0.132	0.604	n.a.	0.354	0.472	0.014	n.a.	0.042	0.507	n.a.	0.017	0.188	3,333	0.078	0.317
1	3	1	0.500	0.000	0.500	0.000	0.500	0.500	0.000	0.000	-0.214	0.500	0.250	0.000	0.143	10,000	0.125	0.375
1	4	0	n.a.	0.104	0.586	n.a.	0.386	0.482	0.007	n.a.	0.029	0.504	n.a.	0.011	0.200	2,500	0.086	0.328
1	4	1	0.500	0.000	0.500	0.000	0.600	0.500	0.000	0.000	-0.315	0.500	0.250	0.000	0.143	10,000	0.125	0.375
1	5	0	n.a.	0.085	0.573	n.a.	0.406	0.488	0.004	n.a.	0.021	0.502	n.a.	0.007	0.209	2,000	0.091	0.336
1	5	1	0.500	0.000	0.500	0.000	0.667	0.500	0.000	0.000	-0.395	0.500	0.250	0.000	0.136	10,000	0.125	0.375
1	6	0	n.a.	0.073	0.563	n.a.	0.421	0.491	0.003	n.a.	0.016	0.501	n.a.	0.005	0.214	1,667	0.095	0.341
1	6	1	0.500	0.000	0.500	0.000	0.714	0.500	0.000	0.000	-0.459	0.500	0.250	0.000	0.128	10,000	0.125	0.375
2	2	0	n.a.	0.266	0.468	n.a.	0.135	0.203	0.131	n.a.	0.131	0.226	n.a.	0.068	0.057	5,000	0.141	0.390
2	2	1	0.397	0.207	0.397	-0.138	0.127	0.190	0.218	0.123	0.095	0.223	0.159	0.036	0.045	5,496	0.182	0.421
2	2	2	0.333	n.a.	0.333	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.111	n.a.	n.a.	5,000	0.222	0.444
2	3	0	n.a.	0.196	0.411	n.a.	0.161	0.215	0.089	n.a.	0.133	0.219	n.a.	0.038	0.064	3,333	0.173	0.415
2	3	1	0.348	0.152	0.348	-0.152	0.196	0.196	0.130	0.168	0.092	0.205	0.126	0.022	0.057	3,936	0.213	0.439
2	3	2	0.291	0.126	0.291	-0.022	0.124	0.165	0.170	0.085	0.071	0.175	0.096	0.014	0.033	3,694	0.251	0.458
2	4	0	n.a.	0.156	0.375	n.a.	0.175	0.218	0.069	n.a.	0.138	0.216	n.a.	0.025	0.068	2,500	0.196	0.430
2	4	1	0.317	0.122	0.317	-0.146	0.235	0.195	0.092	0.196	0.081	0.197	0.111	0.015	0.062	3,115	0.233	0.450
2	4	2	0.265	0.102	0.265	-0.016	0.196	0.164	0.118	0.118	0.076	0.165	0.087	0.010	0.045	2,996	0.270	0.465
2	5	0	n.a.	0.130	0.349	n.a.	0.182	0.219	0.057	n.a.	0.143	0.213	n.a.	0.017	0.070	2,000	0.212	0.439
2	5	1	0.296	0.102	0.296	-0.136	0.258	0.194	0.072	0.216	0.070	0.193	0.103	0.011	0.064	2,605	0.248	0.456
2	5	2	0.248	0.086	0.248	-0.005	0.243	0.162	0.089	0.133	0.065	0.161	0.082	0.007	0.050	2,556	0.283	0.469
2	6	0	n.a.	0.112	0.330	n.a.	0.187	0.218	0.049	n.a.	0.148	0.212	n.a.	0.013	0.072	1,667	0.224	0.446
2	6	1	0.280	0.088	0.280	-0.126	0.274	0.192	0.058	0.231	0.061	0.189	0.098	0.008	0.064	2,258	0.259	0.461
2	6	2	0.235	0.074	0.235	0.007	0.275	0.160	0.071	0.141	0.051	0.159	0.079	0.006	0.052	2,252	0.293	0.473
3	3	0	n.a.	0.219	0.342	n.a.	0.092	0.122	0.128	n.a.	0.128	0.116	n.a.	0.049	0.026	3,333	0.217	0.442
3	3	1	0.302	0.198	0.302	-0.198	0.103	0.103	0.194	0.155	0.117	0.104	0.087	0.039	0.023	3,479	0.244	0.455
3	3	2	0.272	0.184	0.272	-0.070	0.066	0.088	0.257	0.088	0.081	0.095	0.076	0.032	0.014	3,432	0.265	0.463
3	3	3	0.250	n.a.	0.250	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.063	n.a.	n.a.	3,333	0.281	0.469
3	4	0	n.a.	0.175	0.299	n.a.	0.099	0.123	0.101	n.a.	0.135	0.113	n.a.	0.032	0.027	2,500	0.246	0.455
3	4	1	0.261	0.160	0.261	-0.192	0.121	0.101	0.143	0.181	0.123	0.097	0.066	0.026	0.024	2,640	0.273	0.466
3	4	2	0.234	0.149	0.234	-0.085	0.102	0.085	0.184	0.129	0.109	0.084	0.058	0.022	0.018	2,622	0.293	0.473
3	4	3	0.215	0.140	0.215	-0.026	0.060	0.075	0.218	0.073	0.069	0.077	0.050	0.019	0.010	2,568	0.308	0.477
3	5	0	n.a.	0.146	0.269	n.a.	0.102	0.122	0.085	n.a.	0.142	0.112	n.a.	0.022	0.028	2,000	0.267	0.464
3	5	1	0.232	0.134	0.232	-0.178	0.131	0.098	0.113	0.199	0.126	0.093	0.055	0.019	0.025	2,132	0.295	0.473
3	5	2	0.208	0.126	0.208	-0.085	0.123	0.082	0.142	0.153	0.120	0.079	0.048	0.016	0.019	2,127	0.314	0.478
3	5	3	0.190	0.120	0.190	-0.033	0.094	0.071	0.169	0.113	0.101	0.069	0.042	0.015	0.014	2,091	0.328	0.482
3	6	0	n.a.	0.126	0.247	n.a.	0.104	0.121	0.074	n.a.	0.147	0.110	n.a.	0.017	0.029	1,667	0.284	0.470
3	6	1	0.211	0.115	0.211	-0.165	0.137	0.096	0.093	0.212	0.128	0.090	0.048	0.014	0.025	1,790	0.311	0.478
3	6	2	0.188	0.109	0.188	-0.079	0.136	0.079	0.115	0.167	0.124	0.075	0.042	0.012	0.020	1,793	0.330	0.482
3	6	3	0.172	0.104	0.172	-0.031	0.116	0.068	0.136	0.136	0.115	0.065	0.036	0.011	0.015	1,767	0.343	0.485

n_g	n_r	m	y_i	y_j	P_r	S_i	X_j	P_w	Q_j	Z_i	Z_j	P_f	$\Pi_{i,vi}$	$\Pi_{j,r}$	$\Pi_{j,g}$	HHI_r	CS	TS
4	4	0	n.a.	0.184	0.264	n.a.	0.064	0.080	0.120	n.a.	0.120	0.069	n.a.	0.035	0.013	2,500	0.271	0.465
4	4	1	0.238	0.175	0.238	-0.210	0.075	0.063	0.170	0.154	0.118	0.057	0.052	0.032	0.011	2,551	0.291	0.472
4	4	2	0.221	0.168	0.221	-0.113	0.064	0.053	0.218	0.115	0.103	0.050	0.049	0.029	0.008	2,546	0.303	0.476
4	4	3	0.210	0.161	0.210	-0.045	0.039	0.048	0.258	0.065	0.063	0.048	0.045	0.026	0.005	2,528	0.312	0.478
4	4	4	0.200	n.a.	0.200	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.040	n.a.	n.a.	2,500	0.320	0.480
4	5	0	n.a.	0.153	0.233	n.a.	0.066	0.079	0.101	n.a.	0.126	0.068	n.a.	0.025	0.014	2,000	0.294	0.473
4	5	1	0.207	0.147	0.207	-0.195	0.080	0.060	0.135	0.168	0.124	0.054	0.040	0.022	0.012	2,046	0.315	0.479
4	5	2	0.192	0.142	0.192	-0.117	0.075	0.050	0.169	0.137	0.117	0.046	0.037	0.021	0.009	2,046	0.327	0.482
4	5	3	0.181	0.137	0.181	-0.062	0.059	0.044	0.201	0.102	0.095	0.041	0.034	0.019	0.006	2,035	0.335	0.484
4	5	4	0.174	0.132	0.174	-0.023	0.035	0.042	0.225	0.056	0.055	0.040	0.031	0.018	0.004	2,020	0.341	0.485
4	6	0	n.a.	0.132	0.210	n.a.	0.067	0.078	0.087	n.a.	0.131	0.066	n.a.	0.018	0.014	1,667	0.312	0.478
4	6	1	0.184	0.126	0.184	-0.180	0.083	0.058	0.112	0.178	0.128	0.052	0.033	0.017	0.011	1,709	0.333	0.483
4	6	2	0.170	0.122	0.170	-0.113	0.082	0.048	0.138	0.151	0.125	0.043	0.030	0.016	0.009	1,711	0.344	0.486
4	6	3	0.161	0.119	0.161	-0.067	0.071	0.041	0.163	0.125	0.113	0.038	0.028	0.015	0.007	1,703	0.352	0.487
4	6	4	0.154	0.116	0.154	-0.034	0.054	0.038	0.184	0.092	0.088	0.035	0.025	0.014	0.005	1,693	0.358	0.488
5	5	0	n.a.	0.157	0.214	n.a.	0.047	0.057	0.110	n.a.	0.110	0.045	n.a.	0.026	0.008	2,000	0.309	0.477
5	5	1	0.194	0.153	0.194	-0.204	0.055	0.041	0.149	0.143	0.113	0.035	0.034	0.024	0.006	2,021	0.325	0.481
5	5	2	0.184	0.149	0.184	-0.132	0.052	0.034	0.186	0.120	0.106	0.030	0.033	0.023	0.005	2,021	0.333	0.483
5	5	3	0.177	0.146	0.177	-0.077	0.041	0.031	0.221	0.090	0.085	0.027	0.031	0.022	0.004	2,017	0.339	0.484
5	5	4	0.172	0.142	0.172	-0.032	0.025	0.030	0.246	0.049	0.048	0.028	0.030	0.021	0.002	2,010	0.343	0.485
5	5	5	0.167	n.a.	0.167	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.028	n.a.	n.a.	2,000	0.347	0.486
5	6	0	n.a.	0.135	0.190	n.a.	0.047	0.055	0.095	n.a.	0.115	0.044	n.a.	0.019	0.008	1,667	0.328	0.482
5	6	1	0.171	0.132	0.171	-0.188	0.057	0.040	0.124	0.151	0.117	0.033	0.027	0.018	0.006	1,686	0.343	0.485
5	6	2	0.161	0.129	0.161	-0.129	0.055	0.032	0.152	0.132	0.114	0.028	0.026	0.017	0.005	1,687	0.352	0.487
5	6	3	0.155	0.127	0.155	-0.084	0.049	0.028	0.179	0.110	0.102	0.025	0.024	0.017	0.004	1,684	0.357	0.488
5	6	4	0.150	0.124	0.150	-0.048	0.037	0.026	0.202	0.082	0.078	0.023	0.023	0.016	0.003	1,679	0.361	0.489
5	6	5	0.147	0.120	0.147	-0.019	0.022	0.026	0.218	0.044	0.043	0.024	0.022	0.015	0.002	1,674	0.364	0.489
6	6	0	n.a.	0.137	0.179	n.a.	0.036	0.042	0.101	n.a.	0.101	0.031	n.a.	0.020	0.005	1,667	0.337	0.484
6	6	1	0.164	0.135	0.164	-0.192	0.042	0.029	0.131	0.130	0.105	0.023	0.024	0.019	0.004	1,677	0.350	0.487
6	6	2	0.156	0.133	0.156	-0.138	0.041	0.024	0.161	0.116	0.103	0.019	0.023	0.018	0.003	1,677	0.356	0.488
6	6	3	0.152	0.131	0.152	-0.094	0.036	0.021	0.189	0.098	0.092	0.017	0.023	0.018	0.002	1,676	0.360	0.488
6	6	4	0.148	0.129	0.148	-0.057	0.028	0.020	0.214	0.072	0.070	0.016	0.022	0.017	0.002	1,674	0.363	0.489
6	6	5	0.146	0.126	0.146	-0.024	0.017	0.020	0.231	0.039	0.038	0.017	0.021	0.016	0.001	1,671	0.365	0.489
6	6	6	0.143	n.a.	0.143	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.020	n.a.	n.a.	1,667	0.367	0.490