DEEQA Research Report

The Effects of Vertical Integration, Forward Trading and Competition, on Investment and Welfare, in an Imperfectly Competitive Industry

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Dedication

To my first-born son, Maxwell.

1. Introduction

Securing investment in infrastructure-like industries is a pressing concern in most developed countries. This is because deregulation of such industries has decentralised responsibility for the typically large and sunk investments required to maintain supply quality and security, to meet demand growth, and to sustain wider economic growth in technologically-advanced economies. Politicians, policymakers, regulators and competition authorities face the challenge that they do not directly control investment levels in such industries, yet they remain at least partially accountable for sector conduct and performance. Their accountability is made all-the-more acute because the large investments required in these industries limits competition and raises market power concerns. A natural question arises, therefore, as to how best to elicit welfare-enhancing investment in imperfectly-competitive, infrastructure-like industries?

This research seeks to fill a gap in the existing literature by focusing on the interplay between competition, vertical industry structure, and market configuration (specifically, the use of forward markets) in affecting decentralised investment decisions. Attention is directed primarily at industries in which there are successive oligopolies - i.e. at each of the upstream/wholesale/production and downstream/retailing levels - operating with at least upstream and downstream markets. Examples include the electricity and natural gas sectors. A key characteristic of such sectors is that large, sunk investments are required at the upstream stage - i.e. in generation capacity for electricity sectors, or in extraction and/or processing for natural gas sectors. By contrast, relatively little investment is required at the downstream stages, or such investment (e.g. in call centres and billing systems) is more easily redeployable to other sectors, as the industries involve homogenous goods which require (indeed, permit) little by way of downstream transformation. In these sectors substantial transportation network infrastructures are also required, but they are assumed to be owned and/or operated by third parties on a non-discriminatory basis, to enable focus on issues relating to production and retailing. Since upstream production is a key feature, this research is not directly relevant to other infrastructure industries such as telecommunications, in which the upstream stage primarily involves competing network infrastructures (e.g. mobile, fixed-line, cable and/or fibre communication networks).

The electricity sector presents particular reasons for focusing on how competition, vertical industry structure and forward markets affect investment levels. Firstly, eliciting competition, at least at the downstream level, but also upstream in generation, has often been a goal in its own right, as formerly monopolistic or highly regulated electricity industries are deregulated. This is particularly so in the European Union, where successive EU directives have required increasing levels of electricity sector contestability. In some cases Member states have responded by facilitating competition at both upstream and downstream levels (e.g. as in the UK), but in others downstream competition has been grudgingly accommodated while upstream arrangements are largely preserved (e.g. France). An important question in France's case is how to price upstream supplies to separated downstream firms, given the lack of effective upstream competition. Existing literature highlights how excessive competition can hinder investment by reducing the returns available to cover fixed investment costs (e.g. Von der Fehr and Harbord (1997)), while investment in turn can affect competitive dynamics (e.g. Fudenberg and Tirole (1984)). Hence the interplay between competition and investment is an important question.

Secondly, the European Commission - unlike US antitrust authorities - is generally suspicious of vertical arrangements such as long-term contracting or vertical mergers, including in the electricity sector. Vertical integration between upstream and downstream stages, for example, can facilitate apparently anti-competitive strategies such as foreclosure, in which integrated firms withdraw from upstream markets and limit available supplies to separated downstream firms. Additionally, vertical integration can involve buying (rather than supplying) by integrated firms in upstream markets, so as to raise the input costs (i.e. upstream price) of separated downstream rivals - so-called "raising rivals' costs". Beyond these general concerns the EC has expressed particular concern at the impact of vertical integration between electricity generators and retailers on upstream market power (European Commission (2007)). Similar concerns have been explored by the New Zealand Commerce Commission (Wolak (2009)) in the predominantly integrated New Zealand electricity sector, with the result that integrated firms are now required by regulation to sell a minimum level of their output via forward contracts. Hence the interplays between investment and both vertical industry structure forward contracting and investment are also important questions.

Thirdly, supply security is a pressing challenge in reformed electricity sectors. Often reformed sectors begin with excess capacity stemming from investment decisions taken under state or regulated ownership. As demand grows and excess capacity falls, decentralised replacement or expansion investment becomes necessary, with the result that upstream electricity prices rise, and become highly volatile in periods when demand nears capacity. This raises political sensitivities, and is often addressed by introducing upstream price caps, which impede the necessary investment. In turn, additional mechanisms are often developed to address the resulting blunting of investment incentives, such as capacity mechanisms (Meade (2005)). Yet even with these remedial measures the US experience has been that generation investment cannot be sustained - the so-called "missing money" problem (Joskow (2006)). Relatedly, due to concerns regarding human-induced climate change, international pressure is mounting for countries to decarbonise their electricity production, raising the need for substantial new investment (GBP 200 billion in the UK alone). Devising arrangements to eilicit such investment in a sustainable way is squarely a policy priority in many developed countries. For both supply security and environmental sustainability reasons, investment is therefore an area of policy concern in its own right in electricity sectors.

Finally, it is acknowledged that investment is not a direct proxy for economic welfare. Just as under-investment presents difficulties, over-investment (relative to welfare-maximising levels) can also present problems in either decentralised or centralised contexts. Hence, while this research examines how competition, vertical industry structure and forward contracting affect investment, care is taken to also assess how these features also affect economic welfare.

The contribution of this paper is to combine institutional features not found together in other models, and to more fully explore investment and welfare than has been done in previous research. Specifically, classical oligopoly investment models (Shapiro (1989), Dixon (1986), Kreps and Scheinkman (1983), Okuno-Fujiwara and Suzumura (1993)) do not account for vertical industry structure, which is an important feature of infrastructure-like industries. Conversely, oligopoly models with vertical integration (Salinger (1988), Gaudet and Van Long (1996), Schrader and Martin (1998), Meade (2010)), including those in the electricity sector with forward trading (Powell (1993), Green (2004)), do not consider investment. Another class of models considers investment in oligopoly industries, including in the electricity industry, but ignores questions of vertical structure (Castro et al. (2005), Boom (2002), Von der Fehr and Harbord (1997)). Conversely, investment under imperfect competition and with vertical integration is examined in other studies, but for industries in which the upstream part involves network infrastructures instead of production *per se* (Cremer et al. (2006), Buehler and Schmutzler (2004)). Finally, other strands of literature related but not directly comparable to the current study includes that exploring vertical relations (Rey and Verge (2005), Rey and Tirole (2007)), excess entry models (Mankiw and Whinston (1986)), and general models of forward trading (Allaz and Vila (1993), Mahenc and Salanie (2004), Liski and Montero (2004), Hughes and Kao (1997), Janssen et al. (2010)). Indeed, literatures based on real options analysis, and other dynamic investment models, can also be distinguished from this static and deterministic study (which focuses just on strategic issues, but in a richer institutional context).

The existing studies most closely related to this study are stochastic oligopoly investment models in electricity with vertical integration (Boom (2004), Boom and Buehler (2005)) and deterministic oligopoly models with vertical integration (Buehler and Schmutzler (2008)). The former models do not consider forward trading, however, and nor do they allow for general downstream competition. Their contribution is instead to examine investment incentives when demand shocks expose the entire industry to the risk of blackouts. Under strong assumptions as to the consequence of blackout, the first study shows that competition can lead to over-investment, as suppliers facing uncertain capacity investments by rivals must increase their own investment to avoid profit losses from blackouts. Monopolist suppliers, by contrast, do not face such investment externalities, and therefore choose a socially preferable level of capacity. The second study shows that vertical separation can be preferable to integration, in contrast to other studies, which the authors attribute to the novel timing, market rules, and investment effects on welfare assumed in their model. In their setup increased capacity can only improve welfare if greater demand is served absent blackouts, which requires vertical separation since that structure results in price falls, whereas integration results in higher prices and lower demand.

The study most closely related to ours is Buehler and Schmutzler (2008). These authors develop a static model of investment under successive duopolies, with varying degrees of vertical integration. They model "cost-reducing" investment at the downstream industry level, and find that under asymmetric integration - when there is one integrated firm and one separated firm in each of the upstream and downstream levels - the integrated firm invests much more than its separated downstream rival. Doing so makes it a much stronger downstream competitor. Buehler and Schmutzler then go on to examine incentives for endogenous vertical integration.

In this study we modify and extend the model of Buehler and Schmutzler in multiple ways. Firstly, in recognition that large sunk investments in infrastructure-like industries more commonly arise at the upstream level, we relocate investment from downstream to upstream. Secondly, we expand their treatment of competition in two ways. To reflect our assumption that fixed costs in the downstream part of infrastructure-like sectors are relatively small (compared with upstream), we allow for more general competition in the downstream part of the industry. This is also better reflective of experience, where liberalising countries often open up the retail part of their electricity and gas sectors due to the relative ease of doing so, and political seductiveness of championing consumer-level competition. We also model upstream monopoly scenarios, in addition to upstream duopoly, under both integration and separation. This enables us to explore - to a more limited degree than for downstream - how changing from monopoly to duopoly upstream, under verying degrees of integration, affect investment and welfare. Finally, we provide formal welfare analysis for each of the scenarios considered.

Our analysis shows that vertical integration, competition and forward contracting do indeed interact to influence investment and welfare. Vertical integration proves valuable in a welfare sense due to its resolution of vertical coordination problems across the upstream and downstream industry levels (as might, for example, resale price maintenance, or two-part tariffs - see Rey and Verge (2005)). In particular, greater integration results in lower double marginalisation (as in Gaudet and Van Long (1996)), with the resulting lower prices and increased output at each industry level benefiting consumers, and sometimes also firms. Greater downstream competition can have a similar effect, simply by forcing firms to supply more aggressively. Indeed, the same can also be said of increased upstream competition, but this study identifies scenarios when in fact lower levels of competition (i.e. integrated and foreclosed successive monopoly) can be superior in welfare terms to separated, successive duopolies. In other words, the benefits of integration can in some cases more than substitute for a lack of competition. Additionally, we identify scenarios in which integrated firms engage in apparently anti-competitive or otherwise undesirable practices, yet separating them would result in worse outcomes. In particular, under asymmetric integration the integrated firm chooses not to supply the upstream market, but instead buys on that market so as to raise the upstream price - i.e. input cost - of its separated downstream rival. Moreover, such an integrated firm chooses to reduce investment in response to increased downstream competition. Yet we find that both welfare and total investment under asymmetric integration exceed that when all firms are separated. Finally, we show that introducing forward trading opportunities fundamentally alters the strategy of separated downstream firms under asymmetric integration. Indeed, forward trading causes integrated firms to more aggressively engage in raising rivals' costs. However, it also causes separated downstream firms to change from being net buyers on the upstream market to being net sellers (and thus to being beneficiaries of any raising rivals' costs strategy of the integrated firm). They do so by buying more on the forward market than they need to meet their downstream commitments, and sell the excess on the upstream market - an "over-buy and recycle" strategy. This strategy confronts integrated and separated upstream firms with a prisoner's dilemma (as in Allaz and Vila (1993)), causing them to commit to supply in the forward market even though this causes them to be tougher competitors in the upstream market. While forward trading leads to little change in total investment, the resulting constraint on both upstream and downsteream prices serves to increase welfare, complementing the benefits of competition and vertical integration.

This paper is structured as follows. The next section begins by setting out our basic model setup, highlighting where it differs to that in Buehler and Schmutzler (2008). It then establishes a First Best benchmark for output, investment and welfare, and describes the measure of welfare we use for each of the scenarios we consider. In turn we then describe the approach and basic results we obtain under upstream duopoly scenarios (asymmetric integration, maximal vertical integration, full vertical separation), and upstream monopoly (integrated and separated). The results of that section are summarised in two lemmas at its conclusion. In Section 3 we then discuss our results in relation to our principal question of interest - how vertical integration, competition and forward trading interact to affect investment and welfare in our imperfectly-competitive industry - setting out these results in three propositions. Section 4 sets out desirable extensions to the model, as well as the authors' ambitions for future research. Section 5 provides a concluding discussion, with a focus on what the results of this analysis suggest for practice in liberalised or liberalising electricity and gas industries.

2. Model

2.1 Basic Setup

Our basic framework combines the cost-reducing investment approach of Buehler and Schmutzler (2008) with the successive oligopolies approach of Gaudet and Van Long (1996) and Schrader and Martin (1998). In Section 3.7, where forward contracting is introduced, the approach of Meade (2010) is also used, which differs to the Allaz and Vila (1993) approach commonly used elsewhere.

The context is of an industry in which a non-storable, homogeneous good is produced at an upstream stage, with fixed and variable production costs depending on the level of previous upstream investment. Thus upstream production cost takes the form:

$$C(q; b, c, K) = (c - K)\ q - b.K^2$$

where q is a placeholder variable for production quantity, K is the level of capital in physical units, and $b > 0$ is a measure of capital cost. To ensure all optimisation problems are concave, and that all variables which should be non-negative are, it is assumed that b is not "too small", which for our purposes is typically satisfied if $b \geq 1$. The cost of invested capital, which is a fixed cost of upstream production, is given by the last term above, while marginal production cost is $(c - K)$. It is assumed that $0 < c < \infty$, implying that marginal production cost is finite even when $K = 0$ - i.e. c is some form of "underlying" marginal production cost. Thus, implicitly, this setup assumes there has been some level of past investment made even before K is procured, enabling production at finite marginal cost even if $K = 0$. In turn this implies that investment is being made by existing/incumbent firms, rather than by entrants.

As in Buehler and Schmutzler (2008), no explicit justification is offered for this form of cost function, aside from its obvious attraction in terms of tractability, and its simple interpretation. In particular, investment can be interpreted as "cost-reducing", in that higher investment by upstream firms results in lower marginal production cost (but higher fixed cost) at the upstream level.

The downstream stage uses the upstream output as an input in a 1-1 fixed-proportions production function, with zero marginal costs of downstream production assumed for convenience (and also in reflection of the assumed far greater production costs incurred upstream). There are also no fixed costs of downstream production. Hence, while Buehler and Schmutzler assume that cost-reducing investment occurs at the downstream level, with zero upstream production costs, here the reverse is the case.

There are two upstream firms, but $n_{\mathrm{D}} \geq 2$ downstream firms, $m \in \{0,1,2\}$ of which are vertically integrated (in Buehler and Schmutzler $n_{\mathrm{D}} = 2$ was assumed). Thus there are m symmetric vertically integrated firms operating at both upstream and downstream levels, $n_{\mathrm{D}} - m$ symmetric separated firms operating at just the downstream level, and $2 - m$ symmetric separated firms operating at just the upstream level. The potential imbalance between the number of firms competing upstream and downstream is to reflect the assumed fixed costs of, and hence lower competition in, upstream production, and absence of fixed costs downstream. As special cases, integrated monopoly ($m = 1$) and separated monopoly ($m = 0$) - each with $n_{\mathrm{D}} \geq 2$ - are also considered.

Upstream and downstream trade is respectively conducted in upstream and downstream markets, in which firms compete in quantities (i.e. Cournot). Quantity competition has been chosen in preference to price competition (i.e. Bertrand) for reasons of tractability (e.g. to ensure existence of equilibrium even with a homogenous product) and also because the differences between price and quantity competition can be more apparent than real (Kreps and Scheinkman (1983)).

Downstream firms face linear inverse demand of the form:

$$P_{\mathrm{D}} = a - \left(\sum_{i=1}^{m} y_i \right) - \left(\sum_{j=m+1}^{n_{\mathrm{D}}} y_j \right)$$

with y_i and y_j denoting the downstream outputs of the integrated and separated downstream firms, respectively. To ensure the market is covered, and also that equilibrium outputs and investment levels are non-negative, it is assumed that $a > c$. Timing is as shown in Figure 2.1.

Figure 2.1 - Timing

Investment Choices → Upstream Market → Downstream Market

As usual, the model is solved using backward induction, with subgame perfect equilibrium being the relevant equilibrium concept. In the following sub-sections we respectively discuss the approach adopted for solving each of the following cases:

- **First Best:** the welfare-maximising choice of a benevolent and informed planner is derived for benchmarking purposes, and we also introduce the welfare measure we use for each of the following cases;
- **Case 1 - Asymmetric Integration ($m = 1$):** only one firm is integrated, the other upstream firm is separated, and there is at least one separated downstream firm;
- **Case 2 - Maximal integration ($m = 2$), with sub-cases for balanced full integration ($n_D = m = 2$) and unbalanced full integration ($n_D > m = 2$):** in the first sub-case there are just two integrated firms, and hence no role for upstream (or forward) trade, while in the second sub-case both integrated firms might still conceivably supply upstream in order to meet demand from one or more separated downstream firms;
- **Case 3 - Full separation ($m = 0$):** there are two separated upstream firms, supplying at least two separated downstream firms;
- **Case 4 - Upstream monopoly, with sub-cases for either an integrated or separated upstream monopoly facing one or more possible downstream rivals:** this case allows us to examine in at least a limited way the impact of changing upstream competition (i.e. from monopoly to duopoly) on investment; and
- **Forward trading with successive duopolies:** we introduce forward trading - i.e. trading between integrated and/or separated upstream firms on the one hand, and separated downstream firms on the other, prior to upstream and downstream market trading (forward trading is thus a form of advance upstream trading).

2.2 First Best Benchmark, and Welfare Measure

To establish our First Best welfare benchmarks, we assume that a social planner chooses total retail output $\widehat{y}$ and investment level $\widehat{K}$ to maximise net social surplus S - i.e. the area under the downstream inverse demand curve up to $\widehat{y}$, net of production and capital costs, with S defined as follows:

$$S = \int_0^{\widehat{y}} (a - Y)\, \mathrm{d}Y - (c - \widehat{K})\, \widehat{y} - b\, \widehat{K}^2$$

Evaluating S, and maximising with respect to $(\widehat{y}, \widehat{K})$ yields:

$$\widehat{y} = \frac{2\,(a - c)\, b}{-1 + 2\, b}$$

$$\widehat{K} = \frac{a - c}{-1 + 2\, b}$$

$$\widehat{S} = \frac{b\,(a - c)^2}{-1 + 2\, b}$$

These define our First Best downstream output, investment, and welfare respectively. Examination of the relevant first order conditions reveal that we require b to not be too small for this solution to be a maximum, which for our reference scenario, with $a = 10$ and $c = 5$, requires that $b \geq 1$. Implicitly this maximisation is also subject to output, investment and marginal cost each being non-negative, which has been verified *ex post*. With $b \geq 1$ this is commonly the case.

To measure welfare in each of the cases below, we use the standard measure of total surplus, namely:

$$TS = CS + \Pi_{tot}$$

where Π_{tot} represents total industry profits, and CS measures consumer surplus, defined as the area under the downstream inverse demand curve up to industry output y_{tot}, net of consumer expenditure on y_{tot}, i.e.:

$$CS = \int_0^{y_{tot}} (a - Y)\, \mathrm{d}Y - P_{\mathrm{D}}\, y_{tot}$$

2.3 Case 1 - Asymmetric Integration ($m = 1$)

In this sub-section a detailed discussion of the model's solution is provided, with more summary presentations provided in subsequent sub-sections. Whenever figures are provided they assume a reference scenario in which $a = 10$ and $c = 5$ (i.e. satisfying our assumption that $a > c$), and plot the variables on interest against investment cost $b \geq 1$. As discussed above, this set of parameters ensures profits are always maximised and with interior solutions, and that all equilibrium outputs that should be non-negative are so. It is noted that earlier analysis confirms - for the case

$n_{\mathrm{D}} = 2$ at least - that no conclusions change with other combinations of a and c.

2.3.1 Downstream Sub-Stage

Integrated firm i faces downstream inverse demand $P_{\mathrm{D}} = a - (y_i + A_i)$, where in equilibrium, with symmetric firms and $m = 1$, we have $A_i = (n_{\mathrm{D}} - 1)\, y_j$. Taking its rival's output and investment levels as given, firm i chooses y_i to maximise the following integrated firm profit function:

$$\Pi_{i,\, VI} = P_{\mathrm{D}}\, y_i + P_U\, S_i - (c - K_i)\,(y_i + S_i) - b\, K_i^2$$

where P_U is the price in the upstream market, and S_i is the integrated firm's upstream output. Taking first order conditions, substituting for A_i, and solving for firm i's downstream market reaction function yields:

$$y_i(y_j, K_i) = \left(-\frac{1}{2}\, n_{\mathrm{D}} + \frac{1}{2}\right) y_j + \frac{1}{2}\, K_i + \frac{1}{2}\, a - \frac{1}{2}\, c$$

Similarly, a separated downstream firm j faces downstream inverse demand $P_{\mathrm{D}} = \mathrm{a} - (y_j + A_j)$, where in equilibrium, with symmetric firms and $m = 1$, we have $A_j = y_i + (n_{\mathrm{D}} - 2)\, y_j$. Taking its rival's output and investment levels as given, firm j chooses y_j to maximise the following separated downstream firm profit function:

$$\Pi_{j,\, \mathrm{D}} = P_{\mathrm{D}}\, y_j - P_U\, y_j$$

Proceeding as before, we obtain firm j's downstream market reaction function:

$$y_j(y_i, P_U) = \frac{a - y_i - P_U}{n_{\mathrm{D}}}$$

Solving for the subgame perfect equilibrium of this sub-stage yields the following functions in terms of investment K_i and upstream price P_U:

$$y_i(K_i, P_U) = \frac{(n_{\mathrm{D}} - 1)\, P_U}{n_{\mathrm{D}} + 1} + \frac{n_{\mathrm{D}}\, K_i}{n_{\mathrm{D}} + 1} + \frac{a - c\, n_{\mathrm{D}}}{n_{\mathrm{D}} + 1}$$

$$y_j(K_i, P_U) = -\frac{2\, P_U}{n_{\mathrm{D}} + 1} - \frac{K_i}{n_{\mathrm{D}} + 1} + \frac{a + c}{n_{\mathrm{D}} + 1}$$

$$P_D(K_i, P_U) = \frac{(n_D - 1)\, P_U}{n_D + 1} - \frac{K_i}{n_D + 1} + \frac{a + c}{n_D + 1}$$

Notice that y_i (y_j) is directly increasing (decreasing) in K_i, while downstream outputs are also indirectly affected by both the integrated and separated upstream firms' investments via P_U. Also observe that y_i (y_j) is increasing (decreasing) in P_U.

2.3.2 Upstream Sub-Stage

Upstream demand derives from the aggregate of separated downstream firm demands, and is supplied by the aggregate upstream output of integrated firm *i* and separated upstream firm *j*, which we write as $S_i + X_j$. Upstream derived inverse demand is thus obtained by solving $(n_D - 1)\, y_j = S_i + X_j$ for P_U, yielding:

$$P_U(K_i, S_i, X_j) = \frac{1}{2}\,\frac{(-n_D - 1)\, X_j}{n_D - 1} + \frac{1}{2}\,\frac{(-n_D - 1)\, S_i}{n_D - 1} + \frac{1}{2}\,\frac{(1 - n_D)\, K_i}{n_D - 1} + \frac{1}{2}\,\frac{-a + a\, n_D + c\, n_D - c}{n_D - 1}$$

Given the equilibrium from the downstream sub-stage, and using this derived inverse demand in the above expression for firm *i*'s profits, firm *i* chooses its profit-maximising upstream output S_i taking its rival's upstream output and investment levels as given, from which we obtain that firm's upstream market reaction function (in terms of its upstream rival's output, but not of either firm's investment):

$$S_i(X_j) = -\frac{2\, X_j}{n_D + 3}$$

As to be expected in a linear-Cournot setup, each firm's upstream output is a strategic substitute for the other's. Meanwhile, the separated upstream firm *j* faces the same derived upstream inverse demand function, and chooses its profit maximising upstream output X_j, to maximise the following separated upstream firm profit function:

$$\Pi_{j,\,U} = P_U X_j - (c - K_j)\, X_j - b\, K_j^2$$

Proceeding as above produces firm *j*'s upstream market reaction function (in terms of the integrated firm's upstream output, as well as of both firms' investment):

$$X_j(K_i, S_i, K_j) = \frac{1}{2}\,\frac{(-n_D - 1)\,S_i}{n_D + 1} + \frac{1}{2}\,\frac{(1 - n_D)\,K_i}{n_D + 1} + \frac{1}{2}\,\frac{(2\,n_D - 2)\,K_j}{n_D + 1} + \frac{1}{2}\,\frac{a\,n_D - c\,n_D - a + c}{n_D + 1}$$

Here we see that not only is the separated upstream firm's output declining in the integrated firm's upstream output, but also that it is increasing in its own investment, while decreasing in the integrated firm's investment. Solving for the subgame perfect equilibrium for this sub-stage yields:

$$S_i(K_i, K_j) = -\frac{(2\,n_D - 2)\,K_j}{(n_D + 1)\,(n_D + 2)} - \frac{(-n_D + 1)\,K_i}{(n_D + 1)\,(n_D + 2)} - \frac{a\,n_D - c\,n_D - a + c}{(n_D + 1)\,(n_D + 2)}$$

$$X_j(K_i, K_j) = \frac{1}{2}\,\frac{(n_D + 3)\,(-n_D + 1)\,K_i}{(n_D + 1)\,(n_D + 2)} + \frac{1}{2}\,\frac{(n_D + 3)\,(2\,n_D - 2)\,K_j}{(n_D + 1)\,(n_D + 2)} + \frac{1}{2}\,\frac{(n_D + 3)\,(a\,n_D - c\,n_D - a + c)}{(n_D + 1)\,(n_D + 2)}$$

$$P_U(K_i, K_j) = \frac{1}{4}\,\frac{(-2\,n_D - 2)\,K_j}{n_D + 2} + \frac{1}{4}\,\frac{(-n_D - 3)\,K_i}{n_D + 2} + \frac{1}{4}\,\frac{5\,c + a\,n_D + 3\,c\,n_D + 3\,a}{n_D + 2}$$

Here it is clear that each firm's upstream output is increasing in its own investment but decreasing in the other firm's investment, while P_U is decreasing in both, though more so in respect of K_j. Since upstream production costs are decreasing in investment this is as expected, with the weaker impact of K_i on P_U being due to an increase in K_i producing offsetting direct and indirect (via P_U) impacts on y_i and y_j. In contrast, an increase in K_j results in a stronger net increase in y_j and hence upstream demand, with consequent upward pressure on P_U. These influences are demonstrated by substituting for P_U in y_j from the subgame perfect equilibria in the downstream sub-stage, recalling that upstream demand derives exclusively from separated downstream output:

$$y_j(K_i, K_j) = \frac{K_j}{n_D + 2} - \frac{1}{2}\,\frac{K_i}{n_D + 2} + \frac{1}{2}\,\frac{a - c}{n_D + 2}$$

2.3.3 Investment Sub-Stage

Given the above, and taking the separated upstream firm *j*'s investment as given, integrated firm *i* chooses its profit-maximising level of investment as a function of K_j:

$$K_i(K_j) = \frac{\left(-2\,n_D - 6\,n_D^3 + 30 - 22\,n_D^2\right) K_j}{80\,b\,n_D^2 + 128\,b\,n_D - 39\,n_D^2 - 9\,n_D^3 - 35\,n_D + 11 + 16\,b\,n_D^3 + 64\,b}$$
$$+ \frac{-17\,c\,n_D^2 + 19\,a + 17\,a\,n_D^2 + 33\,a\,n_D + 3\,a\,n_D^3 - 19\,c - 3\,c\,n_D^3 - 33\,c\,n_D}{80\,b\,n_D^2 + 128\,b\,n_D - 39\,n_D^2 - 9\,n_D^3 - 35\,n_D + 11 + 16\,b\,n_D^3 + 64\,b}$$

Likewise, for the separated upstream firm j we have:

$$K_j(K_i) = \frac{1}{2}\,\frac{\left(-n_D^3 - 5\,n_D^2 - 3\,n_D + 9\right) K_i}{10\,b\,n_D^2 - n_D^3 + 2\,b\,n_D^3 - 5\,n_D^2 + 16\,b\,n_D - 3\,n_D + 9 + 8\,b}$$
$$+ \frac{1}{2}\,\frac{3\,a\,n_D - 3\,c\,n_D + 5\,a\,n_D^2 + 9\,c + a\,n_D^3 - c\,n_D^3 - 5\,c\,n_D^2 - 9\,a}{10\,b\,n_D^2 - n_D^3 + 2\,b\,n_D^3 - 5\,n_D^2 + 16\,b\,n_D - 3\,n_D + 9 + 8\,b}$$

For example, with $n_D = 2$ we have:

$$K_i(K_j) = -\frac{110\,K_j}{-287 + 768\,b} + \frac{177\,a - 177\,c}{-287 + 768\,b}$$

$$K_j(K_i) = -\frac{25}{2}\,\frac{K_i}{-25 + 96\,b} + \frac{25}{2}\,\frac{a - c}{-25 + 96\,b}$$

From these simplified expressions it is clear that investments are strategic substitutes, as expected in a linear-Cournot setup. For $n_D \geq 2$ this remains true for so long as investment cost b is not too small, as is required for second order conditions and for non-negative investment, output, marginal cost and prices. Solving for the subgame perfect equilibrium of this sub-stage we find our equilibrium investment level for the integrated and separated upstream firms in terms of model parameters:

$$K_i = \Big(\big(3\,b\,n_D^5 - 3\,n_D^5 + 26\,b\,n_D^4 - 23\,n_D^4 + 90\,b\,n_D^3 - 50\,n_D^3 - 2\,n_D^2 + 152\,b\,n_D^2 + 123\,b\,n_D + 69\,n_D + 38\,b + 9\big)\,(a - c)\Big) \Big/ \big(3\,n_D^5 - 17\,b\,n_D^5 + 16\,b^2\,n_D^5 - 130\,b\,n_D^4 + 128\,b^2\,n_D^4 + 23\,n_D^4 + 50\,n_D^3 + 400\,b^2\,n_D^3 - 330\,b\,n_D^3 + 608\,b^2\,n_D^2 + 2\,n_D^2 - 252\,b\,n_D^2 + 131\,b\,n_D + 448\,b^2\,n_D - 69\,n_D - 9 + 166\,b + 128\,b^2\big)$$

$$K_j = \Big((n_D - 1)\,(n_D + 3)^2\,\big(4\,b\,n_D^2 - 3\,n_D^2 + 12\,b\,n_D - 8\,n_D - 1 + 8\,b\big)\,(a - c)\Big) \Big/ \big(3\,n_D^5 - 17\,b\,n_D^5 + 16\,b^2\,n_D^5 - 130\,b\,n_D^4 + 128\,b^2\,n_D^4 + 23\,n_D^4 + 50\,n_D^3 + 400\,b^2\,n_D^3 - 330\,b\,n_D^3 + 608\,b^2\,n_D^2$$

$$+ 2 n_D^2 - 252 b n_D^2 + 131 b n_D + 448 b^2 n_D - 69 n_D - 9 + 166 b + 128 b^2)$$

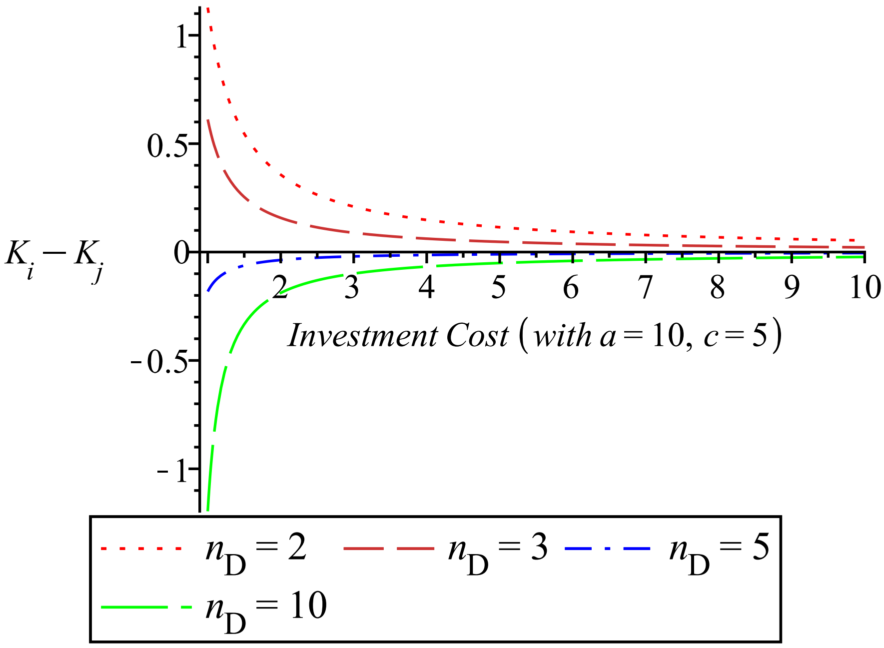
For example, with $n_D = 2$ we have:

$$K_i = \frac{(-725 + 2124 b)(-c + a)}{725 - 5844 b + 9216 b^2}$$

$$K_j = \frac{25(-29 + 48 b)(-c + a)}{725 - 5844 b + 9216 b^2}$$

Thus each firm's equilibrium investment is an increasing function of b, given our assumption that $a > c$, with the sensitivity greater for the integrated firm. As illustrated in Figure 2.2, we see that the integrated firm's investment exceeds that of the separated upstream firm for lower levels of downstream competition ($2 \leq n_D \leq 3$), but the reverse is true when downstream competition is more intense ($n_D \geq 5$). Hence it can be conjectured that the finding in Buehler and Schmutzler (2008) - that with asymmetric integration the integrated firm invests much more (downstream) than the separated firm so as to make it a tougher downstream competitor - is likely to be sensitive to their assumption of there being only two downstream firms.

Figure 2.2 - Difference between integrated (K_i) and separated (K_j) firm investment under asymmetric integration



Furthermore, as shown in Figures 2.3 and 2.4, equilibrium investment is decreasing in downstream competition intensity for the integrated firm, while the opposite is true for the separated upstream firm. On balance total investment under asymmetric integration proves to be increasing in n_D, though even with higher levels of downstream competition it falls well short of first best investment when b is low, as shown in Figure 2.5 (in a related context, Meade (2010) shows that the attainment of First Best requires greater than duopoly levels of upstream competition, though with just four upstream firms almost First Best levels of key variables can be obtained). These investment sensitivites in turn mean that marginal cost is increasing in n_D for the integrated firm, while decreasing for the separated upstream firm, with the consequence that the separated firm's marginal costs are higher than those of the integrated firm for lower levels of downstream competition, but lower when competition increases. These basic results mirror those for downstream output: it is decreasing in n_D for the integrated firm while increasing for the separated downstream firm, and increasing in n_D overall.

Figure 2.3 - Integrated firm investment decreasing in downstream competition

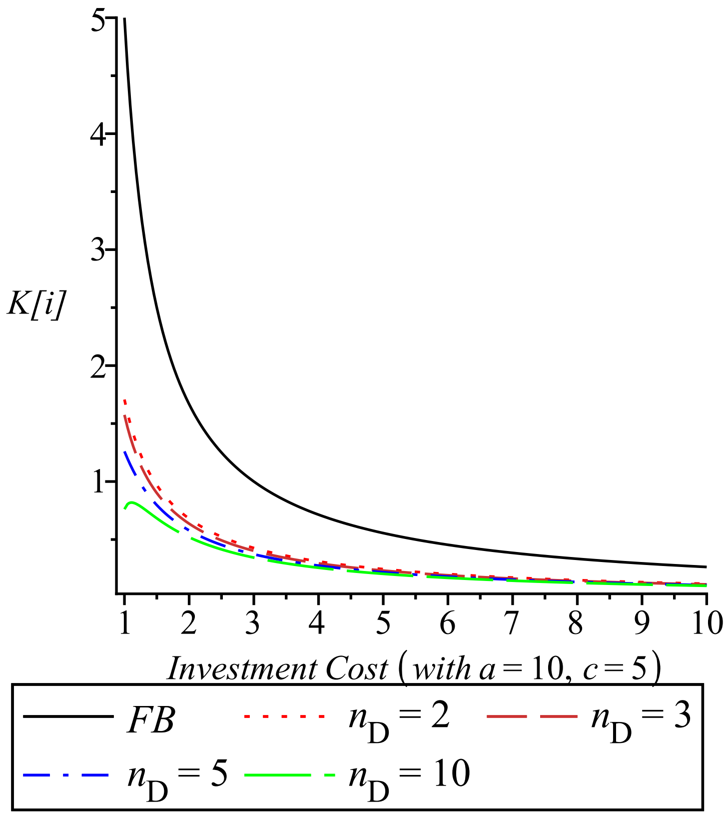


Figure 2.4 - Separated upstream firm investment increasing in downstream competition

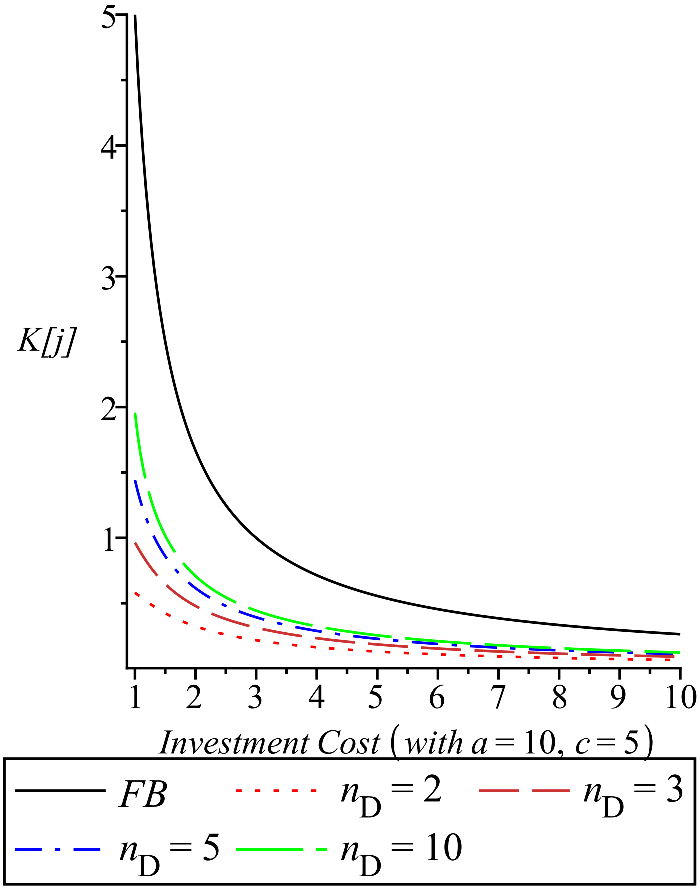
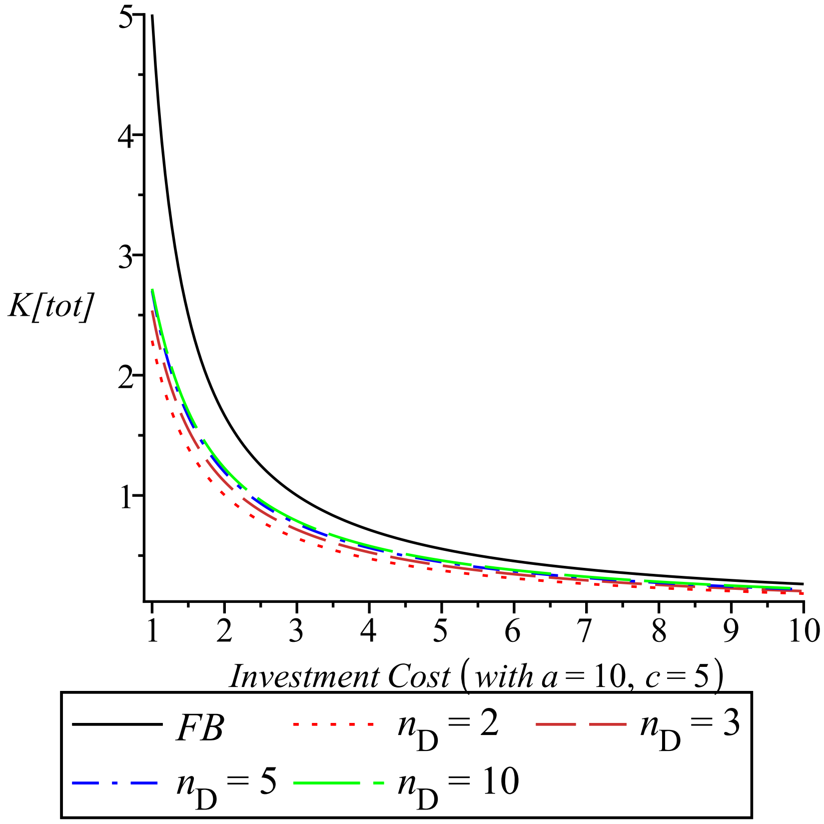
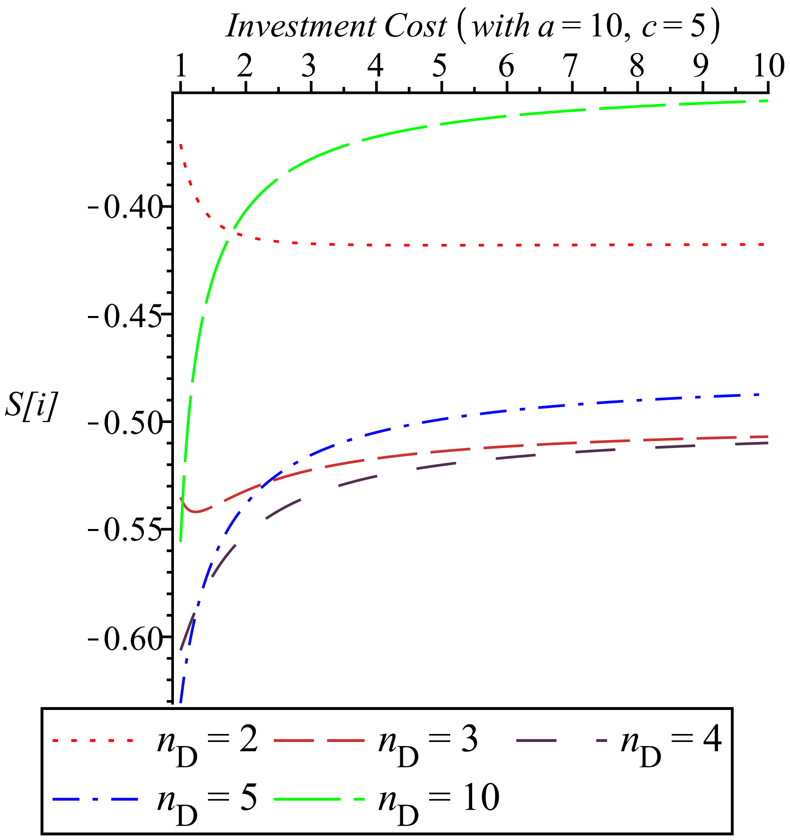


Figure 2.5 - Total investment under asymmetric integration versus First Best



Finally, of additional note in the case of asymmetric integration is that the equilibrium upstream output S_i of the integrated firm is unambiguously negative, as illustrated in Figure 2.6:

Figure 2.6 - Raising rivals' costs ($S_i < 0$) by integrated firm under asymmetric integration



The implication of this result is that under asymmetric integration the integrated firm finds it always most profitable to engage in a strategy of raising rivals' costs - that is, to purchase rather than sell on the upstream market, so as to increase P_U and hence the input cost of its separated downstream rival(s). The upstream firm uses the output purchased from its upstream rival to augment its own production in satisfying its own downstream demand y_i. This incentive is increasing in n_D for $2 \le n_D \le 4$, but decreasing (though never disappearing) for higher levels of downstream competition, and occurs despite the integrated firm being able to produce at a marginal cost that is lower than P_U (since Cournot competition in the upstream market ensures the upstream price exceeds production cost). As downstream competition intensifies, and the integrated firm's downstream market share shrinks, this strategy becomes too costly for the integrated firm, and so softens.

2.4 Case 2 - Maximal Integration

2.4.1 Sub-Case 2.1 - Balanced Full Integration ($n_D = m = 2$)

In this case we have just two, symmetric, vertically integrated firms. As such, there is no scope for raising the input costs of separated downstream rivals (as there are none). Hence there is also no scope for upstream market trade, as neither firm would wish to purchase at an upstream price in excess of their own marginal cost of production, since doing so would simply raise the cost of supplying their own downstream output. Thus in this sub-case, working backwards, we simply need to determine each firm's downstream output choice, and then their investment choice.

Downstream Sub-Stage

Integrated firms *i* and *l* each face an inverse demand function of the form $P_D = a - y_i - y_l$, and in this sub-stage - taking their rival's output and investment levels as given - choose their downstream output to maximise a simplified profit function of the form:

$$\Pi_{i,\,VI} = P_D y_i - (c - K_i)\, y_i - b\, K_i^2$$

This yields a reaction function of the form:

$$y_i(y_l, K_i) = \frac{1}{2}\, K_i + \frac{1}{2}\, a - \frac{1}{2}\, y_l - \frac{1}{2}\, c$$

which can be solved simultaneously for each firm to yield the subgame perfect equilibrium as follows:

$$y_i(K_i, K_l) = \frac{2}{3}\, K_i + \frac{1}{3}\, a - \frac{1}{3}\, K_l - \frac{1}{3}\, c$$

$$y_l(K_i, K_l) = \frac{2}{3}\, K_l + \frac{1}{3}\, a - \frac{1}{3}\, K_i - \frac{1}{3}\, c$$

$$P_D(K_i, K_l) = \frac{1}{3}\, a - \frac{1}{3}\, K_i - \frac{1}{3}\, K_l + \frac{2}{3}\, c$$

Thus, in contrast to the asymmetric integration case derived previously, each firm's downstream output is directly increasing in own investment and directly decreasing (to a lesser degree) in their rival's investment. Own investment reduces production costs and enables stronger competition, while a rival's investment affects own output indirectly through making the rival a stronger competitor.

Investment Sub-Stage

Given the above, and taking their rival's investment as given, each integrated firm now chooses its profit-maximising invesmtment level in terms of its rival's investment:

$$K_i(K_l) = -\frac{2\,K_l}{-4+9\,b} + \frac{2\,(a-c)}{-4+9\,b}$$

$$K_l(K_i) = -\frac{2\,K_i}{-4+9\,b} + \frac{2\,(a-c)}{-4+9\,b}$$

As for Case 1, our linear-Cournot setup once again results in investments being strategic substitutes for b sufficiently large. Simultaneous solution then yields our symmetric equilibrium investment level for this sub-case:

$$K_i = K_l = \frac{2\,(a-c)}{9\,b-2}$$

Observe that unlike for asymmetric integration, equilibrium investment is now declining in investment cost b. Also, investment is not a function of n_{D}, since we fixed $n_{\mathrm{D}} = 2$ in this sub-case (in Section 3.4.2 below we include this sub-case in our discussion of how changing n_{D} affects our variables of interest).

2.4.2 Sub-Case 2.2 - Unbalanced Full Integration ($n_{\mathrm{D}} > m = 2$)

Here we proceed along the same lines as in Case 1, except now we explicitly include a third firm (the second integrated firm) in the analysis of each sub-stage. This is necessary because the presence of at least one separated downstream firm means that our two integrated firms have cause to produce output in the upstream market, so as to supply the downstream demand of separated firms. It is also required because subgame equilibria in each sub-stage will now depend on the investment of each integrated firm, hence it is necessary to keep track of such investments separately in each sub-stage.

Downstream Sub-Stage

Thus, for example, an integrated firm i facing integrated rival l and $n_{\mathrm{D}} - 2$ symmetric separated rivals j faces downstream inverse demand $P_{\mathrm{D}} = a - (y_i + A_i)$ where in equilibrium, with symmetric firms, we have $A_i = y_l + (n_{\mathrm{D}} - 2)\,y_j$. With an integrated firm profit function of the same form as in Case 1, taking its rival's outputs and investment levels as given, integrated firm i chooses its profit-maximising downstream output level, from which as before we obtain its reaction function, but now in terms of both y_l and y_j. Repeating the procedure for firms l and j, and solving simultaneously, yields the subgame perfect equilibrium for this sub-stage:

$$y_i(K_i, K_l, P_U) = \frac{(n_{\mathrm{D}}-2)\,P_U}{n_{\mathrm{D}}+1} - \frac{K_l}{n_{\mathrm{D}}+1} + \frac{n_{\mathrm{D}}\,K_i}{n_{\mathrm{D}}+1} + \frac{c - c\,n_{\mathrm{D}} + a}{n_{\mathrm{D}}+1}$$

$$y_l(K_i, K_l, P_U) = \frac{(n_D - 2)\,P_U}{n_D + 1} + \frac{n_D\,K_l}{n_D + 1} - \frac{K_i}{n_D + 1} + \frac{c - c\,n_D + a}{n_D + 1}$$

$$y_j(K_i, K_l, P_U) =- \frac{3\,P_U}{n_D + 1} - \frac{K_l}{n_D + 1} - \frac{K_i}{n_D + 1} + \frac{a + 2\,c}{n_D + 1}$$

$$P_D(K_i, K_l, P_U) = \frac{(n_D - 2)\,P_U}{n_D + 1} - \frac{K_l}{n_D + 1} - \frac{K_i}{n_D + 1} + \frac{a + 2\,c}{n_D + 1}$$

In this sub-case we see that each integrated firm's downstream output is directly increasing in own investment and decreasing in its integrated rival's investment. Conversely, the one or more separated downstream firms' output is decreasing in both integrated firm's investment. Furthermore, while the integrated firms' outputs are increasing in P_U, which will also depend on both firms' investment, any separated downstream firms' outputs are decreasing in P_U, meaning indirect investment effects operate in the opposite direction for such separated firms.

Upstream Sub-Stage

Upstream demand derives from the $n_D - 2$ separated downstream firms' demands, which is supplied by the aggregate upstream output of our two integrated firms, $S_i + S_l$. Thus we have derived upstream inverse demand:

$$P_U(K_i, S_i, K_l, S_l) = \frac{1}{3}\,\frac{(-n_D + 2)\,K_l}{n_D - 2} + \frac{1}{3}\,\frac{(-n_D + 2)\,K_i}{n_D - 2} + \frac{1}{3}\,\frac{(-n_D - 1)\,S_l}{n_D - 2} + \frac{1}{3}\,\frac{(-n_D - 1)\,S_i}{n_D - 2} + \frac{1}{3}\,\frac{-2\,a + a\,n_D + 2\,c\,n_D - 4\,c}{n_D - 2}$$

Proceeding as in Case 1, but now with upstream output decisions being taken by two, symmetric integrated firms, we derive upstream market reaction functions for integrated firms *i* and *l* of the following form (for firm *l* just reverse indices *i* and *l*):

$$S_i(K_i, K_l, S_l) = \frac{1}{2}\,\frac{(-7 - n_D)\,S_l}{2\,n_D + 5} + \frac{1}{2}\,\frac{(-n_D + 2)\,K_l}{2\,n_D + 5} + \frac{1}{2}\,\frac{(2\,n_D - 4)\,K_i}{2\,n_D + 5} + \frac{1}{2}\,\frac{2\,c + a\,n_D - 2\,a - c\,n_D}{2\,n_D + 5}$$

These can then be solved for the subgame perfect equilibrium of the sub-stage (as above, reverse indices *i* and *l* to obtain the corresponding result for firm *l*):

$$S_i(K_i, K_l) = \frac{\left(-4\, n_D + 16 - 2\, n_D^2\right) K_l}{17 + 22\, n_D + 5\, n_D^2} + \frac{\left(3\, n_D - 18 + 3\, n_D^2\right) K_i}{17 + 22\, n_D + 5\, n_D^2}$$
$$+ \frac{-2\, a + c\, n_D + 2\, c - a\, n_D - c\, n_D^2 + a\, n_D^2}{17 + 22\, n_D + 5\, n_D^2}$$

$$P_U(K_i, K_l) = \frac{\left(-2\, n_D - 6\right) K_l}{5\, n_D + 17} + \frac{\left(-2\, n_D - 6\right) K_i}{5\, n_D + 17} + \frac{5\, a + 4\, c\, n_D + a\, n_D + 12\, c}{5\, n_D + 17}$$

Since $n_D > 2$ in this sub-case, it is easily shown that each integrated firm's upstream output is increasing in own investment and decreasing (to a lesser degree) in its rival's investment. Moreover, P_U is decreasing in both integrated firms' investment (to an equal degree). In contrast to asymmetric integration, in which separated downstream output (and hence upstream demand) is *decreasing* in integrated firm investment but increasing in separated upstream firm investment, here is it *increasing* in both integrated firms' investment, as can be seen by substituting for P_U in our downstream sub-stage result for y_j:

$$y_j(K_i, K_l) = \frac{K_l}{5\, n_D + 17} + \frac{K_i}{5\, n_D + 17} + \frac{-2\, c + 2\, a}{5\, n_D + 17}$$

Investment Sub-Stage

As for the full balanced integration sub-case, we once again find that each integrated firm's investment is a strategic substitue for the others, e.g. for firm *i*:

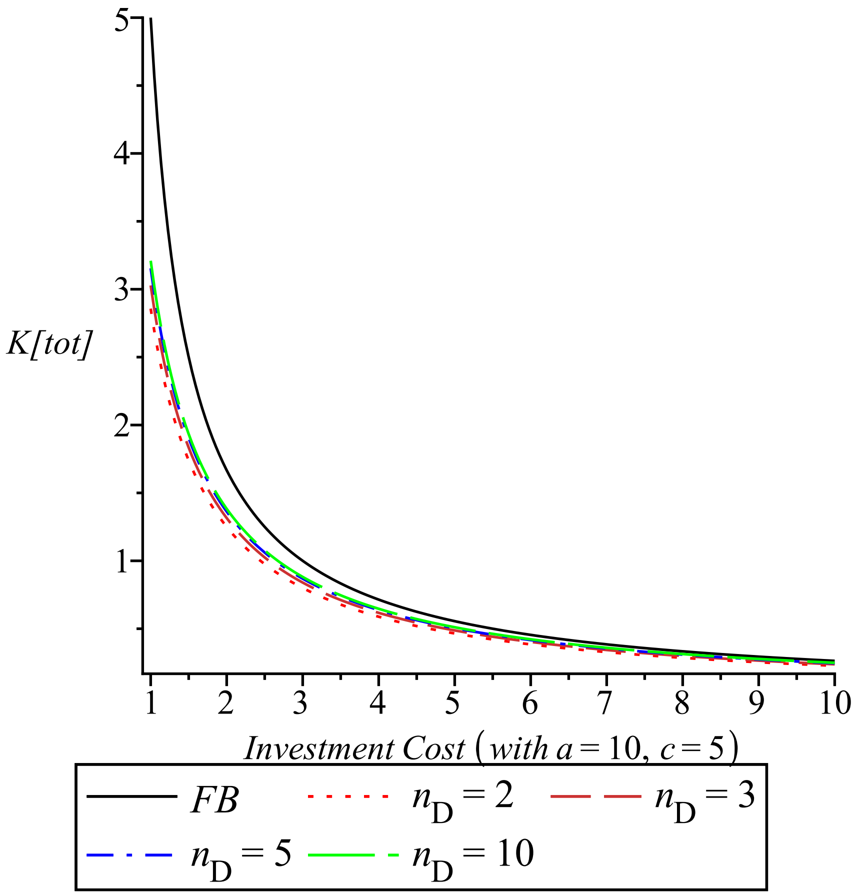
$$K_i(K_l) = \frac{\left(82 - 12\, n_D^3 - 74\, n_D^2 - 88\, n_D\right) K_l}{459\, b\, n_D - 195\, n_D + 54 + 195\, b\, n_D^2 + 25\, b\, n_D^3 + 289\, b - 18\, n_D^3 - 123\, n_D^2}$$
$$+ \frac{28\, a - 28\, c - 107\, c\, n_D + 49\, a\, n_D^2 + 107\, a\, n_D + 6\, a\, n_D^3 - 49\, c\, n_D^2 - 6\, c\, n_D^3}{459\, b\, n_D - 195\, n_D + 54 + 195\, b\, n_D^2 + 25\, b\, n_D^3 + 289\, b - 18\, n_D^3 - 123\, n_D^2}$$

and equilibrium investment is found in the manner as before to be:

$$K_i = K_l = \frac{\left(n_D + 4\right)\left(6\, n_D^2 + 25\, n_D + 7\right)(a - c)}{459\, b\, n_D + 195\, b\, n_D^2 + 25\, b\, n_D^3 + 289\, b - 28 - 107\, n_D - 49\, n_D^2 - 6\, n_D^3}$$

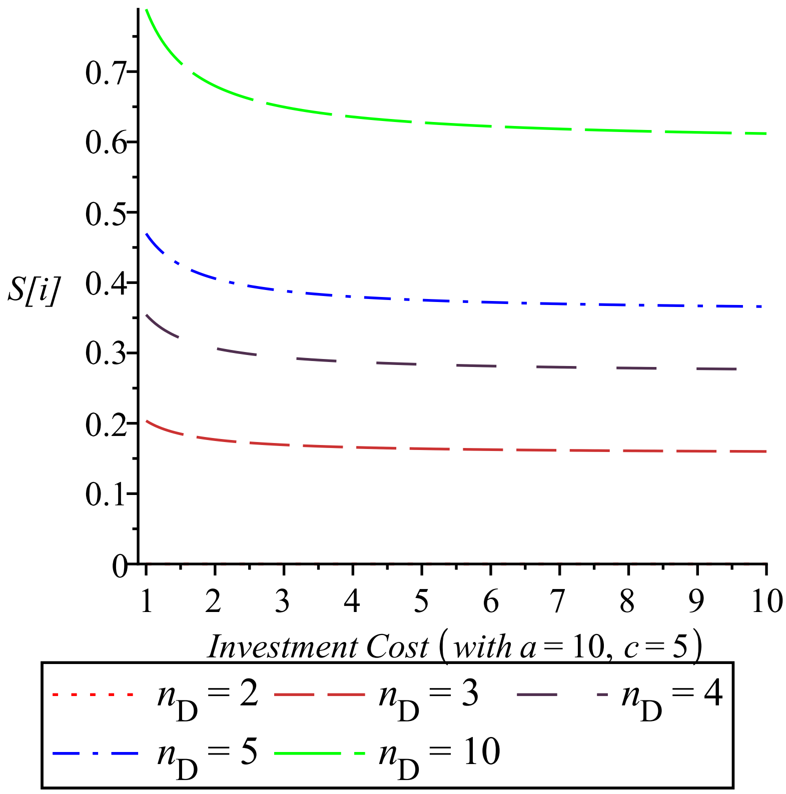
Combining this expression with that for equilibrium investment under balanced full integration, we find - as in Case 1 - that total investment falls short of First Best when b is low (to a lesser degree than Case 1), with investment increasing in the level of downstream competition. However, as illustrated in Figure 2.7, total investment is relatively insensitive to n_D, implying that marginal cost is also relatively invariant to changes in downstream competition in this case.

Figure 2.7 - Total investment under maximal integration (m = 2) versus First Best



Another notable feature of maximal integration is that despite the possibile presence of one or more separated downstream rivals, the symmetric integrated firms are unable to pursue the raising rivals' costs strategy revealed in Case 1. This is because no integrated firm can be buying in the upstream market, since its symmetric upstream rival would wish to do the same, and hence there is no net supply to the upstream market with which to satisfy such integrated firm purchases. In contrast, under asymmetric integration, the separated upstream firm - which does not share an integrated firm's gain from harming separated downstream firms - is the net seller upstream from which the integrated firm makes its purchases. The fact that upstream output of each integrated firm remains positive irrespective of the level of downstream competition is illustrated in Figure 2.8 (i.e. showing $S_i \geq 0$ for $2 \leq n_D \leq 10$).

Figure 2.8 - Absence of raising rivals' costs under maximal integration



2.5 Case 3 - Full Separation ($m = 0$)

Once again, we proceed much as in Case 1, with the key difference being that now we have only n_D separated firms at the downstream level, and two separated firms at the upstream level, thus simplifying the derivations at each sub-stage. Hence, here we provide only limited discussions of each of the sub-stages.

2.5.1 Downstream Sub-Stage

The subgame perfect equilibrium is:

$$y_j(P_U) = \frac{a - P_U}{n_D + 1}$$

$$P_D(P_U) = \frac{a + n_D P_U}{n_D + 1}$$

Notice that neither downstream output nor price depend directly on investment in this case, with upstream investment exerting only indirect impacts on either via upstream price.

2.5.2 Upstream Sub-Stage

Unlike in previous cases, here we find that derived upstream inverse demand is also not directly affected by investment, though it is indirectly via the separated upstream firms' outputs X_j and X_k:

$$P_U(X_j, X_k) = \frac{(-n_D - 1) X_k}{n_D} + \frac{(-n_D - 1) X_j}{n_D} + a$$

Reaction functions take the form (swap indices *j* and *k* for separated upstream firm *k*'s reaction function):

$$X_j(K_j, X_k) = \frac{1}{2} \frac{(-n_D - 1) X_k}{n_D + 1} + \frac{1}{2} \frac{n_D K_j}{n_D + 1} + \frac{1}{2} \frac{a n_D - n_D c}{n_D + 1}$$

The subgame perfect equilibrium is of the form (once again, reverse *j* and *k* to obtain the corresponding result for X_k):

$$X_j(K_j, K_k) = \frac{2}{3} \frac{n_D K_j}{n_D + 1} - \frac{1}{3} \frac{n_D K_k}{n_D + 1} + \frac{1}{3} \frac{n_D (a - c)}{n_D + 1}$$

$$P_U(K_j, K_k) = -\frac{1}{3} K_k - \frac{1}{3} K_j + \frac{1}{3} a + \frac{2}{3} c$$

As for unbalanced full integration, upstream outputs are increasing in own investment, but decreasing (to a lesser degree) in rival's investment. Upstream price is symmetrically decreasing in both separated upstream firm's investment, with the result that y_j is symmetrically increasing in each upstream firm's investment. Also as before, the linear-Cournot setup means investments are strategic substitutes.

2.5.3 Investment Sub-Stage

Proceeding as before we find each separated upstream firm's investment reaction function takes the form (reverse indices for firm *k*):

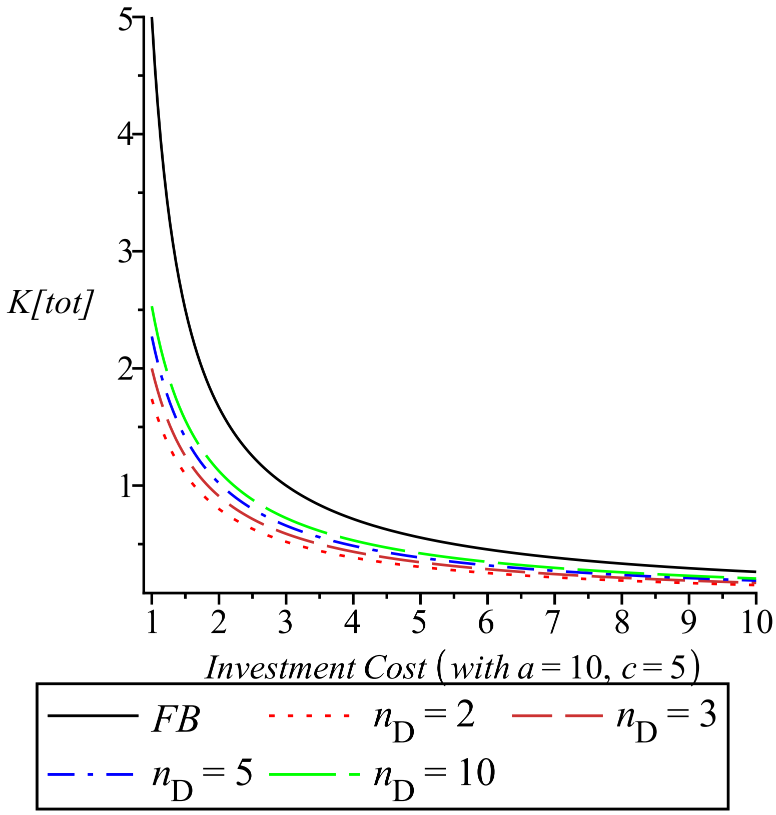
$$K_j(K_k) = -\frac{2 n_D K_k}{-4 n_D + 9 b n_D + 9 b} + \frac{2 n_D (a - c)}{-4 n_D + 9 b n_D + 9 b}$$

and in the subgame perfect equilibrium we have:

$$K_j = K_k = \frac{2 n_D (a - c)}{9 b n_D + 9 b - 2 n_D}$$

As shown in Firgure 2.9, and as for the other cases, we find that total investment is increasing in downstream competition, though still well short of first best when b is low (in fact, more so than in the other cases). Consequently, as before upstream marginal costs are decreasing in competition, and symmetrically for each upstream firm in this case. Unlike Case 1, but as in Case 2, equilibrium investment levels are decreasing in investment cost b.

Figure 2.9 - Total investment under total separation versus first best



2.6 Case 4 - Upstream Monopoly

In this case we change the level of upstream competition by assuming monopolistic rather than duopolistic upstream production, and examine how changing downstream competition affects investment. We consider integrated and separated monopoly as separate sub-cases.

2.6.1 Sub-Case 4.1 - Integrated Monopoly

Downstream Sub-Stage

Proceeding as in Case 1, we have one integrated firm and at least one separated downstream firm competing in quantities. For the integrated monopolist i the downstream reaction function is:

$$y_i(y_j, K_i) = \left(-\frac{1}{2}\, n_D + \frac{1}{2}\right) y_j + \frac{1}{2}\, K_i + \frac{1}{2}\, a - \frac{1}{2}\, c$$

while for a separated downstream firm j it is:

$$y_j(y_i, P_U) = \frac{a - y_i - P_U}{n_D}$$

The resulting subgame perfect equilibrium is:

$$y_i(K_i, P_U) = \frac{n_D K_i}{n_D + 1} + \frac{(n_D - 1) P_U}{n_D + 1} + \frac{-c\, n_D + a}{n_D + 1}$$

$$y_j(K_i, P_U) = -\frac{2 P_U}{n_D + 1} - \frac{K_i}{n_D + 1} + \frac{a + c}{n_D + 1}$$

$$P_D(K_i, P_U) = -\frac{K_i}{n_D + 1} + \frac{(n_D - 1) P_U}{n_D + 1} + \frac{a + c}{n_D + 1}$$

From the results of the next sub-stage, however, we will see that the result for y_j is moot, as the integrated monopolist endogenously withdraws from the upstream market and forecloses any separated downstream rivals.

Upstream Sub-Stage

In the absence of an upstream rival, the integrated monopolist faces the entire derived upstream inverse demand function:

$$P_U(S_i, K_i) = \frac{1}{2}\,\frac{(-n_D - 1) S_i}{n_D - 1} + \frac{1}{2}\,\frac{(1 - n_D) K_i}{n_D - 1} + \frac{1}{2}\,\frac{c\, n_D - c - a + a\, n_D}{n_D - 1}$$

Unlike in the upstreram duopoly case, however, the integrated monopolist is free to choose its profit-maximising level of upstream output S_i without fear that if it reduces its output to raise upstream price, a rival will increase upstream production to dampen the resulting increase. As a consequence, in this case we find the integrated monopolist's profit-maximising upstream output is $S_i = 0$, with the result that $y_j = 0$ for any separated downstream rivals (irrespective of the level of n_D). In other words, any separated downstream rivals are foreclosed by the integrated monopolist's endogenous withdrawal from the upstream market. The fact that $y_j = 0$ flows from the fact that by choosing $S_i = 0$, we find in equilibrium that $P_U = P_D$, with the result that separated downstream firms earn zero profits for any level of production. The integrated firm's downstream output remains positive, however, and is increasing in the monopolist's investment level:

$$y_i(K_i) = \frac{1}{2} K_i + \frac{1}{2} a - \frac{1}{2} c$$

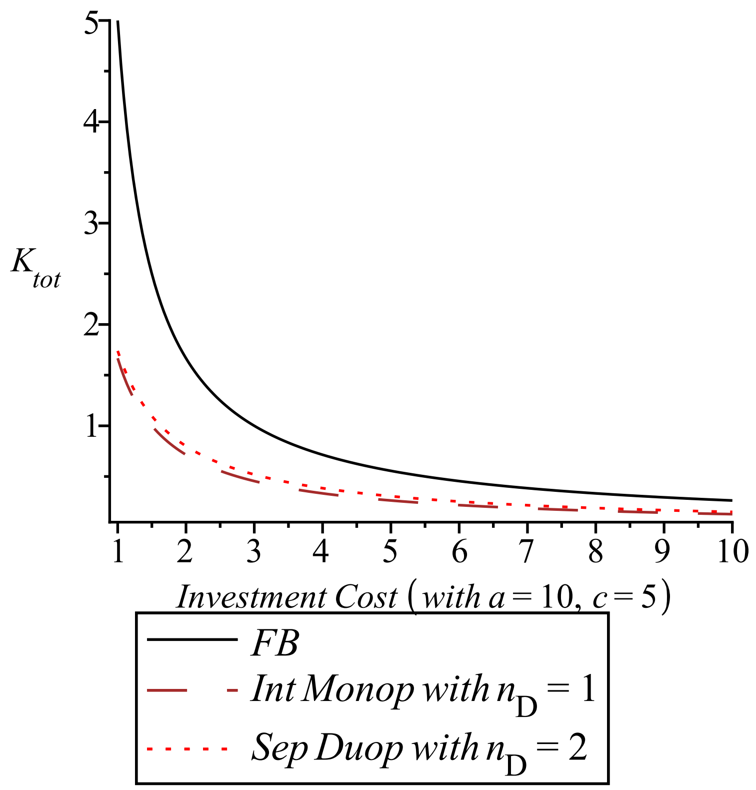
Investment Sub-Stage

Once again, the integrated monopolist *i* faces no rival upstream investor, so is free to choose its profit-maximising level of investment, which is:

$$K_i = \frac{a - c}{-1 + 4b}$$

As shown in Figure 2.10, the resulting level of investment falls well short of First Best. It is interesting to observe, however, as shown in the figure, that investment under integrated/foreclosed monopoly can be almost as high as that with greater competition at both upstream and downstream levels - in particular, as high as the total investment arising under separated duopolies at both upstream and downstream levels. We return to this point in Section 3.2.1, but simply observe here that to some extent at least vertical integration can substitute for greater competition at both industry levels (i.e. in terms of eliciting investment).

Figure 2.10 - Total investment under integrated/foreclosed monopoly and separated duopolies



2.6.2 Sub-Case 4.2 - Separated Monopoly

Here the approach is a simplified version of that in Case 3. We have just separated firms competing downstream, and one firm supplying upstream and choosing investment.

Downstream Sub-Stage

As in Case 3, we find that the subgame perfect equilibrium involves no direct impacts from investment, and indeed, that the results are identical to those in Case 3 (so they are not repeated here) . In contrast to sub-case 4.1, however, here there is no reason for the separated monopolist to foreclose the separated downstream firms, as it has no downstream presence and would earn zero profits by doing so. Hence y_j is non-zero in equilibrium for this sub-case.

Upstream Sub-Stage

As in Case 3, derived upstream inverse demand depends only on output, and not investment:

$$P_U(X_j) = \frac{(-n_D - 1)\, X_j}{n_D} + a$$

Similarly, as in the integrated monopoly case, the separated monopolist j is free to choose its profit-maximising upstream output level, resulting in the following subgame perfect equilibrium, with upstream output increasing, and upstream price decreasing, in investment:

$$X_j(K_j) = \frac{1}{2}\,\frac{(a - c + K_j)\, n_D}{n_D + 1}$$

$$P_U(K_j) = \frac{1}{2}\, a + \frac{1}{2}\, c - \frac{1}{2}\, K_j$$

As a consequence, as in Case 3 we once again find that y_j is increasing in investment, while P_D is decreasing in investment.

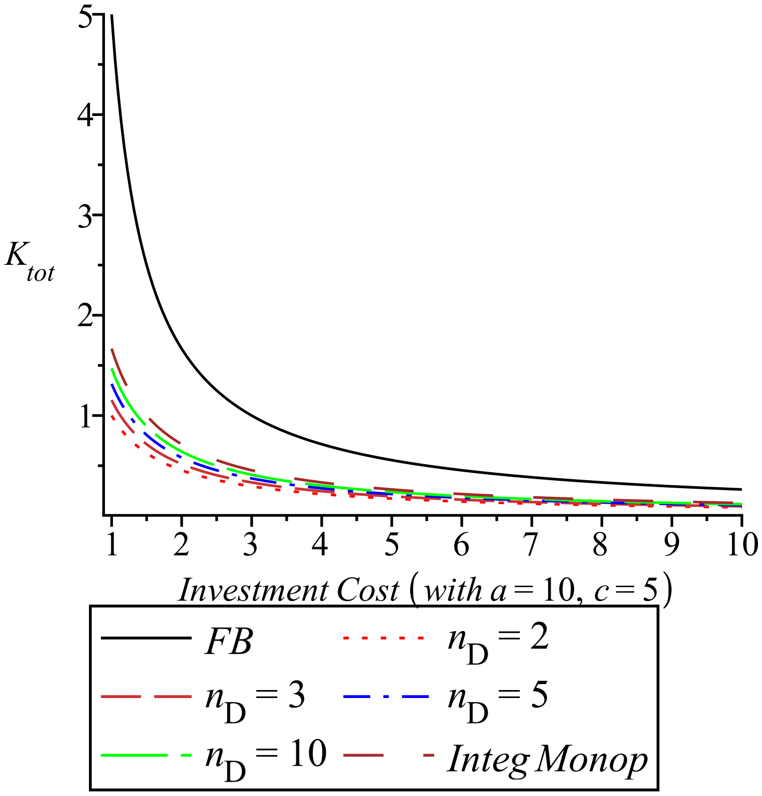
Investment Sub-Stage

As for the integrated monopolist, the separated monopolist j is free to choose its profit-maximising investment level without regard to any rival's investment:

$$K_j = \frac{n_D\,(a - c)}{-n_D + 4\, b\, n_D + 4\, b}$$

Thus we see that, unlike in the integrated monopoly case in which all downstream rivals are foreclosed, here investment is once again increasing in downstream competition. It is also well short of First Best when b is low - in fact more so than any other cases considered so far - as well as investment under integrated monopoly (at least for $n_D \leq 10$). This is illustrated in Figure 2.11.

Figure 2.11 - Investment under separated monopoly versus First Best



2.7 Forward Contracting with Successive Duopolies

The preceding cases have all been based on an industry structure in which there are, at most, separate upstream and downstream markets in which integrated and/or separated firms compete (in quantities). They have also allowed for $n_D \geq 2$ downstream firms, with either two or one upstream firm. Here we focus on the case of successive duopolies, with $m \in \{0, 1, 2\}$, and enhance the market structure by adding the opportunity for forward trading, in which integrated or separated upstream firms can compete in quantities to sell output to downstream firms prior to upstream and downstream market competition, but after investment choices have been made. This modified timing is as shown in Figure 2.12.

Figure 2.12 - Timing with Forward Trading

Investment Choices → Forward Market → Upstream Market → Downstream Market

In contrast to the approach taken in Allaz and Vila (1993), in which the buyers of forward quantities are financial speculators, here they are the separated downstream firm(s). We show that adding this forward trading possibility fundamentally alters the trading strategy of separated downstream firms. Here we provide details of the asymmetric integration case, but only summarise results for the balanced full integration and full separation cases, since the approach is largely as before.

2.7.1 Asymmetric Integration ($m = 1$)

Downstream Sub-Stage

Here the integrated firm *i*'s profit function writes as:

$$\Pi_{i,\, VI} = P_{\mathrm{D}} y_i + P_U S_i + P_f Z_i - (c - K_i)\,(y_i + S_i + Z_i) - b\,K_i^2$$

where P_f is the forward market price, and Z_i is the output quantity dsold forward by integrated firm *i* in the forward market. It can be shown that an integrated firm does not buy on the forward market in the downstream sub-stage, so we omit any such forward purchases here. Similarly, once we allow for separated downstream firms to purchase output forward as well as upstream, the profit function of separated downstream firm *j* differs to that in Case 1, namely:

$$\Pi_{j,\, \mathrm{D}} = P_{\mathrm{D}} y_j - P_U\,(y_j - Q_j) - P_f Q_j$$

where Q_j is the output purchased forward by firm *j*, and $y_j - Q_j$ represents firm *j*'s purchases on the upstream market. Proceeding as in Case 1 we find the following subgame perfect equilibrium:

$$y_i(K_i, P_U) = \frac{2}{3}\,K_i + \frac{1}{3}\,a + \frac{1}{3}\,P_U - \frac{2}{3}\,c$$

$$y_j(K_i, P_U) = \frac{1}{3}\,a - \frac{1}{3}\,K_i - \frac{2}{3}\,P_U + \frac{1}{3}\,c$$

$$P_{\mathrm{D}}(K_i, P_U) = \frac{1}{3}\,a - \frac{1}{3}\,K_i + \frac{1}{3}\,P_U + \frac{1}{3}\,c$$

Upstream Sub-Stage

Now that demand in the upstream market derives from the single, separated downstream firm's demand $y_j - Q_j$, we find that derived upstream inverse demand now depends on Q_j, as well as upstream outputs, and integrated firm investment:

$$P_U(K_i, S_i, X_j, Q_j) = -\frac{3}{2} S_i - \frac{3}{2} X_j + \frac{1}{2} a - \frac{1}{2} K_i + \frac{1}{2} c - \frac{3}{2} Q_j$$

The integrated firm *i*'s upstream reaction function takes the form:

$$S_i(X_j, Q_j) = -\frac{2}{5} X_j - \frac{2}{5} Q_j$$

The separated upstream firm *j*'s profit function now includes the possibility of forward sales Z_j, and so takes the form:

$$\Pi_{j,U} := P_U X_j + P_f Z_j - (c - K_j)(X_j + Z_j) - b K_j^2$$

Hence the upstream firm *j*'s reaction function is:

$$X_j(K_i, K_j, S_i, Q_j) = -\frac{1}{6} c - \frac{1}{2} S_i + \frac{1}{6} a - \frac{1}{6} K_i - \frac{1}{2} Q_j + \frac{1}{3} K_j$$

While the separated upstream firm's output is dependant on investment (increasing in own investment, and decreasing in its rival's), the integrated firm's output depends only on its upstream rival's output and downstream rival's forward purchases. The subgame perfect equilibrium can be shown to be:

$$S_i(K_i, K_j, Q_j) = \frac{1}{12} c - \frac{1}{6} K_j - \frac{1}{12} a + \frac{1}{12} K_i - \frac{1}{4} Q_j$$

$$X_j(K_i, K_j, Q_j) = -\frac{5}{24} c + \frac{5}{12} K_j + \frac{5}{24} a - \frac{5}{24} K_i - \frac{3}{8} Q_j$$

$$P_U(K_i, K_j, Q_j) = \frac{11}{16} c - \frac{3}{8} K_j + \frac{5}{16} a - \frac{5}{16} K_i - \frac{9}{16} Q_j$$

Forward Sub-Stage

In this sub-stage, as in the upstream sub-stage, demand is derived - in this case from the profit maximising choice of Q_j by the separated downstream firm. Using the profit function from above, this is:

$$Q_j(K_i, K_j, P_f) = \frac{13}{27} a - \frac{13}{27} K_i + \frac{19}{27} c - \frac{2}{9} K_j - \frac{32}{27} P_f$$

Derived forward inverse demand is given by equating this demand with aggregate forward output $Z_i + Z_j$, and solving for P_f:

$$P_f(K_i, K_j, Z_i, Z_j) = -\frac{27}{32} Z_i - \frac{27}{32} Z_j + \frac{13}{32} a - \frac{13}{32} K_i + \frac{19}{32} c - \frac{3}{16} K_j$$

The integrated firm *i* and separated upstream firm *j* compete in quantities to supply this derived inverse demand, resulting in the following forward reaction functions:

$$Z_i(K_i, K_j, Z_j) = \frac{7}{57} K_i + \frac{3}{19} a - \frac{3}{19} c + \frac{2}{57} K_j - \frac{7}{19} Z_j$$

$$Z_j(K_i, K_j, Z_i) = -\frac{11}{81} c + \frac{22}{81} K_j + \frac{11}{81} a - \frac{11}{81} K_i - \frac{1}{3} Z_i$$

and the following subgame perfect equilibrium:

$$Z_i(K_i, K_j) = \frac{133}{675} K_i + \frac{83}{675} a - \frac{83}{675} c - \frac{2}{27} K_j$$

$$Z_j(K_i, K_j) = -\frac{64}{675} c + \frac{8}{27} K_j + \frac{64}{675} a - \frac{136}{675} K_i$$

$$P_f(K_i, K_j) = -\frac{161}{400} K_i + \frac{89}{400} a + \frac{311}{400} c - \frac{3}{8} K_j$$

$$Q_j(K_i, K_j) = \frac{49}{225} a - \frac{1}{225} K_i - \frac{49}{225} c + \frac{2}{9} K_j$$

Investment Sub-Stage

As in Case 1, the two firms choose their profit-maximising investment level given the investment choice of their rival, yielding the following reaction funrctions:

$$K_i(K_j) = \frac{32751\, a - 32751\, c - 33850\, K_j}{-66601 + 135000\, b}$$

$$K_j(K_i) = \frac{1}{5}\, \frac{-34\, c + 34\, a - 61\, K_i}{-19 + 54\, b}$$

and subgame perfect equilibrium:

$$K_i = \frac{(-852449 + 1768554\, b)\,(-c + a)}{852449 - 6161454\, b + 7290000\, b^2}$$

$$K_j = \frac{(-852449 + 918000\, b)\,(-c + a)}{852449 - 6161454\, b + 7290000\, b^2}$$

As in Case 1 we find that investment is increasing in investment cost b under asymmetric integration. Equilibrium forward quantities can be shown to be:

$$Q_j = \frac{24\, b\,(-47737 + 66150\, b)\,(-c + a)}{852449 - 6161454\, b + 7290000\, b^2}$$

$$Z_i = \frac{40\, b\,(-11929 + 22410\, b)\,(-c + a)}{852449 - 6161454\, b + 7290000\, b^2}$$

$$Z_j = \frac{16\, b\,(-41783 + 43200\, b)\,(-c + a)}{852449 - 6161454\, b + 7290000\, b^2}$$

2.7.2 Balanced Full Integration, Full Separation, and Discussion

Balanced full integration remains the same as in Case 2, since just as symmetric integrated firms do not trade upstream, they have no reason to trade forward either. Thus equilibrium investment is as in Section 2.4.1.

In the case of full separation, however, modifications are required. Firstly, both separated downstream firms i and j now purchase forward (quantities Q_i and Q_j respectively), which translates into derived upstream and forward demands. Secondly, we have symmetric upstream firms i and j supplying forward (quantities Z_i and Z_j respectively). Thus we find equilibrium investment levels to be:

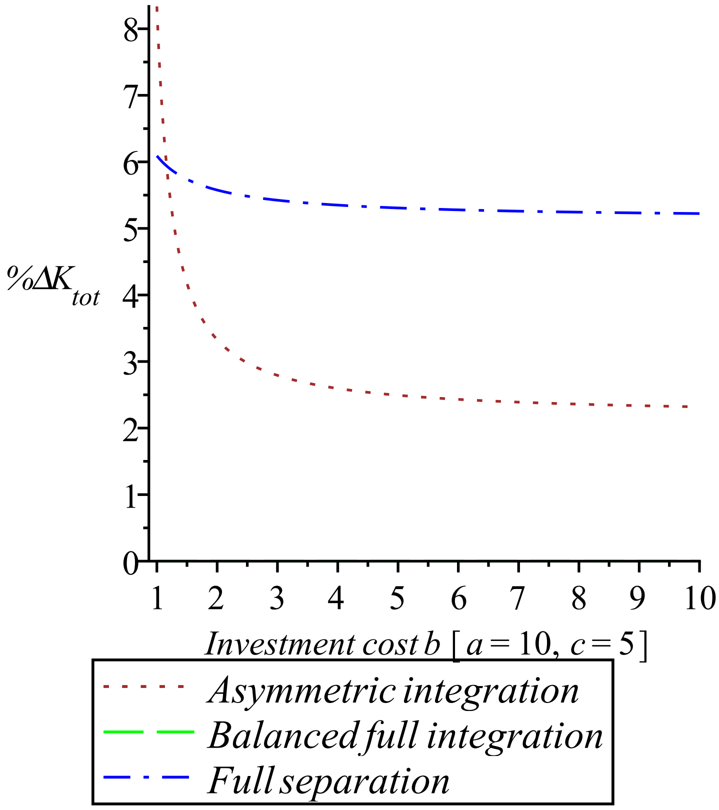
$$K_i = K_j = \frac{820424\,(a - c)}{5267025\, b - 820424}$$

and equilibrium forward quantities:

$$Q_i = Q_j = Z_i = Z_j = \frac{688500\, b\,(a - c)}{5267025\, b - 820424}$$

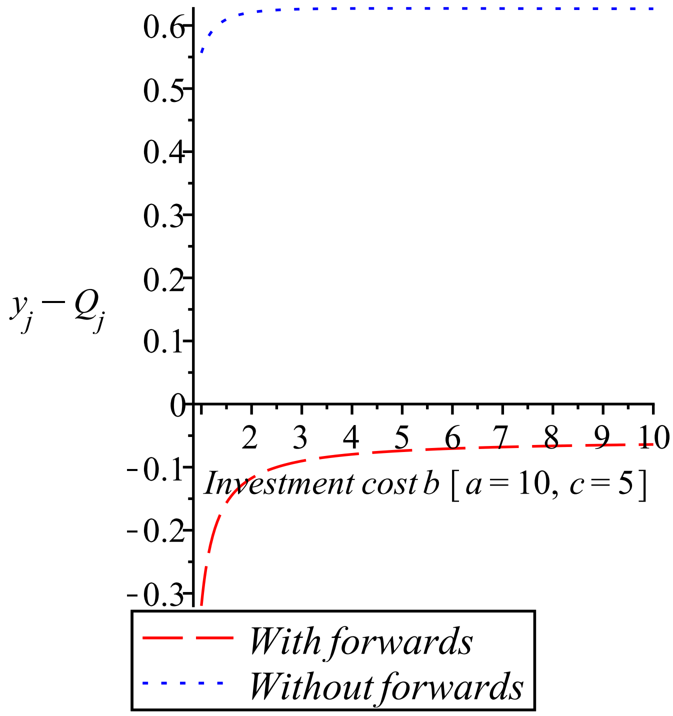
As shown in Figure 2.13, forward trading does not change investment under balanced full integration, and does not significantly alter investment for the cases of asymmetric integration or full separation either.

Figure 2.13 - Percentage change in investment with forward trading under successive oligopolies (m ∈ {0, 1, 2})



This conclusion is to be contrasted with a much more striking finding in relation to how forward contracting affects strategic behaviour by separated downstream and integrated firms. As shown in Figure 2.14, in the case of asymmetric integration, the addition of forward trading fundamentally alters separated downstream firm behaviour in the upstream market, with upstream purchases in the absence of forward trading being transformed into upstream *sales* by separated downstream firms.

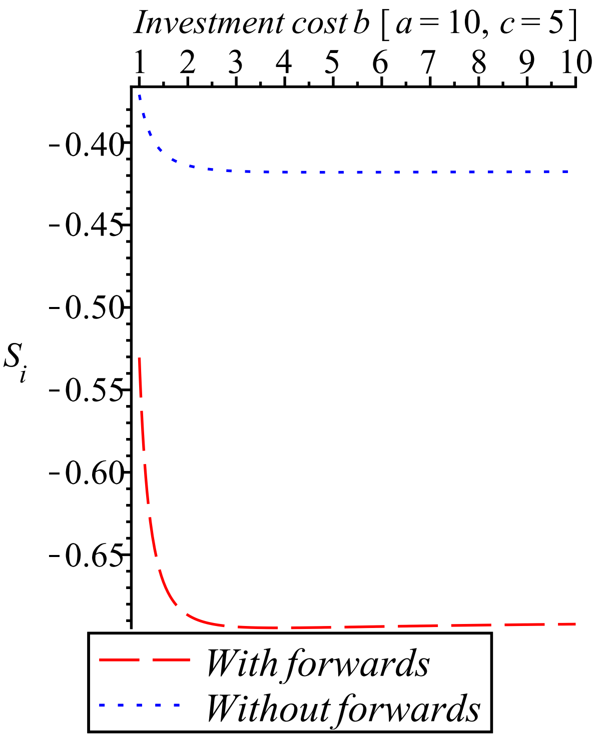
Figure 2.14 - Forward trading transforms separated downstream firm into upstream seller under asymmetric integration



This striking result is made possible due to the ability of the separated downstream firm to purchase more in the forward market than it needs to supply its own downstream output, and then to sell the excess purchases on the upstream market. Meade (2010) derives a similar result in a related context, and calls this strategy of separated downstream firms an "over-buy and recycle" strategy.

As in Case 1, the integrated firm purchases on the upstream market so as to raise the input cost of the separated downstream firm (indeed, to a greater degree with forward trading), which is illustrated in Figure 2.15. Meade (2010) shows in a related context that this arises not just under asymmetric integration, but also in the case of unbalanced full integration. This is in contrast to Sub-case 2.2 above, since absent forward trading in that case it was not possible for symmetric integrated firms to make upstream purchases, as separated downstream firms could not forward buy more than their downstream output quantities. As for Case 2, however, since symmetrically integrated firms do not buy forward and would have little reason to do so (just so they could resell such purchases to themselves), raising rivals costs does not arise under balanced full integration even with the possibility of forward trading.

Figure 2.15 - Forward trading reinforces raising rival's cost strategy of integrated firm under asymmetric integration



Since the separated downstream firm is now a seller on the upstream market, this means it actually gains from the integrated firm's tougher strategy. With forwards, however, the upstream price in fact falls, as does downstream price, and the separated upstream firm's output - thus, with forward trading both integrated and separated downstream firms engage in profit-preservation rather than outright profit-enhancement. In contrast, the separated downstream firm's output rises.

Thus, with forward trading under asymmetric integration, we find that the integrated and downstream separated firms enjoy roughly stable and significantly increased profits respectively, at the expense of the separated upstream firm (whose output is displaced by the separated downstream firm's upstream). Consumers gain from lower prices and increased downstream output, and since investment is largely unchanged by forward contracting, this translates into improved consumer surplus and total surplus.

2.8 Summary of Preliminary Findings

The main results of the above discussions are summarised in the following lemmas (based on our reference scenario, with $a = 10$ and $c = 5$):

Lemma 1 - Investment

1.1 Integrated or separated upstream firms' investment choices are strategic substitutes.

1.2 Total investment is increasing in n_D, and less than First Best investment (particularly when *b is low), irrespective of the degree of vertical integration.*

1.3 Integrated or separated upstream firm investment is increasing in n_D, except for integrated firms under asymmetric integration, for whom investment is decreasing in n_D.

1.4 Under asymmetric integration, investment is higher for the integrated firm than for the separated upstream firm for $n_D \in \{2, 3, 4\}$, with the reverse true for higher levels of n_D.

The fact that total investment is found to be less than First Best investment is striking because it runs counter to earlier research findings (e.g. Shapiro (1989)) that in linear-Cournot investment models an investing firm has an incentive to over-invest (whereas under price competition the incentive is to under-invest). Also, the result that Beuhler and Schmutzler's finding - that an integrated firm invests much more than its separated rival under asymmetric integration - is sensitive to their assumption of downstream duopoly echoes similar findings that higher levels of downstream competition can overturn conclusions in Cournot models based on weaker competition (e.g. Hackner (2000), Gaudet and Van Long (1996)).

Lemma 2 - Forward Trading under Successive Duopoly

2.1 Forward trading does not change investment under balanced full integration, and results in only small increases in investment under asymmetric integration and full separation.

2.2 Under asymmetric integration, forward trading causes integrated firms to more strongly pursue a strategy of raising rivals' costs (i.e. to make larger upstream purchases), and separated downstream firms to pursue an "over-buy and recycle" strategy (i.e. to use forward purchases to enable them to become upstream sellers rather than upstream buyers).

3. Results

In Section 1 the question we set out to address was how industry vertical structure, forward contracting and competition interact to affect investment and welfare in an imperfectly competitive industries such as electricity and gas. In this section we use the results from Section 2 to provide our response. We begin by considering the interactions between vertical integration and competition, and then look at the interactions between vertical integration and forward trading. We also examine two special cases. The first develops the observation made in Section 2.6.1 that integrated/foreclosed monopoly can be favourably compared with fully separated successive duopoly - indeed, here we show it can in fact be superior. The second applies some of the preceding analysis to a situation analogous to that of the French state-owned electricity company, EDF. Specifically, we consider how a regulated upstream price might be set so that an integrated monopoly that should otherwise wish to foreclose its rivals might accommodate a downstream rival in a welfare-enhancing way.

3.1 Vertical Integration and Competition

3.1.1 Investment

Based on Figures 3.1 and 3.2 below (and intermediate cases not shown) we have the following investment proposition for our reference scenario in which $a = 10$ and $c = 5$, and considering $2 \leq n_D \leq 10$:

Proposition 1 - Investment

1.1 Except for the case of Integrated/foreclosed monopoly, in which K_{tot} is unaffected by n_D, K_{tot} is increasing in n_D for the three upstream duopoly cases considered (Asymmetric integration, Maximal integration and Full separation), as well as for Separated monopoly.

1.2 Ranking these cases in terms of highest K_{tot} to lowest, we have: First Best > Maximal integration > Asymmetric integration > Full separation > Integrated monopoly > Separated monopoly.

Figure 3.1 - K_{tot} across cases

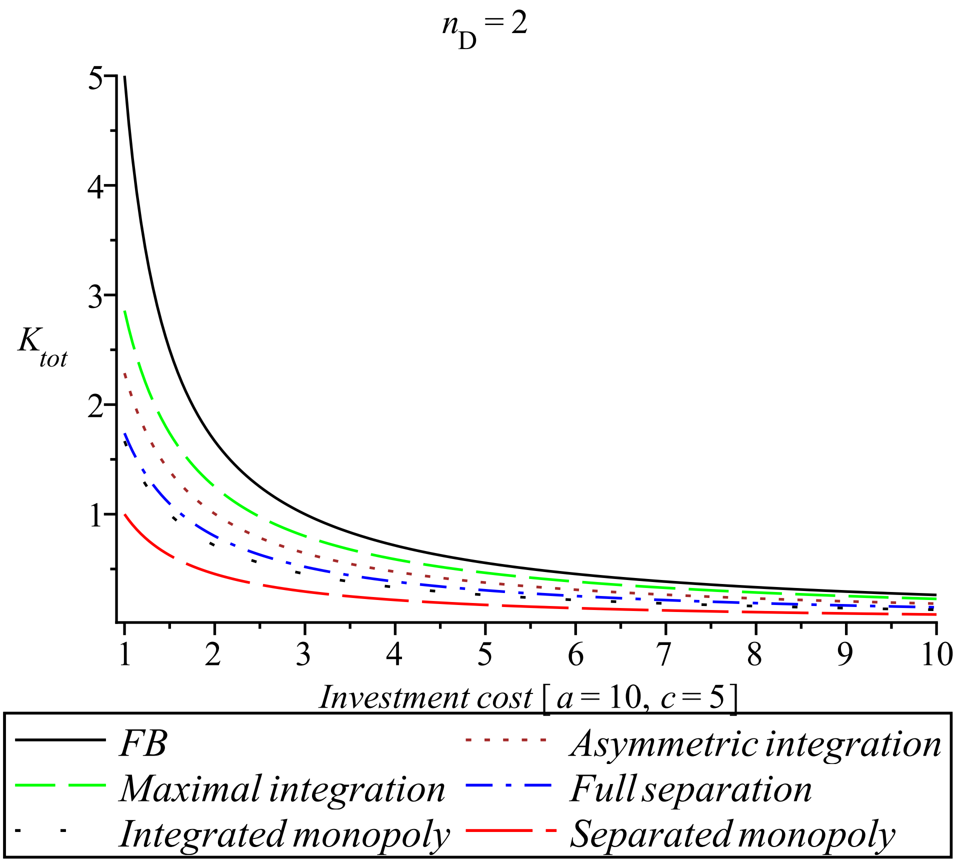
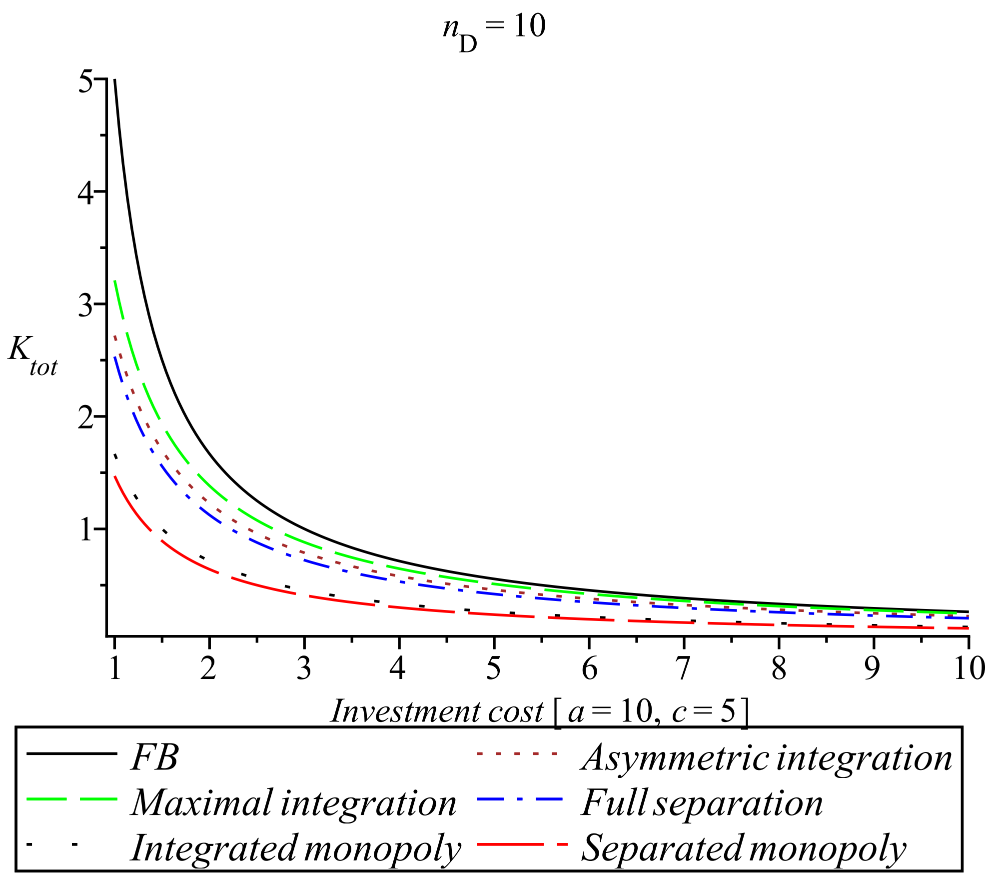


Figure 3.2 - K_{tot} across cases



Observe that since total investment under integrated/foreclosed monopoly is not affected by changes in downstream competition, while total investment in this case is almost at the same level as total investment under separated duopoly when $n_D = 2$, the gap between these two cases increases as n_D rises. Furthermore, as n_D rises, total investment under separated monopoly rises toward that under integrated/foreclosed monopoly. In all cases considered, however - indeed for $n_D \leq 25$ when comparing the two monopoly cases - the rankings indicated in Proposition 1 are preserved.

3.1.2 Welfare

Based on Figures 3.3 and 3.4 below (and intermediate cases not shown) we have the following welfare (i.e. total surplus) proposition for our reference scenario in which $a = 10$ and $c = 5$, and considering $2 \leq n_D \leq 10$:

Proposition 2 - Welfare

2.1 Except for the case of integrated/foreclosed monopoly, in which welfare is unaffected by n_D, welfare is increasing in n_D for the three upstream duopoly cases considered (Asymmetric Integration, Maximal integration and Full separation), as well as for Separated monopoly.

2.2 Provided b is not very low, the following welfare rankings are robust to increases in n_D:

First Best > Maximal integration > Asymmetric integration > Full separation > Separated *monopoly.*

2.3 For $n_D \in \{2, 3\}$ and provided b is not very low, the welfare ranking for the remaining cases has Asymmetric integration > Integrated monopoly > Full separation, while for higher n_D we have that Asymmetric integration > Full separation > Integrated monopoly.

Figure 3.3 - Welfare (i.e. total surplus) across cases

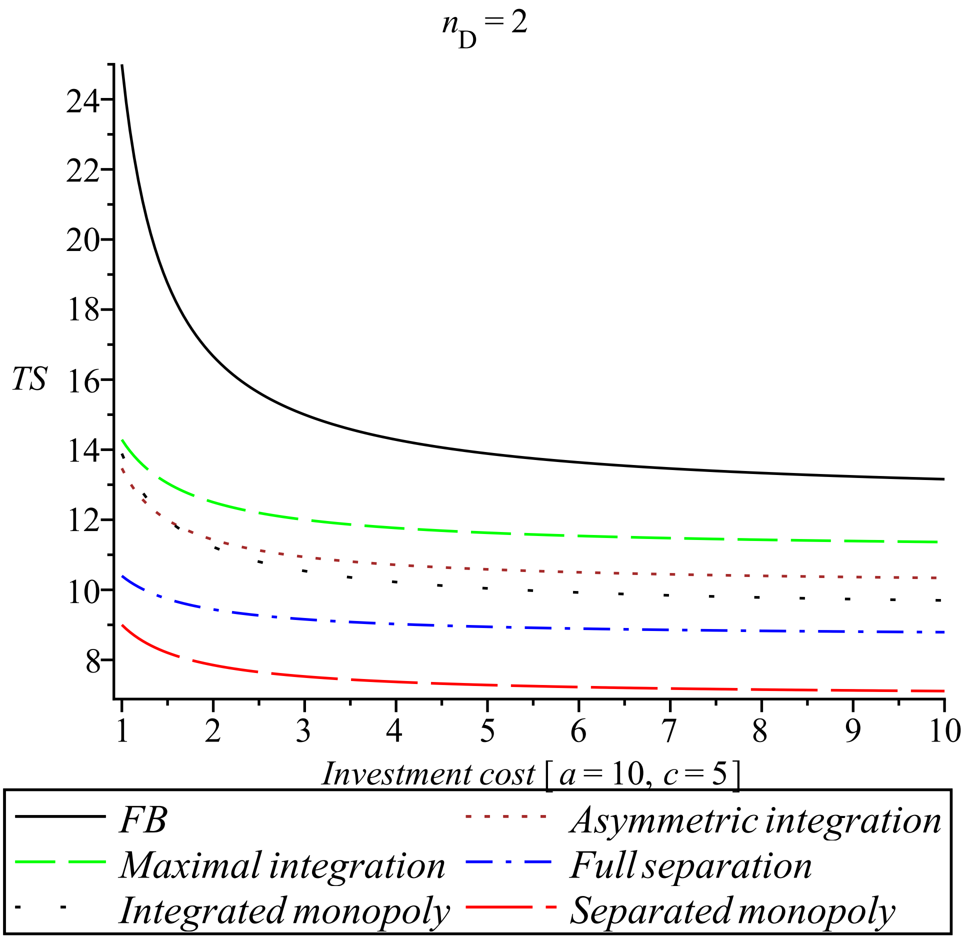
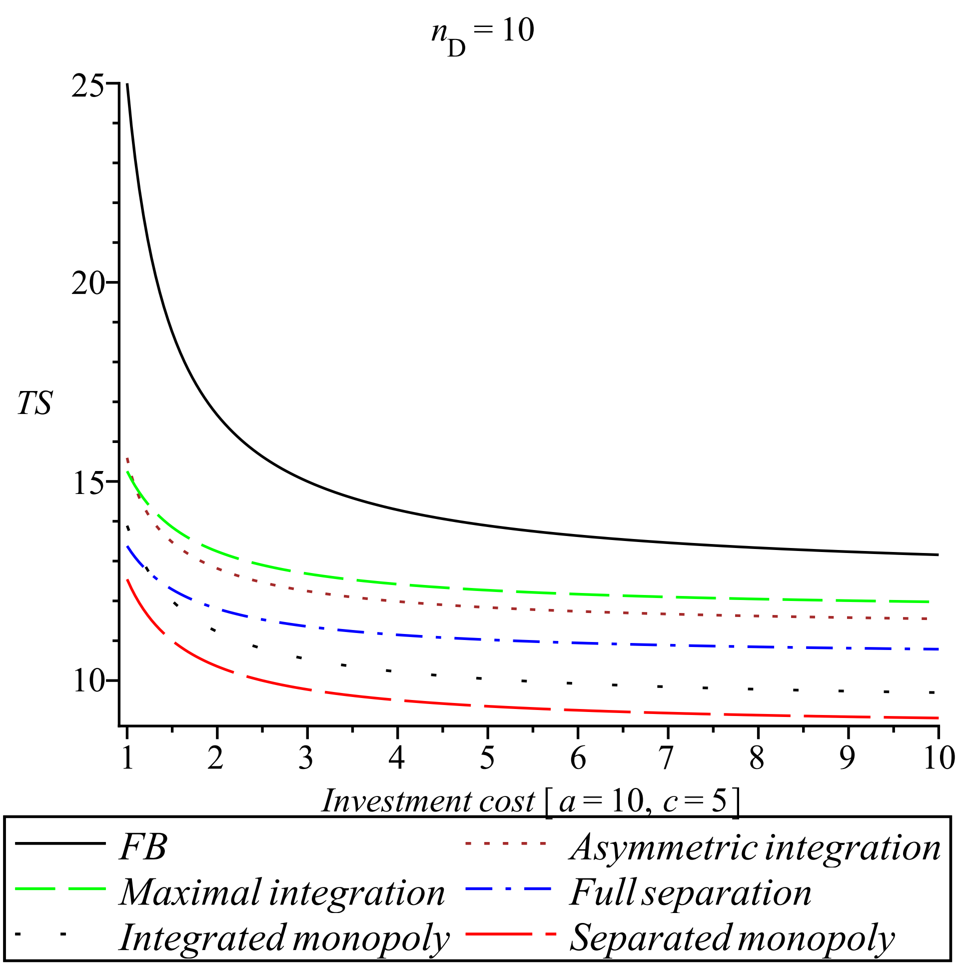


Figure 3.4 - Welfare across cases



Thus we find that welfare and investment rankings are not identical for the scenarios we consider. Furthermore, while the investment rankings are robust to changes in downstream competition, we find that the n_D-insensitive welfare under integrated/foreclosed monopoly is superior to that under separated duopoly for low levels of downstream competition. Conversely, it is either superior or inferior to separated duopoly depending on the level of investment cost for intermediate levels of downstream competition (e.g. $n_D = 4$, figure not shown), and inferior to separated duopoly for higher levels of downstream competition.

This latter result is of note, since it indicates that to some extent vertical integration - even in a case exhibiting the two apparently undesirable features of monopoly and foreclosure - can substitute for simultaneous increases in both upstream and downstream competition, if those increases do not involve vertical integration. Thus, for example, if policymakers contemplating liberalisation in a monopolised electricity or gas industry were contemplating the breakup of that monopoly into separated upstream and downstream duopolies, in welfare terms this step could be retrograde. Either they should consider allowing integrated duopolies instead, or aim for higher levels of competition at both industry levels (i.e. more than duopoly upstream, and/or - depending on the level of investment cost - more than around three or four firms downstream). Behind this finding is the fact that vertical integration is one way of resolving vertical coordination problems in industries with successive imperfectly-competitive stages. Resolving this problem reduces the double marginalisation that occurs in such industry structures. So too does increasing competition at either or both of the industry levels (since, under Cournot competition, firms' margins at any industry level are decreasing in the number of competing firms in that level). Our analysis shows that in welfare terms, to some extent at least, vertical integration and competition are substitutable.

Furthermore, just as foreclosure under intergated monopoly is not necessarily worse in welfare terms than separation with higher levels of upstream and downstream competition without foreclosure, we can make similar observations regarding the apparently anti-competitive strategies of integrated firms. In particular, we identified in Section 2 that integrated firms buy rather than sell on the upstream market in the case of asymmetric integration, so as to raise the input cost of its separated downstream rival. Furthermore, under balanced full integration the integrated firms have no reason to trade in the upstream market, implying foreclosure of that market. However, our welfare rankings show that both scenarios are to be preferred to full separation, even though that scenario has the apparent attraction of neither forclosure nor raising rivals' cost strategies. This too presents reason for policymakers, regulators or competition authorities to exercise caution when addressing any apparently anti-competitive behaviours, as in welfare terms the alternatives may be worse. Indeed, one of the lessons of this analysis is that even a partial resolution of vertical coordination problems via vertical integration can produce sufficient gains to outweigh the disbenefits of such apparently anti-competitive practices.

3.2 Vertical Integration and Forward Trading

Based on Figure 2.13 above, and Figures 3.5. and 3.6 below (and other figures not shown), we have the following forward trading proposition for our reference scenario in which $a = 10$ and $c = 5$, and considering $n_D = 2$:

Proposition 3 - Forward Trading

3.1 Forward trading does not change either investment or welfare in the case of Balanced full integration..

3.2 The introduction of forward trading leads to both investment and welfare gains under both Asymmetric integration and Full separation, with the gains strongest under Symmetric separation.

3.3 A key source of the welfare gains from forward trading is the decline in downstream prices that results from its introduction, with the declines greater under Full separation than under Asymmetric integration.

Figure 3.5 - Percentage change in total surplus from introduction of forward trading

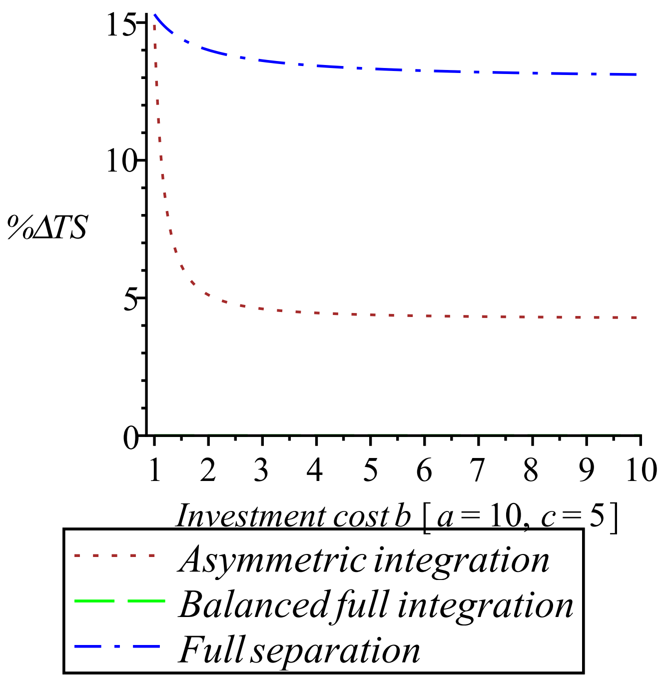
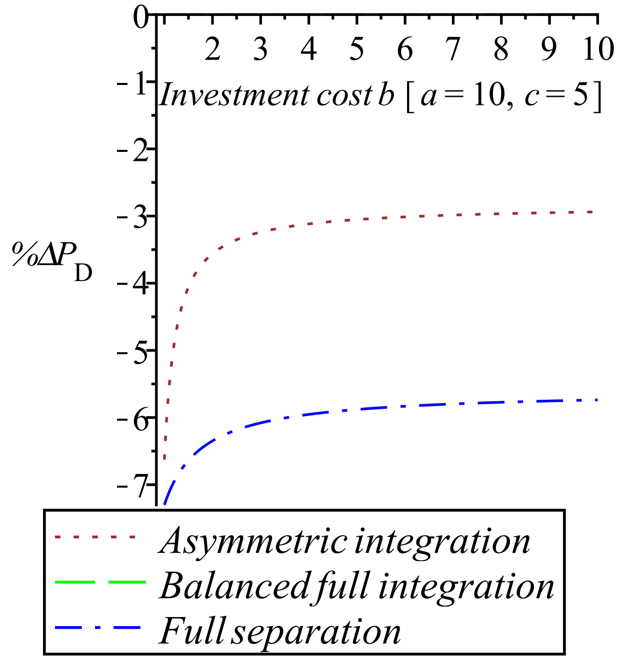


Figure 3.6 - Percentage change in downsteam price from introduction of forward trading



As identified in Section 2, the introduction of forward trading in our institutional setup, under asymmetric integration, provides separated downstream firms with an additional strategy that helps to preserve their profits in the face of an integrated rival's raising rivals' cost strategy. They choose to buy more forward than they require for their own downsteeam output, and sell the surplus on the upstream market. While the integrated firm's raising rivals' cost strategy serves to support upstream price, with forward trading that price in fact falls, as does the output of a separated upstream firm (meaning that firm's profits also fall).

Additionally, as in Allaz and Vila (1993), integrated or separated upstream firms (other than under full balanced integration) choose to sell forward even though it causes them to compete more aggressively in the upstream market. In effect, they confront a prisoner's dillemma, in that if they fail to sell forward then in the presence of an upstream rival that does sell forward they risk losing market share in both the forward and upstream markets. Thus they pre-commit to forward sales, leaving them with a smaller residual demand in the upstream market. Separated downstream firms and consumers are the chief beneficiaries.

We note that under full separation there is no incentive for separated upstream firms to purchase on the upstream market (since they do not benefit from raising downstream rival's costs, as they do not compete downstream). Hence in this case separated downstream firms have strictly positive upstream market demands ($y_j - Q_j$), though with the introduction of forward trading this demand is much reduced. Their upstream market demand falls, as they can now purchase some of their supplies in the forward market, and benefit by doing so through pre-committing their upstream suppliers and thereby constraining upstream market prices.

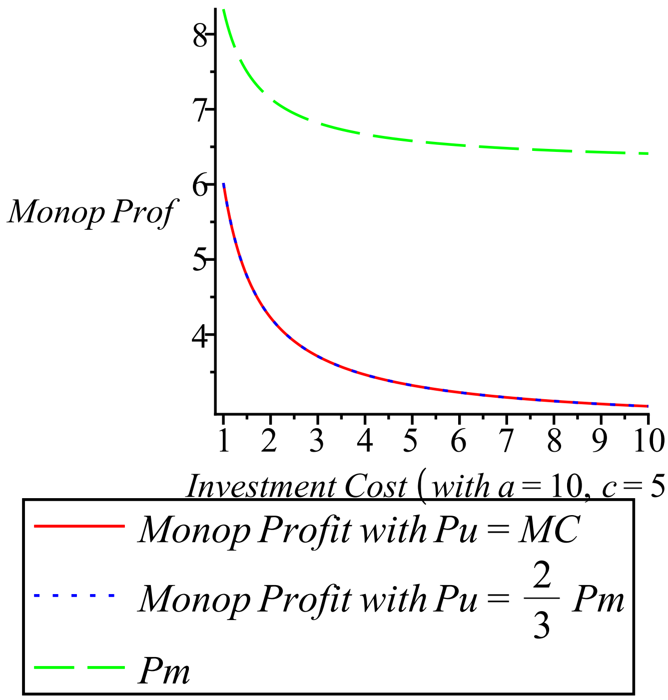
3.3 Special Case - Regulated Access Pricing under Integrated Monopoly - "EDF Scenario"

As shown in Section 2, an integrated monopolist - if left to its own devices - would choose to foreclose any downstream rivals. In doing so it choses to supply no output in the upstream market, with the result that the implied upstream price is the same as the resulting downstream price. Consequently no downstream rivals can profitably supply the downstream market at this upstream price.

It is not unusual, however, for integrated monopolists - e.g. in electricity sectors - to be required to supply a downstream entrant, as downstream electricity markets become liberalised even when it it technically or politically difficult to liberalise upstream industry arrangements. Such a scenario reflects that in France, where successive EU directives require the country to make its electricity sector more open to competition, but for political or other reasons France has limited the extent to which upstream competition has been implemented. A natural question, in such a scenario, is how to price the upstream supply to any new downstream rival of the incumbent, integrated monopoly? Since the incumbent would choose an unprofitable price, a regulated upstream price is one possible solution. The consequent question is, therefore, how to set such a regulated price? The incumbent would naturally favour the downstream price it enjoys under foreclosed monopoly, while an entrant might optimistically vie for the upstream price to be set at marginal cost of upstream production (which the incumbent would oppose since that would not allow for recovery of fixed costs).

As a special case of our preceding analysis we compared two scenarios - one in which upstream price is set by regulation at marginal cost ($P_U^R = c - K$), and another in which it is set at some proportion $\beta \in [0, 1]$ of the downstream price that would otherwise be chosen by the integrated/foreclosed monopolist ($P_U^R = \beta P_U^M$). As shown in Figure 3.7, in our reference scenario with $a = 10$ and $c = 5$, and when $\beta = \frac{2}{3}$, we find that the integrated firm earns exactly the same profits as if the upstream price was set at marginal cost, noting that at this level upstream price still exceeds marginal cost, but the integrated firm's profits are much reduced compared to the unregulated case. Clearly the integrated firm would oppose either marginal cost or this alternative regulated pricing due to its reduced profits under either.

Figure 3.7 - Integrated monopolist's profits with $P_U^R = \beta P_U^M$ and $\beta = \frac{2}{3}$



However, as shown in Figures 3.8 and 3.9 respectively, regulating at this higher upstream price results in both significantly higher investment and welfare than that arising under either marginal cost pricing or foreclosure. Curiously, if policymakers should be persuaded by entrants (or pressured under economic treaties) to offer downstream entrants access to upstream production at marginal cost, then in fact they should opt for a slightly higher price (in this case with $\beta = \frac{2}{3}$), as this results in much improved investment and welfare. The integrated firm fares no worse than if marginal cost pricing was imposed, while the downstream entrant in fact enjoys profits almost to the same level as if they succeeded in securing marginal cost pricing.

Figure 3.8 - Integrated monopolist's investment with $P_U^R = \beta P_U^M$ and $\beta = \frac{2}{3}$

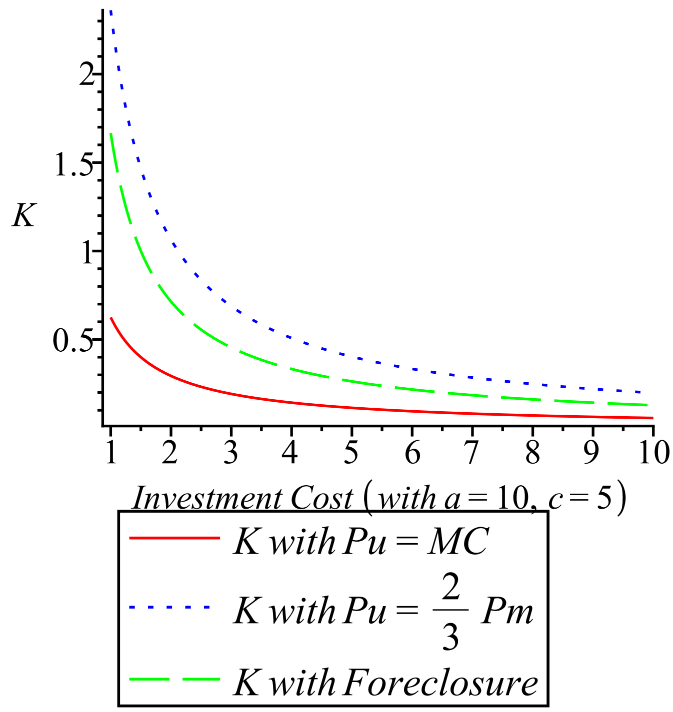
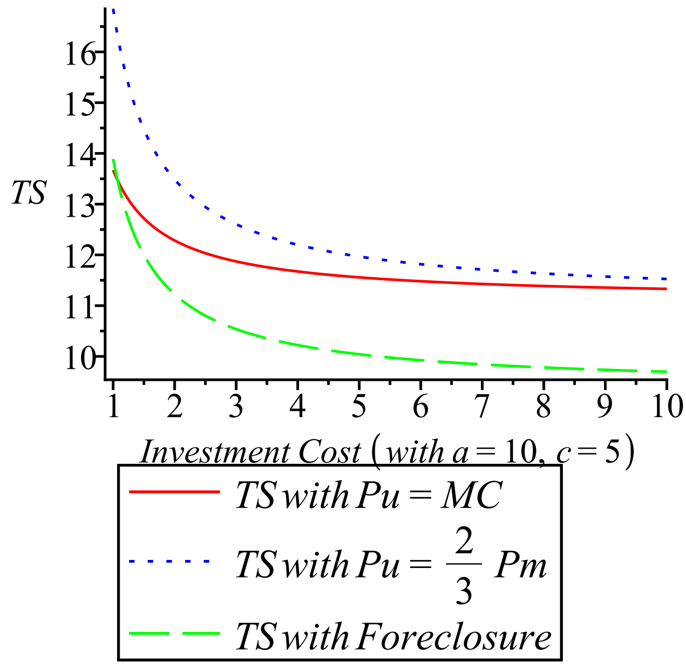


Figure 3.9 - Total surplus with $P_U^R = \beta P_U^M$ and $\beta = \frac{2}{3}$



4. Extensions, and Other Future Research

Desirable extensions to this study's approach include consideration of:

- **Uncertainty** - e.g. random supply shocks, to see how hedging benefits and insurance opportunities vary with vertical structure, competition and/or forward trading.

- **Asymmetric information (relates to uncertainty)** - e.g. regarding supply shocks, since operators of power staions know their availability and fuel security better than customers or rivals (noting that regulating for greater "transparency" may result in worsened anti-competitive practices) - cf Sakai (1985) for an example of possible approach to asymmetric information under duopoly.
- **Incentive issues/contracting** - attempt to get inside the "black box" of integrated firms and explore how incentive problems (e.g. between upstream and downstream managers) affect the merits of vertical integration relative to separation, under differing degrees of competition, and consider how best to resolve those incentive issues (e.g. through market or intra-firm contracting).
- **Smart metering** - examine how investment in "smart metering" by either upstream or downstream firms is affected by vertical structure, competition and/or forward trading, in particular, exploring how best to endogenise the benefits of such investments to the investing parties - leads to empirical possibilities given mandated roll-outs of smart meters in EU countries, New Zealand, the US and elsewhere.
- **Investment in renewable energy technologies** - introduce multiple investment technologies and examine how vertical structure, competition and/or forward trading affect the uptake of higher-cost and/or intermittent renewable technolgies.
- **Competing customer-level investment (related to renewable energy investments, and uncertainty)** - consider how vertical structure, competition and/or forward trading affect investment by customers, such as in subsidised wind turbines or photovoltaics. Probably requires some form of discrete or continuous choice random utility model, and lends itself to empirical testing the given range of subsidised programmes for customer investment in renewables in the EU and elsewhere.
- **ETS/Carbon markets (related to renewables investments)** - examine how differential degrees of market power across energy and emission permit markets interact with vertical structure, competition and/or forward trading to affect technology mix choices by electricity generators (also lends itself to empirical testing).
- **Joint gas and electricity supply** - explore how vertical structure, competition and/or forward trading affect investment and welfare when firms supply electricity and/or gas at either or both of upstream and downstream levels.

Possible applications of this paper's modelling technology to other sectors:

- **Structural separation in banking** - e.g. model the recent Vicker's reforms in the UK banking sector, ring-fencing investment banking and retail banking operations.
- **Financial contagion** - build on work done in Macro III exploring how market power held by financial institutions reduces financial contagion, by better internalising (than

competition) the price-reducing effects of asset fire sales which impact on all other financial institutions holding similar assets and thereby propagate shocks.

- **Model consumer choice of multiple competing upstream networks** - applications in telecommunications (e.g. structural separation debates - UK, Australia, New Zealand), and transport sectors, with likely empirical applications.

5. Conclusions

This study provides a simple and tractable way to explore how vertical industry structure, competition and forward trading interact to affect investment and welfare in imperfectly competitive infrastructure-like industries such as electricity or gas. It has shown that all three factors can be important for welfare and/or investment. It also shows that they can each serve to reinforce or undermine the benefits or disadvantages of the others, and that measures designed to enhance investment may not also enhance welfare.

Importantly, this study highlights how vertical integration provides vertical coordination benefits (i.e. reduced double marginalisation) even when it is also associated with apparently anti-competitive practices (e.g. foreclosure, or raising rivals' costs, by integrated firms). While addressing those practices may lead to welfare gains, this depends on how they are addressed, as solutions involving vertical separation may in fact prove worse in welfare terms. Additionally, it highlights how vertical integration can effectively substitute for competition - at both upstream and downstream levels.

Alternatively, the study highlights how reformers intent on introducing competition in apparently undersirable industry configurations (e.g. integrated/foreclosed monopoly) might in effect harm welfare. They might do so by opting for the intuitively appealing - but counter-productive - solutions of imposing vertical separation as a means of enhancing competition, or in association with increased competition (e.g. through horizontal separation of upstream firms, or (de)regulating for greater downstream market competition). Conversely, they may opt for facilitating downstreeam competition by regulating upstream market prices. This study shows that care should be exercised in choosing such a regulated price, in that naive solutions such as imposing marginal cost pricing can be significantly bettered in welfare and political economy terms by less restrictive pricing.

Having said this, the study also highlights how increasing competition at either the upstream or downstream level can be beneficial for both investment and welfare. Just as vertical integration helps to resolve double marginalisation problems, so too does the margin-constraining effects of increased competition. The challenge for reformers is to identify the relative costs and achievability of different industry configurations. If competition can be easily achieved, then this study shows that in principle it is a desirable innovation. However, if competition is costly or difficult to achieve, then vertical integration is possibly a relatively low-cost substitute, to a point. Once again, however, this study highlights a possibly adverse practice arising under asymmetric integration - namely the incentive for an integrated firm to reduce its investment in the face of increased downstream competition. While regulators or policymakers might regard such a practice with suspicion, once again caution must be exercised in concluding that vertically separating such a firm (so as to increase investment) is the solution. This study shows that decreasing vertical integration, all other things being equal, is in fact negative for both investment and welfare - hence policymakers and regulators must be mindful of wider industry incentives when contemplating measures to address isolated instances of apparently undersirable practices.

Finally, this study shows that introducing forward trading may have no effect on investment and welfare in industry structures characterised by balanced full integration (whether the number of upstream and downstream firms is two, three or more). It has little impact on investment, but is otherwise welfare-enhancing, in industries with asymmetric integration or full separation. These welfare gains arise in the context of separated downstream firms - in the asymmetric integration case - being able to use forward trading as a means of pre-committing suppliers with upstream market power, thus constraining the subsequent exercise of that market power. Curiously, this involves separated downstream firms becoming suppliers on the upstream market, as a consequence of an over-buy and recycle strategy that sees them purchase more than their downstream market requirements through forward trading, and then selling the excess on the upstream market. This too might attract regulatory or political attention, but in fact it is associated with higher welfare, and so *prima facie* should be tolerated.

References [to be completed]

Allaz, B. and J.-L. Vila, 1993, “Cournot competition, forward markets and efficiency”, *Journal of Economic Theory*, 59, 1-16.

Buehler, S. and A. Schmutzler, 2008, "Intimidating competitors - Endogenous vertical integration and downstream investment in successive oligopoly", *International Journal of Industrial Organization*, 26, 247-265.

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.

Fudenberg, D. and J. Tirole, 1984, "The fat-cat effect, The puppy-dog ploy, and the lean and hungry look", *American Economic Review*, 74(2), May, 361-366.

Gans, J. and F. Wolak, 2008, *A Comparison of Ex Ante versus Ex Post Vertical Market Supply: Evidence from the Electricity Supply Industry*, Working Paper Draft, October.

Gaudet, G. and N. Van Long, 1996, “Vertical integration, foreclosure, and profits in the presence of double marginalization”, *Journal of Economics & Management Strategy*, 5(3), 409-432.

Hackner, J., 2000, "A note on price and quantity competition in differentiated oligopolies", *Journal of Economic Theory*, 93, 233-239.

Joskow, P., 2006, *Markets for Power in the United States: An Interim Assessment,* AEI-Brookings Joint Center Working Paper No. 05-20.

Kreps, D. and J. Scheinkman, 1983, "Quantity pre-commitment and Bertrand competition yield Cournot outcomes", *Bell Journal of Economics*, 14(2), summer, 326-337.

Meade, R., 2005, "Electricity investment and security of supply in liberalized electricity systems", in W. Mielczarski (ed.), *Development of Electricity Markets*, Series: The European power supply industry.

Meade, R., 2010, *Vertical Integration vs Vertical Separation in an Industry, such as Electricity, with Retail, Wholesale and Forward Markets*, thesis submitted in partial fulfilment of requirements of Masters 2 degree, Toulouse School of Economics, June.

Sakai, Y., 1985, "The value of information in a simple duopoly model", *Journal of Economic Theory*, 36, 36-54.

Schrader, A. and S. Martin, 1998, "Vertical market participation", *Review of Industrial Organization*, 13, 321-331.

Shapiro, C., 1989, "Theories of oligopoly behaviour", in Schmalensee, R. and R. Willig (eds.), *Handbook of Industrial Organization*, Elsevier, Volume 1, 329-414.

Von der Fehr, N.-H. and D. Harbord, 1997, *Capacity Investment and Competition in Decentralised Electricity Markets*, November.

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