Reforming a Network Industry: Consequences for Cost Efficiency and Welfare

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Abstract: Competition in an industry with an upstream natural monopoly infrastructure requires vertical separation. However, this cannot increase welfare unless marginal costs are reduced, given the advantages of vertical integration. It turns out that entry increases marginal costs and has ambiguous welfare effects if there is a downstream agency problem, and reduces marginal costs and increases welfare if it occurs upstream. While vertical separation and competition are outperformed even by a profit-maximising monopoly, a welfare-maximising vertically integrated monopoly yields in both cases superior cost efficiency and welfare.

Keywords: liberalisation, privatisation, vertical separation, cost efficiency.

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1. Introduction

The network industries, which represent 15% of the production and 7% of the employment of the EU15-countries are being restructured through liberalisation, and in general also privatisation. However, many of them, such as electricity, gas, telecommunications and railways, are typically associated with an upstream bottleneck infrastructure. Competition therefore requires the natural monopoly bottleneck to be separated from the services that use the infrastructure (vertical separation). This contribution deals with the social costs and benefits of such a restructuring.

Reforms in this spirit are part of the so called Washington-consensus (Williamson, 2000) and are also prescribed by the EU, as reflected in directives such as 2003/54/EC and 2003/55/EC (Reforming Network Industries, 2006). They are based on a belief in price reductions (by up to 36% in EU network industries according to Martin et al., 2005) through competition, because of lower profit margins, higher cost efficiency and, in the long run, enhanced dynamic efficiency (Reforming Network Industries, 2006).

However, the old-fashioned vertically integrated public utilities were, like many other public firms, in general associated with some extent of non-commercial objectives. For example, state-owned firms in Britain and Argentina were required to act in the public interest, which meant either marginal-cost pricing or welfare maximisation subject to a break-even constraint (Vickers and Yarrow, 1988: 127, 130-34, Xu and Birch, 1999). Wider objectives have occurred in other countries as well, such as France, Finland and the US (Sheahan, 1966, Miettinen, 2000, Martin, 1959). With these experiences in mind, we limit our attention below to welfare maximisation, not least because of the belief that costs become too high without a profit motive.2

The scope for lower profit margins through competition is limited in the case of an incumbent with wider objectives, and nonexistent under full welfare maximisation. A restructuring can then increase welfare only through cost reductions (or increased dynamic efficiency), as shown by for example Ceriani and Florio, 2011).3 In a network industry,

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1 These numbers from Martin et al. (2005) refer to the electricity, gas, water supply sectors, and to transport and storage and communication, as included in the STAN database.

2 As showed elsewhere, distorted objectives and higher wages because of internal rent capture do not necessarily make a public monopoly welfare-reducing (Willner, 2001; Grönblom and Willner, 2008). Note however that public ownership has also been associated with corruption in some countries, not least because of the wide international variations in the quality of governance (Kauffmann et al., 2004).

3 Prices may in practice be too high, for example because of a need to raise public-sector revenues. But there may then exist other and possibly cheaper ways to reduce profit margins than by structural reforms.
the costs reductions would also have to overshadow the benefits of vertical integration (see for example Vickers, 1995), and potential drawbacks of separation, such as excessive network charges, markups both up- and downstream (double marginalisation), underinvestments in the infrastructure, and vertical foreclosure (under less than full vertical separation).

Competition can be introduced only downstream because of the upstream bottleneck, so we ask the fundamental question about whether the downstream activity would really become more cost efficient after liberalisation and full vertical separation.  

Downstream marginal costs are therefore modelled as endogenous through managerial efforts, which are unobservable because of random shocks. The upstream activity remains a monopoly, but section 5 asks how upstream cost efficiency is affected by downstream liberalisation, given an upstream agency problem. De Fraja (1993), Martin (1993), and Beiner et al. (2011) apply agency models on the impact of ownership and/or competition on marginal costs, but this contribution is the first to address the welfare impact of vertical separation and downstream competition (in combination with privatisation).

It turns out that combining profit maximisation, liberalisation and vertical separation reduces welfare. The advantages of vertical integration and welfare-maximising public ownership are in other words strengthened by the agency problem, because of its impact on marginal costs. The combination of separation and competition can outperform an integrated profit-maximising (but not welfare maximising) monopoly, provided that regulation or public ownership yields zero upstream profits. But requires the value of an agency parameter (which reflects risk, risk-aversion and disutility of effort) to be high, and intermediate upstream fixed costs relative to demand. Our analysis also suggests that entry (after separation) can be beneficial despite the higher marginal costs, but the opposite may also hold true (unless the agency problem occurs upstream). Such results contradict the conjecture by Newbery (2002) and Vickers (1995) about cost reductions that would overshadow the advantages of vertical integration and wider objectives. Liberalisation and vertical separation may still be beneficial, but if so, there must be other explanations than cost-cutting incentives.

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4 Partial vertical separation, and hence a downstream mixed oligopoly is dealt with in a companion paper, which assumes exogenous marginal costs and asks by how much they would have to be reduced so as to overshadow the benefits of vertically integrated profit- or welfare-maximising monopoly (Willner, 2008).
Next section describes the basic model of a market with vertical relations and a downstream principal-agent problem. Section 3 outlines organisational alternatives for a network industry. Section 4 compares marginal costs, output and welfare for each alternative. The agency problem occurs upstream instead of downstream in section 5. Section 6 presents concluding remarks and relates the findings to the empirical literature. An appendix includes proofs and more technical details.

2. The basic model: Principals, agents and vertical relations

The industry consists of an upstream and a downstream activity, with outputs $x$ and $y$ respectively. Upstream total costs are $TC^U = F + c^U x$, where $c^U$ stands for marginal costs and $F$ for the sunk cost that makes the activity a natural monopoly. (Full) vertical separation means that $x$ is provided at the price $p$ (which can also be interpreted as the access charge for using a network infrastructure) to at least one independent downstream firm.

The activities are related through a simple Leontief-technology, so that $y$ units of downstream output require $zy$ units of $x$. The input coefficient $z = x/y$ then expresses the amount of upstream output needed to produce one unit of the downstream output. It can make sense to assume that the use of the infrastructure is proportional to the downstream output, but the analysis also gets simpler, and we abstract from changes in $z$ as a potential advantage of vertical integration.

Downstream variable costs are $c^U x + c^D y$. The first component depends on the input from the upstream activity and the second on the cost-reducing effort of a manager, who is appointed by the public or private owner, like in Raith (2003) or Beiner et al (2011). More precisely, $c^D y$ is linear in the effort $e$. Let $c_0$ denote a constant intercept, and $u$ an (approximately) normally distributed random variable with the variance $\sigma^2$ and zero mean. The shocks are independent in the case of several downstream firms. It follows that the downstream variable costs, are $c^U x + (c_0 - e - u) y$ in an integrated firm and

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5 Vertical separation can also mean that the downstream activity is cooperative or in local and possibly partial public ownership. The agency problems associated with such solutions are ignored here.

6 Strictly speaking, this assumption implies an infinite range of $u$, but it works as an approximation also if the range is such that $u \in [-\hat{u}, \hat{u}]$, where $\hat{u} \leq c_0$, if the distribution is bell-shaped and such that $\sigma < \hat{u}/3$.

7 This assumption is stringent (although widely used in the literature; see Raith, 2003). However, we may think of the procedure as focusing on firm-specific risks only, assuming that those risks that are common to all firms are observable.
pany $pzy+(c_0-e-u)y$ after vertical separation. As for the downstream fixed costs, we ignore all other components than the manager's salary (see below). There is no uncertainty and agency problem upstream (until section 5).

The owner can observe $c_0-e-u$, but cannot know whether for example high average variable costs depend on bad luck or laziness. The manager gets a salary that depends on $e+u$ with the coefficient $\beta$ (which will turn out as strictly positive whenever $e>0$) and the intercept $w_0$:

$$w = w_0 + \beta(e+u).$$

The manager's utility depends on income and a quadratic disutility of effort, $ke^2/2$, where $k$ is a disutility parameter such that $k>1$. Moreover, while most results can be generalised, we simplify by assuming constant absolute risk aversion $r$:

$$U = -\exp\left[-r\left(w - \frac{ke^2}{2}\right)\right].$$

The variance of the salary is $\beta^2 \sigma^2$. Substitute (1) for $w$, use the assumption of normally distributed shocks to write the expected utility as a function of expected income and variance, and use an expression that is proportional to its logarithm as a shortcut:

$$V = w_0 + \beta e - \frac{r\beta^2\sigma^2}{2} - \frac{ke^2}{2}.$$  

Incentive compatibility means that the manager maximises (3) given the parameters of the reward function:

$$e = \frac{\beta}{k}. $$

We normalise the reservation utility $v_0$ to zero, like in Beiner et al. (2011). This implies that $Ew$ tends to zero as the number of firms tends to infinity. The ambiguous welfare
effect of competition below is therefore not explained by duplicated fixed costs (see section 3 and the Appendix).

With this assumption, the binding participation constraint then becomes \( V = 0 \). Solve for \( w_0 \) and insert \( w_0 \) and \( e \) into the expected wage \( E_w = w_0 + \beta e \):

\[
E_w = \frac{1}{2} \left( \frac{\beta}{k} \right)^2 \left( r \sigma^2 k^2 + k \right).
\]

(5)

The expressions (4) and (5) will remain the same when the industry is reorganised (although we add subindices \( i \) to \( \beta \) and \( e \) if there is competition), but the equilibrium value of \( \beta \) will change.

It will be convenient to introduce the following abbreviation:

\[
\varphi = r \sigma^2 k^2 + k.
\]

(6)

It is obvious that \( \varphi \) is increasing in risk (interpreted as \( \sigma^2 \)), risk-aversion (\( r \)), and the disutility coefficient (\( k \)), so \( \varphi \) indicates the severity of the agency problem. We therefore interpret \( \varphi \) as an agency parameter; note that the assumption \( k > 1 \) implies \( \varphi > 1 \).

The downstream output is homogeneous. Let its price be denoted by \( q \) and let \( a \) stand for a positive intercept. Normalising the slope to \(-1\), the inverse demand is:

\[
q = a - y.
\]

(7)

It will be convenient to introduce another abbreviation,

\[
\alpha = a - e^U z - c_0,
\]

(8)

which stands for a shift parameter that reflects demand and (the exogenous components of the) marginal costs. Feasibility and the natural monopoly assumption rule out too low and too high values relative to \( F \).

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\(^8\) Linear demand means that demand uncertainty is formally similar, provided that \( u \) means a normally distributed additive demand shock that affects each downstream firm independently.
The total costs of a vertically integrated firm are

\[ TC = zyc^U + (c_0 - e - u)y + F + w = zyc^U + c^D y + F + w. \]  \(9\)

Vertical separation means a split of (9) into an up- and downstream part (indexed by \(U\) and \(D\)):

\[ TC^U = c^U x + F, \] \(10\)

\[ TC^D = pzy + (c_0 - e - u)y + w = pzy + c^D y + w. \] \(11\)

In the case of liberalisation and entry we add subindices \(i\) to \(x, y, w_0,\) and \(e\)

3. From a vertically integrated public monopoly to competition

3.1. Public ownership vs privatisation in a vertically integrated monopoly

Consider a vertically integrated public monopoly that chooses the highest expected total surplus (or in this case consumer surplus) that yields zero profits, given (4) and (5).\(^9\) Solve the zero-profit condition \(\alpha y - y^2 + ey - w - F = 0\) and maximise the solution with respect to \(\beta.\)

We then get the following effort, output and total surplus in equilibrium:

\[ e^* = \frac{\beta^*}{k} = \frac{\alpha + \sqrt{\alpha^2 - 2F(2\varphi - 1)/\varphi}}{2\varphi - 1}, \] \(12\)

\[ y^* = \frac{\varphi \left[ \alpha + \sqrt{\alpha^2 - 2F(2\varphi - 1)/\varphi} \right]}{2\varphi - 1}, \] \(13\)

\[ TS^* = \frac{1}{2} \left[ \frac{\varphi \left[ \alpha + \sqrt{\alpha^2 - 2F(2\varphi - 1)/\varphi} \right]}{2\varphi - 1} \right]^2 \] \(14\)

\(^9\) Setting prices equal to marginal costs might yield even higher social welfare, but the possible social costs of funding a deficit is outside our scope.
The corresponding values for a profit maximising monopoly are:

$$e^M = \frac{\beta}{k} = \frac{\alpha}{2\varphi - 1},$$ \hspace{1cm} (15)

$$y^M = \frac{\varphi \alpha}{2\varphi - 1}.$$ \hspace{1cm} (16)

$$TS^M = \frac{\varphi \alpha^2 (3\varphi - 1)}{2(2\varphi - 1)^2} - F.$$ \hspace{1cm} (17)

3.2. Vertical separation with profit maximisation up- and downstream

Suppose now that the upstream activity has become a private profit-maximising monopoly and separated from the downstream activity, which has become an \(n\)-firm oligopoly. Each oligopolist decides about its output and managerial reward given its competitors' strategies and the input price. The profits of firm \(i\) are then:

$$\pi_i = qy_i - zpy_i - c_i^p y_i - w_i.$$ \hspace{1cm} (18)

Use (5)-(7) to write their expected value as follows:

$$E\pi_i = ay_i - y_i^2 - y_i \sum_{j \neq i} Ey_j - zpy_i - c_i y_i + \frac{\beta_i}{k} y_i - \frac{\beta_i^2}{2k^2 \varphi}.$$ \hspace{1cm} (19)

While (19) is concave in \(y_i\) given \(\beta_i\), the maximum profits as a function of \(\beta_i\) or \(e_i\) may be non-concave. To ensure concavity we therefore assume \(\varphi > 2n^2/(n+1)^2\), which ensures that \(\beta > 0\) and rules out combinations of large values of \(n\) and low values of \(\varphi\).\(^{10}\)

We get the following symmetric equilibrium (see the Appendix:)

(For details, see the Appendix.)
\[ e^V = \frac{\beta^V}{k} = \frac{\alpha n}{\varphi(n+1)^2 - 2n}, \quad (20) \]

\[ y^V = \frac{n(n+1)\alpha\varphi}{2(\varphi(n+1)^2 - 2n)}, \quad (21) \]

\[ TS^V = \frac{[3n+4(n+1)^2\varphi - 4n(2n+1)]\alpha^2\varphi n}{8[\varphi(n+1)^2 - 2n]} - F. \quad (22) \]

Near-perfect competition (a very large number of firms) would mean that output tends towards \( \alpha/2 \) and the total surplus to

\[ TS^V_0 = \frac{3\alpha^2}{8} - F. \quad (23) \]

Downstream fixed costs, i.e. \( w = \varphi e^2/2 \), would then tend to zero, so there is no upper limit to the number of downstream firms (see the Appendix for more details).

### 3.3. Vertical separation with upstream regulation or public ownership

The analysis of the profit-maximising monopoly in 3.1 and 3.2 above is relevant for several results in section 4. But a bottleneck monopoly would in most cases in reality either remain in public ownership or be regulated. Enforcing zero upstream profits (below indexed by \( R \)) would eliminate double marginalisation.\(^{11}\)

This would mean the following levels of effort and downstream output:

\[ e^R = \frac{\beta^R}{k} = n\frac{\alpha + \sqrt{\alpha^2 - 4[\varphi(n+1)^2 - 2n] F / (n+1)n\varphi}}{\varphi(n+1)^2 - 2n}, \quad (24) \]

\(^{10}\) The Hessian would always be positive under simultaneous maximisation (because \( \varphi > 1 \)), which would on the other hand ignore the oligopolistic interaction in choosing \( \beta \).

\(^{11}\) Note that the model does not distinguish between upstream public ownership and regulation, although the difference is likely to be substantial in practice.
\[ y^* = n(n+1)\varphi \frac{\alpha + \sqrt{\alpha^2 - 4}\varphi(n+1)^2 - 2nF/(n+1)n\varphi}{2\varphi(n+1)^2 - 2n}. \] (25)

However, it will be useful for the welfare comparison to replace the break-even constraint with an assumption that the upstream firm maximises a \( \lambda CS + \pi^U \), where \( CS \) stands for the downstream consumer surplus (because consumers can buy only the downstream output), \( \pi^U \) for its profits, and \( \lambda \) for a weight parameter. Values of \( \lambda \) of 0 and 1 would then correspond to pure profit and welfare maximisation, so there must exist a value \( \lambda_0 \) in the open interval \((0,1)\) that yields zero profits. A welfare comparison that applies for any \( \lambda \) in \((0,1)\) then also applies for \( \lambda_0 \). We index this solution by \( C \):

\[ e^C = \frac{\beta^C}{k} = \frac{2n\alpha}{2\varphi(n+1)^2 - 4n - \lambda\varphi(n+1)n}, \] (26)

\[ y^C = \frac{n(n+1)\alpha\varphi}{2\varphi(n+1)^2 - 4n - \lambda\varphi(n+1)n}. \] (27)

If \( \lambda = \lambda_0 \), the total surplus consists of the consumer surplus \((y^C)^2/2\) and the downstream profits \( n(y^C/n)^2 \):

\[ TS^C = \frac{\left[(n+2)(n+1)^2\varphi - 4n^2\right]e^2\varphi n}{2[2\varphi(n+1)^2 - 4n - \lambda_0\varphi n(n+1)]} - F. \] (28)

Finally, vertical separation can also mean a bilateral monopoly with up- and downstream welfare-maximisation. The downstream firm then chooses a zero-profit \( y \) and maximises \( CS \) with respect to \( \beta \). Set \( y_i = y \) and \( \beta_i = \beta \) in (19) and solve for \( y \) when \( \pi = 0 \) to get \( y(\beta) \). Maximise \( y(\beta) \) to get \( \beta = ke \) as a function of \( p \) and insert into \( e = \beta/k \) and \( y \) to get:

\[ e(p) = \frac{\beta(p)}{k} = \frac{2(a - c_0 - zp)}{2\varphi - 1}, \] (29)
To get the upstream price, solve \( zy(p)(p-c_U)-F=0 \) and index the solution by \( BM \):

\[
p_{BM} = \frac{1}{z} \left[ \alpha \frac{z}{2} + \frac{1}{2} \left( \frac{\alpha}{2} \right)^2 - \frac{(2\varphi - 1)F}{2\varphi} \right].
\]  

(31)

Inserting (31) into (29) and (30) implies that the optimal values of \( y \) and \( e \) are identical to (12) and (13).

4. A comparison of cost efficiency, output and welfare

4.1. The ownership effect

Sections 4.1-4.6 section present a series of propositions that compare cost efficiency, output and welfare, given linear demand, a downstream agency problem in the presence of CARA-utility, an upstream bottleneck activity, constrained welfare maximisation under public ownership, and (potential) downstream Cournot-competition.

Consider first ownership. Few would recommend privatising a monopoly without regulation, but the low profit margins of a public monopoly are often believed to be overshadowed by higher marginal costs. Proposition 1 contradicts this belief:

**Proposition 1.** A vertically integrated public monopoly that maximises welfare subject to a break-even constraint yields a) a higher effort and hence lower marginal costs, b) a higher output, and c) a higher total surplus than under private ownership.

Part a) is needed for the proof of Proposition 6 below, but it is significant also because of the prominent role of privatisation utility reforms not least in the UK. The result extends earlier agency models on ownership to vertical relations, and its intuition is again based on the fact that wider objectives strengthen the incentive to cut costs via
higher efforts. Pure profit maximisation means on the other hand that only the impact on profits matter.

It may appear trivial that a welfare maximising monopoly yields a higher total surplus, in particular because marginal costs are also lower. However, the fact that a firm maximises a given variable such as $TS$ or $\pi$ does not rule out even higher values of the objective function if some other variable is maximised. For example, $TS$ can become higher in a mixed oligopoly if a public firm maximises profits rather than welfare (under increasing marginal costs), but a firm may also get higher profits by maximising a weighted sum of profits and welfare instead of just profits (De Fraja and Delbono, 1989; Fershtman, 1990).

4.2. The separation effect

While vertical separation is usually seen as just a precondition for downstream competition, it makes sense also to analyse its impact as such in the presence of an agency problem. It turns out that this kind of vertical separation is inferior when costs are endogenous if both the upstream and the downstream firm maximise profits, but not if they maximise welfare as described in section 3.3. We shall refer to this case as a bilateral public monopoly.

**Proposition 2.** a) Splitting an integrated profit-maximising monopoly into an upstream and a downstream profit-maximising monopoly leads to a lower effort, higher marginal costs, lower output, and a lower total surplus. b) Splitting a welfare-maximising monopoly into a bilateral welfare-maximising monopoly does not change the marginal costs, the output, or the total surplus.

Part a) adds to the previous literature on advantages of vertical integration (see for example Perry, 1978; Buehler, 2005) by showing that they are reinforced by the presence of a downstream agency problem. Vertical separation leads to weaker efforts and hence higher marginal costs. However, part b) implies that this applies only to profit maximisation, because separation as such has no adverse effects on costs and welfare in
bilateral public monopoly. The benefits of vertical integration are therefore not associated with economies of scope in this model.\textsuperscript{13}

4.3. The impact of competition in a vertically separated industry

In this section we analyse the impact of a change in the number of downstream firms in an industry given vertical separation. The belief that competition has a stronger positive impact than ownership (see Vickers and Yarrow, 1988; Parker, 2006) has often been the rationale for liberalisation through vertical separation. It will follow that the conventional wisdom applies to output and hence to the consumer surplus, but not to the marginal costs, which become higher by entry. Moreover, the direction of the change in the total surplus depends on the market structure and the agency parameter.

To assess the impact of competition requires differentiation with respect to the number of firms we reinterpret $n$ as a variable in $\mathbb{R}^+$. A positive value of the derivative of a function $f(n)$ then means that it is associated with larger value for $n+1$ than for $n$, at least if $f(n)$ is monotone. The maximum profits are concave in $\epsilon$ or $\beta$ only if $\phi$ is above the boundary $\phi_1(n) = \frac{2n^2}{(n+1)^2}$ in Figure 1, as explained in the proof of Proposition 3 (see the Appendix).\textsuperscript{14} The total surplus increases with entry above and to the left of another boundary, $\phi_2(n)$. Both approach 2.0 from below, but $\phi_2(n) > \phi_1(n)$.

![Figure 1 here]

**Proposition 3.** An increase in the number of firms in a vertically separated industry with an upstream profit-maximising monopoly leads a) to lower efforts and higher marginal costs, b) to a higher output c) to a higher total surplus for values of $n$ above and to the left of a boundary $\phi_2(n)$ and vice versa.

\textsuperscript{12} Note that the manager gets her reservation utility under both forms of ownership, and there is no deficit or surplus that may affect the taxpayers, so the welfare change affects only the consumers and the owners.

\textsuperscript{13} Kwoka (2002) associates the benefits of vertical integration in the US electricity industry from economies of scope, meaning that a firm that produces both the up- and the downstream output has lower costs than the sum of the costs associated by producing each output separately.

\textsuperscript{14} For example, suppose that the post-liberalisation outcome is imperfectly competitive, as in many liberalised network industries. The profits are always concave in $\beta$ in a monopoly or duopoly, but the critical value of $\phi=\phi_1(n)$ that ensures concavity increases from 1.125 to 1.653 as $n$ increases from 3 to 10.
Part a) contradicts the belief that competition leads to higher cost efficiency, but extends an earlier result on the impact of competition by Martin (1993) to vertical relations and welfare comparisons.\(^{15}\) To understand the intuition, note that the presence of \(n\) in the numerator of (20) reflects the positive impact of lower costs as compared to a firm's rivals. This effect gets stronger if there are more firms. However, the term \(\phi(n+1)^2\) in the denominator reflects the impact of a higher \(n\) on the ability to afford a salary that induces a high effort. The latter effect dominates, so \(\beta\) and \(e\), decreases with \(n\), thus causing an increase in the expected marginal cost \(c_0 - \beta/k\). Part b) states on the other hand that consumers may benefit despite higher marginal costs, and part c) that entry reduces welfare if \(n\) is higher than a critical number.

Entry always increases welfare if \(n=1\), but further entry may reduce welfare at some point if \(\phi\) is low. The possibility of an optimal number of firms if \(\phi<2\) is illustrated by Table 1, which is based on \(\alpha^2=100\), \(F=10\), and different values of \(\phi\) and \(n\) in (22). Welfare then has a maximum for three or five firms if \(\phi=1.5\) and 1.819 respectively, while being increasing in \(n\) everywhere if \(\phi=3\).\(^{16}\)

Thus, the model suggests that the sum of the consumer surplus and profits might be observed to increase with increased fragmentation in for example high-variance industries (as reflected in a high \(\phi\)), whereas this sum would otherwise decrease at some point.

4.4. The profit-maximising monopoly versus separation and entry

The comparison between liberalisation and separation with a private profit-maximising monopoly is needed for the proof of Proposition 6 below, but is also interesting in its own right. While the superiority of competition to monopoly in conventional industries is well established, Proposition 2 states that the benefits associated with vertical integration dominate when there is a downstream agency problem and no competition. Proposition 3

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\(^{15}\) Beiner et al. (2011) have on the other hand shown that more intense competition can lead to higher efficiency in a setting with a given number of firms.

\(^{16}\) It also follows from (22) that a downstream duopoly is always superior to a profit-maximising monopoly, because \(\phi>1\) must hold true.
says that the impact of competition after separation is then ambiguous and that marginal
costs will in fact increase, but Proposition 4 provides an unambiguous ranking between a
vertically integrated commercial monopoly and separation with competition:

**Proposition 4.** The vertically integrated profit maximising monopoly always yields
a) a higher effort and lower marginal costs, b) a higher output, and c) a higher total
surplus than after vertical separation and entry.

There are two explanations for this result. The first is based on the benefits of
vertical integration; we have shown that these are reinforced by the principal-agent
problem (see the discussion after Proposition 1). But competition makes it in addition
harder to afford paying for the managers' cost-reducing efforts, so marginal costs increase
(see 4.3).

4.5. The case of upstream public ownership or regulation

Suppose that the upstream monopolist remains in public ownership or is regulated, so that
the access price is so low that the firm only just breaks even. Will this lead to a superior
result as compared to vertical separation without upstream regulation, or to a vertically
integrated profit-maximising monopoly?

It turns out that upstream regulation as described in 3.3 increases the consumer
surplus as compared to separation without regulation. The same applies to the total surplus
at least if $n$ is sufficiently high. However, the integrated profit-maximising monopoly may
nevertheless outperform regulation. The comparison depends on the significance of the
agency problem and the sunk costs relative to net demand.

The natural monopoly assumption means that one but not two vertically integrated
firms can break even. This applies to values of $f=F/\alpha^2$ between the boundaries, $f_1(\phi)$ and
$f_2(\phi)$; $f_1$ converges to 0.25 from above and $f_2$ to 0.1111 from below. Proposition 5a
therefore refers to the area $A-E$ between $f_1(\phi)$ and $f_2(\phi)$. But to assess the impact of
regulation under downstream fragmentation makes sense only for values of $f$ below a
boundary $f_3 = 0.25$ and for values of $\phi$ to the right of a boundary $\phi_0 = 2$ (see section 3.2
and the proof of Proposition 5 in the Appendix). Proposition 5b therefore refers to the
areas $D$ and $E$ in Figure 2. According to Proposition 5c, vertical separation with
downstream fragmentation and upstream regulation yields the same total surplus as the profit-maximising monopoly along the curve \( f_4(\phi) \), which is the boundary between \( D \) and \( E \). It approaches 0.25 from below and intersects \( f_2 \) in \( \phi = 2.7446 \) and \( f = 0.1070 \). The monopoly is then superior in \( D \), and vice versa.

\[ <\text{Figure 2 here}> \]

**Proposition 5.** a) Regulating the upstream firm after vertical separation increases efforts and reduces marginal costs, and increases downstream output and the consumer surplus. b) The total surplus becomes higher if there is also downstream fragmentation. c) Such an allocation leads to a higher total surplus than in a vertically integrated profit maximising monopoly for combinations of \( \phi \) and \( F/\alpha^2 \) between the boundaries \( f_2 \) and \( f_4 \) (\( E \)), and to a lower total surplus below \( f_3 \), to the right of \( \phi_0 \), above \( f_2 \), and above or to the left of \( f_4 \) (\( D \)).

Thus, while the allocation in a separated industry can be improved by upstream regulation, it cannot outperform an integrated profit-maximising monopoly even through downstream fragmentation, unless the agency parameter is large and the upstream sunk cost high. This does not depend on double marginalisation, which is prevented by regulation, nor on economics of scope, because the cost functions do not depend on vertical integration or separation. The superiority of the integrated profit-maximising monopoly in \( D \) depends on stronger incentives to cut costs. But Proposition 5 also suggests that the choice between post-privatisation solutions is not straightforward.

**4.6. An overall comparison**

We know from Proposition 1 that welfare maximisation makes a vertically integrated public monopoly superior to an otherwise similar profit maximising firm, and from Proposition 4 that a profit maximising vertically integrated monopoly is superior to vertical separation and liberalisation for any number of downstream firms. Proposition 2 in turn establishes that a vertically separated bilateral monopoly performs equally well as under vertical integration, provided that both firms maximise welfare. This establishes the superiority of the integrated or bilateral public monopoly to vertical separation with
competition between profit maximising firms (including a profit-maximising monopoly, oligopoly or near-perfect downstream competition) in Proposition 6 below. Also, it follows from Proposition 5c that vertical separation outperforms an integrated private monopoly in some cases if separation and competition are combined with upstream regulation, but it cannot outperform the integrated or bilateral public monopoly.

Proposition 6. The vertically integrated or bilateral welfare-maximising public monopoly always yields higher efforts, lower marginal costs, and higher welfare than vertical separation and competition both when the upstream monopolist is profit-maximising and regulated.

We refer to the discussions after Propositions 1 and 4 for the comparison of vertical separation without regulation and a profit- or welfare-maximising monopoly. As for regulation, the deadweight loss caused by an upstream profit-maximising is reduced, but separation and competition lead to excessive marginal costs because of reduced efforts. Maximisation of the total surplus takes the consumers and not only the owner in consideration, which increases the willingness to pay for cost-reducing efforts.

5. An upstream agency problem

The absence of an upstream agency problem may have biased the analysis in favour of vertical integration. To assess robustness we therefore now assume that the agency problem occurs upstream, for example caused by asymmetric information related to passive public or private ownership. Marginal costs are $c_U - e - u$, where $c_U$ is an intercept. The manager gets an incentive wage that is modelled as in the previous sections. $17$ The fixed cost $F$ then consists of the wage $w$ and an exogenous component $F_0$. The downstream firms are now owner-managed, so we can approach perfect competition without loss of downstream cost-efficiency. $18$ Downstream marginal costs are always $c^D + zp$.

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$17$ We have to think of approximately normally distributed shocks $u \in [-\hat{u}, \hat{u}]$ such that $\hat{u} \leq c_U$.

$18$ Downstream competition is here associated with profit maximisation, but might also be linked to municipal ownership or cooperatives.
Use the abbreviation $A = a - zc_u^U - c^D$ in the objective function and maximise $TS$ or $CS$ (subject to breaking even) to get downstream output and effort for the vertically integrated monopoly:

$$y^* = \frac{\varphi A}{2 \varphi - z^2} + \sqrt{\left( \frac{\varphi A}{2 \varphi - z^2} \right)^2 - \frac{2 \varphi F_0}{2 \varphi - z^2}}, \quad (32)$$

$$e^* = \frac{zA}{2 \varphi - z^2} + \sqrt{\left( \frac{zA}{2 \varphi - z^2} \right)^2 - \frac{2 z^2 F_0}{(2 \varphi - z^2) \varphi}}, \quad (33)$$

Privatisation would on the other hand mean two-stage profit maximisation, which would yield:

$$y^M = \frac{\varphi A}{2 \varphi - z^2}, \quad (34)$$

$$e^M = \frac{zA}{2 \varphi - z^2}. \quad (35)$$

Next, consider vertical separation and downstream competition. The marginal costs $zp + c^D$ of a downstream firm cannot be affected by its own actions. Maximising its profits and aggregating yields output as a function on the upstream price and the number of firms. Use the fact that $x = zy$, rearrange and solve for $p$ to get the derived upstream inverse demand function $p(x,n)$. Write out the upstream profit function, maximise in two steps, and use $y = x/z$. As explained in more detail in the Appendix, we get

$$y^V = \frac{n \varphi A}{2(n+1) \varphi - nz^2}, \quad (36)$$

$$e^V = \frac{nzA}{2(n+1) \varphi - nz^2}. \quad (37)$$
It is obvious from (32)-(35) that a public welfare-maximising monopoly outperforms privatisation both in terms of cost efficiency and total surplus, if there is no competition and vertical separation, because effort and output are higher in the former case. As for combining privatisation, competition and vertical separation, it follows that an increasing number of downstream firms leads to higher upstream cost efficiency. This stands in contrast to result about reduced efficiency in the case of a downstream agency problem. The intuition is the fact that increasing downstream competition now works as an outwards shift in the derived upstream demand, so it becomes easier to afford cost-reducing efforts.

The consumer surplus is increasing in \( n \), because \( CS = \frac{y^2}{2} \), and it can be shown that the upstream profits are also increasing. This implies that the total surplus is also unambiguously increasing. The impact of more competition given that vertical separation has taken place is therefore unambiguously beneficial, in contrast to sections 3 and 4.

However, near-perfect competition would just mean that (36)-(37) approach (34)-(35), so as \( n \) approaches infinity we get the same consumer surplus (and hence total surplus) and effort as in a profit-maximising monopoly (where the total surplus would on the other hand include positive profits as well). It follows that our results are otherwise unchanged, with the exception of the impact of \( n \) on costs and welfare (given vertical separation).

6. Discussion and concluding remarks

Our point of departure has been the widespread belief in gains from competition that overshadow the benefits of vertical integration and welfare maximisation. We have asked whether this is true if marginal costs depend on the unobserved efforts of a manager, and we have based the analysis on standard components such as oligopolistic competition, and a principal-agent model with approximately normally distributed cost (or demand) shocks and constant absolute risk-aversion.

An increase in the number of firms after vertical separation always increases output, and can increase welfare (despite higher marginal costs) if the variance of the random shocks is large, if the manager is highly risk-averse and/or if her disutility of effort is high. The combination of vertical separation, near-perfect competition and upstream regulation can then outperform a vertically integrated and profit-maximising monopoly,
but only if the upstream sunk cost is relatively low. Finally, splitting the incumbent into an up- and a downstream welfare-maximising monopoly will neither increase costs nor reduce welfare.

However, our main results suggest that possible favourable effects of a restructuring must be sought elsewhere than in higher cost-reducing efforts. Privatisation without separation increases costs and reduces welfare, and profit maximising monopolies both up- and downstream are worse than an integrated profit maximising monopoly. While increased competition may both increase and reduce welfare, a restructuring (sometimes even if combined with regulation) is inferior even to a profit maximising integrated monopoly, and consequently also to a welfare-maximising monopoly. This striking result has been reached despite a simplifying assumption causing the sum of the downstream fixed costs to vanish as the number of firms becomes large, and despite the absence of genuine economies of scope.

As for the empirical literature, privatisation (which is often an essential part of the process of vertical separation) has been questioned by many authors. Kwoka (2006) finds that public ownership enforces cost discipline in the US electricity industry. Martin and Parker (1997), Hodge (2000), Iordanoglou (2001), Florio (2004), and Parker (2006) have shown that privatisation does not always improve corporate performance. While Megginson and Netter (2001) interpret the empirical literature in favour of private ownership, the overviews in Boyd (1986), Millward (1982) and Willner (2001, 2003) suggest that the differences in cost efficiency tend to go both ways. In particular, most studies on electricity and water tend to suggest that public ownership is often even more cost efficient (Willner, 2001, 2003; Abbott and Cohen, 2009).

The electricity market was liberalised by the turn of the century in 51 out of 62 countries, with planned vertical separation in 27 countries (Newbery, 2002). For example, the British transmission network (subsequently the National Grid) became separated from generation before privatisation, despite evidence of benefits from vertical integration from many countries (Michaels, 2004, Kwoka, 2002, Nemoto and Goto, 2004, Arocena, 2008, Jara-Diaz et al., 2004, Fraquelli et al., 2005). Consumer prices did fall after restructuring in some countries (mainly for non-household customers), but this may have been achieved

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19 Kwoka (2005) suggests that the comparative advantage of public ownership lies in electricity distribution, whereas the reverse applies to generation.

20 Newbery (2006) expects the benefits of competition to overshadow the benefits of integration, but argues that the degree of success is mixed for other reasons.

Telecommunications have on the other hand been characterised by rapid technical change and heavy regulation, so our theoretical analysis might be less applicable. Liberalisation and unbundling were based on a perceived loss of natural monopoly. The process is often described as more successful than in other industries (Newbery, 2006). Prices have tended to fall, but regulation may also have contributed (Björkroth et al., 2006). Boylaud and Nicoletti (2000) find evidence for a productivity increase, but Daßler et al. (2002) find that the European experiences are mixed and that there is no evidence of higher total factor productivity. Moreover, there have been concerns about concentration, and the views on the change in service quality are mixed (Björkroth et al., 2006).

Water and sewerage utilities have been privatised in Britain, but are also subject to heavy regulation, which may explain some observed efficiency gains (Saal and Parker, 2000). Vertical integration still dominates the industry, but the British regulator now recommends unbundling (Lobina and Hall, 2008). However, a report by ICS Consulting has warned that a similar restructuring as in the electricity industry might increase costs by 26% (as reported by Utility Week, 5 July 2011). While the literature on the benefits of vertical integration in the water industry is limited, Abbott and Cohen (2009) find no evidence in favour of vertical separation, at least for smaller companies.

As for railways, there seems to be evidence from Europe (including the transition economies) of benefits of a vertical structure (Cantos-Sánchez, 2001; Pittman, 2003, 2005). Nevertheless, the EU recommends vertical separation, and Britain has combined full privatisation, vertical separation, and downstream competition (but only for the market). Initially, the rail infrastructure became a private monopoly (Railtrack), but it was subsequently reorganised as a non-profit company (Network Rail), not least because of criticism for underinvestments and concerns about safety (Crompton and Jupe, 2003, Newbery, 2006; Björkroth et al., 2006). The restructuring also failed to achieve a

21 While such quality-related issues are outside our scope, they imply that empirical results on cost and price reductions must be interpreted with care.

22 It also seems that forced divestiture of generators had an adverse effect on US distributing companies (Kwoka et al., 2010).
reduction of the state subsidies, which might not be possible with the present network size (Shaoul, 2004; Newbery, 2006). The railways seem to be the least suitable of the utilities for a restructuring based on vertical separation (Newbery, 2006, Pittman, 2005). Our findings on ownership and vertical separation are not necessarily at variance with the empirical literature, given that cost and/or subsidy reductions have often failed to materialise. However, the role of competition might be seem more controversial. We may have to accept that competition makes it more difficult to afford paying a manager whose effort is essentially modelled as a commodity with a price. Moreover, the benefits of performance-related pay are controversial, not least because of the possibility of motivation crowding out (see Frey, 1997). The analysis may also be extended to internal rent capture (analysed in the bargaining model without principals and agents in Grönblom and Willner, 2008) or issues of governance quality. There are also disadvantages related to competition and vertical separation that we have not dealt with, such as issues related to quality, reliability, price volatility, and remaining market power, which many contributions cited above have addressed.

Acknowledgements

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Appendix
Deriving the monopoly solutions in 3.1. The optimal output can be obtained from the budget restriction $\alpha y - y^2 + e y - w - F = 0$. As for the next stage, the participation constraint and the incentive compatibility constraint yield $w_0$ and $e$; combining (4)-(6) and (7)-(8) yields the following expressions for expected profits and output:

$$E\pi = \alpha y - y^2 + \frac{\beta}{k} y - \phi \left( \frac{\beta}{k} \right)^2 - F = 0,$$  \hspace{1cm} (A.1)

$$y(\beta) = \frac{\alpha + \beta / k}{2} + \sqrt{\left( \frac{\alpha + \beta / k}{2} \right)^2 - \frac{\beta^2 \phi}{2k^2} - F}.$$  \hspace{1cm} (A.2)

The use of the upstream activity (i.e., the upstream output) is then $x = zy(\beta)$. The zero-profit condition means that the total surplus is $y(\beta)^2 / 2$. Straightforward but tedious calculations will show that $y(\beta)$ is concave. We get the optimal $\beta$ in (12) by differentiating (A.2) and setting the derivative equal to zero. The expected downstream marginal costs are therefore $c_0 - \beta^*/k$. Inserting (12) into (A.2) and rearranging yields the downstream output in (13); the total surplus in (14) is then $(y^*)^2 / 2$. The upstream output is $zy^*$.

Next, consider a profit-maximising monopolist. Maximising the profits with respect to $y$ given $\beta$ yields:

$$y(\beta) = (\alpha + \beta / k)/2.$$  \hspace{1cm} (A.3)

Gross profits are then $y(\beta)^2$. Subtract $F + \phi \beta^2 / 2k^2$ to get net profits and differentiate with respect to $\beta$ to get (15). The second-order condition requires $\phi > 0.5$, but we know that $\phi > 1$. Inserting (15) into (A.3) yields output. Adding consumer surplus and profits yields the total surplus.

Deriving the Cournot-solution in 3.2: The Cournot-output of firm $i$ when marginal costs differ ex ante is:

However, Kwoka (2006) finds that competition does not strengthen the performance of public firms.
\[ y_i(\beta_1, \beta_2, \ldots, \beta_n) = \frac{1}{n+1} \left( a - zp - nc_o + \sum_{j \neq i} Ec_j + n \frac{\beta_i}{k} \right). \] (A.4)

Its expected profits are:

\[ E\pi_i(\beta_1, \beta_2, \ldots, \beta_n) = \frac{1}{(n+1)^2} \left( a - zp - nc_o + \sum_{j \neq i} Ec_j + n \frac{\beta_i}{k} \right)^2 - \frac{1}{2} \left( \frac{\beta_i}{k} \right)^2 \varphi. \] (A.5)

Note that (A.5) is concave if and only if \( \varphi > 2[n/(n+1)]^2 \) as we have assumed. Maximise and impose ex-post symmetry to get \( e = \beta/k \) as a function of \( p \):

\[ e^v(p) = \frac{\beta^v(p)}{k} = \frac{2n(a - zp - c_o)}{\varphi(n+1)^2 - 2n}. \] (A.6)

Use ex-post symmetry in (A.4) and insert (A.6) to get the industry output:

\[ y^v(p) = \frac{n(n+1)(a - zp - c_o)\varphi}{\varphi(n+1)^2 - 2n}. \] (A.7)

We have assumed that \( x = zy \), so the derived demand for the upstream monopolist's output is

\[ x(p) = \frac{zn(n+1)(a - c_o - zp)\varphi}{\varphi(n+1)^2 - 2n}. \] (A.8)

The upstream monopoly maximises its expected profits \((p-c)x\) or \((p-c)zy\), so the optimal price would be

\[ p^v = \frac{a - c_o + ze}{2z}. \] (A.9)
Inserting into (A.6) and (A.7) then yields $e^V$ and $y^V$, as expressed by (20)-(21). Use (20), (A.8) and (A.9) to get (22), i.e. the total surplus as the sum of the consumer surplus $(y^V)^2/2$, the downstream profits $n(y^V/n)^2$, and the upstream profits $x(p^M)(p^M-c^U)-F$.

Note also that $x(p^M)(p^M-c^U)-F$ must be positive for all finite $n$, although the expression approaches zero as $n$ approaches infinity. This happens because the fixed cost $w = \phi e^2/2$ also tends to zero. As for the total fixed costs in the industry, $nw = n\phi e^2/2$, they also ultimately approach zero, but they increase until $n = \tilde{n} = \sqrt{4-(\phi-1)\phi^2 + (\phi-1)\phi}$, which belongs to the open interval $]2,3[$. It follows that there may be duplication of fixed costs (in the sense that $nw$ increases) as $n$ increases to 2 or 3, but further entry will mean that the $nw$ tends to vanish. In other words, duplication of fixed costs contribute to the adverse effects of entry (see section 4.3) for such small values of $n$. In other words, such duplication takes place only if vertical separation and liberalisation have failed to yield a fragmented market.

**Deriving the solutions for upstream regulation in 3.3:** The presence of upstream regulation does not change the second-order condition associated with an $n$-firm downstream oligopoly, because each downstream firm maximises its profits given the upstream price. The derived demand $x(p)$ is expressed by (A.8). Set $x(p)(p-c^U)-F = 0$:

$$
p^o = \frac{1}{z} \left[ c^U z + \frac{\alpha}{2} - \sqrt{\left(\frac{\alpha}{2}\right)^2 - \frac{\phi(n+1)^2 - 2nF}{(n+1)n\phi}} \right]. \quad (A.10)
$$

To get (24) and (25), insert (A.10) into (A.6) and (A.7).

As for the simplified setting with a weighted objective function, maximise $x(p)(p-c^U)+\lambda y^2/2$ with respect to $p$, use (A.8) and note that $y=x/z$:

$$
p^c = \frac{1}{z} \left[ c^U z + \frac{\phi(n+1)^2 - 2n - \lambda\phi(n+1)n}{2\phi(n+1)^2 - 4n - \lambda\phi(n+1)n} \right]. \quad (A.11)
$$

Insert (A.11) into (A.6) and (A.7) to get (26) and (27).
Proof of Proposition 1: a) Note that the marginal costs are $zc + c_0 - \beta/k$. The results follow directly from the fact that $\beta^* > \beta^M$ according to (12) and (15). Part b) is obvious from (13) and (16). c) Suppose that the reverse is true. According to (14) and (17), this would mean

$$\frac{\phi\alpha^2(3\varphi - 1)}{2(2\varphi - 1)^2} - F > \frac{1}{2} \left[ \varphi \left[ \alpha + \sqrt{\alpha^2 - 2F(2\varphi - 1)/\varphi} \right] \right]^2.$$  \hspace{1cm} (A.12)

Rearranging would then yield

$$\left( \varphi - 1 \right) \left( \alpha^2\varphi^2 - 2F\varphi(2\varphi - 1) \right) > 2\alpha\varphi^2 \sqrt{\alpha^2\varphi^2 - 2F\varphi(2\varphi - 1)},$$ \hspace{1cm} (A.13)

or

$$\left( \varphi - 1 \right) \sqrt{\alpha^2\varphi^2 - 2F\varphi(2\varphi - 1)} > 2\alpha\varphi^2.$$ \hspace{1cm} (A.14)

Taking the square of both sides and rearranging then yields

$$- \left( 2\varphi - 1 \right) \alpha^2\varphi^2 - 2\varphi(2\varphi - 1)(\varphi - 1)^2 F > 3\alpha^2\varphi^4.$$ \hspace{1cm} (A.15)

This cannot be true, because $k>1$ implies $\varphi>1$. The antithesis is therefore false. Q.E.D.

Proof of Proposition 2: a) Set $n=1$ in (20) and (21). As follows from (15) and (20), marginal costs are lower in the integrated monopoly, because the relevant part of the marginal costs equals $c_0 - \beta/k$. Inspection of (16) and (21) shows that $y^M > y^V$. Set $n=1$ in (22) and compare with (17). It follows that $TS^M > TS^V$. Part b) follows directly from the last paragraph of section 3.3. Q.E.D.

Proof of Proposition 3: It is obvious from (20) that a) holds true. As for part b), differentiation of (21) and rearranging shows that output is increasing in $n$ if
\( \varphi > \varphi_1(n) = 2[n/(n+1)]^2 \). However, this inequality is also implied by the second order-condition, so output is increasing in \( n \) if the profit function is concave.

c) To see the impact of a change in \( n \) on the total surplus, differentiate (22) with respect to \( n \) and rearrange:

\[
\frac{dTS}{dn} = \alpha^2 \varphi \left[ \varphi^2(n+1)^2(n+2) - 2\varphi(n+1)n^2(n+6) + 8n^3 \right].
\]

(A.16)

It follows that this derivative is positive if

\[
\varphi > \varphi_2(n) = \frac{n^2(n+6) + \sqrt{n^2(n^3 + 4n^2 + 12n - 16)}}{(n+1)(n+2)},
\]

(A.17)

that \( \varphi_2(n) \) approaches 2.0 when \( n \) approaches infinity, and that \( \varphi_2(n) < 2.0 \) for all \( n > -0.333 \). Any value of \( \varphi \) higher than 2 therefore means that the total surplus is always increasing in \( n \). As for values of \( \varphi \) below 2, note that \( \varphi_2(n) \) is a monotone and increasing (see Figure 1). It therefore is obvious that there exist values \( n^* \) such that \( n^* \) is on one side of \( \varphi_2(n) \) and \( n^* + 1 \) on the other, so that the total surplus is increasing up to \( n^* \) and decreasing from \( n^* + 1 \) onwards. Part c) is thereby proved. Q.E.D.

Proof of Proposition 4: It is obvious from (15)-(16) and (20)-(21) that a) and b) hold true. To understand c), suppose as an antithesis that \( TSM' - TSM > 0 \) (see (22) and (17)). Insert values for \( n \) below 5 into (22) and rearrange so as to get a third-degree inequality in \( \varphi \). It follows that there are then no real values of \( \varphi \) strictly above 1.0 for which the antithesis can hold true. The same applies when \( n \) becomes very large, as follows from comparing (23) to (17). As for intermediate values of \( n \), suppose first that \( \varphi = 1 \). It is then obvious that the antithesis is false if \( n \geq 5 \); the fact that \( \varphi > 1 \) must hold true just reinforces the inequality, because the coefficients for \( \varphi^3 \) and \( \varphi^2 \) are then negative. Q.E.D.

Proof of Proposition 5: a) As follows from (12) and (13), the zero-profit condition for a monopoly has a meaningful solution only if the expression inside the square-root sign is positive. This restricts \( f \) to values below or to the left of the curve \( f_i(\varphi) \) in Figure 2:
\[ f < f_1(\phi) = \frac{\phi}{2(2\phi - 1)}. \] (A.18)

The natural monopoly assumption means on the other hand that \( f \) is too large for two vertically integrated firms to break even. Consider the profit functions of two vertically integrated firms with different marginal costs ex ante and the two-step Cournot equilibrium. It turns out that \( \epsilon = \beta/k = 4\alpha(9\phi - 4) \) and \( y_i = 3\phi\alpha(9\phi - 4) \). Insert these values into the profit functions. It follows that two firms can break even only for values of \( f \) below \( f_2(\phi) \). The relevant area of an upstream natural monopoly is therefore restricted to values of \( f \) above \( f_2(\phi) \) but below \( f_1(\phi) \) in Figure 2, i.e. the area \( A-E \):

\[ \frac{F}{\alpha^2} > f_2 = \frac{\phi(9\phi - 8)}{(9\phi - 4)^2}. \] (A.19)

Suppose now that the downstream activity is separated. It is then obvious from (20), (21) and (26) and (27) that marginal costs are lower and output and the consumer surplus higher in a vertically separated industry if there is also upstream regulation. This holds true in \( A-E \) for all values of \( \lambda \) in the open interval \((0,1)\) and hence also for \( \lambda_0 \).

b) Fragmentation means that \( n \) becomes sufficiently high for downstream profits to vanish. The total surplus associated with upstream regulation when \( n \) becomes very large approaches the consumer surplus:

\[ \frac{\left(y^0\right)^2}{2} = \frac{(\alpha + \sqrt{\alpha^2 - 4F})^2}{8} \], (A.20)

as follows from (25). A comparison with (23) shows that regulation is then superior if \( f = F/\alpha^2 < 0.25 = f_5 \). This must hold true, because the combination of regulation and fragmentation would not otherwise be feasible.

c) Consider now the comparison between regulation with fragmentation as described in 2b above. Compare (A.20) with (17) and rearrange. It follows that such an allocation can outperform the vertically integrated profit maximising monopoly, but only if
so that \( f \) is below or to the right of the curve \( f_4(\phi) \) in Figure 2. This boundary is increasing and approaches 0.25 from below as \( \phi \) becomes very large. It does not intersect \( f_1 \), but it intersects \( f_2 \) in \( \phi = 2.7446 \) and \( f = 0.1070 \). The relevant area is bounded by \( \phi_0, f_2, \) and \( f_3 \). Within this area, \( TS^M > TS^R > TS^F \) holds true in \( D \) to the left of \( f_4 \), and \( TS^R > TS^M > TS^F \) in \( E \) to its right. Q.E.D.

**Proof of Proposition 6:** The fact that marginal costs are lower in the public monopoly than under separation without upstream regulation is obvious from (12) and (20). The fact that welfare is higher follows from Proposition 4 (or from the fact that \( TS^F > TS^* \) can only hold true if (A.18) and (A.19) are contradicted). As for the case of separation and upstream regulation, it is obvious from (12) and (24) that marginal costs are lower in the public monopoly. To understand why welfare is higher in the vertically integrated public monopoly than after vertical separation, competition and upstream regulation, note that the total surplus associated with the welfare maximising public monopoly is expressed by (14). Compare (14) with (A.20) and abbreviate \((2\phi-1)/\phi \) as \( \delta \). The antithesis can then formulated as follows:

\[
\frac{\alpha + \sqrt{\alpha^2 - 2F\delta}}{\delta} < \frac{\alpha + \sqrt{\alpha^2 - 4F}}{2},
\]

(A.22)

It is obvious that \( \delta < 2 \), so the numerator of the expression to the left in (A.22) is larger and the denominator smaller. The antithesis is therefore false. Q.E.D.

**Deriving the solutions in section 5:** The expected profits of a vertically integrated firm is

\[
E\pi = Ay - y^2 + zey - F_0 - \frac{\phi}{2} e^2.
\]

(A.23)
Maximising the total surplus or the consumer surplus with respect to $y$ and $e$ subject to the constraint $\sum \pi = 0$ then yields (32) and (33). Maximising (A.23) with respect to $y$ yields $y(e)$; inserting into (A.23) and maximising with respect to $e$ yields (35). Inserting (35) into $y(e)$ yields (34).

Vertical separation and Cournot-competition downstream would mean that each firm maximises

$$\pi_i = ay_i - yy_i - zpy_i - eDy_i,$$

so the total downstream output would be:

$$y(n, p) = \frac{n(a - zp(x, n) - eD)}{n + 1}.$$  \hfill (A.25)

Use the fact that $x = zy$ and solve for $p$ to get the derived upstream demand function:

$$p = \frac{a - eD}{z} - \frac{n + 1}{nz^2}x.$$  \hfill (A.26)

The upstream expected profits are then:

$$E\pi = \left(\frac{A}{z} + e\right)x - \frac{n + 1}{nz^2}x^2 - F_0 - \frac{\phi}{2}e^2.$$  \hfill (A.27)

Maximise with respect to $x$ to get $x(e)$ and insert into (A.27) to get the maximum profits as a function of $e$:

$$\pi(e) = \frac{n(A + ze)^2}{4(n + 1)} - F_0 - \frac{\phi}{2}e^2.$$  \hfill (A.28)

Maximising yields (37). Inserting into $x(e)/z$ yields (36).

As for upstream profits, inserting (37) into (A.28) yields:
\[ \pi^C = \frac{n \varphi A^2}{2(n + 1) \varphi - nz^2} - F_0. \]  

(A.29)

The fact that both (37) and (A.29) are increasing in \( n \) implies that the total surplus is also unambiguously increasing.

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Figure 1. The impact of increased competition on welfare in a vertically separated market
Figure 2. A comparison of vertical separation, competition and upstream regulation with an integrated upstream monopoly.
Table 1. The relationship between total surplus and competition for different values of $\varphi$.

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