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Efficient Price Regulation of Networks that have Sunk Costs: should caps be based on historical or replacement cost?

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Note: This is a simpler version of the paper *Dynamically-Efficient Incentive Regulation of Networks with Sunk Costs (2002b)* by the authors and available from them. It does not include the detailed specifications and proofs of that paper.

Summary Discussion

Incentive regulation allows decentralised decision-making under regulatory settings that are based upon industry characteristics. This study considers the design of regulatory profit caps and the choice of historical or replacement cost for incentive regulation when there is uncertainty, sunk costs, and flexibility in the timing of investment. It demonstrates that which of historical or replacement cost regulation is desirable depends upon the sources and extent of supply and demand uncertainties and trends, and thereby characteristics of the industry. The welfare optimising level of the cap differs between historical and replacement cost regulation, the caps are generally higher than the weighted average cost of capital, and welfare is degraded much more if the cap is set below, as opposed to above, the optimal cap.

In the presence of uncertainty and sunk costs investment thresholds that exceed the standard WACC are required to enable investment. The WACC just reflects systematic risk. It does not reflect the probability of bankruptcy or idiosyncratic risks that firms prudently consider when making investment decisions. From society's point of view the WACC is frequently too low to act as an investment hurdle rate. In practice, hurdle rates are often distinctly higher than equity holders' average rates of return and much higher than return on debt.

We have considered a situation where the firm has no competition. The presence of competition will generally mean that firms' investments are desirably timed from society's point of view, although investment will not occur immediately.

The imposition of a cap to improve welfare may, if it is too tight, reduce welfare substantially, even relative to the situation of no regulation and no competition. It arises because investment is delayed. In such circumstances the regulator may respond by removing scope for decentralised investment by forcing investment, or reaching some regulatory pact with the firm. It is easy to show that such regulation does not remove the issues of specific risks, and timing considered in this paper: they are intrinsic to the industry. Unless the regulator agrees to pick up the costs of risks – eg the costs of stranded assets – a reasonable rate of return under regulatory investment requirements should cover the real options that these risks imply.

We have focussed on encouraging the optimal timing of sunk investments. While the approach has been cast as provision of the entire network the same approach applies to maintenance of an existing network that is also sunk. Unless maintenance expenditure is allowable in line with the optimal caps considered in this paper, networks may deteriorate or require forced maintenance by regulation. The issues are the same.

Introduction

This paper examines societal welfare produced by regulated firms that have a significant proportion of their costs generated by irreversible (sunk) investment. While the extent to which investment in networks is sunk is arguable (see Hausmann (1998) and Economides (2000) for the debate)[1], it is widely accepted that much investment in physical networks is sunk because it has a specific application and because once in place is very expensive to recover for use elsewhere. The uncertainty attached to network costs and demand varies across industries. Irreversibility implies that the value attached to waiting is a critical determination of the optimal time to invest. In this paper we examine the effect of an imposed profit-cap, on the timing of investment. It considers both the form of the cap and whether it is applied to historical cost or future best-practice cost estimates of the network. The regulation is dynamically efficient if it produces the largest (present value) of the sum of producer and consumer gain (welfare) to the indefinite future.

Our setting is regulation within the context of decentralised firm investment decision-making. It presumes that the only instrument of regulatory policy is the profit cap. There are three points to be made about such an environment. First, the approach is in the spirit of most forms of incentive price regulation and rate-of-return regulation. [2] Incentive regulation can be viewed as a weak form of rate-of-return regulation. In the latter prices are set on the basis of a revenue requirement generated by actual, or estimated, production costs and a regulatory-chosen rate-of-return. Incentive regulation is weaker in that profits are allowed to exist without the regulator adjusting the cap over intervals of time, but ultimately the determination of the level of the cap is revised and a significant input to the revision is some indicator of profitability. Our approach is the pure form of incentive regulation where the cap is entirely determined by the fundamental demand and supply characteristics of the industry.

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1 Hausmann (1998) argues that because of their sunk costs telecommunications network cannot mimic a contestable market but must be competitively imperfect and criticizes the ECPR rule of Baumol on that basis. It does not compare replacement and historical-cost regulation, but does consider aspects of replacement-cost price setting.

2 The profit cap could be replaced with a revenue, even price, cap without altering the qualitative features of our results under certain conditions.

Incentive, rate-of-return and central-government dictation lie on a continuum of increasing centralised control: from decentralised to centralised decision-making. Along this continuum the regulator increasingly assumes responsibility for investment and cost control: in tandem, principal-agent issues arising from asymmetric information, moral hazard, a concentrated decision-making view of the future and of consumers' demands all increasingly affect the performance of the industry. Our approach allows entirely de-centralised decision-making subject only to a profit cap that is designed to maximise societal welfare by the level of the cap and by its application to historical cost or future best-practice costs. In fact, under incentive regulation and, more so, under rate of return regulation, investment is significantly influenced by the regulator. Regulatory prescription of investment that firms may not otherwise have carried out has precipitated the phenomenon of stranded assets that have so constrained de-regulation and the adoption of technological advance in electricity and telecommunications in the USA – the home of rate-of-return regulation - since the 1970s (Spulber (1989), Sidak and Spulber (1997)). The extent to which the regulator's influence on investment is driven by a regulatory view of appropriate types of investment or by a perceived need to undo the effect of regulatory constraints on de-centralised investment decision-making is arguable. In our paper the profit cap allocates the total surplus generated by the relevant market between the firm's shareholders and consumers but it does not affect the size of the surplus. Social welfare is affected by the timing of investment. We do not specifically consider issues of divergence of firm and regulator actions made available by asymmetric information holdings between the firm and the regulator or allow the regulator to dictate investment. The effect of consumer and economic welfare of mis-timed investment or product adoption is often very substantial and we examine this independently of other regulatory issues.[3]

Thirdly, our approach treats uncertainty explicitly. Uncertainty stemming from both systematic risk and industry-specific idiosyncratic risk properly affect investment decisions and these are jointly considered in our model. The standard approach is for systematic risk to be reflected in the calculation of a firm's weighted average cost of capital (WACC). However, systematic risk is but one element of risk that investment

[3] Goolsby (2000) makes the point that the welfare cost of delayed investment may be very high especially where new products are being introduced. The cost arises because, in contradistinction to existing products, delayed investment results in a "missing market" where all consumer and producer surplus is "missing".

decisions must factor in if they are to enhance social welfare. To ignore industry-specific risks is to ignore a firm's inputs to investment decision-making and thereby important factors determining investment. It is rational and socially desirable for investment to recognise these sources of uncertainty because of the economic costs of getting the timing of investment wrong and the potential downside of investments; including, the costs of bankruptcy. Our model suggests that demand and supply uncertainty are critically important in setting the level of the profit cap and in the choice of historical or future costs. Indeed, these industry-specific characteristics determine which of these cost-bases should be chosen, and which should be chosen affects the extent to which systematic risk should be incorporated in the design of the cap.

Our findings are that, if a regulated firm has flexibility in timing of investment, regulating it utilising as an input historical or replacement costs induce some delay in investment. For some levels of the cap utilising as an input historical (backward looking) cost can lead to earlier investment than the unregulated case, but only if replacement cost is expected to fall and/or is significantly negatively correlated with changes in the welfare surplus produced. Otherwise, backward-looking regulation also leads to later investment. We conjecture telecommunications – with rapid technical change producing future cost uncertainty and cost reductions correlated with gains in consumer welfare – is more a candidate for historical-cost regulation than are more technologically stable industries such as gas and electricity transmission. In the presence of expected inflation replacement cost regulation is likely to achieve earlier investment at the same profit rate cap. We show that the systematic risk component of the profit-rate cap differs between backward and forward looking regulation and that the welfare effect of the cap is strongly asymmetric: setting the cap below the optimal level produces a much greater degradation of welfare and consumer performance than does setting the cap too high. We also note that the company's WACC will generally be affected by the profit cap, and our examples reveal that the welfare-maximising level of the caps is generally higher than the companies' WACCs. This is consistent with evidence about investment hurdle rates that companies adopt.

Our approach is closest to Guthrie, Small and Wright (2001) which is the only other formal analysis of this issue that we are aware of. That paper considers setting cost-based access charges for a network whose cost is uncertain. The profit and consumer surplus flow from that access charge is known. Guthrie, Small and Wright's broad conclusion is that historical cost is preferred on welfare grounds to replacement cost in most situations. Only when replacement cost is expected to rise with little uncertainty is it likely to be preferred as it induces earlier investment. Our paper differs from Guthrie, Small and Wright in respect that it incorporates uncertainty in both network cost and the economic surplus to be divided between the firm and consumers. Our different results stem in large part from the importance of the correlation between this surplus (welfare) and costs, but they are affected by other characteristics of the market as well.

The Set-up

Although formal proofs are omitted in this paper, the results and their interpretation depend upon certain factors that have to be expressed as parameters to enable their effect to be explained.[4] Readers who are less interested in the basis of the approach may wish to skip this and the next section.

The cost of the network and the economic surplus it generates are both subject to random shocks. Network costs are presumed to be generated by a relationship[5]

$$k(t) = k(\square_k, \square_k, \square_t)$$

where $k(t)$ is the cost of the network at date t,

$\square_k$ is the average change (trend) in the cost of the network in a short interval of time at date t,

$\square_k$ is the standard deviation of the random shocks that affect the capital cost at date t, and

$\square_t$ is the random shock to costs at date t.

To this is added a depreciation rate $\square$ which represents the probability that the network becomes redundant in any short period of time. This approach essentially

4 The formal proofs are contained in Evans and Guthrie (2002b).

5 The exact relationships are specified in Evans and Guthrie (2002b).

means that $1/\lambda$ is the expected life of the network. At the date the network expires the firm may replace it on the same criterion as it invested in the first instance. A network built at date *T* has cost $k(T)$ and once established this cost is sunk: that is, the investment is irreversible.

The other relationship we need to specify is the production of economic surplus. Economic surplus may be interpreted as the aggregate of producers' and consumers' surplus. It is presumed to be generated by the process

$$s(t) = s(\mu_s, \sigma_s, \varepsilon_t)$$

where $s(t)$ is economic surplus,
μ_s is the average change (trend) in this surplus in a short interval of time at date t,
σ_s is the standard deviation of the shocks to the economic surplus at time t, and
ε_t is the random shock to the surplus at date t.

In sum, network costs are subject to a trend over time and shocks. Networks depreciate over time once installed. The shocks represent sharp, largely unpredictable, changes in the costs of constructing a network and technical change. Economic surplus evolves over time with a trend and random shocks. These shocks can represent sudden gains in surplus generated by welfare-enhancing technical change. They arrive independently over time but once appear they have persistent effects over time. We presume that the profit component of the surplus is the amount $\theta s(t)$ where $0 < \theta < 1$ is the share of surplus that is profit. Consumers' surplus is therefore $(1 - \theta) s(t)$.

There are two relationships between network costs and economic surplus. The first is that there can be no surplus with no network. Economic surplus starts at the date of installation of the network. Put another way, if at date *T* the network is installed then cost *k(T)* is incurred and sunk, and economic surplus starts to flow. Secondly, the random shocks of costs and economic surplus may be correlated: denoted by ρ_{sk}. Positive correlation might arise with technological enhancements that are costly so costs and welfare both rise. If the enhancements lower costs and at the same time enhance the welfare yielded by the network the correlation, ρ_{sk}, will be negative.

We consider two forms of regulation. Backward-looking, or historical cost, regulation describes the case where the regulator places a cap on profits determined by the profit cap rate $\square_{hc}$ applied to the cost of the investment at the date it was installed. For investment at date *T*, actual profit under this regulatory scheme is the smaller of the actual profits or the cap as[6]

$$\square^{b}_{T+t} = \min\{profits, cap\} = \min\{\square s(T+t), \square_{hc} k(T)\}$$

In the second form of regulation the regulator applies a cap that is the product of a profit cap rate, $\square_{rc}$, and the replacement cost of the network. In this case at time t profits are given by the smaller of actual profits and the cap based on the replacement cost of the network, as

$$\square^{f}_{T+t} = \min\{profits, cap\} = \min\{\square s(T+t), \square_{rc} k(T+t)\}$$

We evaluate these schemes by comparing their present values of total economic surplus and of consumers' surplus. It requires specifying the investment decision of the firm in general and under the regulatory schemes. Thus we need to value future flows of profit and economic surplus. In order to do this we apply risk-neutral pricing (see Cochrane s. 3.2, 2001) in which we discount the expected profit and economic surplus flows at the risk free interest rate where these flows are adjusted by risk premia suggested by the correlation between profit (costs) and economic surplus and traded assets. In particular, suppose that the expected return of an asset perfectly correlated with network costs is $r + \square_k$ and that with economic surplus is $r + \square_s$, where *r* is the real risk-free interest rate and the $\square$ are the risk premia that may be determined by equilibrium asset pricing models such as the capital asset pricing model (CAPM). If we re-define the processes

$k(t) = k(\square_s \square \square_k, \square_s, \square_t)$ and
$s(t) = s(\square_s \square \square_s, \square_s, \square_t)$

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[6] The censoring of profit by the imposition of the upper limit is incorporated in our model. Its effect on the determination of a reasonable rate of return is considered by Hausmann (1998, 4).

we can discount at the risk free rates .

It is tempting to regard some combination of the $r + \square$ expressions as the WACC in our set-up. In fact, as we shall see the WACC is affected by whether it is historical or replacement cost regulation and the level of the profit cap. To anticipate following discussion, we shall take the risk adjustment on costs as zero and $r + \square_s$ as indicating the unregulated firm's WACC.

Given the form of the processes that produce the cost of the network and economic surplus, the decision variable for the firm and for the social planner that is seeking to set regulations that maximise social welfare is the ratio of total surplus to network cost, $y(t) = s(t)/k(t)$. The social planner would invest as soon as

$$s(t)/k(t) > y^* = \tfrac{\square_3}{1\square\square_3}(r + \square_s + \square\square\square_s)$$

where $\square_3$ is a complicated function of all parameters of the model. The unregulated firm would invest as soon as

$$\square s(t)/k(t) > y^* = \tfrac{\square_3}{1\square\square_3}(r + \square_s + \square\square\square_s)\,.$$

First, note that the social planner will not invest immediately, It may obtain a higher economic surplus by waiting: indeed, it will wait until $y(t) > y^*$. Waiting may yield a higher surplus depending upon technological shocks that affect cost and economic surplus either separately or through their correlation. The firm will base its decision on profits, not total economic surplus, and so will invest later than the social planner. Because they face the same costs they will invest at different times.

The social planner will not invest if the present value of the flow of total surplus is less than the cost of building the network. Furthermore, if the investment was a "now or never" proposition the social planner would invest if $s(t)/k(t) > (r + \square_s + \square\square\square_s)$. We see from this and y^* that the flexibility to delay investment is utilised by the planner (and the firm). The cost of the delay is that society does not receive the flow of total surplus until some later date. This opportunity cost must be balanced against the value of waiting. Delaying investment decisions may enable investment to be timed when construction cost has fallen and/or the flow of surplus has increased in which case investment would occur on more favourable terms, equivalently the pay-off to society will be higher. In the event the flow of surplus actually falls and/or the cost of building rises investment can be further delayed. This asymmetry produces unlimited upside, and limited downside, potential from delay. Investment will only occur when the opportunity cost of delaying investment exceeds the expected payoff from delay. Thus $z = \frac{\beta_3}{1 - \beta_3} > 1$. Dixit and Pindyck (1994,153) argue that z may be as high as 2. This argument also applies to the firm, but with respect to the profit component of economic surplus.

The firm will delay investment longer than the social planner in our model, but this result reflects our standard regulatory assumption of a single non-contested firm. Where there is competition the firm may invest earlier, indeed, at the right time from society's point of view.[7] In the absence of competition the regulator seeks to induce the firm to invest earlier.

The Effect of Regulation on the Firm's Investment Decision

First, we consider the investment policy of the firm when it is regulated on the basis of replacement cost. As described, when investment occurs at date T the firm's profits are $\pi^f_{T+t} = \min\{\theta s(T+t), \rho_{rc} k(T+t)\}$ when regulated on the basis of replacement cost. In this case the firm invests when

$$s(t)/k(t) = y(t) > y^* = \beta_3 (g_{fl}(y^*) - 1)/g'_{fl}(y^*).$$

where y^* is defined implicitly and $g_{fl}(y)$ is the present value (discounted at $r + \lambda_s + \delta$) of expected profits when the regulatory cap is non-binding, plus the present value of profits (discounted at $r + \lambda_k + \delta$) when the regulatory cap is expected to be binding. Note that profits fixed at the cap will be discounted with a risk premium, and that this complicates calculation of the WACC. Given our earlier definition of the WACC, the term $r + \lambda_s + \delta$ is the unregulated WACC adjusted for

7 See Dixit and Pindyck (1994, pp. 282-284)

depreciation. The $\square_s$ appears in discounted expected unregulated profits because of the systematic risk that attaches to the economic surplus and thereby profits. The $\square_k$ appears in discounting when the cap is binding because whether the cap is binding depends, under the replacement valuation, on cost shocks whose systemic risk is given by $\square_k$.

Under historical-cost regulation profits are $\square^l_{T+t} = \min\{\square s(T+t), \square_{hc} k(T)\}$ and the policy of the firm is to invest when

$$s(t)/k(t) = y(t) > y^* = \square_3 (g_{bl}(y^*) \square 1)/g_{bl}^{'}(y^*)$$

and $g_{bl}(y)$ is the present value (discounted at $r + \square_s + \square$) of expected profits when the regulatory cap is non-binding, plus the present value of profits (discounted at $r + \square$) when the regulatory cap is expected to be binding. The term $r + \square_s + \square$ is the unregulated WACC adjusted for depreciation. Again the $\square_s$ appears in the discounted of expected unregulated profits because of the systematic risk that attaches to the economic surplus and thereby profits.

The firm's investment policy under backward-looking, or historical, cost differs in two ways from forward-looking, or replacement cost, regulation. Firstly, $\square_s$ does not appear in discounting when the cap is always binding[8] under historical cost regulation because after the investment the cost, and hence the profit cap, is certain and therefore known: a fundamentally different situation from replacement-cost regulation. Secondly, the likelihood that profits, if they were not regulated, exceed the cap is unaffected by the stochastic process that affects costs. In short, the level of the price cap is affected by the fact that the systematic risk component relating to cost does not enter the firm's investment policy under historical-cost regulation although it does do so under replacement-cost regulation.

The WACC plays such a role in investment and in regulatory price setting that it deserves further comment. The WACC consists of the risk free rate, *r*, and a mark-up, $\square$, that, if determined by the CAP model, depends upon the market rate of return

[8] It will appear in the WACC if the cap is not always binding.

of equities and the “beta” of the firm representing the correlation between the market return and that of the firm’s cash flows. [9] Before the unregulated firm invests its *ex ante* WACC consists of r and some combination of $\square_k$ and $\square_s$ because its prospective cash flows depend upon both costs and profits. However, once investment has been under-taken costs are sunk and cash flows depend only upon correlation of profit, and hence economic surplus, with the market. Thus we take $r + \square_s$ as the WACC of the unregulated firm. The WACC of the historical-cost regulated firm may be lower than this because costs are fixed and the profit cap may reduce correlation of profit with the market.[10] Under replacement-cost regulation the co-variation of costs, economic surplus and the equities market remain and so the relationship between the regulated and unregulated firm’s WACCs is not clear although it is likely to be bounded by $r + \square_k$ and $r + \square_s$.[11]

Finally, we note that historical-cost regulation entails applying a revenue-requirement cap on historical cost, not depreciated historical cost. Although depreciation may welfare-optimally affect the level of the profit-rate cap, this cap is not applied to the depreciated value of the asset.

Regulatory Comparison and the Bad News Principle

The key insight for the comparison of replacement-cost and historical cost regulation is provided by the so-called bad news principle of Bernanke (1983). Applied to our problem it means that the profit flow at the time of investment must be sufficient not only to compensate the firm for its investment of capital in the network, but also for any bad news that may arise following the (irreversible) investment decision. In our set-up the bad news can take two forms: a fall in network replacement cost, or economic surplus and hence profit. With a reduction in network cost the firm would sooner have delayed investment, with the fall in profits it may wish it had not invested at all. The situation is depicted in Table 1.

9 We ignore taxation.

10 We assume that depreciation is uncorrelated with economic surplus and the market.

11 Application of the standard calculation of the WACC is further complicated by the fact that our model enables random (steady) changes in relative prices, for example, via different shocks (trends) in surplus and cost. Where such changes imply an inflation rate it should be incorporated in the nominal interest rate, r. But the inflation rate is not well defined when relative prices are changing because any index depends upon its purpose.

Capping profit according to the network's replacement cost alters the potential for bad news to affect a firm that has invested in the network. Unregulated, the firm just gets two categories of bad news from negative random shocks to costs and economic surplus.[12] The effect of replacement-cost regulation is to extend the potential for bad news: lower costs lower profits as well, through the effect of the lower replacement costs on the profit cap. The effect of the cap on profits is to lower the present value of expected profits, and when this is combined with the cap being determined by replacement cost the source of bad news is extended. Some good news becomes bad news, and all bad news becomes worse. Expected potential for bad new is made worse and the effect of replacement-cost regulation is to incentivise the firm to delay investment beyond that which it would carry out if unregulated.

Table 1: Profit cap and the bad news principle

Regulation	Event	Cost of Project	Profit Flow
Unregulated Firm	Cost reduction	Bad news	------------
	Ec. Surp. reduction	-------------	Bad news
Regulation	Cost reduction	Bad news	Bad news
Replacement cost	Ec. Surp. reduction	-------------	Bad news
Regulation	Cost reduction	Bad news	Good news
Historical cost	Ec. Surp. reduction	-------------	Bad news

Notes: the Table classifies shocks to network costs and economic surplus as either good or bad news for a firm that has already invested in the network. News can affect the replacement cost of the network and the present value of profit produced by the network.

Historical-cost regulated firms are in a different position. For them, lowered costs are a mixed blessing. A firm could have invested at lower cost had it delayed construction, however, this potential bad news is tempered by the fact that had it delayed investment it would have been subject to a lower profits cap. This reduces

[12] It may seem that we are treating the cost and profit shocks as though they are independent whereas we allow the possibility that the two are correlated. In fact, in the discussion of the bad news principle we are referring to realised shocks and, although the correlations will affect the probability of joint occurrences and their likely magnitude, it does not affect our discussion of this principle.

the bad news from a reduction in replacement cost.[13] A potential downwards shock to economic surplus is bad news and, as with the unregulated case, it may be lowered to the extent that the network cannot provide an adequate return on the network investment. The cap on profits exacerbates the adverse effect of downwards shocks to demand (economic surplus). In sum, regulating according to historical costs worsens the bad news relating to economic surplus shocks, but reduces the severity of cost shocks.

The effect on the timing of investment relative to the unregulated firm is ambiguous. It depends upon the correlation between economic surplus and cost shocks. If these are negatively correlated lower (higher) costs will be associated with higher (lower) profits thereby augmenting the importance of the profit effect on bad news. Thus, historical-cost regulation does an especially good job of reducing the bad news of downwards cost shocks when the shocks to cost and economic surplus are negatively correlated. Under this form a regulation the firm will be relatively happy that it has locked in the higher cap by investing early since otherwise much of the gain from the higher than expected surplus would have been lost.

If the shocks are positively correlated lower (higher) costs will be associated with lower (higher) profits and the high cap associated with being locked in early is of little use since the new lower surplus means that the cap may not even be binding: in which case locking in a high cap early may not be of much benefit. In this case historical-cost regulation might do little to reduce the severity of bad news received by a firm that invested early.

The news, whether good or bad, is not cumulative in our set-up: it arises independently in each period.[14] If the shocks are negatively correlated under historical cost regulation the two sources of profit news are likely to be either both

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13 The effect is likely to be greatest for intermediate values of the profit cap rate cap $\square_{hc}$. When $\square_{hc}$ is very large the cap will seldom be binding and the reduction in present value from a lowered cost lowering the cap may be small. Conversely, when $\square_{hc}$ is small the cap will bind more often but profits are capped tightly and the reduction in present value may be small. At intermediate levels the cap will bind often enough for the reduction in the cap ($\square_{bl}$ times the reduction in capital cost) to have a significant effect.

14 Although the news arrives independently over time it may have long-term effects because the effect of the news persists.

good, or both bad. When averaged across all potential outcomes the potential for bad is lessened. When shocks are negatively correlated, historical-cost regulation has the effect of reducing the potential for bad profit news, and investment occurs sooner as a consequence.

We conclude that the relative merits of the two regulatory schemes are likely to depend upon characteristics of the industry. For example, characteristics such as: is technical change of such a nature that depreciation is high or shocks to costs and economic surplus are important and correlated in some way. In general, the sizes of the two profit-cap rates, $\square_{bl}$ and $\square_{fl}$, are affected by most of the factors we have listed, but the effects are so complicated that they can only be illustrated by means of numerical analysis.

Comparison: Welfare and Consumers' Surplus

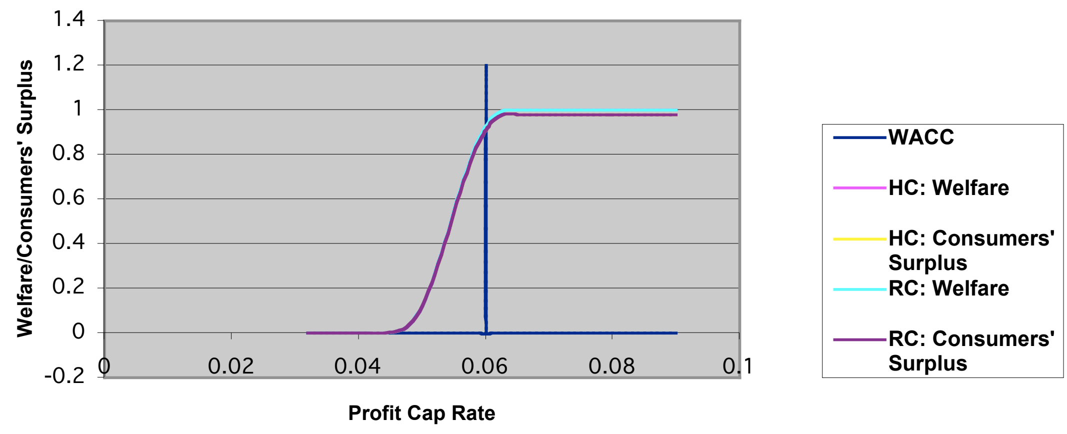
We use numerical analysis to show the relationship between welfare and consumers' surplus and profits for historical- and replacement-cost regulation. In doing this the profit requirement caps that are welfare or consumers'-surplus maximising will be depicted.

We have already shown that the allowable profit-requirement cap for backward-looking regulation is fundamentally different from that which is applicable to replacement cost regulation. As we shall see, there is no reason why these caps should be the same even if they maximise welfare under the schemes. But for the particular case $\square_k = \square_k$ and $\frac{\square_{sk}\square_s}{\square_k} = \frac{1}{2}$ - where the risk neutral process for capital costs has no trend, and the random shocks to economic surplus and network costs are positively correlated – any cap produces the same present value of welfare. A trend in capital costs is likely to affect the qualitative effects of historical- and replacement-cost regulation as well as the magnitude of the profit-requirement caps. It is interesting that caps will not imply the same present value of welfare if there is negative correlation between the economic and cost shocks: precisely the circumstances in which bad news may be ameliorated under historical-cost regulation.

Table 2: Baseline specification

Parameter	Cost		Economic Surplus
Trend (Drift)	$\square_k = 0.0$		$\square_s = 0.0$
Volatility (standard deviation)	$\square_k = 0.05$		$\square_s = 0.05$
Shock Correlation		$\square_{ks} = 0.5$	
Risk Premium	$\square_k = 0.0$		$\square_s = 0.02$
Risk Free rate of Interest		r = 0.04	
Depreciation	$\square = 0.0$		
Unregulated Profit (share of surplus)	$\square = 0.3$		

Figure 1: Comparison of Historical- and Replacement-Cost Regulation: The Base Case

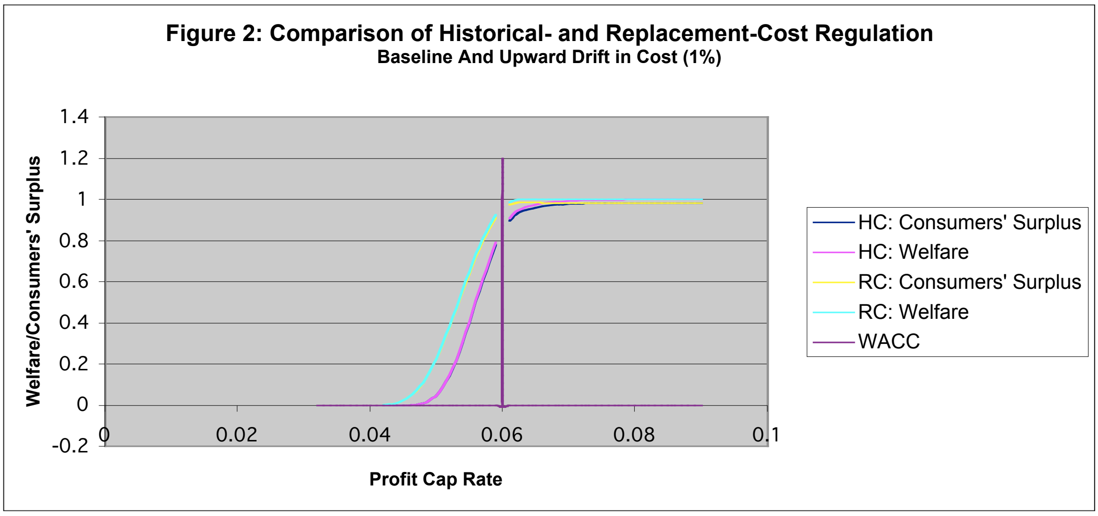


We conduct our comparisons as variations of the base-case specified in Table 2. The base case outcomes are depicted in Figure 1 where the expected present value of each of welfare and consumers' surplus are presented as a function of the profit-rate caps. The baseline meets the requirements of identical outcomes under the two regulatory schemes and this is reflected in the concomitant graph. The welfare and consumers' surplus of historical-cost (HC) and replacement-cost (RC) regulation are identical. Investment will never take place if the cap is held to the risk free rate and as the cap is raised welfare rises with the potential of early investment to the level of the unregulated case indicated by the welfare index of 1. Welfare and consumers' surplus are very close and so the present value of expected profit is low. These results depend upon the characteristics of the industry of the base case. The graph does indicate two results that are standard in all our examples.

The first is that the welfare-maximising profit cap rate is greater than the WACC of an unregulated firm. Thus our earlier result for the unregulated firm carries over to the case of welfare-maximising profit-cap regulation. It stems from the fact that the option value attached to waiting implies an opportunity cost of investing and a higher investment trigger than the WACC, and it holds no matter whether the regulation is based upon historical cost or replacement cost.[15] As pointed out in a previous section, even a welfare-maximising social planner would not choose the WACC as its investment threshold, but rather some larger figure.

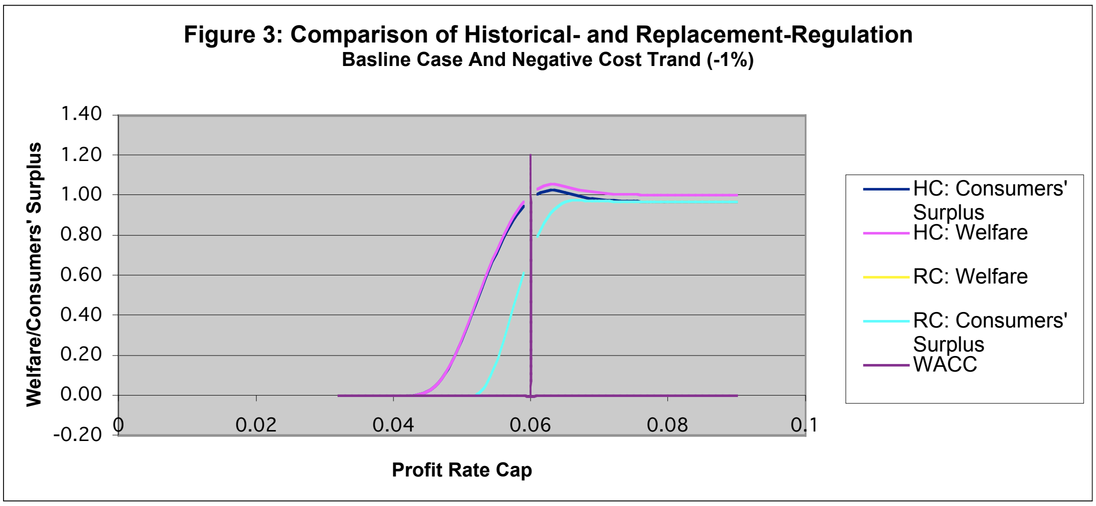
The second general result revealed by the base case is that welfare and consumers' surplus are quite asymmetric in the level of the profit-rate cap. It reflects the fact that without investment the market is "missing" and this carries a huge welfare cost. It corresponds to "missing" new innovations and services. The welfare and consumers' surplus loss associated with setting, say, a threshold 20% below the welfare-maximising rate is very much larger than the welfare cost of setting the rate 20% higher. Figure 1 depicts a case where nothing is lost by setting the rate higher than need be, whereas setting the rate at the unregulated firm's WACC or below so impedes investment that welfare and consumers' surplus fall markedly.

[15] Note that in order to achieve the WACC the cap would have to be higher than the WACC if the cap was not always binding.

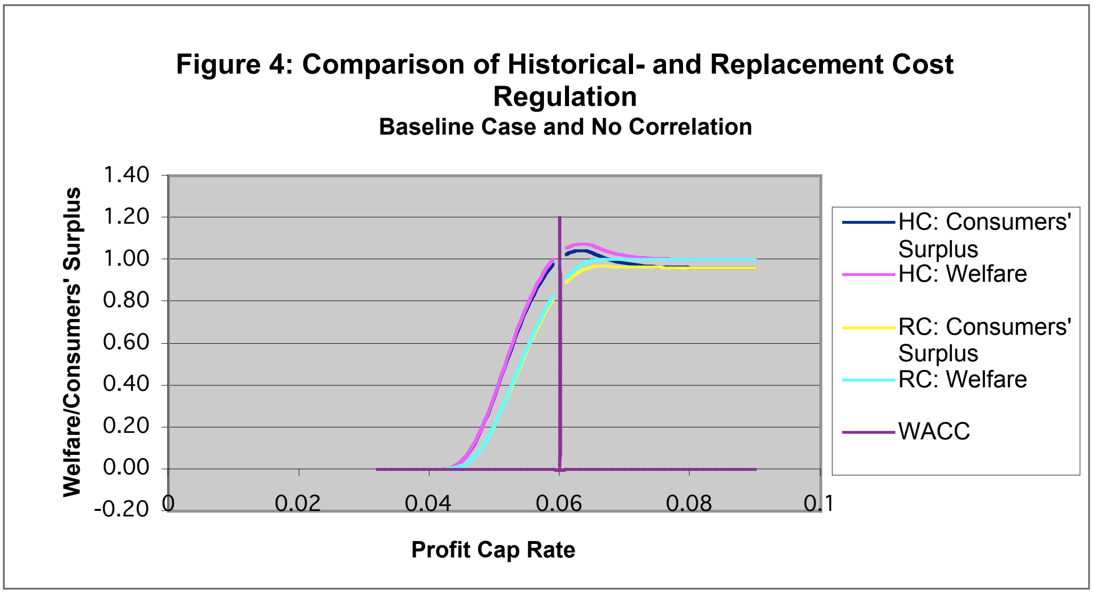


We next vary the assumption of no trend or drift. Figure 2 depicts the welfare and consumers' surplus that emanates from historical-cost regulation and replacement-cost regulation. At the baseline case for all other factors, Figure 2 shows that where there is a positive drift in costs replacement-cost regulation does at least as well as historical-cost regulation. It out performs the latter, over some range, although it does not produce a higher global maximum of welfare. It indicates that the ranking of historical- and replacement-cost regulation depends upon the characteristics of the industry as represented by the parameters of Table 2. Figure 2 reinforces consistent themes. The welfare-maximising profit-rate cap for each form of regulation exceeds the WACC and welfare and consumers' surplus are very sensitive and asymmetric in the effect of deviations for the optimal profit rate.

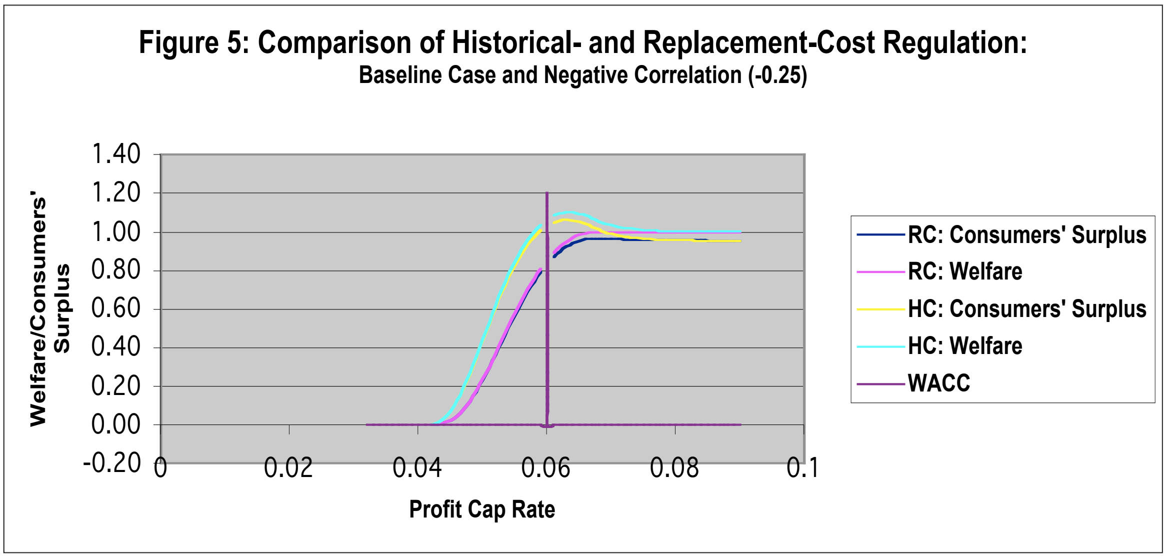
The second case we consider is the baseline for all characteristics except the cost trend that we set at –1% per period. The outcome is depicted in Figure 3. The change in trend has predicated a change in the relative desirability of the schemes. With the higher probability of lower costs in the future, the ability to lock in a higher cap under historical-cost regulation benefits the firm but also induces earlier investment that is in the interest of profits and social welfare. In this case historical cost regulation produces a higher level of welfare than replacement-cost regulation or the unregulated firm. The associated welfare-maximising profit-rate cap is higher than the WACC, and the optimal replacement-cost regulatory rate is higher yet again. The results continue to exhibit the point that setting a profit-rate cap that is lower than the optimal rates can be very costly to social welfare. In this case there is a very narrow range of profit-rate caps above the optimal one for which there is any difference between the two schemes.



In Figure 4 we show the effect of zero correlation between the random shocks of network costs and economic surplus, where the other characteristics take their baseline values. It has the same qualitative features as Figure 2.



In Figure 5 we show the outcome of the baseline case adjusted to have negative correlation between the random shocks to network costs and economic surplus. It has a slightly more pronounced maximum than the case of positive or zero correlation, and it occurs under historical-cost regulation. These outcomes for negative correlation are in accord with our earlier conclusion that the effect of negative correlation is to diminish the import of bad news under historical-cost, but



not replacement-cost regulation. The qualitative characteristics of the other solutions also arise here: the asymmetric loss arising from mis-setting the profit-cap rate and the greater than WACC optimal threshold are present, as is the fact that the optimal profit-cap rate is higher under replacement-cost regulation.

The effect of changes in the variation of economic surplus on welfare is shown in Figure 6. If the volatility of the surplus is large replacement-cost regulation dominates historical-cost regulation and the optimal profit cap is considerably above the WACC. Alternatively, if the variance is low the optimal cap shrinks closer to the WACC and historical-cost regulation becomes preferable. Tightening the variation in economic surplus has a similar effect to reducing the correlation between surplus and capital costs.

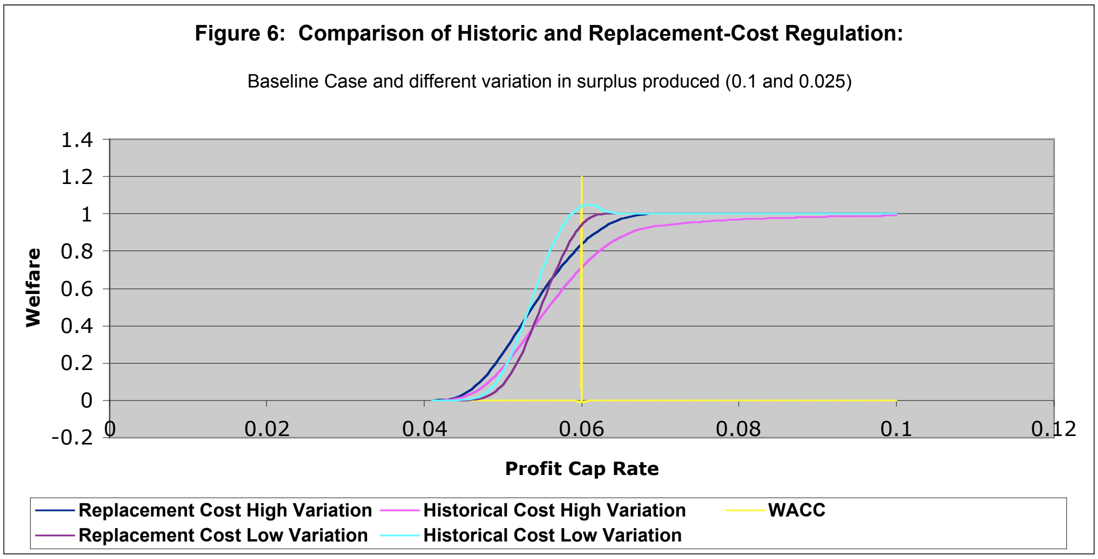
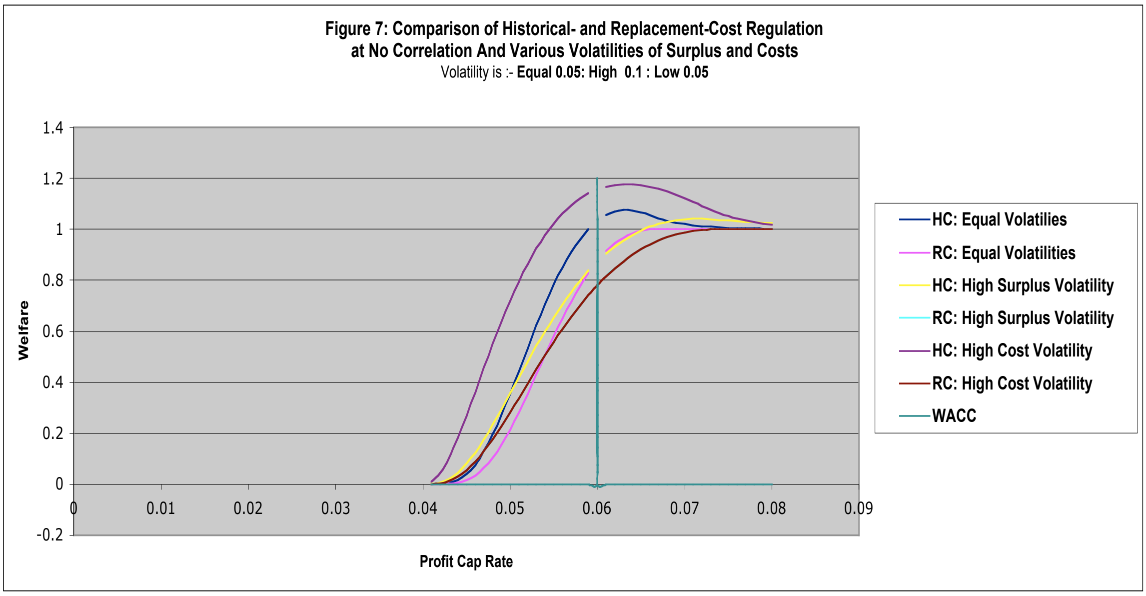
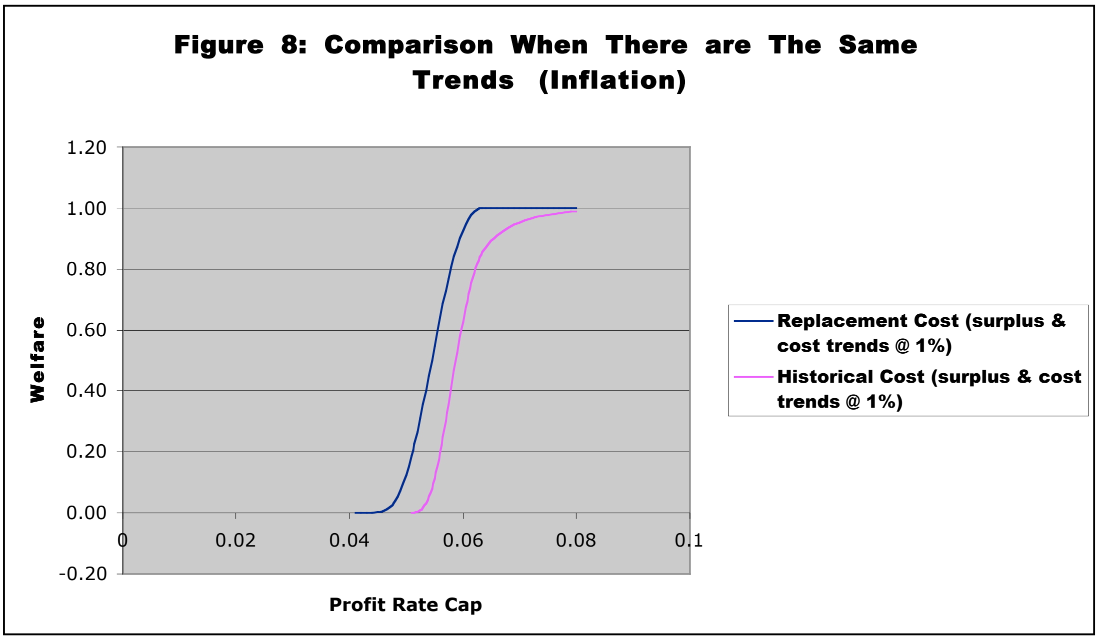


Figure 6 has the correlation between costs and surplus of 0.5. The final graph, Figure 7, shows that setting the correlation equal to zero affects the results. In each variation historical-cost regulation does at least as well as replacement-cost regulation. When the volatility of the surplus is high the welfare maximum is the same for both sorts of regulation.



Finally, we consider Figure 8 where common positive trends in surplus and cost have been added to the base case.[16] Because shocks are quite strongly positively correlated, these circumstances crudely mimic an environment of inflation. The graph indicates that replacement-cost regulation induces high welfare at the same profit cap over a wide range. Indeed, because historical cost regulation fixes profits in nominal terms it is not surprising that relatively high caps would be required to induce investment under this form of regulation. The positive correlation between surplus, and thereby profits, and network costs enables replacement-cost regulation to perform relatively well. There are potentially other ways of examining the portent of inflation, and we plan to examine this issue in more depth.



[16] At an interest rate r = 5%.

Concluding Remarks

Various configurations of industry characteristics can be considered in this framework, and they may yield various outcomes. The model can be calibrated against measures of these characteristics. We have shown enough to indicate that historical-cost or replacement cost are not to be chosen between *a priori*, rather the choice should be guided by industry characteristics. In telecommunications that is experiencing real cost declines and for which cost-reducing innovations may be yielding new consumer benefits ($\square_{sk} < 0$) historical cost regulation may be more in the public interest. In gas, where technology is stable and where there may not be real cost declines in transmission, replacement-cost is likely to be preferable.[17] However, although this paper indicates the factors that are important for the choice of regulatory scheme, it does not investigate their measurement or application.

In the presence of uncertainty and sunk costs investment thresholds that exceed the standard WACC are important to enable investment. The WACC just reflects systematic risk. It does not reflect the probability of bankruptcy or idiosyncratic risks that firms prudently consider when making investment decisions. Poterba and Summers (1995) report hurdle rates that surveyed CEO's[18] claimed to utilise in investment decision-making. They concluded that the *average discount rate applied to constant-dollar cash flows was 12.2 percent, distinctly higher than equity holders average rates of return and much higher than return on debt for the past half century.* Although this does indicate that as a practical matter the use of hurdle rates that exceed a companies' WACC is common place, the height may reflect various factors. High among these is the need to screen projects against the principal-agent issue of vested enthusiasm of project proposers. Importantly, the survey does not distinguish among firms on the basis of the size of sunk investments, for which we would anticipate higher hurdle rates. There is limited hard evidence about these rates.

We re-iterate that we have considered a situation where entry is such that the firm has no competition, and that the presence of competition will very often mean that

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[17] The model has been constructed in real terms. In an economic environment where prices of many goods are falling and there are many new goods, it is possible for the nominal price of a network to decrease and yet real costs increase.

[18] The survey was conducted of *Fortune* 1000 firms.

firms' investments are optimally timed from society's point of view, although investment will not occur immediately.

In this context we note that the imposition of a cap to improve welfare may, if it is too tight, reduce welfare substantially, even relative to the situation of no regulation and no competition. It arises because investment is delayed. In such circumstances the regulator may respond by removing scope for decentralised investment by forcing investment, or reaching some regulatory pact with the firm. It is easy to show that such regulation does not remove the issues of specific risks, and timing considered in this paper: they are intrinsic to the industry. Unless the regulator agrees to pick up the costs of risks – eg the costs of stranded assets – a reasonable rate of return under regulatory investment requirements should cover the real options that these risks imply.

Under dynamic efficiency we can have consumers' surplus and profits and welfare higher under one scheme than the other.[19] That is , there need not be a trade-off between profits and consumers' surplus. This is apparent from the previous figures because profit is an element of welfare. In Figure 5, for example, profits and consumer surplus are higher under historical-cost regulation than replacement-cost regulation. This occurs despite that fact that the optimal profit-rate cap of replacement cost regulation is higher than that of historical-cost regulation: indeed, at every profit-rate cap depicted there can be an increment in the cap for replacement-cost regulation over that for historical cost, and historical-cost regulation remains more profitable. The quantitative results will reflect the construction of our model, but this does not detract from the important principle of dynamic efficiency, that it can improve both consumer and producer welfare. Indeed, inducement of producers is key for dynamically efficient performance.

We have focussed on encouraging the optimal timing of sunk investments. While the approach has been cast as provision of the entire network the same approach applies to maintenance of an existing network that is also sunk. Unless maintenance expenditure is allowable in line with the optimal caps considered in this paper,

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19 As we have shown, which scheme is preferable will depend upon supply and demand characteristics.

networks may deteriorate or require forced maintenance by regulation.[20] The issues are the same.

[20] Forced investment also requires costly monitoring.

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