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by

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The Allocation of Contracts for Infrastructure Operation Under Uncertainty

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Abstract

We analyze the relative merits of long-term versus repeated short-term auctions in the allocation of access to a scarce infrastructural resource. Uncertainty about future valuations creates for the infrastructure owner an option value of waiting, and thus a benefit from repeated short-term auctions, but long-term auctions can avoid the costs of leaving infrastructure unutilized due to unattained reserve prices. Short-term auctions turn out to be relatively attractive when there is uncertainty about relative valuations of different operators, due to shocks to idiosyncratic costs or demand. Long-term auctions are better when shocks are mainly to common demand or costs. In the presence of specific investments we show an additional disincentive effect of short-term auctions on investment. This can be partially offset by a competition effect that makes firms invest more in order to increase their chances in the future auction. We also consider what we call "lock-in" investment, which does not change the value of outcomes but only their correlation over time. We show that firms may invest for strategic reasons, as a way for committing themselves to more aggressive bidding in a future auction. We discuss applications to railway investment.

Executive Summary

This paper examines how to allocate a scarce productive asset between rival users under conditions of uncertainty. Specifically, there is uncertainty about which user can make best use of the asset, which can be thought of as a section of railway track or a similar piece of infrastructure. What gives this problem its particular character is that the users have private information about the value of the asset to them, information that becomes more precise over time. This creates an option value of waiting to make decision about future allocations (so as to benefit from the more precise information in the future), which must be set off against the cost of waiting, which can come from various sources. The model is in two periods, so the choice is between making allocations one period at a time or making the allocation for both periods at the beginning. However, the general trade-off has a very general interpretation, highlighting the factors that tend to favour longer-term contracts as opposed to shorter-term ones. We model the allocation process as a type of auction, though we believe the broad principles would apply to a broader range of allocation mechanisms, such as multilateral negotiation.

We begin by considering situations where the cost of waiting arises because short-term contracts create a greater risk of leaving the asset unallocated. This is because reserve prices are set at levels that trade-off revenue-raising considerations against efficiency criteria; we show that under short-term contracts the temptation for revenue raising is higher so the risks of inefficiency will be higher as well. We show that that the more future uncertainty consists in common shocks to demand or to technology, the lower will be the value of waiting to allocate future access and consequently the more desirable it will be to use long-term auctions. If, however, future uncertainty is mostly about the *relative* efficiency of rival operators, because shocks are principally to the idiosyncratic demand or costs of individual firms, the more desirable it will be to use short-term auctions.

We then move on to consider situations in which waiting also imposes a cost in that it discourages specific investment - namely investment that is only profitable if the user making it continues to have access to the asset. Once again, examples are common in the field of infrastructure - electricity plants built to connect to the grid, or trains built to run along high-speed lines. As a rule, the more specific is the investment, the more it will be desirable to have long-term auctions, which avoid the uncertainty in the mind of a winner of a first-period short-term auction about whether it will see a return on its investment. However, this Uncertainty Effect can be somewhat mitigated by a Competition Effect, under which the investment itself can be encouraged as a means to increase the probability that a user winning the first auction also wins the second. Though this Competition Effect can never completely outweigh the Uncertainty Effect, we show conditions under which it can significantly dampen its effect.

In addition, we show that some kinds of specific investment are not necessarily to be encouraged, since the very fact of competing for access to the asset may induce users to invest for purely strategic motives, as a means of committing themselves to more aggressive bidding in future auctions. We derive conditions for this to occur, and discuss applications to infrastructure management, across a range of industries but with a particular focus on railways.

1 Introduction

In this paper we consider how to allocate the right to operate an asset (such as a piece of rail infrastructure), or to provide services that make use of this asset, in the presence of uncertainty about its value to alternative users[1]. The uncertainty has a dynamic character - it is resolved over time. This creates an option value of waiting to allocate the right, to diminish the risk of allocating it to the "wrong" user. However, this option value needs to be traded off against the cost of waiting, which may come from various sources. If the value of waiting is greater than the cost, it will be preferable to take decisions sequentially, so that each decision takes into account the full up-to-date information available. If the cost of waiting is greater than the benefit, it will be preferable to take decisions for future as well as current periods. This means that there will need to be a procedure for weighing future choices against current ones. For instance, suppose the allocation procedure is an auction. If participants in the auction are allowed to bid for rights in the future as well as in the present, the rules of the auction must specify how to compare a bid for present and future rights against another bid for purely present rights. It is not enough to allocate rights to "the highest bidder" since in the absence of a ranking criterion we do not know which bid is effectively higher: 1.01 million dollars bid for two years of operating rights may not be "higher" than 1 million bid for one year of rights.

We develop a model of the allocation procedure as an auction with two participants who are bidding for monopoly operating rights to an infrastructure asset in two separate periods. The model here is abstract enough to fit several different natural interpretations, provided only that the asset is a scarce resource in the sense that granting operating rights to one operator prevents (or reduces the value of) rights for the second operator. For instance, it can represent the properties of negotiating mechanisms that are not auctions, but share with auctions certain broad features such as the dependence of the price paid by a successful participant on the willingness to pay of second highest bidder. Thus we believe that it can capture features of many different institutional forms of infrastructure

[1] We acknowledge with gratitude the advice and comments received from Guido Friebel, Marc Ivaldi, Ralph Koerfgen, Markus Ksoll, Marko Niffka, Klaus Vestner and Christiane Warnecke. The opinions expressed in this paper are those of the authors alone.

allocation, such as the "framework contracts" introduced in the 2001 EU railway package to allow for limited rights of railway track access to extend for longer than one scheduling period. These do not allow monopoly access as such, but they do create value for operating companies that extends over time, subject to a degree of uncertainty. The issues they raise are similar to those in the present model. Similarly, the authority in charge of allocating operating rights in our model may be interpreted as a commercial operator of infrastructure, or a public authority tendering out services, or a regulatory body, though the weight given to revenue in that body's objective function may vary from case to case.

In our model the allocating authority (hereafter just "the authority") must decide whether to hold a repeated short-term auction, first for one period and then for the other, or a single long-term auction, in which bids for both periods are allowed. The two periods need not be interpreted as of any particular length: the results of the model can be interpreted instead as telling us what are the circumstances that would favour a relatively longer term allocation as opposed to a relatively short-term one. As in any auction there is asymmetric information in any one period between the authority and the bidders about their private valuation in that period. But the twist here is that bidders also know more than the authority about their valuations in future periods. Their information is not complete, otherwise we could collapse the periods and treat them as one, but the bidders nevertheless have information not available to the authority about their likely future valuations.

We begin by considering just the option value of waiting, while the cost of waiting comes just from the risk that valuations will be revealed to be low, thus lowering the revenue that can be extracted from bidders. We go on subsequently to consider the intertemporal trade-off due to the parties' ability to make specific investments that affect their future valuations.

There is already a substantial literature on dynamic incentives and access to infrastructure, including the use of auction mechanisms. Laffont & Tirole (1993) remains the central reference work in this area, and chapters 7 and 8 are the closest in spirit to this paper (see also Laffont & Tirole (1987)). However, they are not very close, since the adverse selection questions there arise in a static context, and the dynamic incentive problems arise from the interaction of the one-time asymmetric information about agent types with the need to give incentives for effort so as to reduce costs over time. In particular there is no analogue in their model of the option-value effect in our paper. Similar considerations apply to Meyer & Vickers (1997), which involves using comparisons between the performance of different agents to increase incentives for effort. The value of long-term contracts in the presence of specific investments has, of course, been recognized for a long time, and indeed is a central point of the transactions cost literature going back to Coase (1937) and revived by Williamson (1985) and, more formally by Grossman & Hart (1986) and Hart & Moore (1990) - see also Hart (1995) and for an empirical test in the context of railways, Affuso & Newbery (2003). For empirical studies looking specifically at the application of auction mechanisms to infrastructure, see Janssen (2004). Similarly, the notion that there is an option value of waiting to make a potentially irreversible allocation decision is of course not new (see Abel & Eberly, 1994 and Dixit & Pindyck, 1994). However, we are not aware of other work exploring the interaction of specific investments with an auction giving rise to such option values. Finally the idea of strategic investment to deter entry goes back at least to Fudenberg & Tirole (1984) if not before (see Spence, 1977, for example). However, what is new here (as far as we are aware) is the idea that strategic investment may act by increasing the informativeness of firms' current signals about future payoffs, thus encouraging them to bid more aggressively against each other.

We now turn to the basic model.

2 The Simple Model

2.1 Non-technical summary

- This model considers a revenue-maximizing authority (who may be a public authority or a private firm), allocating access to a single infrastructure asset to one of two firms, at two periods.
- The value to each of the firms of operating the infrastructure can take the value High or Low. Each is equally likely, except that there are correlations between periods and between firms.
- If one firm has a High value in any period, the probability that the other firm also has a High value is given by a parameter that measures *inter-firm* correlation (the same correlation holds for Low values).
- If a firm has a High value in the first period, the probability that it has a High value in the second period is given by a parameter that measures *inter-period* correlation.
- Each firm observes its own value for the current period before participating in the auction.
- The authority faces a choice between a repeated short-term auction, in which access is auctioned in each period for that period only, and a long-term auction, in which firms can bid for access for both periods.

- The revenue-maximizing short term auction will be a second-price auction with a reserve price which may be equal to the High or the Low value (according to circumstances we describe).
- If it is set to High, then with some probability the asset will remain unallocated, since both firms will observe a Low value and will be unwilling to bid the reserve price.
- The revenue-maximizing two-period auction will also be a second-period auction with a reserve price (the formula for which we derive); if the reserve price is not reached, the owner holds a short-term auction with a Low reserve price, followed by a short-term auction with a High- reserve price in the second period.
- We compare the revenue raised under each type of auction and show that the comparison depends on the inter-firm and inter-period correlations in an inuitive way.

2.2 Formal description of the model

There are two firms, $i = 1, 2$, and two periods, $t = 1, 2$.

v_t^i is the value for firm i of operating the asset during period t.

For any firm and in any period, it can take the value H or L with unconditional probability $\left(\frac{1}{2}, \frac{1}{2}\right)$. We define $\sigma = \frac{H-L}{H}$, which we call the "variability index" of firms' value, and note that (provided L is non-negative) its value must lie between zero and one.

There are, however, correlations in valuation across firms and across periods.

For example, $\rho = corr\left(v_1^i, v_2^i\right)$ is the intra-firm correlation in valuations across periods. This means we can write the probability that a given firm has the same valuation in each period as a function of ρ as follows:

$$\Pr\left(v_1^i = v_2^i = H\right) = \Pr\left(v_1^i = v_2^i = L\right) = \frac{1}{4}\left(1+\rho\right). \tag{1}$$

ρ measures the degree of “persistence” of the “type” of any given firm across time. Indeed:

$$\Pr[v_2^i = H | v_1^i = H] = \Pr[v_2^i = L | v_1^i = L] = \frac{1}{2}(1+\rho).$$

For simplicity we assume that the conditional distribution of v_2^i given v_1^i is independent of v_1^j.

We can also write the probability that two firms have the same valuation at date 1 as follows:

$$\Pr\left(v_t^1 = v_t^2 = H\right) = \Pr\left(v_t^1 = v_t^2 = L\right) = \frac{1}{4}\left(1+\theta\right), \tag{2}$$

where $\theta = corr\,(v_t^1, v_t^2)$ is the intra-period correlation in valuations across firms.

θ measures the degree of "similarity" between the two firms at date 1. Indeed:

$$\Pr[v_2^1 = H | v_1^2 = H] = \Pr[v_1^1 = L | v_1^1 = L] = \frac{1}{2}(1+\rho).$$

Table $A1$ in the appendix gives the probabilities of the 16 different combinations of high and low valuations for the two firms over the two periods.

For further reference, we denote by $v(H)$ (resp. $v(L)$) the expected two-period profit of a H firm (resp. L firm). We have:

$$v(H) = H + E[v_2^i | v_1^i = H] = 2H - \frac{1-\rho}{2}(H-L).$$

Similarly:

$$v(L) = L + E[v_2^i | v_1^i = L] = 2L + \frac{1-\rho}{2}(H-L).$$

We now suppose that the authority faces a choice between a repeated short-term auction, in which access is auctioned in each period for that period only, and a long-term auction, in which firms can bid for access for both periods, but if there is no bid above the reserve price, bids are accepted for the first period only. We begin also by considering the goal of the owner as consisting of simple revenue-maximization, before considering how this relates to broader social welfare considerations.

2.3 Short-term auction

We solve first for the revenue-maximizing short-term auction.

This will be a second price auction with reserve price p_1 set at either H or L.

If L is small then H is the revenue-maximizing reserve price, since with a reserve price of L the revenue will be H only when both bidders have high valuations, instead of when at least one of them does:

$$H - (H-L)[1 - \Pr(v_t^1 = v_t^2 = H)] < H[1 - \Pr(v_t^1 = v_t^2 = L)]. \tag{3}$$

This is equivalent to the following condition on σ:

$$\sigma = \frac{H-L}{H} > \frac{\Pr(v_t^1 = v_t^2 = L)}{1 - \Pr(v_t^1 = v_t^2 = H)} = \frac{1+\theta}{3-\theta}. \tag{4}$$

Under this condition, if the short-term auction is held twice in succession, expected revenue can be written as follows:

$$R_{ST} = 2H\left[1 - \left(\frac{1+\theta}{4}\right)\right] = H\left[\frac{3-\theta}{2}\right]. \tag{5}$$

In the alternative case where

$$\sigma < \frac{1+\theta}{3-\theta},$$

the optimal reserve price for a short term auction is $p_1 = L$, leading to an expected revenue

$$R^2_{ST} = 2L$$

for the short term auction repeated twice. The properties of the optimal short term auction are summarized in the following proposition:

Proposition 1 *1. When σ, the variability index of firms value is high and/or θ, the degree of similarity between the two firms is low (specifically, $\sigma > \frac{1+\theta}{3-\theta}$) the optimal reserve price of the short term auction is H, leading to an expected revenue $R^1_{ST} = H\left[\frac{3-\theta}{2}\right]$, and a probability $\frac{1}{4}(1+\theta)$ that the asset is not operated at each period (1st regime).*

2. When on the contrary σ is low and/or θ is high, the asset is allocated with probability one at each period, for a low price L. The expected revenue for the short term auction repeated twice is then $R^2_{ST} = 2L$ (2nd regime).

Figure 1 represents the two regimes in the (θ, σ) plane.

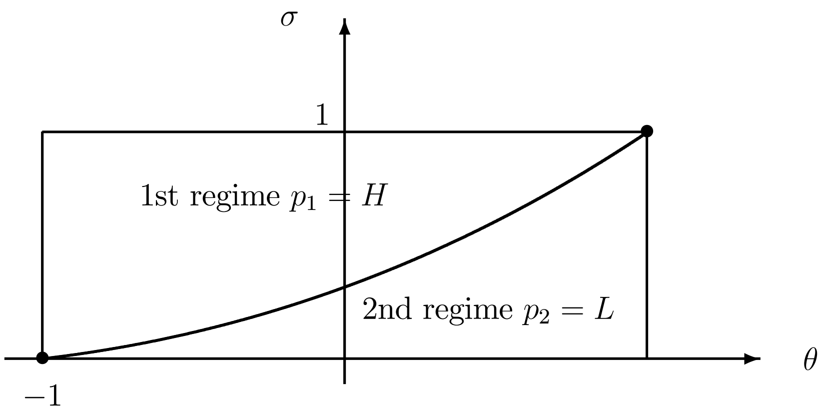

Figure 1: The two regimes for the short term auction.

We now consider the alternative possibility of allocating the asset through a long-term auction.

2.4 Long-term Auction

The revenue-maximizing long-term auction will also be a second price auction, but with a two-period reserve price p_2 that is lower than the expected two-period profit $v(H)$ of a H-firm. This is because whenever there is no bid above p_2 (i.e. if $v_1^i = v_2^i = L$), then the authority will choose a repeated short-term auction, and offer 1st period access[2] for a reserve price L, then 2nd period access for a reserve price H. The reserve price must therefore be chosen so as to avoid giving a firm of type H the incentive to make a low bid so as to influence the authority into offering a repeated short-term auction. This reserve price p_2 is therefore equal to the expected total value $v(H)$ for a firm of type H (as of date 1), minus the rent that such a firm would obtain from the repeated short-term auction. This rent equals the difference in values $(H - L)$ multiplied by the probability that the other firm is L, conditional on oneself being H. We rule out the less interesting case where the two-period reserve price is $v(L)$ and the second period reserve price is L, due to a low value of σ.

The allocation rule implemented by the long-term auction is summarized as follows:

- If (at $t = 1$) at least one firm is H, the asset is allocated for two periods at a price p_2.
- If both firms are L at $t = 1$, the asset is allocated to one of them at a price L. At $t = 2$, a short term auction at reserve price p_1 is organized. We focus on the case where $p_1 = H$ (see footnote 2).

This yields

$$p_2 = v(H) - \frac{1-\theta}{2}(H - L).$$

Now

$$\begin{aligned} v(H) &= 2H - \Pr\left[v_2^i = L \mid v_1^i = H\right](H - L) \\ &= 2H - \left(\frac{1-\rho}{2}\right)(H - L). \end{aligned}$$

Thus $p_2 = 2H - \left(\frac{2-\rho-\theta}{2}\right)(H - L)$.

We can write expected revenue as follows:

$$R_{LT} = p_2\left[1 - \left(\frac{1+\theta}{4}\right)\right] + \frac{1+\theta}{4}\left\{L + H\left(1 - \frac{(1+\rho)^2}{4}\right)\right\} \quad (6)$$

[2] We rule out the less interesting case where ρ is so high that the optimal reserve price for 2nd period access is L, because $\Pr[v_2^1 = v_2^2 = L | v_1^1 = v_1^2 = L]$ is close to 1. In this case, it can be shown that the long term auction always gives a higher revenue to the auctioneer.

2.5 Comparing the auctions

The revenue expressions simplify to

$$R_{ST} = H\left[\frac{3-\theta}{2}\right]$$

and

$$R_{LT} = \frac{3-\theta}{4}\left[2H - \left(\frac{2-\rho-\theta}{2}\right)(H-L)\right] + \frac{1+\theta}{4}\left[L + H\left(1 - \frac{(1+\rho)^2}{4}\right)\right].$$

Thus a long-term auction will be preferable for the authority when the expected long-term revenue exceeds the expected short-term revenue:

$$R_{LT} > R_{ST} \Longleftrightarrow \frac{H-L}{H} < \sigma_{LT} = \frac{\frac{1+\theta}{2}\left(1 - \frac{(1+\rho)^2}{8}\right)}{1 - \frac{(3-\theta)(\rho+\theta)}{8}}. \tag{7}$$

We show in Appendix 2 that this expression is increasing in θ and also in ρ, except when ρ is close to unity.

What are the general messages to draw from this? The advantages of each type of auction can be summarized as follows:

- The benefit of repeated short-term auctions should be understood as consisting of the opportunity to optimize the allocation of the asset to the operator that can best make profitable use of it. The option value of waiting until later to allocate access for the later period consists in the expected improvement in the efficiency of that period's allocation that comes about from choosing on the basis of more up-to-date information. This will be unambiguously decreasing in θ, since the higher is θ the lower is the probability that the two firms have different values for track access in the second period.

- The benefit of a long-term auction consists of the revenue from being able to operate the asset even when both users have low valuations in the first period, while still extracting any rent due to ρ, the high expectations of the first-period auction winner, when at least one user has a high valuation in the first period.

In practice this means that the more future uncertainty consists in common shocks to demand (this corresponds to an increase in θ) or to technology (this corresponds to an increase in ρ) the lower will be the value of waiting to allocate future access and consequently the more desirable it will be to use long-term auctions. If, however, future uncertainty is mostly about the *relative* efficiency of rival operators, because shocks are principally to the idiosyncratic demand or costs of individual firms, the more desirable it will be to use short-term auctions.

It is worth noting that the potential inefficiency of the repeated short-term auction is artificial in that it comes about because of the revenue-maximizing objective of the authority that leads it to set a high reserve price. By contrast, the potential inefficiency of the long-term auction is intrinsic in that it comes about because at the time the decision is made there is less information than would be available if the decision on second-period access were delayed; this inefficiency would persist whatever the objective of the owner. This suggests that the comparison between the two auctions might look different if the authority maximized social welfare instead of revenue. And so indeed it proves. If the social welfare function were indifferent between revenues of the authority and the service operators, the optimal short-term auction would have a reserve price equal to L in both periods, since this would ensure that the asset was still operated even when both operators have observed L. In these circumstances the short-term auction would always be at least as good for social welfare as the long-term auction, and often strictly better.

However, the revenue forgone under such a set-up would be large (the price paid by the winner of the auction would be L instead of H whenever only one firm observed a high value). Thus when revenues to the authority have higher weight in the social welfare function than those to the operators (high enough to imply setting high reserve prices in the short-term auction) the relevant comparison will still be given by the trade-off described above.

Finally, it is worth explaining more fully the intuition behind the result that the short-term auction tends to give a higher probability of leaving the asset unallocated. The reason for this is that in a long-term auction firms bid according to their expected future revenues. In repeated short-term auctions they bid according to their actual revealed revenues (since they observe the value of operating the asset before they bid in the auction). Since there is higher variance in the ex post revealed outcomes than in their ex ante expected values, and since the winners of the auction will be those who bid highest, the owner will set higher reservation prices when bidders know their ex post values, being thereby able to extract more rent from the winners. In a long-term auction, by contrast, the firms that turn out after the event to have the highest values gain thereby a rent (if they are lucky enough to have been the successful bidder) that it is too late for the owner to extract. This means in turn that the two kinds of auction involve different kinds of inefficiency - the short-term auction risks leaving the asset unallocated because the reserve price is too high, while the long-term auction risks leaving the asset allocated to the "wrong" user in the second period.

This result that an owner charges higher prices on the basis of ex post revealed valuations underlies a model of a quite different phenomenon due to Kremer & Snyder (2003), who argue that the reason pharmaceutical companies invest less in vaccines than in curative drugs is that vaccines are purchased by those who only know their expected probability of illness, while curative drugs are purchased by those who know their actual state of health, and who therefore have a higher willingness to pay.

We now turn to consider specific investments, which complicate the inter-temporal trade-off in interesting ways.

3 Extending the Model with Specific Investments

Specific investments have a return to the investor that is conditional on the continuation of an economic relationship between the investor and some third party. In the present context, a specific investment by a bidder would be one whose return was conditional on the bidder's having access to the infrastructure in the second period.

We begin by assuming that an investor who wins the auction for first-period access can choose to make an investment that will have a pay-off only if the investor continues to have access in the second period. The question then arises what difference it makes whether the investor knows that it will continue to have access in the second period (because it has won a long-term auction), or must instead take part in a second short-term auction.

3.1 The Extended Model: non-technical summary

- The firm that wins the first-period auction can choose to make an investment that affects the value of operating the asset only in the high-value state

- There is uncertainty about the value to the unsuccessful rival of operating the asset in the second period

- The incentives for investment under a long-term auction depend on the correlation between periods, since this will influence how confident a successful bidder can be that demand will be high in the second period

- In comparison, a repeated short-term auction has two effects on investment: one negative (the uncertainty effect, arising from not being sure that it will still be the incumbent in the second period), and one positive (the competition effect, arising from the fact that its investment may yield a return via the increased probability of winning the second-period auction

- The competition effect can significantly offset but cannot completely outweigh the uncertainty effect, so specific investment is always lower under a repeated short-term auction

3.2 The Extended Model: formal description

Let I be the value of investment chosen by the firm that has won the first-period auction (to simplify matters we suppose that no investment takes place prior to the first-period auction). This investment has a cost $C(I)$ which is increasing and strictly convex. The investment affects the value of using the asset in only the high state (generalizing this to investment that affects the value of the asset in both states is straightforward but adds no particularly novel insight). Thus we can write that $v_2^i \in \{H(I), L\}$, where $H(I)$ is increasing and weakly concave.

Let H^j, which is the value of access in the high state to the firm that has not won the first-period auction, be stochastic,[3] and distributed uniformly on $[H - \varepsilon, H + \varepsilon]$. This can be interpreted as the probability distribution for the possible technologies that may be discovered, in the future, by some rival to the incumbent.

Then it is straightforward to write down the first-order conditions for investment when there is a long-term auction, since the firm that has won the auction is guaranteed to be incumbent for the second period. Supposing that the first-period auction has been won by firm i, this firm chooses an investment I such that its marginal cost equals the product of the probability of the high state at date 2 (conditional on the high state at date 1) multiplied by the marginal benefit $H(I)$ derived from the investment in the high state. Specifically:

$$C'(I) = \Pr[v_2^i = H | v_1^i = H] H'(I) = \frac{(1+\rho)}{2} H'(I) \tag{8}$$

When there is a repeated short-term auction the first-order conditions are more complex, since the firm that has won the auction faces a new auction in the second period. It is not certain to win this auction (so it will receive the increased value of access with a probability less than unity, thus diminishing its incentives to invest), but the investment may also increase its probability of winning above what it would be without investment,

[3] The reason for making the values for the rival firm stochastic is to avoid the discontinuities in bidding strategies that would arise if the incumbent firm knew that a tiny increase in its investment would enable it to increase its probability of winning the second-period auction from zero to unity.

thus giving it an additional incentive to invest that it would not have if access were guaranteed.

On the assumption that the reserve price will be set above what the firm would bid if it observed a low state, we can therefore write:

$$\begin{aligned} C'(I) &= \Pr[v_2^i = H(I),\ v_2^j = L | v_1^i = H] H'(I) \\ &+ \frac{\partial}{\partial I} \left\{ \Pr[v_2^i = H(I),\ v_2^j = H^j | v_1^i = H] E[\max(0, H(I) - H^j)] \right\}. \end{aligned} \quad (9)$$

The first term on the right-hand side is analogous to the right-hand side of formula (8). However, since the incumbent is not sure to win the auction, the probability that it can benefit from the investment is reduced: we call this the Uncertainty Effect. Specifically, the probability table in Appendix 1 shows that

$$\Pr[v_2^i = H(I),\ v_2^j = L | v_2^i = H] = \frac{1+\rho}{4}(1-\theta\rho) \leq \frac{1+\rho}{2}.$$

The impact of the Uncertainty Effect of a repeated short-term auction is always to discourage specific investment.

However the second term in formula (9) represents what we can call the Competition Effect. It consists of the effect of investment on the probability that the incumbent firm wins the auction, multiplied by the value of winning (the value to the incumbent if it wins less the price it has to pay). It represents the additional inducement to specific investment that comes from being in competition for second-period access. It will always be positive, so the natural question that arises is whether it can be sufficiently large to outweigh the negative impact of the Uncertainty Effect. The answer is that it cannot, but it can come closer to doing so when the the investment makes a significant difference to the incumbent's probability of winning the auction.

To see this it will be helpful to rewrite expression (9):

$$\Pr[v_2^i = H(I),\ v_2^j = H | v_2^i = H] = \frac{1+\rho}{4}(1+\theta\rho).$$

Notice that this is independent of I. Moreover:

$$\frac{\partial}{\partial I}[\max(0, H(I) - H^j)] = H'(I)\Pr(H(I) > H^j).$$

Thus we obtain:

$$C'(I) = \frac{1+\rho}{2} H'(I) \left[\frac{1-\theta\rho}{2} + \frac{(1+\theta\rho)}{2} \Pr(H(I) > H^j) \right].$$

Since $\Pr(H(I) > H^j) \leq 1$, we see that the term between brackets is always less than one. However, it is decreasing in θ and ρ and increasing in $H(I)$. This means that, the more the specific investment increases the probability of an incumbent's having a higher valuation than a rival, the more nearly the competition effect can compensate for the uncertainty effect. Nevertheless, the overall impact of a repeated short term auction is always to reduce, even if only slightly, the specific investment compared to a long-term auction.

3.3 Comparing auctions with specific investment

The main efficiency costs of the two auction types can be characterized as follows:

- The cost of using long-term auctions is the risk that the winner will have a low value in the second period (exactly as in the simple model), or that the rival would have had an even higher value.
- The cost of using short-term auctions is that, even though the incumbent may win in the second period, it will do so with a lower value of investment than it would have undertaken if it had known in advance that this would be the outcome.

The cost of the short-term auctions will be high if underinvestment significantly lowers the value of access without significantly increasing the probability of being displaced by a rival. Alternatively expressed, short-term auctions are relatively attractive in circumstances where non-incumbents can with high probability mount credible challenges to incumbents, but where incumbents can significantly influence this probability by their investment decisions. We call investment that has this characteristic "rival-sensitive". The opposite, namely rival-insensitive investment, is the kind which rivals cannot realistically hope to match, so that although incumbents may be moved to undertake some of it by the desire to outstrip its rival, it has no real motivation to achieve efficient rather than inefficient levels of the investment.

What does this imply for the suitability of different allocation mechanisms for the various characteristics of investments in infrastructure and its associated services? Consider the four following types of investment:

- A) Relatively unspecific investment: such as investment in rolling stock or general marketing
- B) Infrastructure-specific but not incumbent-specific investment: such as marketing to develop routes and destinations, or investment in track

- C) Incumbent-specific and rival-sensitive investment: such as spending on customer relations, or minor improvements to non-transferable rolling-stock
- D) Incumbent-specific, but rival-insensitive investment: such as major improvements to non-transferable rolling stock, investments designed to improve punctuality and reliability of interlining (which a rival without a network presence could not match), or major investments in maintenance operations

For investment types A) and C) there should be relatively little disincentive effect of short-term auctions, A because the uncertainty effect is relatively weak and C) because the competition effect is relatively strong. Therefore, if there are good reasons to think that different operators are likely to have different values in period 2, there is a good case for using short-term auctions. For investment types B) and D), however, the disincentive effect of short-term auctions is potentially high (the uncertainty effect is large and the competition effect is weak, for B) because investments spill over to the benefit of the rival as well as the incumbent, and for D) because the rival is no longer a credible challenger once the incumbent has made a significant degree of investment. In such circumstances, therefore, to avoid discouraging investment it is desirable either to hold long-term auctions or (if uncertainty about which operator will have the highest future value is sufficiently great), to design cost-sharing or leasing arrangements in which the authority bears a share of the burden.

Overall, therefore, we have seen that in the presence of specific investments, a sequence of short-term auctions has a tendency to discourage investment compared to a single long-term auction. Thus the balance of advantage between short-and long-term auctions that we discussed in section 2 will tend to shift against short-term auctions in circumstances where specific investments are an important component of operating efficiency. However, the disincentive for investmen due to short-ter auctions can be partly offset by the strength of the competition effect. We have indicated some types in investment for which this is relatively likely and others for which it is relatively unlikely.

We now turn to consider a kind of investment which may be encouraged by the presence of auctions even though it has no impact on the value of outcomes - all it does is to increase the correlation of outcomes in the future with those in the present. The value of the investment to the operators nevertheless consists in the way it commits them to bidding more aggressively in the auction in the future.

4 "Lock-in" Investment

We consider next a type of specific investment that does not necessarily increase firms' valuations in the second period; instead, it increases the correlation between first- and second-period valuations. For firms that experience high valuations in the first period, the investment increases their probability of high valuations in the second period, while for firms experience low first-period valuations it reduces their probability of high second-period valuations. In other words, firms can invest to increase the value of ρ. We call this type of investment "lock-in" investment.

An example of lock-in investment would be investment in terminal facilities such as passenger lounges. Another would be frequent-traveller programmes. When demand conditions are good these increase the profitability of operating a route. When demand conditions are bad they lower the profitability of operating a route, since they still incur fixed costs of operation in addition to the set-up costs.

Why would any firm wish to make lock-in investments? There is one obvious reason and one more subtle reason. The obvious reason is that firms that have already observed their first-period valuations have a reason to invest in increasing ρ if those valuations are high. Conditional on a high valuation, increasing ρ just increases the probability of a high outcome, and can be considered a specific investment of a standard kind.

The more subtle reason for investing to increase ρ applies even to a firm that has not yet observed its first-period valuation, and it applies in the context of a long-term auction. This is that, the higher the value of ρ, the more aggressively the firm will bid in the event that it observes a high valuation in the first period (since this raises its expected gains from second period access). Thus, investing in ρ may be a way to committing the firm to bid aggressively in the event that it observes a high valuation.

To see this we shall model firms as making investment decisions before they observe their first-period valuations. We call this "uninformed investment", and we show that firms may nevertheless wish to invest for purely strategic reasons - committing themselves to bid more aggressively in case they subsequently observe high valuations. This involves some wasteful duplication of costs by firms. In practice, of course, real investment decisions will combine informed and uninformed components. It is straightforward to show that the results of our model generalize to this mixed setting[4].

4.1 Lock-in investment: non-technical summary

- Firms choose investment levels before they have observed first-period valuations, but after they know what kind of auction mechanism will be implemented. Investment

[4]However, informed investment is negatively affected by reserve prices (though uninformed investment is unaffected by them). This suggests that, in a more general model, the setting of reserve prices should take account the induced impact on investment, a problem we have not considered explicitly.

increases the correlation between periods. By definition, therefore, such investment has no expected social value as it is as likely to increase the probability of a bad as of a good outcome in the second period

- In a short-term auction the returns are independent of the correlation between periods, so if this method is chosen investment levels are zero
- In a long-term auction investments are increasing in the mean value of returns in the high state, and also increasing in the degree of correlation between firms. This means that firms are investing to commit themselves to more aggressive bidding, which is a purely strategic motive and has no social value

4.2 Lock-in investment: formal description

Let the value of ρ^i be chosen by each firm i.There is a cost $c(\rho^i)$ which is increasing convex.

The order of events is as follows:

Period -1:	authority chooses an auction method (short- or long-term) and the reserve prices
Period 0:	each firm chooses ρ^i
Period 1:	firms observe v_1^i and bid in the auction.

Firms therefore choose ρ^i before observing v_1^i.

However, they observe v_1^i before bidding in the auction.

In period 0: If the short-term auction is chosen with a reserve price H_R, a firm will set ρ^isuch that

$$c'(\rho^i) = \frac{\partial}{\partial \rho^i} E\left(H^i - H_R \mid E^i(1)\right) \cdot \Pr\left[E^i(1)\right] + \frac{\partial}{\partial \rho^i}\left[E\left(H^i - H^j \mid E^i(2)\right) \cdot \Pr\left[E^i(2)\right]\right],$$

where $E^i(1) =$ is the event that i is the only bidder in period 2, and $E^i(2)$ is the event that i wins a 2-bid auction in period 2

In the short-term auction the expressions $\Pr\left[E^i(1)\right]$ and $\Pr\left[E^i(2)\right]$ are independent of ρ^i.

This is because the unconditional probability that $v_2^i = H^i$ is independent of ρ^i, and bids by firm i are made in the knowledge of v_2^i so are likewise independent of ρ^i.

The expressions $E\left(H^i - H^j \mid E^i(2)\right)$ and $\left(H^i - H_R \mid E^i(1)\right)$ are likewise independent of ρ^i.

Therefore $\rho^i = 0$.

If the long-term auction is chosen, firm i will choose

$$\begin{aligned} c'(\rho^i) &= \frac{\partial}{\partial \rho^i}\left[(H - H_R)\left(\frac{1-\theta}{4}\right)\right] \\ &+ \frac{\partial}{\partial \rho^i}\left[E\left(H^i - H^j \mid H^i > H^j\right)\left(\frac{1+\theta}{2}\left(pr\left(v\left(H^i\right) > v\left(H^j\right)\right)\right)\right)\right]. \end{aligned}$$

Since $E\left(H^i - H^j \mid H^i > H^j\right) = \frac{2}{3}\varepsilon$, this yields

$$\begin{aligned} c'(\rho^i) &= \frac{\partial}{\partial \rho^i}\left[\frac{\varepsilon(1+\theta)}{3}\left(pr\left(\frac{(1+\rho^i)H^i}{2} > \frac{(1+\rho^j)H^j}{2}\right)\right)\right] \\ &= \frac{\partial}{\partial \rho^i}\left[\frac{\varepsilon(1+\theta)}{3}\left(pr\left(\left(1+\rho^i\right)H^i > \left(1+\rho^j\right)H^j\right)\right)\right] \\ &= \frac{\partial}{\partial \rho^i}\left[\frac{\varepsilon(1+\theta)}{3}\left(\frac{(1+\rho^i)H - (1+\rho^j)(H-\varepsilon)}{(1+\rho^j)\left[(H+\varepsilon)-(H-\varepsilon)\right]}\right)\right] \\ &= \frac{(1+\theta)H}{6(1+\rho^j)} \end{aligned}$$

At a symmetric solution with $\rho^i = \rho^j = \rho^*$ this yields $c'(\rho^*) = \frac{(1+\theta)H}{6(1+\rho^*)}$ which gives ρ^* increasing in H and θ and independent of ε.

What these results highlight is that specific investment is not always socially valuable - indeed here by assumption it has no value since it increases the persistence of good and bad valuations alike. Nevertheless, uncertainty about future outcomes may make firms willing to bid more aggressively in the first period of a long-term auction in order to gain benefits in the second period.

5 Applications

What do these results mean in practice for policy towards infrastructure industries? Conditions vary widely between industries, and among different activities within any given industry, so it is unlikely that a "one size fits all" policy is appropriate. The following are some illustrative remarks about ways in which the insights of these findings might be used to suggest adapting allocation mechanisms to the different conditions between and within industries, though we stress that any such conclusions remain tentative:

- The influence of the contract regime on specific investments highlights the fact that longer-term contracts are more suitable for, say, railways and telecommunications than, say, bus transport services and air transport services, which use capital that is relatively easily transferable from one location to another, including across national boundaries.

- Authorities that insist on very detailed service specifications in tender contracts, rather than allowing service operators to optimise in the light of their experience and the information available, risk making investment more specific than it need or should be. This not only discourages investment but is likely to reduce the amounts that firms are willing to pay for access to the asset.

- Anti-incumbent biases, sometimes motivated by the idea that competition is working effectively only if new entrants are systematically taking market share from incumbents, can do a lot of damage to the incentives for investment (including for investments by new entrants once they in turn become incumbents).The ability of the Competition effect significantly to offset the Uncertainty effect implies that allocation rules need to ensure that incumbent firms can have a realistic chance of retaining access to infrastructure if they make significant investments[5].

- Not all specific investment is socially productive, and some (such as customer loyalty programmes) may be privately profitable chiefly through committing firms to bid more aggressively against each other. While more aggressive bidding is not to be deplored per se, spending significant resources principally for this purpose is indeed wasteful. This is not to say that the authorities should actively seek to discourage such investment, merely that they should not make efforts to encourage it by making contracts longer than they would otherwise be.

- The importance of uncertainty about industry-wide conditions (about demand or technology) varies considerably from one sector to another, and even from one activity to another within a given sector. In telecoms, for example, uncertainty over future demand for services, and over the evolution of technology, probably dwarfs uncertainty over which firm will be best able profitably to operate a given infrastructural asset such as an interval of radio spectrum. In contrast, railways are a sector in which there is less uncertainty about industry-wide conditions and considerably more uncertainty about the relative efficiency of different service operators. This suggests that short-term contracts are likely to be relatively more desirable in (at least some parts of) the railway industry than in telecoms. Extreme short-term contracts (less than a year) are sometimes associated with "open access" arrangements, and it is not surprising therefore that we see them being encouraged in (some kinds of) railway service. However, open access as such implies that several operators

[5] Affuso & Newbery (2002) argue that this motivation is an important reason why shorter contracts in the UK railway industry did not appear to discourage specific investment.

may have rights to use closely substitutable units of infrastructure, and does not intrinsically imply that the contracts under which they do so must be short term.

6 Conclusions

This paper has modelled the factors that influence the trade-off between short-term and long-term auctions for the allocation of infrastructure. We can now draw the results together and discuss what they mean for different kinds of allocation procedure in a particular sector such as railways.

Repeated short-term auction auctions are likely to prove relatively desirable when

- there is high uncertainty about the relative efficiency of rival operators, because shocks are principally to the idiosyncratic demand or costs of individual firms
- most investment by the operators is not specific to the routes (or kinds of routes) operated
- investment that is route-specific has a large impact on the value to an incumbent operator of obtaining future infrastructure access, and therefore on its likelihood of outbidding a future rival that has not made such investment
- specific investments are undertaken more out of strategic motives (and may involve wasteful cost duplication) than because they are intrinsically productive

Long-term auctions are likely to prove relatively desirable when

- there is more uncertainty about absolute than about relative valuations, since shocks are principally to the common costs or demand of all firms in the industry
- there is significant route-specific investment, which nevertheless leaves a large margin of uncertainty as to an incumbent's chances of outbidding a future rival, perhaps because some of the value of the investment spills over to rivals
- specific investment is socially valuable (by increasing the value of operating the asset) rather than just strategically valuable (by committing the firm to more aggressive future bidding)

Different parts of the railway infrastructure will be differently suited to these two kinds of method: high-speed train operations, for instance, require more specific investment, some of which may spill over to rivals, so that the case for long-term auctions is stronger for other types of operation, such as in regional transport. On the other hand, routes on which there is an important degree of interlining between the services of different operators (as may be true in some parts of the regional network) are ones in which the benefits of some specific investments may spill over to rival operators, and in which therefore long-term contracts may be important to avoid disincentives.

The extent to which investment is specific is not always simply given by the technology, but can be affected by the actions of the regulatory authorities. For instance, detailed specification of rolling stock characteristics by the authorities in tendering contracts may increase the specificity of the required investment and require longer contract periods in order to avoid adverse incentive effects. Similar consequences may arise from regulatory enforcement of interlining between operators, since this will increase the extent to which investments by one firm can spill over to rivals. On the other hand, harmonization of technical standards (within the EU, for instance), may have indirect as well as direct benefits through making it possible to grant shorter contracts to operators because their investments are less specific.

All of these factors affecting investment specificity can evolve over time: technological sophistication (of high-speed trains, for instance) is probably making investments more specific on average, but regulatory convergence is probably making them less specific.

Further research, empirical as well as theoretical, will be needed to see to what extent performance outcomes (efficiency of operation, levels of investment and so on) are sensitive in practice to the length and nature of asset allocation mechanisms. Once this is done it should be possible to develop rules of thumb for selection allocation mechanisms for different kinds of infrastructure access.

Appendix 1: The Probability Table

$t=1$ \ $t=2$	$H,\ H$	$H,\ L$	$L,\ H$	$L,\ L$
$H,\ H$	$\frac{(1+\theta)(1+\rho)^2}{16}$	$\frac{(1+\theta)(1-\rho^2)}{16}$	$\frac{(1+\theta)(1-\rho^2)}{16}$	$\frac{(1+\theta)(1-\rho)^2}{16}$
$H,\ L$	$\frac{(1-\theta)(1-\rho^2)}{16}$	$\frac{(1-\theta)(1+\rho)^2}{16}$	$\frac{(1-\theta)(1-\rho)^2}{16}$	$\frac{(1-\theta)(1-\rho^2)}{16}$
$L,\ H$	$\frac{(1-\theta)(1-\rho^2)}{16}$	$\frac{(1-\theta)(1-\rho)^2}{16}$	$\frac{(1-\theta)(1+\rho)^2}{16}$	$\frac{(1-\theta)(1-\rho^2)}{16}$
$L,\ L$	$\frac{(1+\theta)(1-\rho)^2}{16}$	$\frac{(1+\theta)(1-\rho^2)}{16}$	$\frac{(1+\theta)(1-\rho^2)}{16}$	$\frac{(1+\theta)(1+\rho)^2}{16}$

This table gives the probabilities of the 16 possible configurations of our model over the two periods. One can check for example that the sum of the first row (or the first column) equals $\Pr\left(v_t^1 = v_t^2 = H\right) = \frac{1}{4}(1+\theta)$. Similarly the sum of the 4 probabilities in the northwest square equals $\Pr\left(v_1^i = v_2^i = H\right) = \frac{1}{4}(1+\rho)$, and analogously for the southeast square. This table allows for the computation of the probabilities used in the text.

Appendix 2 The properties of σ_{LT}

Recall the expression of σ_{LT}:

$$\begin{aligned}
\sigma_{LT}(\rho,\theta) &= \frac{(1+\theta)[8-(1+\rho)^2]}{2[8-(3-\theta)(\rho+\theta)]} \\
\frac{1}{\sigma_{LT}}\frac{\partial \sigma_{LT}}{\partial \theta} &= \frac{1}{1+\theta} + \frac{3-\rho-2\theta}{8-(3-\theta)(\rho+\theta)}.
\end{aligned}$$

Thus, $\frac{\partial \sigma_{LT}}{\partial \theta}$ has the same sign as

$$\begin{aligned}
P(\rho,\theta) &\equiv 8-(3-\theta)(\rho+\theta)+(1+\theta)(3-\rho-2\theta) \\
&= 8-3\rho-3\theta+\theta\rho+\theta^2+3+3\theta-\rho-\rho\theta-2\theta-2\theta^2.
\end{aligned}$$

After simplifications we obtain:

$$P(\rho,\theta) = 11-2\theta-4\rho-\theta^2,$$

which is non negative for all $(\rho,\theta) \in [-1,1]^2$.

Thus σ_{LT} increases in θ.

Now

$$\frac{1}{\sigma_{LT}}\frac{\partial \sigma_{LT}}{\partial \rho} = \frac{-2(1+\rho)}{8-(1+\rho)^2} + \frac{3-\theta}{8-(3-\theta)(\rho+\theta)}.$$

Thus $\frac{\partial \sigma_{LT}}{\partial \rho}$ has the same sign as

$$Q(\rho,\theta) \equiv [8-(1+\rho)^2](3-\theta) - 2(1+\rho)[8-(3-\theta)(\rho+\theta)],$$

which after simplifications gives:

$$Q(\rho,\theta) = (3-\theta)\rho^2 + 2\rho(3\theta-\theta^2-8) + (5-\theta-2\theta^2).$$

When $\rho = 1$, this is negative

$$Q(1,\theta) = -4\theta^2 + 4\theta - 8.$$

However for ρ positive or close to zero this is positive for $\theta \in [-1,1]$

$$\begin{aligned}
Q(0,\theta) &= -2\theta^2 + 5 \geq 2 \quad (\text{for } \theta \leq 1) \\
\frac{\partial Q}{\partial \rho}(\rho,\theta) &= 2\rho(3-\theta) - 2[\theta^2 - 3\theta + 8] \\
&< 2[3-\theta-\theta^2+3\theta-8] = 2[-\theta^2+2\theta-5] < 0.
\end{aligned}$$

■

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