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Least Present Value of Net Revenue: A New Auction-Mechanism for Highway Concessions

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Abstract

This paper presents a new mechanism for awarding tolled-highways, based on the variable-term concept proposed by Engel et al (1997). These authors claim that a mechanism based on bids for least-present-value of revenue (LPVR) eliminates the risk of demand and simplifies renegotiations. However, if maintenance and operation costs are non-negligible, it is proven that, under LPVR, bidders need to estimate future traffic to make their offers, so the risk of demand is still present. Moreover, LPVR does not guarantee the selection of the best concessionaire.

An alternative mechanism (least-present-value of *net* revenue, LPVNR) is proposed. The idea is to use bids that do not force firms to estimate future traffic. Under LPVNR, firms must make offers on: (i) total amount of revenue, net of maintenance costs; (ii) annual operation and routine-maintenance costs; and (iii) cost of road re-pavement. The concession is awarded to the firm with the lowest total expected cost, and the selection rule is adapted to the information available. The new mechanism is simple, does not impose additional efforts from firms, and eliminates the risk of demand more effectively. Although initially conceived for the road sector, the idea of LPVNR could easily be extended to other infrastructure sectors.

Keywords: Highways, roads, concessions, auctions

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1. Introduction

Many countries around the world are presently building large infrastructure projects by issuing concession contracts to the private sector. These contracts are commonly used in the transport sector (highways, port terminals, airport runways, and so forth), but also in some other public utilities, like water, gas or electricity. For many decades, the traditional approach to all these industries was to consider that they belonged exclusively to the public sector, because their basic infrastructure assets have some characteristics of public goods. Therefore, it was concluded, investments for these sectors should be made and funded by governments. Tight budget constraints and limitations to the use of debt –specially in developing countries– have forced many governments to seek participation of private investors to finance infrastructure projects. Concession contracts then appear as an optimal solution for the construction of publicly-used infrastructure, because investments are made by the private sector, but ownership of assets remains public, thus easing the problems associated with private monopolies controlling those assets.

However, in order for a concession to work satisfactorily, both the mechanism to select the concessionaire and the contract regulating its operations must be carefully designed. Infrastructure projects require large investments, and they have long lives, which means that they are usually built under high uncertainty about demand, costs and interest rates. In particular, for the case of highway concessions, uncertainty about future levels of traffic is one of the main origins of problems for concessionaires. Apart from rising the cost of capital, demand fluctuations can cause severe financial distress to firms building roads. If the number of vehicles using a concessioned road is significantly smaller than initially forecasted by the operator, low revenues may even cause bankruptcy for the private firm.

There are many international experiences about road concessionaires entering into difficulties due to deviations between forecasted and actual levels of traffic. Some illustrative examples are the Dulles Greenway project (Virginia, USA), with an initial forecasted volume of traffic of 34,000 vehicles per day, but in practice it only reached an effective level of 23,000 vehicles; the M1 project (Hungary), where traffic was 50 percent below expectations; and the large program of road concessions implemented in Mexico during the 1990's, where the average traffic using the different concessioned highways was 68 percent below expected levels, and for 16 concessions it was below 50 percent (Fishbein and Babbar, 1996; Gómez-Ibáñez, 1997).

The case of Mexico is probably on of the most dramatic examples of problems caused by errors made when estimating road traffic. Between 1987 and 1995, the federal government of Mexico granted 52 road concessions, as part of a program to enlarge its highway network with 6,000 km of new high-capacity tolled roads. Due to political and credit-market reasons, concession contracts' terms had to be short, and consequently tolls needed to be relatively high for private concessionaires to recover their investments in short periods. The result was a financial catastrophe, both for the private firms and for the government. Effective levels of traffic fell very short from forecasted levels, in great part because initial studies for demand forecasting were not very accurate, but also due to high tolls. The 1994 peso crisis aggravated the situation, and even if most of the concession contracts were renegotiated, it was already impossible to avoid bankruptcy for many of the concessionaires. In 1997, the Mexican government recovered 25 concessions, and assumed their debts for an estimated amount of 7.7 billion US$. Besides, losses for private investors were estimated in another 3 billion US$ (Gómez-Ibáñez, 1997).

One negative effect that uncertainty about future levels of traffic creates is the distortion that it may introduce in the mechanism for selecting concessionaires. The most commonly used mechanism for granting road concessions is a sealed-envelope auction in which firms make offers for the tolls to charge to users, while the period for the concession is fixed and determined from the outset. A selection mechanism like this relies on expected revenues, which in turn depend on expected volumes of traffic. Therefore, it is not guaranteed that the best candidate is always selected by such a mechanism. Easily, concession contracts could be granted to firms that are highly optimistic about expected traffic, but not necessarily to the best in terms of cost efficiency.

A recent study (Guasch, 2000), based on a large sample of concession contracts[1], shows that renegotiation of concession contracts for projects related to infrastructure is frequent (65 percent of contracts are renegotiated during the life of the concession). Interestingly, the type of mechanism used for awarding contracts has an impact on the probability or renegotiation. When a concession is based on offers for the minimum price to charge to users, 92 percent of contracts are renegotiated. Clearly, the mechanism now commonly used to award road concessions is not optimal, unless renegotiation is considered acceptable.

Recently, there has been a proposal (Engel et al, 1997) for a mechanism to award highway concessions, which aims to solve the difficulties posed by the fixed-term concession system. The basic idea is to use concession contracts with variable terms, in which the duration of the contract is left open as a function of the actual level of traffic that uses the road. The proposed mechanism is undoubtedly better than those presently used in practice. However, contrary to the opinion of its authors, it still forces firms to estimate future levels of traffic, therefore not solving satisfactorily the problems posed by the risk of demand fluctuations.

This paper discusses the aspects where this mechanism of variable-term concessions does not perform adequately, and it proposes a new alternative auction-mechanism for awarding concession contracts to private firms, which solves the main problems. Although the discussion is basically centered on the road sector, the use of this new type of mechanism can be easily extended to concessions of infrastructure projects in other sectors.

The paper is organized as follows: section 2 briefly describes the idea of variable-term concessions proposed by Engel et al (1997), and the advantages over fixed-term concessions. Section 3 discusses the limitations of this mechanism. Section 4 studies some features about highway maintenance in practice and standards for road quality. Section 5 describes the new proposal for a refined awarding mechanism, which is compared to the alternative of Engel et al in section 6. Finally, section 7 concludes.

2. Variable-term concessions: the least-present-value-of-revenue (LPVR) mechanism

Most systems used in practice to select private firms to build highways under concession contracts are some type of auction. In these auctions, candidates compete by bidding offers on a pre-determined variable or set of variables. Generally, the selection process involves two phases: first, potential concessionaires are evaluated on their financial status and experience. Those firms

[1] The sample is formed of 700 concession contracts, of which 45% are infrastructure projects in the transport sector, 25% water sector, 20% power sector, and 10% in telecommunications. By region, 60% are located in Latin America, 20% in Asia, and 20% in Eastern Europe.

qualified as apt are allowed to enter the second phase, which usually requires the submission of a closed-envelope offer on the specified variables. Criteria used to select the winner are publicly known before offers are made, and rules are generally simple: e.g., to choose the firm with the lowest toll, the highest payment to the government, or some weighted index of several variables. A key feature of all these concession systems is that the period during which the concessionaire will operate the road is fixed from the outset by the government.

As discussed by Engel et al (1997), these systems share the defect that they impose severe demand risks on the concessionaire. Consider for example a system based on a fixed-term concession (e.g. 25 years), in which the contract is awarded to the firm bidding for the lowest toll rate to be charged to motorists. When making its offer, a firm needs to estimate the levels of expected traffic for those 25 years, and calculate fares that would allow it to recover its construction and financial costs, and to obtain some return on investment. On the other hand, the firm must bid for the lowest possible fare in order to increase the probability of being selected as the auction's winner. The result is that, in most cases, these mechanisms do not select the most efficient firm to build the infrastructure, but the firm that is more optimistic about future traffic.

If afterwards the number of vehicles is below the winner's expectations, the concessionaire might not be able to obtain enough revenues during the concession term even to repay credits. In practice, these problems are frequent and concession contracts for highways are commonly renegotiated. Apart from its economic and political costs, renegotiations break the credibility of a government for future auctions. If firms bidding for a concession anticipate that their contracts will probably need to be altered in the future, their offers will tend to be unrealistic. When calculating the price to bid for, a firm will be more interested in being selected as concessionaire, no matter the assumed risk, than in proposing an accurate toll rate.

In the case of Mexico, the selection process was based on bids for the shorter term for the concession, while toll rates were fixed by the regulator. However, the problems of demand risk were exactly the same as in the typical fixed-term concession described above, where firms bid for the toll rates. In many concessions of the Mexican program, firms bided for extremely unrealistic periods (5-7 years), which eventually proved too short for the actual levels of traffic using the roads. When consortia building the Mexican highways started to have financial problems, the government was forced to renegotiate and extend concession terms, and eventually to recover a major part of the concession program[2].

Demand risk rises the cost of capital for firms. In some cases, governments even have to provide some guarantees of revenue, in order for private firms to obtain loans for highway projects. Those higher financial costs are passed to highway users in the form of higher toll rates, which reduce demand and thus aggravate the problem of obtaining revenues to repay debts. On the other hand, renegotiations are costly for public budgets, since they involve governments paying for concessionaires' debts, or some other forms of financial support. Therefore, any mechanism that could reduce demand risk for highway concessions is a Pareto improvement for society: users could pay lower tolls, firms would reduce the risk of bankruptcy, and taxpayers would not be forced to pay for the recovery of highway concessions.

[2] An additional problem in the case of Mexico was that, as required by the Constitution, users always must have alternative parallel roads to tolled highways. Short-term concessions implied high toll rates, which deviated a lot of traffic to the free roads, thus aggravating the problem of low demand affecting the concessionaires.

Compared to fixed-term concessions, the least-present-value-of-revenue (LPVR) mechanism presented by Engel et al (1997) helps to reduce the risk of demand, based on a simple idea. The problem of demand uncertainty for a concessionaire is that it does not know how many years of road operation are needed until its investment is recovered. When demand is low, the fixed period allowed for the concession might be shorter than the period required for cost recovery. This is the origin of troubles for concessionaires. Therefore, a feasible solution is to allow a variable term for the concession, so that when demand is low, the concessionaire would keep running the highway during a longer period to be able to obtain funds to recover its costs. Because cost recovery is always guaranteed by the automatic extension of the concession term (provided a sufficiently high long-run level of demand), the risk of demand is greatly reduced.

In practice, the LPVR mechanism works as follows. Toll rates are fixed by the government or a regulator, and firms only bid for the total amount of revenue (discounted at a pre-determined rate) that they want to obtain during the life of the concession from the collection of tolls. The firm with the lowest bid wins, and it builds and operates the road until its total revenue is equal to the amount bided for. At that moment, the contract ends and the public sector recovers control over the road. Thus, when picking their offers, firms must calculate their costs and expected profits, and make low bids in order to increase the probability of winning the concession. The mechanism, by design, intends to select the most efficient firm, in terms of having the lowest costs of road building.

It is claimed that this variable-term system relieves the firms from the need to estimate future levels of traffic when bidding for a concession contract. Other advantage is the reduction of renegotiation risk for the government, since when demand is low the system automatically extends the term of the concession. Unarguably, the variable-term concession system improves matters compared to the traditional fixed-term system. However, as it is described in the next section, firms bidding for a concession awarded by LPVR are still forced to perform some demand forecasting when computing their bids. Due to the fact that future demand levels need to be estimated, the proposed mechanism shares with the fixed-term system the drawbacks caused by relying on firms' beliefs about future demand. Most importantly, the mechanism does not guarantee that the most efficient bidder is always selected, which can result in socially sub-optimal solutions.

3. Limitations of the least-present-value-of-revenue (LPVR) mechanism

Although it is simple and neat, the LPVR mechanism has some limitations. In their paper, the authors already recognize some of them, as a lack of incentives for the concessionaire to make efforts to promote the use of the road, because high levels of traffic imply shorter concession terms. Another limitation is that firms could cut on quality of service to decrease their costs, because they are not really interested in attracting motorists (Tirole, 1997). But these limitations may be overcome by monitoring the quality of services provided by the concessionaire.

However, there exists a more severe limitation to the LPVR mechanism. The system is claimed to 'liberate' firms from the uncertainty of demand, but this point is far from clear when the assumptions used for the analysis are slightly modified. In particular, maintenance and operation costs for highway projects are considered as negligible, and disregarded from the simple analytical framework used by Engel et al (1997).

Contrary to that opinion, real data from highways franchised in Europe indicate that total operation and maintenance costs during the life of a highway concession could be around 20% of investment costs, considering average concession periods of 20-30 years (French Highway Directorate, 1997; NatWest, 1997; Louzan et al, 1998). For longer concession periods, the relevance of operation and maintenance costs could be even higher. For example, in the case of a 50-year concession, with a time discount rate of 6% and a low rate of inflation (a likely scenario for a low-demand highway that could be concessioned in a developed country), total operation and maintenance costs during the life of the concession could easily add up to a third of initial investment costs. On the other hand, most of the highway concession contracts that are awarded around the world are not for greenfield projects, but for enlargement and improvement of existent roads. Thus, for many highway projects in practice, investment costs can be not so huge compared to maintenance and operation expenses, so the assumptions used for the analysis of the LPVR mechanism could turn out not to be completely realistic.

The existence of maintenance and operation costs, which have to be paid by a private firm operating a highway under a concession contract, poses two basic problems for the LPVR mechanism. First, firms bidding for a contract still need to estimate future levels of traffic when making their offers. Thus, although the risk of demand is mitigated compared to fixed-term systems, it is far from eliminated. Second, the mechanism does not guarantee that the best firm is selected as concessionaire, because firms' beliefs may interfere with the selection process. It is then possible that a high-cost overoptimistic candidate is chosen, while a more efficient low-cost firm with accurate demand forecasts is rejected. Finally, the claimed advantage of easy renegotiations under LPVR can be much more controversial if there are maintenance and operation costs involved.

In order to illustrate these points formally, the following simple framework is proposed. Consider that the level of traffic that will use a highway in the future is uncertain at the moment of drafting a concession contract. Only two states of nature are considered: traffic may be high (Q^H), with probability π, or low (Q^L) with probability $1-\pi$, and by definition, $Q^L < Q^H$. Expected level of traffic is denoted by $Q^e = \pi Q^H + (1-\pi) Q^L$. Once that uncertainty about the state of nature is resolved, and found to be Q^H or Q^L, the level of demand is considered to be constant over time, i.e. the road will be used by Q^H or Q^L vehicles each year during all the life of the concession[3].

There are n firms bidding for the contract, but not all of them are equal in terms of efficiency. Construction costs of each firm *i* are denoted as I_i, $i = 1..n$. Apart from the investment for the construction of the road, which is made at the beginning of the life of the concession, the firm running the highway has to assume some maintenance and operation costs. Part of these costs may depend on the volume of traffic (basically, wear and tear of pavement), but other parts are fixed and must be paid each year (personnel, equipment, signaling, insurance, lighting, cleaning, and so forth). Consider that the variable part can be expressed in terms of a unit cost c_i per vehicle that uses the road, while the fixed part is equal to a total cost M_i per year. Monetary units for costs c_i and M_i are those of the year when they are generated.

As indicated by the chosen notation, it is assumed that firms may differ according to their efficiency levels regarding both construction costs and maintenance and operation costs. This

[3] In practice, traffic levels generally grow over time, so Q^H and Q^L should be re-interpreted as annual average values taken over relatively long periods.

assumption is justified by the fact that firms' managers have some degree of control over firms' costs, because they might have different skills, or may exert more or less effort in reducing costs.

Throughout the paper, it is considered for simplicity that all vehicles are equal and there is a single toll rate P. In practice, it is a known fact in the road sector that trucks and buses cause much more deterioration to road pavement than cars (estimated damages can be more than 1,000 times higher for large trucks), and they are charged higher tolls. Therefore, it can be considered that, in practice, P could be a weighted average toll rate, with weights representing the relative shares of each type of vehicle.

Time discount rate is denoted by $\delta = (1+r)^{-1}$, where r is the market's interest rate. The total number of years during which the concessionaire operates the road is denoted as T. The highway is assumed to be built in year t=0, when the concessionaire makes all investment I, and it initiates road operations in year t=1, when the firm starts collecting tolls and incurring into maintenance and operation costs. All cash flows are discounted to monetary values of year t=0.

3.1. Need to estimate future levels of traffic under LPVR

When the concession is auctioned, the objective of bidders will be to win the contract. If the mechanism used is LPVR, offers made for total revenue must be as low as possible, in order to increase the probability of being selected as concessionaire. In terms of auction theory (McAfee and McMillan, 1987; Milgrom, 1989), the LPVR mechanism is equivalent to a first-price-sealed-bid type of auction, where the winner is the firm with the lowest bid for total revenue. If many firms compete for a concession, and no information is available about rivals, each firm faces a trade-off. Making a high bid for revenue may provide substantial profits in the future but, at the same time, it reduces the probability of being selected as winner. In equilibrium, the best strategy for firms would then to make bids close to real costs plus a normal profit, which eventually should lead the auction mechanism to select the most efficient firm.

In theory, the bid offered by each firm would then be determined by a zero-profit condition. If the state of nature about future level of traffic (s = {H, L}) were known, this condition for any firm i could be expressed as follows (for the purpose of clarity, the discount rate δ is considered for the moment to be equal to one. Results are exactly the same for any value δ < 1, but expressions are a bit more complex):

$$I_i + c_i\, Q^s\, T_i^s + M_i\, T_i^s \;=\; P\, Q^s\, T_i^s \tag{1}$$

As it can be deducted from expression (1), the number of years during which the concessionaire *i* would run the highway until it fully recovers its costs can be endogenously determined from the zero-profit condition:

$$T_i^s \;=\; \frac{I_i}{(P - c_i)\, Q^s - M_i} \tag{2}$$

The number of years that a concessionaire would require to operate the road to recover its cost (T_i^s, s={H,L}) depends on the level of traffic that effectively uses the infrastructure. If demand is high (Q^H), the period required to obtain sufficient revenue to pay for costs will be shorter than if demand is low (Q^L), i.e. $T_i^H < T_i^L$, for any type of firm *i*.

However, when preparing their bids for the auction, firms are uncertain about what the level of demand will be in the future. Therefore, the best estimate that each firm can have ex-ante about the duration of the concession will be obtained by using the expected demand Q^e, which in turn depends on the probability assigned to each state of nature.

On the other hand, the time required for cost recovery varies according to each firm. If a firm is more efficient in terms of investment and maintenance costs compared to another, the first one would require a shorter period for the concession contract. As expression (2) indicates, the lower I_i, c_i or M_i, the shorter the required period T_i^s.

Transforming the zero-profit condition (1), and using the level of ex-ante expected traffic Q^e, the bid B_i for total revenue that each firm *i* is going to offer can be calculated:

$$B_i \;=\; P\,Q^e\,T_i^e \;=\; \frac{P}{P-c_i}\left(I_i + M_i\,T_i^e\right) \tag{3}$$

Expression (3) reveals how, in the presence of maintenance and operation costs, the improvements claimed to be obtained by the LPVR mechanism are not so obvious. The bid submitted by firm *i* is going to depend on its own level of cost efficiency (i.e. the private information contained in parameters I_i, c_i and M_i that the auctioneer intends to elicit through the selection mechanism). But B_i is also determined by the period during which each firm expects to hold the concession (T_i^e). Therefore, when computing their bids, firms *do need* to perform some forecasting to determine what is the expected level of traffic that the highway can receive in the future. Relying on estimates is the ultimate origin of the risk of demand that fixed-term concessions suffer from, so the LPVR mechanism does not seem to be a solution for that problem.

Only for a project with $M_i = 0$, that is, in which maintenance and operation costs depended exclusively on the volume of traffic without any fixed components, the required revenue bided by firms would not be a function of the expected concession term. Under those conditions, firms can effectively forget about demand forecasting, since the present value of required revenue would be the same in any state of nature, and equal to $B_i = P\,I_i/(P-c_i)$. This is the case used by Engel et al (1997) to analyze the LPVR mechanism, but since they do not consider any maintenance and operation costs ($c_i = 0$), in their analysis the firms' bids are equal to their construction costs, i.e. $B_i = I_i$.

However, since it seems that in real highway projects the fixed amount of maintenance and operation costs is not generally negligible, the scenario with $M_i = 0$ does not seem appropriate to analyze a proposal for a new mechanism intended to improve over existent fixed-term concessions. By doing so, conclusions obtained about elimination of the risk of demand and easy renegotiations could prove to be invalid.

Demand risk in concessions awarded through the LPVR mechanism will have the same effect as it has under fixed-term concessions: it rises the costs of capital for firms seeking resources to build or enhance highways. When maintenance and operation costs are not negligible, a low demand situation implies that these costs can severely erode expected profits (because operating costs accumulate over time). Creditors are going to perceive this risk and, as a result, they are going to ask for higher interest rates.

Unfortunately, there are not many road concessions in the world which had been awarded by LPVR mechanisms (the only documented cases are those of the Chilean highway *Santiago-Valparaíso-Viña del Mar*[4]; and two other concessions in the UK, the Severn Trent and Dartford Bridge projects). Due to this reduced number of experiences, it is difficult to assess yet how financial markets will evaluate the perceived risk of demand for highway projects concessioned by LPVR.

3.2. Risk of selecting inefficient concessionaires under LPVR

Even more dramatic than the problem of incomplete elimination of the risk of demand, the LPVR mechanism may prove unable to discriminate between efficient and inefficient bidders. Society as a whole, then, can end up paying more than necessary for the construction or rehabilitation of highways, which is clearly a sub-optimal non-desirable outcome.

The inability of the LPVR mechanism to elicit information from bidders about their levels of efficiency stems from the fact that single bids for revenue for the whole concession period can be 'contaminated' with firms' beliefs about future levels of traffic. It is perfectly possible that a highly inefficient construction company, with high costs both for building and operating a highway, might rely on poor estimates about expected demand for the road. This firm could then submit a extremely biased low bid, and win the contract. Even if no strategic behavior is involved (the firm computes its bid according to its real parameters I_i, c_i and M_i), the selection mechanism would make a mistake by choosing this firm –and rejecting another one with lower costs– simply because the first one turns to be more optimistic about expected traffic. If these expectations are eventually incorrect, the concessionaire will enter into financial difficulties, and will ask for contract renegotiation. The same old known situation generated by the fixed-term concession system can be easily reproduced again in concessions awarded by LPVR.

To formally analyze this selection problem, consider two possible examples: (a) two firms, with equal maintenance and operation costs, but with different investment costs; and (b) two firms with equal investment costs, but different maintenance and operating costs.

(a) Firms with different investment costs.

In this scenario, one bidder for a highway project (firm 1) is relatively inefficient compared to another rival (firm 2), in terms of its construction costs. These costs are, respectively, $I_1 = I$ and $I_2 = i$, with, $i < I$. Meanwhile, both firms have the same annual fixed and variable costs related to maintenance and operation of the road, that is, $M_i = M$ and $c_i = c$, for $i=\{1,2\}$.

Consider that firm 1 is more optimistic than its rival about future expected traffic for the highway. It then might be estimating a much shorter term for the concession, which could make it to bid for a low level of revenue and eventually to win the contract. Assume for example that firm 1 assigns a higher probability to the good state of demand Q^H, so that $\pi_1 > \pi_2$. Consequently, average annual traffic expected by firm 1 will be higher than by firm 2 ($Q^e_1 > Q^e_2$). When picking their bids, firms need to estimate how long the concession would last. Estimated periods (T^e_i,

[4] There was another road project in Chile (*Costanera* highway), which was auctioned by LPVR, but apparently did not attracted much attention from private investors, and it only received one offer, which was rejected. However, the fact that the process was not successful for that project must not be completely attributed to the auctioning system used. Lack of attraction could have been partly originated by the special characteristics of this project. This is a busy urban road, for which the only sensible system to collect fares is some form of automatic payment, and this was perceived as risky by potential bidders (for more details, see Gómez-Lobo and Hinojosa, 2000).

i=1,2) will differ between firms, because they depend on expected levels of traffic. As before, expected periods for the concession are implicitly determined by the following zero-profit equations (rewritten now for a more general case with $\delta < 1$):

$$B_i = \sum_{t=1}^{T_i^e} \delta^t \, P \, Q_i^e = I_i + \sum_{t=1}^{T_i^e} \delta^t \, c \, Q_i^e + \sum_{t=1}^{T_i^e} \delta^t \, M \quad ; \quad i = 1,2 \tag{4}$$

Let $K(T^e_i) = [\delta + \delta^2 + \delta^3 + ... + \delta^{T_i^e}]$, $i = \{1,2\}$. As both annual maintenance costs ($M + c\, Q^e_i$) and annual revenues ($P\, Q^e_i$) are assumed to be constant over time, bids submitted by each firm will be the following:

$$B_1 = P \, Q_1^e \; K(T_1^e) = I + c \, Q_1^e \; K(T_1^e) + M \, K(T_1^e) \tag{5}$$

$$B_2 = P \, Q_2^e \; K(T_2^e) = i + c \, Q_2^e \; K(T_2^e) + M \, K(T_2^e) \tag{6}$$

Observe that bids will generally differ, because they depend on the construction costs of each firm (I and i, respectively), and their expectations about the level of traffic, which affect both the level of estimated annual revenue ($P\, Q^e_i$) and the expected life-span of the concession (T^e_i). The LPVR mechanism will award the contract to the firm with the lowest bid B_i, without any further checking. An incorrect decision will be taken if firm 1 is selected[5], which only requires that bids satisfy $B_1 < B_2$. Denoting the difference between expected levels of traffic as $\lambda = Q^e_1 / Q^e_2$; $\lambda > 1$, the following sufficient condition can be found for a wrong decision to be made:

$$\frac{M}{(P-c)\, Q_2^e} > \frac{\lambda}{1 + \dfrac{(\lambda - 1)\, I}{(I - i)}} \tag{7}$$

In words, if the ratio of operation and maintenance costs over annual expected net revenue by the efficient firm is bigger than some benchmark level, the inefficient firm will be selected by the LPVR mechanism. That benchmark is a function of the gap between expected demand levels by both firms (measured by λ), and the difference between their construction costs (I-i). As it can be observed by studying expression (7), the condition is more likely to be satisfied if λ, c or M are large, and if (I-i) is small.

Intuitively, when λ is large it means that firms have very different perceptions about expected traffic for the highway. Firm 1 forecasts a much higher demand, therefore it predicts to be operating the road during a shorter period, and since operating costs will be consequently smaller, a reduced amount of revenue to be collected from tolls is required compared to the revenue demanded by firm 2. When maintenance and operation costs are significantly large, this effect is reinforced, thus making condition (7) to be more easily satisfied.

If the gap between construction costs for both firms is small, it will be more likely that the mechanism could make a wrong decision. This is originated because the part of the bid of firm 1 destined to recover construction costs will tend to be closer to that of firm 2, so the other part

[5] Observe that even when the belief of firm 1 about demand could be eventually correct, it would be preferable to have chosen firm 2, since its construction costs are smaller, and both firms have common operating costs c and M. In this example, society is unambiguously better if the more efficient firm in terms of construction costs is selected.

destined to cover for maintenance and operation costs becomes more relevant for the auction result. In that case, a relatively small difference in the expected level of demand could lead the system to award the contract to the inefficient firm.

(b) Firms with different maintenance and operation costs

Consider now a different scenario in which firms 1 and 2 are equal in terms of their investment costs ($I_1 = I_2 = I$), but firm 1 is again more inefficient than firm 2, so the auction mechanism should choose firm 2. In this case, it is assumed that firm 2 is more efficient in terms of fixed maintenance and operation costs, so that its annual expenses are smaller, $M_2 < M_1$. The vehicle-related variable part of operating cost is equal for both firms (*c* monetary units per vehicle)[6].

Under those conditions, the respective bids offered by the candidates would be:

$$B_i = \frac{P}{P-c}\left[I + \frac{I\,M_i}{(P-c)\,Q_i^e - M_i} \right] \quad ; \quad i = \{1,2\} \tag{8}$$

Expression (8) shows how bids B_i increase proportionally to maintenance costs M_i, because the higher the costs to be covered, the higher the revenue required. Due to that effect, the bid B_1 of firm 1 would tend to be higher than that of firm 2, because firm 1 has larger maintenance costs. In that respect, the selection mechanism works in the right direction. However, as it happens in the previous case, because the expected level of traffic affects to the bids offered by firms, it is feasible to identify cases were firm 1 is more optimistic than firm 2 regarding its expectations about demand, and this second effect can possibly distort bids so that firm 1 ends up winning the concession. As before, consider that $Q^e_1 > Q^e_2$, and the larger the value of the ratio $\lambda = Q^e_1 / Q^e_2$, the more important the divergence between the beliefs of both firms regarding traffic. As before, λ would be a measure of the relative 'optimism' of firm 1, and, by assumption, $\lambda > 1$.

The only condition for the LPVR mechanism to make a wrong decision in this scenario is again that the bid of firm 1 would be smaller than the bid of firm 2, $B_1 < B_2$. Operating with both bids, as defined by expression (8), a simple condition can be found in this case:

$$\frac{M_1}{M_2} < \frac{Q_1^e}{Q_2^e} = \lambda \tag{9}$$

In words, when firms have equal investment costs, but different fixed annual maintenance and operating costs, a sufficient condition for the LPVR to choose the wrong candidate is that the divergence between their beliefs about future traffic is larger than the divergence between their maintenance costs. The intuition for this result is that when firm 1 expects a level of demand significantly higher than the one expected by firm 2, the planned concession term required to recover its cost is sufficiently shorter than the period expected by its rival. This shorter period compensates for the difference in cost-efficiency that firms have, and leads firm 1 to submit a low bid that wins the auction.

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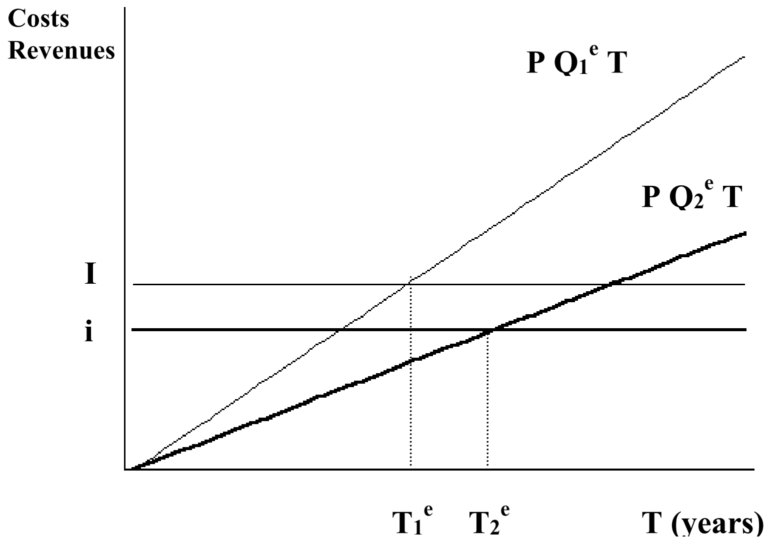
[6] To limit the extension of the paper, only this case is presented here. Another possible scenario that can be analyzed is one where fixed maintenance costs are equal (M_i=M), but variable costs differ (e.g., $c_1 > c_2$). A condition similar to (7) is found for that case.

3.3. Graphical analysis of the problems of the LPVR mechanism

The difficulties in selecting the best candidates for highway concessions suffered by the LPVR mechanism may be easily observed graphically. Consider again a two-firm scenario as above, but in the case of a road where operation and maintenance costs were nil, as assumed in the analysis of Engel et al (1997). Assume that firms differ only in their investment costs, with firm 2 being more efficient ($I_2 = i < I_1 = I$), and their beliefs about demand ($Q^e_1 > Q^e_2$).

In absence of maintenance costs, the difference between firms with respect to their demand expectations has no effect and firm 2 is awarded the concession. In Figure 1, total expected accumulated revenues over the years and for each firm are plotted together with their respective construction costs (for simplicity, no discounting is considered, i.e. δ=1). As figure 1 shows, the only impact that beliefs will have is that firm 1 expects to recover its investment in a shorter period ($T_1 < T_2$). However, this fact does not affect to bids or to the auction's outcome. Firm2, the efficient one, submits a bid $B_2 = i$ lower than firm 1's $B_1 = I$, and wins the concession.

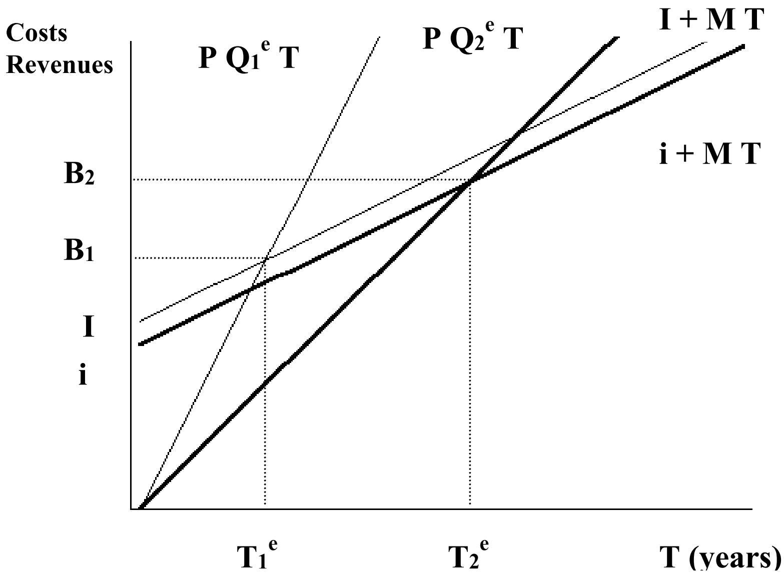
Figure 1: Case with no maintenance and operation costs (M = 0, c = 0)



However, matters turn out to be more complicated when the more realistic case of a road with maintenance and operation costs is considered. Total expected costs by each firm increase over time (since now not only construction is required, but also fixed maintenance and operation costs, which accumulate over time during the life of the concession). Therefore, the lines representing total accumulated costs now have a positive slope. Figure 2 represents a case in which it has been considered for simplicity that there are no maintenance variable costs (c=0). The impact of including also variable maintenance and operation costs would be simply to modify the slopes of the cost lines in the graph but results would be unaltered. Similarly, for expository simplicity, the represented case is one where fixed annual maintenance and operation costs are the same for both firms ($M_1 = M_2 = M$).

Again, if firm 1 is more optimistic about expected volumes of traffic, it might forecast to have a total cost (construction plus operation and maintenance costs over T_1 years) lower than the more efficient firm 2, as represented in figure 2. Because the bid of firm 1 ($B_1 = I + M\,T^e_1$) turns out to be lower than the bid of firm 2 ($B_2 = i + M\ T^e{}_2$), therefore firm 1 would be awarded the concession, although firm 2 would be socially preferable.

Figure 2: Case with fixed maintenance costs (M > 0, c = 0)



This graphic example summarizes the problems suffered by the LPVR mechanism in presence of maintenance and operation costs. First, it is shown once more that the awarding mechanism does not guarantee an automatic selection of the most efficient firm. Second, figure 2 illustrates how firms bidding under an LPVR mechanism are required to estimate future traffic, because they need to calculate the amount of maintenance and operation costs during the life of the concession.

3.4. Renegotiations to recover a concession or to alter its conditions

Another claimed advantage of the LPVR mechanism is that, in case of contract renegotiations due to some conflict between government and concessionaire, or because the government desires to introduce some changes in the original design of the project, the procedure would be much easier than under fixed-term concession. The argument is that, for concessions awarded through LPVR, the concessionaire reveals from the outset the amount of revenue that it wants to obtain. If renegotiation occurs during the life of the concession and it is difficult to reach an agreement, the government can end the contract, calculate how much money has the concessionaire already collected from tolls at that point in time, and compensate it for the rest up to the quantity bided for.

Obviously, this claimed simplicity is valid when private firms are considered to make all investments at the beginning of the concession period, and afterwards they only have to operate the road to collect the required money to recover costs. However, if there are maintenance costs involved, matters turn out to be more complicated. The amount of revenue that a firm bids for is not only for investment costs, but it also includes maintenance costs. Therefore, if a concession is ended before the initially planned term is completed, and the government wants to compensate the concessionaire, it will need to estimate the amount of maintenance and operation costs accumulated up to that point. Because that information cannot be extracted from the single bid provided by the firm, renegotiation of the contract will imply bargaining about the amount of those costs. This was the same point that was criticized about fixed-term concessions.

To illustrate this argument, consider the example of a concession where the effective level of traffic corresponds to the case of an extremely low demand (Q^L), such that the concessionaire faces a situation in which, even if the concession term is extended for ever, revenues will never be sufficient to cover for costs. For this to happen, it is only required that investment costs are relatively high compared to discounted revenues after paying for maintenance and operation costs. This situation would be characterized by the following condition:

$$I_i \quad > \quad \sum_{t=1}^{\infty} \delta^t P Q^L - \sum_{t=1}^{\infty} \delta^t M_i - \sum_{t=1}^{\infty} \delta^t c_i \, Q^L \; = \frac{(P - c_i)\, Q^L - M_i}{r} \tag{10}$$

Consider that the government wants to rescue this firm from bankruptcy, and wants to pay a fair compensation for the costs incurred into. If there were no maintenance and operation costs involved, calculating the amount that the firm should receive is a simple matter. Data from revenues obtained during the concession term would be available, and the firm would have incurred only in construction costs, which can be approximated by the firm's bid for revenue. Assume that the contract is ended after T years of operation. In that case, if the government wants to bail out the concessionaire, its fair compensation payment (R_i) would be the following (expressed in monetary values of year t = 0)[7]:

$$R_i = B_i - \sum_{t=1}^{T} \delta^t \, P Q^L \tag{11}$$

Exactly the same situation would arise if the government wanted to modify the conditions of the highway during the concession term (for example, to enlarge the project). In practice, this situation usually leads to conflicts, because renegotiations imply payments to be determined, and these require estimation of costs. It is claimed that these problems could be avoided under LPVR concessions, because simple solutions as that shown in expression (11) could be applied.

However, in presence of operation and maintenance costs, matters are not so simple even for LPVR concessions. In that case, firms' bids B_i are not simply equal to I_i, but they also include the estimated amount of operating costs during the expected life of the concession (T^e_i). If the government needs to terminate a contract after T years of operation, either because demand is too low to pay for the project, or because it wants to alter the contract's conditions, a fair compensation payment would be (assuming again that the low state of demand Q^L is realized):

$$R_i = \left(I_i + \sum_{t=1}^{T} \delta^t \; c_i \; Q^L + \sum_{t=1}^{T} \delta^t \; M_i \right) - \sum_{t=1}^{T} \delta^t \; P Q^L \tag{12}$$

Because termination date T does not generally coincide with firm's expected period T_i, the task of calculating R_i is much more difficult than simply paying the difference between the bid B_i and the revenue obtained up to date T by collecting tolls, as it was claimed that LPVR concessions could achieve. Comparing expressions (12) and (11), it can be realized that the term in the parenthesis in the right-hand side of (12) is not the amount bided for (B_i). Instead, it would be equal to the actual total costs of the concessionaire during the T years of operation. Without

[7] In real highway projects, if a situation arises in which a government decides to recover a concession and it offers to award a compensation to the firm, clearly the money paid to the concessionaire should be adjusted to its real value at the time when the concession ends. If, for example, that occurs in year T, the actual money paid should be equal to $(1+r)^T R_i$, where r is a legal rate or some other interest rate consider as appropriate.

information about the values of I_i and M_i, contract renegotiation implies once again bargaining about those costs in conditions of asymmetric information, as it is the case with fixed-term concessions. Therefore, the LPVR mechanism may not be as attractive as it appears at first sight for renegotiating highway contracts in practice.

4. Maintenance of highways

One main conclusion can be extracted from the analysis of the previous section: all limitations and problems suffered by the LPVR mechanism are originated by the existence of maintenance and operation costs, which highway concessionaires have to assume during the life of a concession. Therefore, it seems that a way to improve the LPVR mechanism would be to try to extract more information about those costs through the bidding processes by which concession contracts are awarded. Having access to the real cost parameters I_i, c_i and M_i for the candidates to win a contract would be a key for a successful selection of concessionaire, and the implementation of a project with the lowest feasible cost.

In order to study how it could be possible to try to elicit cost information from bidders on these cost dimensions, it is interesting first to revise some features about maintenance of highways in practice, and the models and standards that exist in the road sector to evaluate quality of infrastructure.

4.1 Some technological facts

In engineering, the term 'maintenance' is used to describe the process of sustaining construction elements in usable condition (Atkinson, 1990). Since the moment a road is completed, its different components begin to decline as a result of weather effects, traffic, and changes in subsoil conditions. The aim of maintenance is to carry out protective and repair measures designed to limit the deterioration of the road, thereby prolonging its useful life.

Many empirical studies have analyzed what are the main determinants of road deterioration (Gomez-Ibañez and O'Keeffe, 1986; Paterson, 1987; Small et al, 1989; Ramaswamy and Ben-Akiva, 1990). Modern research started in the 1950's, when the American Association of State Highway Officials (AASHO) performed some pavement tests that were highly influential in the road sector, because their results allowed to determine precisely the impact of vehicle loads on pavements. Since then, many other experimental studies on laboratory and in-service roads, with different types of pavements and weather conditions, have been the base to develop models used in practice by highway agencies to make predictions about expected times when pavement failures start to appear, and forecast the evolution of damages over time[8].

Consensus exists among experts about what are the two most important causes of road deterioration: time and traffic-loads. In addition to these two basic factors, prediction models need to control for environmental conditions (basically, weather conditions such as temperature, moisture, amount of rain, number of days with freezing conditions, and so forth), and structural conditions (type of pavement, subsoil characteristics).

[8] Apart from the AASHTO model, some other pavement distress prediction models based on extensive databases are the RTIM2 model, developed by the British Transport and Road Research Laboratory Overseas unit, with data from Kenyan roads; the GEIPOT model, which used data from a road cost study carried out in Brazil between 1975 and 1981, the Arizona DOT model, and the Texas Flexible Pavement Design System model (Paterson, 1987).

Paterson (1987), from a study on Brazilian roads, determined that pavement roughness –an objective measure for road deterioration– increases with the age of a road at a constant rate, in addition to damages caused by traffic. For the Brazilian case, the rate of roughness' increase was estimated at 2.3 percent a year. This time-effect has been found to vary according to climate conditions: in dry-warm conditions was found to be lower (around 1 percent in a study for Tunisia), but much higher in moist freezing climates (7 percent in Colorado). The time effect, however, seems to affect only to asphalt flexible pavements. The other type of pavement used in roads around the world –rigid pavements, made of Portland-cement concrete– is not altered significantly by the pass of time, although it is still damaged by traffic using the road.

The second main factor determining road deterioration is the volume of traffic using the road, and specially, the type of traffic-mix. From all experiments performed over the years, it is known that heavy-load vehicles (trucks and buses) cause much more damage to roads than cars. As a matter of fact, normal cars contribute to the wear of road surfaces through their use of infrastructure in large numbers, but structural damages to road components are caused mainly by trucks. It has been found that what matters for road deterioration is not total vehicle weight, but weight per axle. The approximate rule is that damages caused by vehicle-axle increase very rapidly with load, between its third and fourth power. Thus, for example, the rear axle of a 13-ton van causes around 1,000 times as much as that of a car (Small et al, 1989).

From the AASHO road tests, a standard to measure traffic loading was developed, and it has been used since then by all road engineers. Traffic using a road is transformed into its equivalent in terms of a standard single axle of 18,000 pounds (around 9 tons). The unit to measure the level of traffic in a road is called ESAL (Equivalent Standard Axle Load). Total traffic loads –quantified in terms of ESALs– are used in models to predict road deterioration.

When a road is designed, its durability can be estimated in terms of total traffic load that will be using the road until it requires rehabilitation. Durability strongly depends on the type of road considered and its characteristics. It is known that rigid pavements have longer lives than flexible ones, and that the durability of a road depends on the thickness of its pavement. Even though deterioration of pavements is an stochastic process, there is enough accumulated experience and knowledge in the road sector for engineers to be able to provide approximate estimations of traffic loads that a road will support before it needs a major resurfacing (overlay of new pavement, probably accompanied of some structural repairs).

The condition of a road pavement at any given point in time is a variable for which there also exist standard measures developed in the road sector. As a matter of fact, indexes of pavement condition are used in practice by highway agencies to determine when a road is in need of a major rehabilitation. In the US, a 'serviceability index' is used, which is a simple one-digit index ranging from 0 to 5. When a road reaches a value below 2.5 a major resurfacing is considered necessary. Other countries use similar measures, and there is already an 'international roughness index' (IRI), elaborated by the World Bank (Sayers et al, 1986a). This is a summary statistic that represents vertical motions induced by pavement irregularities in vehicles circulating on the road studied, which affect their safety and comfort. The IRI uses a scale of roughness with value zero for a perfect surface, 6 for moderately rough paved roads, 12 for extremely rough paved roads with large potholes, and up to 20 for extremely rough unpaved roads[9].

4.2 Implications for road concessions: Can parameters I_i, c_i and M_i be computed in practice?

The conclusions that can be extracted from this brief revision of facts about road maintenance technology is that there exists enough international experience and data on the performance of road pavements under many different conditions and climates. There are also models developed to predict approximately the timing of pavement failures, its evolution over time, and the need for roads' major rehabilitation. Standard measures can be used to analyze the condition of a road objectively, and to establish some quality targets for its routine maintenance[10].

For the concession of tolled highways for construction and rehabilitation projects, all this international knowledge on pavement deterioration and maintenance standards has some important implications. First, experienced private companies, provided with precise technical requirements for a road project, are able to produce accurate cost calculations not only for the construction stage of a project, but also for the maintenance and operation costs generated afterwards during the life of the road. Operation costs have an almost-fixed nature, since these comprise expenses on personnel, equipment, rental payments, and so forth. Meanwhile, the nature of maintenance costs is more difficult to establish, because road deterioration is a complex process resulting from the interaction of time and traffic loads.

For the purpose of control of private concessionaires it can be convenient to classify maintenance expenses into two categories:

- *Routine maintenance*: This will comprise all minor repairs (crack sealing, patching, and so forth) to be done for achieving quality targets on pavement condition. Also, routine operations like cleaning, signaling maintenance or road marking. All costs related to these activities are not extremely dependent on the actual levels of traffic, and could be calculated by firms as average annual expenditures.

- *Major rehabilitation*: These operations would include non-periodical resurfacing of a road, together with some structural repairs. For a concessionaire preparing a bid for a contract, it will be relatively easy to calculate how much it would cost to perform a complete resurfacing of the structure. At the same time that total construction costs are calculated, an operation of resurfacing could be easily estimated as a part of those costs.

If a private firm can produce cost estimates according to the previous classification, the parameters used in the theoretical discussion of the previous section (I_i, c_i, M_i) would be relatively easy to calculate in practice. Then, it will be possible to design an auction mechanism

[9] Some work has been done (Sayers et al, 1986b) to calculate the equivalence between IRI and the most commonly used national indexes, such as the British index based on information from the Bump Integrator trailer (Transport and Road Research Laboratory, UK), or the French Short Wavelength Energy for APL72 Profilometer, developed by the Laboratoire Central des Ponts et Chaussées (Paterson, 1987).

[10] There are standard indicators used by road agencies to establish pavement quality levels. Typical indicators are types of pavement failures, and maximum levels acceptable. For example, the department of transport of Maryland (US) uses the following values for its maintenance standards of a 0.5 mile highway section: potholes, no defect >4 in. wide and >2 in. deep; cracking, 95% of surface free of unsealed cracks >0.25 in.; rutting, 90% of surface free of ruts >0.5 in.; shoved areas >0.75 in. high not to exceed 25ft^2, and 90% of surface free of evidence of dislodging of aggregate particles (Stivers et al, 1999).

based on these three cost dimensions, which can be used to solve the problems suffered by the LPVR mechanism.

Estimated construction cost I_i is the part more easy to calculate for private companies, but only if they are given good technical descriptions for the road projects. Governments need to have road agencies with sufficient resources and technical skills to prepare accurate descriptions of the roads that they want. Road designs must be very specific about the type of structures to be built, materials to be used, and quality standards to achieve. Otherwise, if governments only provide loose terms of reference regarding road technical characteristics, private firms will tend to cut costs by using cheap construction materials, and choosing road designs with low durability. Moreover, there will exist much variability on I_i across firms, derived from the fact that candidates could be conceiving very different types of road.

Nevertheless, the only relevant matter for the government regarding construction costs is to be sure that the final outcome of the project is the initially desired. The new proposed mechanism, which will be described in the next section, does not require direct information about I_i from the firms. Construction costs will be embedded in the total amount of revenue that firms want to receive, but it will go together with the rate of return on investment that each company plans to obtain from the project.

Evaluation of fixed annual maintenance and operation costs M_i can be slightly more complex for a firm bidding for a concession contract, but only regarding the part about minor repairs on pavement. If the government has some reliable predictions about the expected level of traffic, these figures should be offered to all potential candidates for a concession, for them to work out better their maintenance cost estimates. But even in scenarios where no demand studies are available, firms can always produce some approximate estimates based on their own experience in other projects. Adding the fixed-costs related to operations, good estimates for average annual expenses on maintenance and operation (M_i) will be relatively easy to obtain.

The more complicated parameter to estimate in practice would be the unit cost per vehicle (c_i), as defined in the model of the previous section. However, based on the assumption that the major variable impact of traffic on roads is pavement deterioration (with other minor effects already included in M_i), it is conceptually feasible to define some objective measurement for c_i, even when the level of traffic that actually will use the road is unknown. The only requirement to calculate c_i is the possibility of estimating the total maximum traffic load that can use a road before it needs a major rehabilitation (overlay of new pavement).

Observe that this requirement is purely technical. Government engineers must have an approximate idea of the traffic load that they are considering when they choose a particular road design (basic road structure, type of pavement, thickness, and so forth). Therefore, from the technical description of a highway, the 'total ESAL-miles' between two major road rehabilitations can be approximated. One way of accurately estimating this value would be to obtain it from pavement deterioration models. By setting some objective threshold level to trigger a major rehabilitation operation (as it is the practice in US highway agencies, using the 2.5 reference of the serviceability index), and controlling for environmental factors, it is possible to calculate the maximum acceptable traffic load that a road could service during its life. There is enough international experience that can be used as benchmarks of reference, so it is not an irrational assumption to think that for any road project, some estimate of total ESAL-miles could be obtained.

If the technical maximum traffic load is available, the only other information requirement to calculate c_i would be to know the cost of a complete resurfacing operation. But this is nothing but an economic variable that can be provided by a building company with experience in the road sector, so this will be the interesting information to extract from bidders at an auction. Calculating a marginal cost in terms of axle-loads is then straightforward, and the model used before could be easily re-interpreted by considering Q as the traffic load per year and c_i as the cost per standard axle load (ESAL).

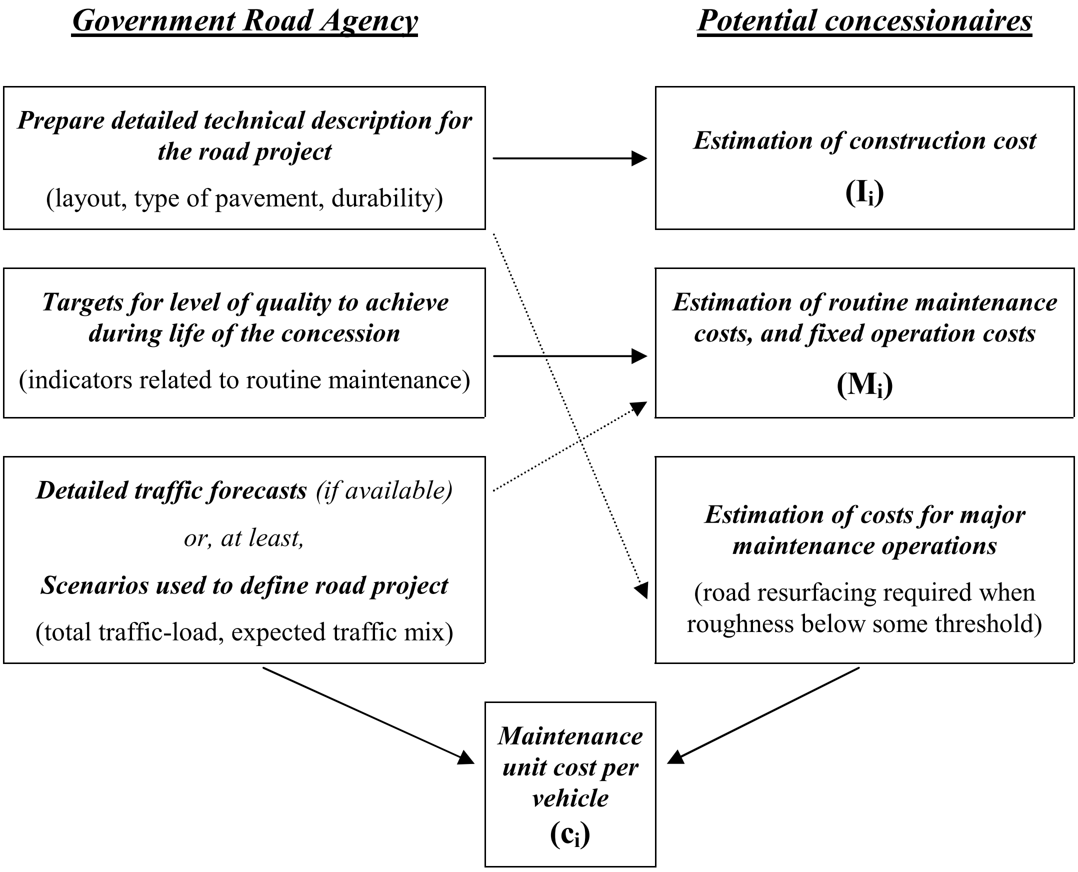
On the other hand, it is still feasible to make conversions between traffic expressed as axle-loads and number of vehicles. This is useful, for example, in terms of setting toll rates to charge to different types of vehicles. In order to make that transformation, it is only necessary to make some assumption on traffic-mix, and to have technical information on axle-loads. No data about total expected volume of traffic would be required. For example, assume that a road is likely to have a traffic-mix with 10 percent of heavy trucks. The total number of car-miles that the road will have serviced between two rehabilitations would then be equal to $n = ESAL / (\alpha + 0.111\,\beta)$, and the number of truck-miles to $N=0.111\,n$

In fact, this type of unit vehicle maintenance costs, in terms of axle-loads, has already been calculated by some highway agencies, and some data exist. For example, Small et al (1987) estimate for the case of US that a standard rural interstate highway (generally, a 10-inch rigid pavement road) withstands the passage of around 9 million ESALs before requiring a major overlay. Resurfacing marginal costs per ESAL-mile are estimated for these roads to be between 1.48-4.38 US cents of 1982 (for other type of US roads, maintenance marginal costs are much higher). Clearly, monetary estimations of marginal costs cannot be automatically compared across countries, because re-surfacing costs are likely to differ due to national differences in wages, cost of materials, and so forth. But, however, data on maximum traffic loads supported by pavements can in principle be compared, controlling for climate and other environmental variables.

The general conclusion to derive from all this discussion is that maintenance and operation costs are more complex to estimate than construction costs, specially when no information on expected levels of traffic is available. However, the experience of many decades and highway agencies around the world seems to be sufficient to consider that information on these variables can be objectively measured and relatively easy to extract from firms participating at an auction. The division of maintenance costs between routine operations and major road rehabilitation could be considered somehow arbitrary. But, as it has been shown, it seems a practical classification aimed to make firms evaluate objectively the impact that traffic usage causes on road infrastructure.

As it has been described, a key aspect for a highway concession program to be capable of making firms provide the required information and commit to lowest feasible costs and standards of quality is to have a public road agency or regulator with sufficient resources and skills to perform its required tasks of project design and supervision. To summarize all the main points regarding these tasks, and the flows of information that have to be established between road agency and potential concessionaires, a scheme is presented in figure 3:

Figure 3: Tasks and flows of information for a road concession bidding process



5. A new auction-mechanism: least-present-value of net revenue (LPVNR)

As discussed in previous sections, the main problem suffered by the LPVR mechanism is that firms competing for a concession contract have to evaluate not only their different costs involved in the project (I_i, c_i, M_i), but they also need to have some estimates for future traffic, in order to have an idea of the expected number of years that the concession is going to last. All this information is required for candidates to be able to provide a single bid (B_i) for the total revenue that they want to collect from tolls charged to road users.

As it happens with fixed-term concessions, there is a risk of demand involved here. If the level of traffic turns out to be much lower than expected, the concession term would be longer, which can be disastrous for the concessionaire, because part of the profits that it planned to obtain can be absorbed by the higher than expected maintenance and operation costs. Moreover, there is the problem of potential incorrect selection of concessionaire, which has already been analyzed above.

A solution to these two basic problems suffered by LPVR is to design an auction mechanism in which the candidates do not have to submit bids for a single variable B_i, but on the three separate dimensions involved (I_i, c_i, M_i). The new proposed mechanism has two desirable properties: it is *simple*, (because it imposes the same information requirements on firms that LPVR does), and it effectively *eliminates the need to forecast future traffic*, thus effectively solving the problems associated to the risk of demand suffered by LPVR and fixed-term concessions.

The new proposal is based on the idea of a concession with variable term, but it effectively guarantees that concessionaires can recover all costs incurred into for building and operating a road (plus a normal return on investment). Revenues are never eroded by fluctuations in maintenance costs generated by low demand levels, in those cases when a firm is forced to run the concession much longer than expected. This is why the proposal is named as Least-Present-Value of Net Revenue (LPVNR), the term '*net*' meaning that revenues accrue to the firm to recover investment costs, but net of maintenance and operating costs.

5.1 Description of the LPNVR mechanism

The proposed auction-mechanism uses the following procedure. Each candidate for a highway concession must submit a closed-envelope bid with three variables:

(1) *Present value of revenue to be obtained from collected tolls, net of maintenance and operation costs*. Competition among firms will induce honest bids, and this revenue will tend to be equal to the construction cost I_i, plus a normal return on investment. Revenues are discounted at a pre-determined rate set by the government.

(2) *Estimated annual routine-maintenance and operating costs (M_i)*. The firm must provide an estimation about its cost per year of performing routine-maintenance operations. These will comprise minor-scale repairs, for the road to reach quality levels above some minimum standards established by the government. In addition to that, all other fixed cost incurred into for running the highway (wages, equipment, rental payments, and so forth) should be added. Declared costs are the only compensation for this concept that the company will be allowed to receive during the life of the concession if it wins the contract. This provides firms an incentive to reveal their real costs M_i.

(3) *Estimated cost to perform a major road overlay*. The objective here is that the firm should provide an estimate of its cost of making a large-scale maintenance operation, to restore the pavement to its initial condition. During the life of the concession, road resurfacing will be required when some objective indicator (like the International Roughness Index) reaches some value determined by the government[11]. At that date, the road will have been used by the total traffic-load for which the road pavement was originally designed. Using that amount of traffic-load (or its transformation in terms of number of vehicles[12]) and the costs estimate provided by firms, it is immediate to derive the implicit unit vehicle cost c_i for each firm.

Observe that bidders have no incentives to inflate their estimates for maintenance and operating costs, because the amounts that they bid for have a direct influence on the probability of being selected as winner. Rising estimated maintenance and operation costs in the bid might

[11] Another possibility, which could be contemplated in practice if the public road agency in charge of supervising the concession does not have the technical skills to perform a close monitoring, would be to define from the outset the frequency of major road rehabilitations to be performed by the concessionaire (for example, a requirement to fully repave the road every ten or fifteen years, with a given degree of pavement quality and thickness).

[12] As described above, the only required information to perform this transformation are technical coefficients to convert vehicle loads in ESALs, and some assumption on the basic traffic-mix using the road.

provide more profits for the firm during the life of the concession, but it reduces its probability of winning the concession. As with construction costs, competition among firms will induce each candidate to pick its true values for c_i and M_i as its best strategy.

After a winner is selected, that firm will be awarded the concession. The values presented in its offer will be used during the life of the concession, to determine what part of revenues from tolls is assigned to cover for operation and maintenance cost, and what other part is accounted for to determine the life of the concession. Each year, the road agency or regulator will have information on the actual figures of traffic using the road (Q), and total revenue perceived by the firm (PQ). From this latter amount, total deduction will be $M_i + c_i Q$, so the net revenue to be computed each year will be $(P-c_i) Q - M_i$, and the sum of annual net revenues is accumulated over time, discounted at the rate δ. Once that the total accumulated revenue reaches the amount bided for by the concessionaire, the contract ends.

The concessionaire will assume all costs related to operations and maintenance during the life of the concession, to keep the infrastructure at a quality level determined in the contract. Additionally, full re-pavements will be required at each moment in time that the overall state of the road demands it, as defined by an objective quality index (e.g. IRI). The road agency should be specially careful in monitoring that these obligations regarding quality are fulfilled, because not performing adequate maintenance operations is a source of extra profits for the concessionaire. However, if the road agency has sufficient capacity to monitor the standards established, the control can be highly effective.

5.2 Selection rule

A final aspect to be described to fully define the new LPVNR mechanism is the rule to be applied for the selection of winner at the auction. The basic objective is to choose the firm with the lowest total expected cost, because it is likely that candidates may differ in their efficiency levels according to the three cost dimensions considered (a firm or consortium can make a good offer in terms of construction costs, but a bad one in terms of maintenance and operation costs, and conversely).

Several alternatives can exist to pick a winner, according to the level of information that a government might have. Three possible scenarios are discussed here, and different rules are suggested. The basic recommendation is to adapt the selection rule to the type of skills and information that the institution awarding the concession possesses. If studies to predict the level of traffic using the road do exist, and many offers are received, the selection mechanism can be very sophisticated. Meanwhile, as it is the case in many road projects in developing countries, the responsible institutions lack the capacity and their information is scarce, so the selection of concessionaire has to be done under much more uncertainty. Nevertheless, as it will be observed, the basic idea of the LPNVR can be applied under different contexts and still keep its basic properties.

The scenarios considered are the following:

(a) The government has good estimates of the level of traffic that a road may receive. This can be a likely scenario in developed countries, specially for road improvement projects.

(b) No reliable information about traffic exists, but the concession attracts a relatively large number of bids.

(c) No information about demand, and few candidates bidding for the concession (usual scenario for developing countries and greenfield projects).

(a) Demand studies are available

If the government has good forecasts about the level of traffic that a road can obtain (Q^e), the first advice would be to make that information publicly available to all candidates competing for the contract, because then submitted proposals will be more reliable.

In terms of selection of concessionaire, the LPVNR mechanism can be highly refined. First, the existence of several bids can be used to obtain average values for estimated construction costs (I_{av}), vehicle unit costs (c_{av}), and fixed maintenance and operation costs (M_{av}). If the number of bids is sufficiently large (for example, five or more), a filter can then be designed to eliminate any proposal which is clearly out of bounds compared to the rest of candidates in any of the three cost dimensions considered. For example, consider a case in which a firm has presented and offer with construction costs I_i equal to 20 percent of I_{av}. This proposal is likely to be highly unrealistic, but, if considered, it will probably win the auction, so a good selection mechanism should eliminate it. Some objective rule to eliminate outliers can be included to avoid this type of problem (e.g. discard proposals with values for I_i, c_i or M_i which are outside the range of 3-4 standard deviations from I_{av},c_{av} and M_{av}, respectively).

Using accepted bids, and the expected level of traffic Q^e, it is possible to calculate an accurate estimation of the likely duration of the concession contract. This can be done by using an expression similar to (2), but using the average cost values computed from the proposals. The final result of this calculation is an expected number of years T_{exp}:

$$T_{\exp} = \frac{I_{av}}{(P - c_{av})\, Q^e - M_{av}} \tag{13}$$

The next step would be to use this value T_{exp} as a reference, and evaluate the total expected costs for each candidate, according to their bids:

$$Total\,Cost_i = I_i + \sum_{t=1}^{T_{\exp}} \delta^t\, c_i\, Q^e + \sum_{t=1}^{T_{\exp}} \delta^t\, M_i \quad ; \quad i = 1 \ldots n \tag{14}$$

The firm with the lowest total cost estimated by this procedure wins the contract.

Observe that, at the moment of submitting bids, firms do not know the value T_{exp} that the government will use to evaluate their proposals, because this expected term is endogenously calculated from the cost information that the firms provide. This point reinforces the LPVNR mechanism, because firms are induced to bid for costs as low as possible to increase their chances of being selected. Another possible variation of this selection rule could be implemented if the road agency had its own estimates for the costs of building, maintaining and operating the highway toll. In that case, an expected term could be calculated before bids are submitted, and it could be offered ex-ante to the firms, together with the information on expected traffic. With this alternative, firms would know in advance what are the values of Q^e and T_{exp} that will be used in expression (14) to evaluate their proposals.

(b) No demand studies available, but large number of bids

In cases where a government does not have any information at all on future traffic expected for a road, it is more difficult to design a rule to select the best concessionaire. The lack of information about Q^e would not allow to compute the expected total costs of candidates as described above, since the variable maintenance costs dependent on traffic would be difficult to calculate.

However, if the project attracts a sufficiently large number of bids (for example five or more), it is possible to implement a modified version of the selection rule above, by studying the costs of firms over a possible range of concession terms. Under these conditions, the selection of concessionaire must necessarily rely on some assumptions and it is performed under more uncertainty. But, nevertheless, if there is enough information that can be extracted from bids, the selection rule can be as effective as above in the selection of the best candidate.

The proposed variation of the selection rule for this scenario is the following. First, the road agency must pick a range of possible terms for the life of the concession. This range would be bound by a lower limit T_{min}, which can be chosen as the minimum estimated time to recover investment costs if traffic is very high, and an upper limit T_{max}, which could be the legal maximum life of a concession in the country, or some estimation of the required time for cost recovery in a very low demand situation[13].

Second, average levels for the three cost dimensions have to be computed from the bids received, exactly as described in the previous scenario (I_{av} ,c_{av} , M_{av}). Again, if the number of bids allows it, some kind of filter to eliminate unrealistic offers can be incorporated. Using these values, it is possible to obtain a vector of possible traffic levels for the road, corresponding one-to-one to the range of expected terms assumed for the concession. Expected traffics can be calculated by re-arranging expression (13):

$$Q_{T_{ref}} = \frac{I_{av} + M_{av} T_{ref}}{(P - c_{av})\, T_{ref}} \quad ; \quad T_{ref} = T_{\min} ... T_{\max} \tag{15}$$

Finally, candidates' total costs are computed, for each firm and *for each expected concession term*, within the range of reference [T_{mim}, T_{max}]. Therefore, after the results of these calculations each firm will not have a single estimated total cost, but a vector of possible total costs (one estimate for each of the possible terms considered):

$$Total\,Cost_{i,T_{ref}} = I_i + \sum_{t=1}^{T_{ref}} \delta^t c_i Q_{T_{ref}} + \sum_{t=1}^{T_{ref}} \delta^t M_i \quad ; \quad T_{ref} = T_{\min} ... T_{\max} \; ; \; i = 1...n \tag{16}$$

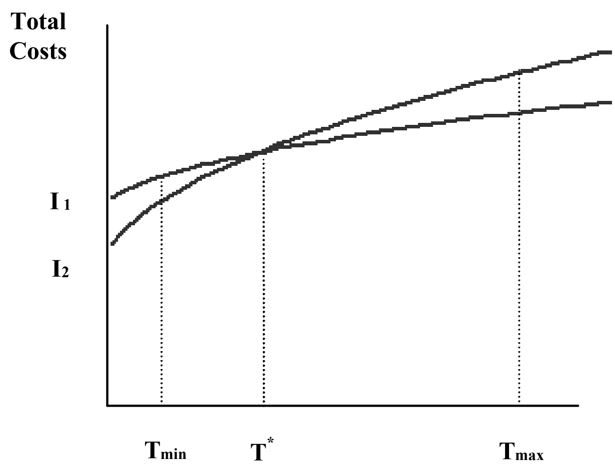
The auction winner would be the firm that for most periods within the range [T_{min}, T_{max}] exhibits a lower expected total cost. Since total costs determined by expression (16) are a concave increasing function of T, firms would be unambiguously ranked by this rule, although

[13] The selection of T_{min} and T_{max} necessarily involves some degree of subjectivity from the road agency or regulator in charge of the concession. However, for most highway projects in practice, the range of likely periods for a concession to repay costs does not fall below 10-15 years, and periods longer than 40-50 years do not seem sensible. Gómez-Lobo and Hinojosa (2000) indicate that, for the case of Chile, interviews with bidders revealed that firms work with a maximum horizon of 30 years. Therefore, some sensible values could be used as rough estimates for T_{min} and T_{max}, although in each case regulators should study carefully the range of periods to be used for the selection of winner. On the other hand, these limits should be publicly known before submitting bids, for firms to adjust their offers accordingly.

ties could also be feasible (in those cases, the winner can be picked randomly, because expected total costs would be equal. Another possibility would be to invite tied winners to resubmit their offers).

Figure 4 show how this modified rule selects the concessionaire in this scenario. As in figures 1 and 2, curves represent total costs incurred into by each firm to build, maintain and operate the highway during a range of possible concession terms. For simplicity, no time discount is considered (δ=1). Total costs represented here are those calculated from expression (16), using the expected terms in the range [T_{min} ...T_{max}], and their corresponding expected demands $[Q_{T_{max}} \cdots Q_{T_{min}}]$.

Figure 4: Selection of concessionaire



In figure 4, it can be observed that construction costs I_i determine the intercept of the total costs curves at the origin, while maintenance and operation costs determine their slopes (for each possible term T_{ref} the slope of the curve –with no time discount– would be equal to $M_i + c_i\ Q_{T_{max}}$. The slope is different for each possible value of T_{ref}, because estimated traffic $Q_{T_{ref}}$ varies). In the example presented in this figure, it is assumed that firm 2 is more efficient than firm 1 in terms of construction cost, but it has higher maintenance and operation costs. These higher costs are the cause that, when expected concession terms are long, total costs of firm 2 increase rapidly.

If the government had an accurate estimation about the length of the concession, the selection of concessionaire would be very easy. As in the previous scenario, it could be done just by comparing total expected costs for both firms. For relatively large volumes of traffic, the number of years required to recover investments would be small, and then firm 2 would be preferable (since it has lower construction costs). However, if demand turns out to be low, and the concession requires more than T^* years of operation (see figure 4), then firm 1 would be a better option. Even if firm 1 is less efficient than 2 in terms of construction costs, its lower operational costs would make it preferable for long-term concessions.

In absence of any information on demand, the decision must necessarily be taken with some stochastic criteria. Assuming that all possible periods within the range [T_{min} , T_{max}] are equally probable, one possible rule would be to grant the concession to the firm with lower costs in more cases[14]. In the example above, the concession would go to firm 1 if the following condition is satisfied:

$$T_{max} - T^* > T^* - T_{min} \tag{17}$$

In practice, the outcomes from this selection rule are likely to be fairly robust to the selection of T_{min} and T_{max}. For a situation to arise in which firms are close to a tie, it would be necessary that their offers for construction costs (I_i) and operation and maintenance costs (c_i, M_i) are very different. This would correspond to weird situations, where some consortia could be very efficient for road construction, but very bad for the operation of the highway, and conversely. The selection process, as described, relies on both dimensions, so it is likely that highly efficient construction companies seek efficient partners for road operations, in order to increase their possibilities of winning the concession.

(c) <u>No information about demand, and few candidates</u>

In cases where the government has no reliable study on the future level of traffic that a road can attract, and only a few bids are received, the selection process described in the previous scenario could still try to be applied. However, the average values I_{av}, c_{av}, M_{av} computed from the candidates' bids can be not representative of the actual average costs that could be achieved for that road project.

In this case, it would be recommendable to go for a much simpler mechanism for the selection of concessionaire, if the government does not have the resources or the skills to perform demand forecasting studies (and probably, neither to prepare highly detailed designs for the road to be constructed). Nevertheless, the concept of a LPVNR type of concession could still be highly attractive for this type of projects, because these are the situations where the risk of demand can be more damaging for the concessionaire.

A possible solution for this scenario would be to require bids from private firms only on two dimensions:

- Total discounted revenue to be collected, net of maintenance and operation costs.
- Average annual expenditure in maintenance and operation.

[14] Another feasible option for the selection rule could be to compare the total expected costs of both firms in terms of areas in figure 4, which would be equivalent to perform the selection using averages of total expected costs calculated from the vectors computed from (16), with equal weight for each observation. In graphical terms, if the area between cost curves in figure 4 for the range [T_{min} , T^*] were larger than the area between curves for the range [T^* , T_{max}], that would indicate that firm 2 can be extremely efficient in terms of construction costs compared to its maintenance costs. If all possible terms [T_{min} , T_{max}] have the same probability, the average expected cost of firm 2 would then be the lowest and it should be selected as winner. However, our intuition is that the correlation between the outcomes of this selection rule and the one described in the text (which is much simpler) must be very high. Only in rare cases where the two firms were extremely different in their estimates for construction and maintenance costs, the outcomes of these two alternative rules would not be the same, and probably a situation like that would be indicative that the estimates of the firms can be unreliable.

The second dimension will not be simple to calculate for the private firms in a very precise form, because of the situation of extreme uncertainty about the level of traffic for the road. It is then impossible to determine in advance what is going to be the deterioration process of the pavement, and what maintenance measures will be required during the life of the concession.

The government, however, can contribute to simplify matters by issuing straightforward conditions regarding quality levels (for example, including in the terms of reference for the project that a major resurfacing is only required every 10 or 15 years, no matter the state of pavement between rehabilitation). In a scenario like this, it is unlikely that this government could monitor the concessionaire very closely in terms of quality indicators, because that would imply a level of resources and skills that its road agency will probably not have, so it is preferable to use simple conditions to help the candidates to calculate some approximation to average annual maintenance costs. The implication is then that bided values for M_i will include costs of major resurfacing operations, spread over some interval of years.

If this simplified process works correctly, the selection rule could then operate as in the previous scenario. It needs to rely on some arbitrary range of possible concession terms $[T_{min}, T_{max}]$, and firms' offers will have to be evaluated for each term in the range. For the road agency, calculating the total costs of each candidate will be much easier, because no variable maintenance cost is involved now, so for each term T_{ref} total cost of firm i will simply be $I_i + M_i T_{ref}$ (assuming no discounting). The firm which has lower total costs in more cases within the range $[T_{min}, T_{max}]$ would be awarded the concession.

Once a winner is selected, the simplified LPVNR concession allows the firm to collect tolls until the moment when total discounted revenues are equal to the value bided for. From these calculations to determine the end of the concession, a fixed amount M_i will be deducted each year from collected revenues, to be assigned to the coverage of maintenance and operation expenses.

Therefore, even in extreme conditions of lack of information and skills to prepare good road designs and monitor quality, a government could make use of the LPVNR system to auction the construction of roads, and thus eliminate the problems associated with the risk of demand. The fact that the selection process is not so accurate as in the other cases, and that firms cannot calculate precisely their variable costs associated to traffic introduces some noise in the process, but the benefits for a government from a developing country of implementing a road project successfully will likely be much higher than the possible distortions.

6. Comparison between the LPVR and LPVNR mechanisms

Regardless of which of the scenarios above is used, and the selection rule employed, it can be observed that the general principles and properties of the LPVNR mechanism are the same. Compared to the LPVR system of awarding concessions, the outcomes of this new proposal dominate, since the risk of demand is effectively eliminated, the selection of concessionaires is always better, and renegotiations are simpler. The basic reason why LPVNR outperforms LPVR is intuitive: it extracts more information from bidders, thus allowing better judgements.

This section is devoted to discuss at some length these points, and also to indicate the limitations suffered by the new proposed LPVNR, which in all cases are shared by LPVR and fixed-term concession systems.

Advantages of LPVNR over LPVR

a) Probably the most relevant advantage of the proposed LPVNR mechanism to auction highway concessions is that the risk of demand is effectively eliminated, because firms know for sure that they will receive each year the quantity bided for as annual operating costs. Therefore, they do not need to be concerned about estimating demand levels, and their bids would reflect more accurately real construction costs. Firms are liberated from having to estimate the amount of maintenance and operation costs during the life of the concession –contrary to what happens under LPVR– because they know they are allocated funds each year from collected tolls to cover for those costs.

b) In terms of selecting the most efficient firm to build and operate a highway, the new mechanism solves the problems identified for LPVR (see sections 3.2 and 3.3). Under the proposed system, it is more unlikely that errors are made when selecting the concessionaire, since more information is used. The LPVR mechanism, due to its single-bid design, is unable to distinguish if a firm is bidding low because is very efficient in building the road, or because it considers that demand is going to be very high. With bids providing separate information on revenue to be obtained on one side, and maintenance and operation costs on the other, the institution awarding the contract can discriminate better across candidates. As discussed, the more available information that exists, the more sophisticated the selection rule can be, and the less likely to make mistakes.

c) In case of contract renegotiation, due to lack of long-run demand to finance the project, or due to the government requiring to alter the characteristics of the road, it is easier to determine those costs in which the concessionaire has effectively incurred into, and to calculate the revenues that it requires to be compensated. Bargaining between parties at renegotiations is much simpler under LPNVR than under LPVR, again because the government has more information from the firm about its revealed costs.

d) Incentives are provided for the concessionaire to be cost-efficient in terms of operation and maintenance of the highway, since when it is able to lower those costs below the level bided for, it can earn some extra profits. If, on the other hand, operation and maintenance costs would rise, that will erode the concessionaire's profitability (this is the same effect that induces candidates to provide accurate bids for M_i and c_i costs). Incentives to reduce operation and maintenance costs are socially optimal, provided that an adequate quality of road service is offered.

Limitations of LPVNR (shared with LPVR)

a) The regulator or road agency need to monitor traffic levels, in order to determine when the concessionaire has obtained the required revenue for the concession to end. However, this is a publicly observable variable that does not pose any special difficulties. Another aspects to be checked out by the regulator are that investments on construction are performed according to contracted conditions, and specially that obligations on road maintenance and quality of service (safety, signaling, number of toll booths, etc) are strictly fulfilled. Most of these aspects are shared by all types of concession mechanisms, including fixed-term franchises, but variable-term systems specially induce concessionaires to cut on quality features, since they do not have incentives to attract traffic.

b) Candidates bidding for a road concession need at least a rough estimate of demand, in order to determine if the project is financially feasible. Apart from that estimation, which is required by firms participating in any type of auction, under the LPVNR system firms only need to refer to the technical conditions of the road to make their offers. Construction costs are mainly determined by geographical conditions of the region crossed by the highway and the type of structure (pavement) required, while operation and maintenance costs are relatively easy to estimate from the quality standards set by the regulator.

c) The calculation of the unit cost per vehicle (or axle-load) to be used to assign resources for major rehabilitation operation relies on having good estimates on total axle-loads supported by roads. This is a highly technical point, which requires sufficient knowledge and skills, and, optimally, the existence of data on other similar roads in the same country/region. A related matter is that the concessionaire has to compromise firmly to accept objective standard measures to determine when major rehabilitation works are required. This point has to be dealt carefully in the concession contract, defining very precisely the measures, who performs the evaluation, what are the procedures in case of discrepancies, and what penalties can be applied in case that the concessionaire does not fulfill its obligations.

d) Although concessionaires are guaranteed to recover their investment costs in the long-run, they might experience some short-run liquidity constraints at some point during the life of the concession (for example, a period of low demand coincident in time with substantial debt repayment obligations), a limitation that is also suffered by concessionaires under the LPVR mechanism. The solution to this potential problem has to be sought in the development of new financial instruments that allow highway investors to obtain funds based on the future revenues, which they are guaranteed to obtain by the automatic extension of the concession (Gómez-Lobo and Hinojosa, 2000).

7. Conclusions

This paper discusses a proposal for a new mechanism to auction highway concessions, based on the variable-term concept for concessions conceived by Engel et al (1997), for their least-present-value of revenue (LPVR) mechanism. Road concessions awarded by LPVR are undoubtedly better than fixed-term concessions used in practice by most countries where private operators run tolled highways. However, in presence of maintenance and operation costs –which in real concessions are generally observed to be non-negligible–, it has been proven that the advantages claimed by the authors for the LPVR mechanism can dilute.

First, firms bidding for a contract under LPVR do need to estimate future traffic levels to compute their bids. Therefore, even though the risk of demand is reduced, compared to fixed-term concessions, it is far from having been eliminated. If a firm is too optimistic about expected traffic, it will make a bid for a low discounted revenue. In a scenario of weak traffic, there is a potential risk that operation and maintenance cost would accumulate up to a point that they might even cause bankruptcy. Creditors are likely to perceive this risk, and they probably will demand higher interest rates. Other problems found for the LPVR mechanism when there are maintenance costs is that the selection of concessionaire is not guaranteed to be optimal, and renegotiations are not so simple as envisaged in the no maintenance cost case.

The proposed new mechanism (least-present-value-of-net-revenue, LPVNR) is based on a closed-envelope auction on three variables: (i) discounted revenue to be obtained from tolls, net of maintenance and operating costs, (ii) estimated annual operation and routine-maintenance costs, and (iii) complete road resurfacing cost. LPVNR is a variable-term concession system based on the same concept as LPVR: the concession-term is extended until the firm obtains its claimed revenue from tolls. However, from the total revenue obtained each year, the amount of operation costs bided for is deducted, so that the firm is guaranteed to recover its real investment, net of maintenance and operation costs. This feature effectively reduces the risk of demand fluctuations, since even though the concession term can be extended if traffic is very low, operation costs never erode expected profits. Therefore, financial costs to build highways under this mechanism are likely to be lower, which will be a Pareto improvement for society (users pay lower tolls, firms have lower costs, and taxpayers do not pay for concessions' recovery).

Under LPVNR, competition among candidates induces firms to reveal their true costs, This is due to the fact that if maintenance and operation costs are inflated, the probability of winning the concession decreases. Thus, extremely useful information is obtained by the regulator or road agency in charge of the concession. The availability of more information is what makes the LPVNR system to perform better than LPVR, on any aspect that can be considered. First, it allows a better selection of efficient concessionaires, because unrealistic offers can be detected in the awarding process, and different beliefs on demand from firms do not affect the selection of winner. Second, renegotiations are easier, since when fair compensations need to be calculated, the regulator can use the values bided for by the firm, both on revenue and on costs. And third, and more importantly, demand risk is more effectively reduced.

The rule to select the winner of the concession contract can be adapted to the amount of information and skills that the road agency or institution awarding the concession may have. Several possible scenarios have been studied, ranging from an optimal situation where the government has studies on demand forecasting, or even its own cost estimates, to another where the government has no information at all on demand, and few bids are received for the contract (a typical situation that can be found for greenfield projects in developing countries). The more information available, the more sophisticated that the selection rule can be, and the more reliable its results. However, even in the more bleak scenario of almost no information, a government can use some adapted solution to award a road concession by LPVNR, thus benefiting from its properties in terms of reduction of the risk of demand fluctuations.

Finally, this paper has focused on the design of an auction-mechanism for highway concessions, because it is for this type of infrastructure asset that it has been originally conceived, to solve the problems found for the LPVR mechanism (which is a clever concept to improve over fixed-term concession, but it has some limitations due to its single-bid design). However, it can be pointed out that the idea of LPVNR is not necessarily restricted to the road sector, but, on the contrary, it could be successfully extended to other areas where concessions to build and operate infrastructure assets are awarded to private companies. Thus, for example, a similar mechanism could be adapted to franchise concessions for port and airport terminals, railways, or urban transport infrastructures (metro, light-trains, etc). Future research, however, needs to be before making an automatic adaptation of the LPVNR mechanism, because technological features of each sector are the key to the optimal design of bids and selection rules.

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