Implementation of Quality Criteria in Tendering and Regulating Infrastructure Management Contracts

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Abstract: In recent years, several public authorities have been making advances in developing bidding terms for contracts regulating the management of infrastructure. Up to now these bidding terms have focused on granting the contract to the bidder who, having agreed to comply with the requirement of a specified level of quality, as stipulated in the contract, submits the lowest tender in terms of price. As a result, the experience of implementing quality-related incentives for the management of infrastructure has been scarce. This paper demonstrates that, if infrastructure quality is verifiable and the social benefit derived from it is measurable, there is a better way both to tender and to regulate those contracts, based on a combination of price and quality standards. In addition, the paper proposes a new procurement procedure to encourage bidders to provide better quality levels. The last part of the paper provides a practical example of how to calculate a quality index for contracts regulating the management of infrastructure. The paper ends with a set of conclusions related to the advantages of the new tendering mechanism and its possible application.

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Introduction

Economic theory demonstrates that, in perfect competition, the supply curve of a producing company matches up with its marginal cost curve. Consequently the market price, as determined by the intersection of the supply and demand curves, is equal to the marginal cost. For this reason, ideal markets provide their own guarantee of optimal efficiency (Varian 1999). This principle (also known as the "first fundamental theorem of welfare economy") justifies Adam Smith's intuition that ideal competition in the provision of goods and services is all that is required to achieve maximum social welfare (Smith 1904).

However, as some of the requirements for a situation of ideal competition are missing, market forces can produce inefficient or unfair results that can be corrected only by public sector intervention (Varian 1999). This scenario—often referred to as "market failure"—is the theoretical justification for the current regulation of public transport infrastructure (Gómez-Ibáñez 2003). Nonetheless Demsetz (1968) has demonstrated the possibility of creating competition in the provision of goods and services with natural monopolistic characteristics through the introduction of carefully designed procurement processes. This allows private companies to provide public services in a competitive way.

This is the reason why, for several decades now, the public sector has progressively tended to transfer some productive tasks to the private sector, through contracting and franchising. For instance, Dunlop (1997) demonstrated how the implementation of maintenance contracts by the private sector in New Zealand resulted in important savings for the overall society.

As a consequence of this experience, contracting out has boomed in the last decades as a way of introducing the private sector into the management of public infrastructure. Competition in terms of price has traditionally been established as the key variable in the awarding of those contracts, whereas quality has traditionally been imposed only in one way: as established through a minimum requirement imposed on all bidders. Although some authors, such as Muren (2000) and Hensher and Stanley (2003), have studied the implementation of performed quality standards in providing bus services, they did not study the implication of those contracts for the management of infrastructure, nor did they evaluate the incorporation of those standards into the procurement process.

This paper analyzes the possibility of incorporating quality as a key variable, along with price, in awarding infrastructure management contracts. This paper consists of three parts: an analysis of the state of the art regarding the implementation of quality standards in infrastructure contracts, a theoretical analysis to define a new way of procuring and regulating contracts involving infrastructure management based on both economic and quality issues, and an evaluation of the feasibility of implementing a verifiable index. The theoretical analysis of this paper is developed in three distinct steps: first, the definition of an approach intended to measure the optimal net social benefit in terms of quality; second, the identification of the requirements to reach this optimal net social benefit; and third, the design of a procurement process for awarding of the contract in terms of both quality and price. As one of the key findings of the theoretical analysis is the need to establish a verifiable quality index, the second part of this paper shows, based on the practical example of contracts related to Chilean highways, that a verifiable quality index can be suc-

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cessfully implemented in practice. The most interesting result from this paper is that the use of quality, together with price as a means of procuring infrastructure management contracts, ultimately yields a higher net social benefit. This result is applicable not only to highways in Chile but also to any public infrastructure as long as a quality index to evaluate infrastructure quality can be implemented at a low cost.

Infrastructure Contracting and Franchising Tendering and Regulation

Despite the problems involved in implementing competition in the management of transport infrastructure, many public authorities, undaunted, have defined new mechanisms to regulate the contracting out of these works to the private sector in order to increase efficiency. This increase in efficiency generally comes from the greater incentive that private companies have to optimize production chains and to implement new technologies.

The most common ways to introduce competition into providing infrastructure management are franchising and contracting out. Infrastructure concessions or franchises incorporate certain features that distinguish them both from other construction and maintenance contracts, and also from asset "privatization" procedures. There are two main differences between franchises or concessions and management contracts. First, franchising entails the transfer of public assets to the private company, whereas management contracting does not. Second, franchising signifies a degree of transfer of demand risk to the private operator, whereas contracting does not generally involve such a transfer (Vassallo 2004).

The main aim of the bidding terms is to provide competition in the tendering process. To this end, it is essential for them to meet a twofold objective: first, ensuring that the most competitive bidder will be granted the contract or concession; and second, providing incentives so that the asset will be managed in the best possible way. A sample of analysis of some of the tools for meeting this twofold objective can be found in Laffont and Tirole (1993) and Engel et al. (1997).

Some authors (Heggie and Vickers 1999; Schliessler and Bull 1994) have noticed that quality criteria in a very simple way have been incorporated in infrastructure contracts. Most of the contracts introduce quality through a set of minimum standards to be fulfilled by the contractor or concessionaire. This consistent trend has involved changes in the design of contracts that, in the past, has paid insufficient attention to the inclusion of quality criteria in their terms, as a way of encouraging the contractor to provide optimal service.

Quality requirements are often included in infrastructure maintenance and operation contracts through the mechanism called maintenance and operation by minimum standards (MOMS) (Schliessler and Bull 1994). In this way, management contracts incorporate a set of standards that the contractor is obliged to fulfill. If the contractor fails to comply with these requirements, the public authority will penalize the contractor or even rescind the contract. In this mechanism, quality is not included among the standard criteria considered in awarding the contract. Rather, the bidder who simply presents the most competitive tender in terms of price will be awarded the contract.

Maintenance and operation contracts by minimum standards (MOMS) are not enough of an incentive for the contractor to provide an adequate level of service. For instance, the implementation of this type of contract in Chile permitted infrastructure quality levels below the requirements subsequently demanded by users (Gómez Lobo and Hinojosa 1999). This was what motivated the public authority in charge of managing road infrastructure in Chile to establish a complete quality index, as a way of encouraging concessionaires to raise quality.

In some cases, infrastructure management contracts have been improved with the incorporation of some bonuses or penalties depending on certain indicators related to safety, pavement conditions, etc. However, the incentives incorporated in such contracts are not equivalent to an evaluation of infrastructure quality in a detailed way, nor are they focused on optimizing net social benefits, nor are they formally incorporated as a factor in the tendering process. Below we describe the experience in the United States and in the United Kingdom regarding the implementation of quality criteria in infrastructure contracts.

Under Special Experimental Project No. 14 (Federal Highway Administration 2002) several innovative contracting formulas were implemented in the United States. The most interesting contracting mechanism regarding quality is the so-called "lane rental." This mechanism consists of charging a rental fee based on the estimated cost of delay or inconvenience to the road user. Rental fee rates are dependent on the number and type of lanes closed and may vary for different hours of the day for a project (Herbsman and Glagola 1998). After a 5 year period of evaluation, the lane rental mechanism seems to have worked well in several states (Connecticut, Indiana, Maine, Oklahoma, and Oregon) in which this concept is fully operational (Strong et al. 2005).

Another example of the implementation of performance-based quality standards in infrastructure contracts is found in the United Kingdom where, since the early 1990s, governmental bodies have exhibited great concern for incorporating the private sector in managing public infrastructure and services. These contracts were implemented for upgrading, maintaining, and operating already-existing highways and other infrastructure facilities in the United Kingdom for a period that was to be fixed in advance. The contract terms establish that the Highways Agency (the British authority in charge of managing the trunk network in the United Kingdom) has the obligation of paying the design, build, finance, and operate (DBFO) contractor according to both the level of traffic and, as well, some preestablished quality requirements.

From the beginning, these contracts were largely concerned with infrastructure quality. In fact, the DBFO motorway contracts granted before 2002 established a variable toll depending on lane availability (number of opened lanes, time of day, and type of vehicle) and some coefficients (depending on safety and level of service). Since 2002, new criteria have been applied, based on paying the contractor according to both the combination of traffic flow and the average speed on the motorway. This system intends to encourage the contractor to keep a free flow on the motorway by carrying out, for instance, road works during off-peak hours. Although this approach is quite interesting, the incentives adopted in DBFO contracts in the United Kingdom neither assess quality as a whole nor have been designed so as to be directly linked to the "net social benefit" produced by them.

Those shortcomings prompted a study carried out by the National Audit Office (NAO 2003) about the maintenance of trunk roads in England. This study shows the government's concern with assessing road quality by incorporating, as much as possible, the opinions of those who use the roads, and also by including incentives in the road contracts in order to encourage the contractor to render an optimal service.

New Approach to Incorporating Quality in Infrastructure Management Contracts

Approach to Problem

In competitive markets, consumers and users choose to buy goods and use services from among several options. Choices depend upon a combination of price and quality, and there are ordinarily many available choices. In the case of infrastructure, however, the situation is different: the market is usually monopolistic or oligopolistic. As a consequence the attention of public regulators has concentrated to date on economic regulation problems (pricing policy, competition, etc.) rather than on quality.

Quality can be considered "observable" when consumers of a good or users of a service can perceive it. This term can encompass two meanings depending on the time when the quality is observed: before or after the consumption of a good or the usage of a service. Moreover, quality can be defined as "verifiable" when it can be measured without undue expense, and it is possible to set up an ex-ante indicator in the contract that can be easily assessed ex-post. When quality is "verifiable," it is possible to impose quality goals on the regulated company by which the regulator can reward or penalize the contractor depending on the level of quality achieved (Laffont and Tirole 1993).

Quality is "observable" after usage in many infrastructures, so they can be classified under the category known as "goods of experience." Moreover, although infrastructure quality is verifiable, the cost of measuring quality is not usually low. To this end, some authors (Laffont and Tirole 1993; Viscusi et al. 1995) carried out studies designed to assess the way to implement quality incentives when quality is "observable" but not "verifiable" because the cost of measuring quality is too high.

As put forward above, present mechanisms for regulating infrastructure quality are generally based on fixing a number of minimum standards to be met by the contractor. Although those mechanisms may sometimes include bonuses or penalties derived from the adequate fulfillment of certain indicators, these contracts are ordinarily awarded in terms of price, and the bonuses and penalties applied are not generally connected with the optimization of social benefit. This paper intends to evaluate the possibility of introducing quality, together with price, as a key factor to procure and regulate infrastructure management contracts, evaluating the social benefit gains derived from its implementation.

One of the most important topics of economics is the maximization of social welfare, which is defined as the sum of the utility levels of all individuals (Just et al. 2004). This assumption has been called the fundamental ethical postulate of economics by Samuelson (1947). Such a social welfare function is called the "Bergsonian function" since Bergson (1938) was the first to use it. Social welfare maximization has been applied to the evaluation of projects through a specific discipline called cost–benefit analysis, whose goal is to provide tools for governments to employ when considering alternative policy actions that are intended to maximize social welfare. The social welfare attained by any given policy choice is calculated to be the difference between the costs that will be incurred, and the benefits that will accrue. This is the reason why, for cost–benefit analysis, the "social welfare" is usually called "net social benefit" (Gramlich 1998). From now on, in this paper we will use the term "net social benefit" instead of the term "social welfare" since the former is more common in the cost–benefit evaluation of projects.

The paper intends to define a function that relates "net social benefit" to quality in order to approach the point of optimal social efficiency in which the "net social benefit" is maximized. "Net social benefit" is calculated as "gross social benefit" (the sum of infrastructure users' benefits and other external agents' benefits stemming from a certain quality level) minus "maintenance and operation costs" (see definitions of this term in the Appendix of this paper). "Gross social benefit" includes both the benefit experienced by the infrastructure users and the benefit experienced by other nonusers affected by the infrastructure (external agents). "Maintenance and operation costs" include both the contractor's cost of maintaining and operating the infrastructure and the government's cost of monitoring the contract.

This section discusses a new mechanism for awarding contracts regulating the management of infrastructure, in terms of both price and quality, to obtain an optimal "net social benefit." The results are based on a simplified microeconomic model that explains the relationship between quality and "net social benefit." The approach for obtaining the results requires four steps: first, a definition of what constitutes quality and the relationship both between quality and "gross social benefit," and between quality and maintenance and operation cost; second, the establishment of the optimal condition and its requirements; third, the evaluation of the "net social benefit" gains derived from an optimal combination of price and quality; and fourth, the design of a new procurement model incorporating quality as a key factor in the tender.

We find that if quality were verifiable, and the social benefit derived from it were measurable in a certain way, it would be possible to introduce quality requirements into the tendering and regulation of infrastructure maintenance and operation contracts.

Definition of Quality

Defining quality is not easy. Quality is strongly related to the "gross social benefit" derived from the consumption of a good or the use of a service. The higher the quality, the greater the "gross social benefit" will be. Quality is determined by the effort, skill, experience, etc., of the contractor. Considering that the infrastructure facility is already built with specific characteristics, and assuming that the contractor maximizes quality according to its efforts, skills, etc., given a certain budget for maintenance and operation costs, we can assert that the higher the amount spent by the contractor for maintenance and operation costs, the higher the quality level will be.

Assuming that it is possible to define a quality index in quantitative units, and assuming that it is feasible to know the "gross social benefit" stemming from a certain quality level, it would be possible to define a function that gives "gross social benefit" in terms of quality $[W=W(Q)]$. We call this mathematical function the WQ curve (see Fig. 1). We know that this function is increasing with quality $(\partial W/\partial Q \geqslant 0)$. However, as quality has arbitrary dimensions—in other words the proper unit for measuring quality depends on how the infrastructure quality index is ultimately defined—it is difficult to determine its concavity or convexity.

Infrastructure quality can be measured by means of an index defined as the sum of a set of weighed indicators for predefined criteria affecting quality, as Eq. (1) shows

$$Q = \alpha_1 \cdot I_1 + \alpha_2 \cdot I_2 + \alpha_3 \cdot I_3 + \cdots + \alpha_n \cdot I_n \tag{1}$$

where Q=quality index; α_i=weight for the criteria i; and I_i=value of the normalized indicator that measures quality criteria i.

The quality index is calculated in terms of a set of criteria, measured through specific normalized indicators, which influence

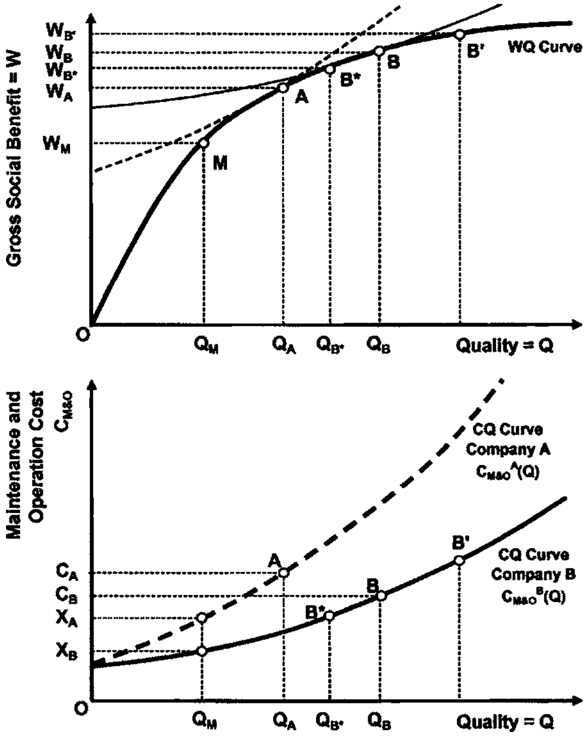

Fig. 1. Gross social benefit and maintenance and operation cost depending on quality level

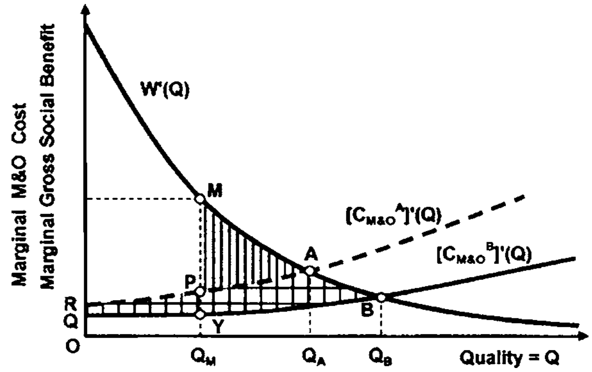

Fig. 2. Marginal gross social benefit and marginal maintenance and operation cost depending on quality level

infrastructure quality. The normalization of the indicators for all the criteria aims at avoiding distortion by establishing a common scale for all the criteria (for instance between 0 and 1). The criteria adopted should fulfill two requirements: first, being relevant; and second, being measurable at a reasonable cost. As Eq. (1) shows, the quality index is calculated as the weighed sum of the values adopted by the indicators. The weights should be fixed by the public authority according to the contribution of each criterion to the increase of "gross social benefit." Assuming that the cost of reaching a certain indicator for each quality criterion is independent of the rest of the criteria, the "maintenance and operation cost" of reaching a certain quality level could be estimated as the sum of the costs of reaching the indicators associated with each of the criteria adopted plus the quality control cost $C_c(Q)$, which is the cost incurred by the public authority to monitor the quality rendered by the contractor [see Eq. (2)]. Quality control cost is either constant or slightly increases with the level of quality provided by the contractor

$$C_{M\&O}(Q) = c(I_1) + c(I_2) + c(I_3) + \cdots + c(I_n) + C_c(Q)$$

$$Q = \alpha_1 \cdot I_1 + \alpha_2 \cdot I_2 + \alpha_3 \cdot I_3 + \cdots + \alpha_n \cdot Q_n \qquad (2)$$

where $C_{M\&O}(Q)$=maintenance and operation cost of reaching a quality level Q (CQ curve); $c_i(I_i)$=cost of reaching a certain indicator for each criteria; and $C_c(Q)$=quality control cost.

As was previously explained, $C_{M\&O}(Q)$ always increases with quality ($\partial C_{M\&O}/\partial Q \geqslant 0$). Assuming that it is possible to establish a quality index that exactly reflects the "gross social benefit" produced when $W=Q$, it is easy to prove that, if the contractor intends to render a certain quality level at the lowest management and operation cost, the CQ curve (see Fig. 2) necessarily has to be convex. If the contractor's objective is to minimize the cost of providing a certain level of quality, the contractor will prioritize those activities that increase quality the most at the same cost. Consequently, if it is possible to establish a quality index in such a way that $Q=W$ we can assert that $\partial^2 C_{M\&O}/\partial Q^2 \geqslant 0$.

As quality has arbitrary dimensions, we cannot assert that the CQ curve (the curve that gives maintenance and operation costs in terms of quality) is necessarily convex. However, as this curve is always convex for a quality index that fulfills $Q=W$, we can assert that the slope of the CQ curve will always be steeper than the slope of the WQ curve. In other words, the previous results demonstrate that whatever units we use to measure quality, the WQ curve will be more concave or less convex than the CQ curve. This condition is very important to demonstrate the existence of an optimum "net social benefit" associated with quality.

Analysis of Proposal

Although the shape of the WQ curve ultimately depends on the units in which quality is defined, Vassallo and Izquierdo (2002) showed that quality indexes are generally fixed in such a way that WQ curves are concave. This means that the higher the quality index, the smaller the net social benefit increase. Assuming that the WQ curve is concave, according to the previous section results, we know that the slope of the CQ curve will be either less concave than the slope of the WQ curve, or linear, or convex.

In order to facilitate the graphic expression of the WQ and CQ curves, from now on we will draw the CQ curve as convex and the WQ curve as concave. However, the necessary condition for demonstrating that there exists a maximum "net social benefit" in terms of quality requires only that the CQ curve be less concave than the WQ curve.

Fig. 1 shows a simple diagrammatic analysis for quality regulation, similar to that used in microeconomic theory for quantity production. This analysis is used to assess the increase in social benefit produced by the adoption of a procurement and regulation mechanism that takes into account both economic and quality criteria.

The x axis in Fig. 1 displays the quality level achieved by the company in charge of managing the infrastructure. The quality level depends on aspects affecting both infrastructure users (pavement condition, attention or vigilance to emergencies, safety, congestion, etc.) and external agents (levels of noise, emissions, cleanliness, attention to landscaping, etc.).

We assume that it is possible to know the curve that links quality to "gross social benefit" (the WQ curve). The top graph in Fig. 1 shows the WQ curve drawn by a thick solid line. The bottom graph in Fig. 1 shows the CQ curve for two different companies. In addition, we suppose that both WQ and CQ curves are continuous functions and consequently are integrable (Spivak 1998). We suppose that Contractor B is able to provide a certain quality level at a lower cost than Contractor A. The analysis can be easily extended to as many potential contractors as we would like to introduce. In order to simplify the figures, we assume that Companies A and B are the most competitive ones among the companies that participate in the tender. As Fig. 1 illustrates, Company A is less competitive than Company B because it requires a higher cost to reach the same level of quality.

The mechanism established by maintenance and operation contracts based on minimum standards (MOMSs), as explained above, is based on the public authority setting a minimum quality Q_M (see Fig. 1) below which the party contracting with the authority would be considered in breach. In this system the successful bidder to which the contract is granted will be the company that quotes the lowest price for providing the service exactly at the Q_M quality level.

As Fig. 1 illustrates, MOMSs do not involve an economic optimum, because such an optimum would be the result of the marginal gross social benefit being equal to the marginal maintenance and operation cost, as Eq. (3) shows

$$\mathrm{Max}[W(Q)+C_{M\&O}(Q)] \Rightarrow \frac{dW(Q)}{dQ}=\frac{dC_{M\&O}(Q)}{dQ} \tag{3}$$

where $W(Q)$=gross social benefit depending on Q quality level; and $C_{M\&O}(Q)$=maintenance and operation cost depending on Q quality level.

The points of optimum "net social benefit" are those on the WQ curve which, for the same level of quality, have a slope equal to the CQ curve. Consequently, the optimum "net social benefit" point for Company A (less competitive) will be Point A, entailing a specific quality level Q_A and a "gross social benefit" W_A. Furthermore, the optimum "net social benefit" point for Company B (more competitive) will be Point B, involving a higher quality level Q_B and "gross social benefit" W_B than those achieved by Company A.

Additionally, Fig. 2 shows the marginal gross social benefit curve and the marginal maintenance and operation cost curves, decreasing and increasing, respectively. If Company A were to provide the service, the "net social benefit" would be optimum at Point A, where the marginal gross social benefit and the marginal maintenance and operation cost curves intersect. In the same way, if Company B were to provide the service, the "net social benefit" would be optimum at Point B.

However, in a "maintenance and operation contract by minimum standards" both Companies A and B would be located at Point M corresponding to a quality level Q_M (see Fig. 2) in order to maximize their profits. This situation implies the subsequent net social loss equal to the MPA striped area in Fig. 2 if the service is rendered by Company A, or MYB area if the contract is rendered by Company B. Eq. (4) shows mathematically what has been displayed diagrammatically in Fig. 2

$$\begin{aligned}(W(Q_A)-W(Q_M))-(C^A_{M\&O}(Q_A)-C^A_{M\&O}(Q_M))\\ =[W(Q)-C^A_{M\&O}(Q)]^{Q_A}_{Q_M}\\ =\int_{Q_M}^{Q_A}\left(\frac{dW(Q)}{dQ}+\frac{dC^A_{M\&O}(Q)}{dQ}\right)\cdot dQ\end{aligned} \tag{4}$$

Fig. 2 shows the net social benefit increase ($RABQ$ checked area) owing to the higher cost effectiveness of Company B in relation to Company A, as displayed in Eq. (5). Consequently, in order to achieve the optimal "net social benefit," it is necessary to design a mechanism that, on the one hand, grants the contract to the most competitive company and, on the other, provides incentives for this company to render the optimal quality level according to its skills

$$\begin{aligned}(W(Q_B)-C^B_{M\&O}(Q_B))-(W(Q_A)-C^B_{M\&O}(Q_A))\\ =\left(\int_{Q_o}^{Q_B}\frac{dW(Q)}{dQ}-\frac{dC^B_{M\&O}(Q)}{dQ}\right)\\ -\left(\int_{Q_o}^{Q_A}\frac{dW(Q)}{dQ}-\frac{dC^A_{M\&O}(Q)}{dQ}\right)\end{aligned} \tag{5}$$

To sum up, maintenance and operation contracts depending merely on "minimum standards" do not achieve an optimal "net social benefit." In this case, the marginal maintenance and operation cost is lower than the marginal gross social benefit. Moreover, from this analysis an interesting conclusion follows: the higher the competitiveness of the company, the higher the optimal quality and the "gross social benefit" produced. Consequently, the tendering process, which is defined below, must achieve a twofold objective: first, that the most competitive company be selected, and second, that the company selected will provide the optimal quality according to its skills.

Tendering Mechanism

So far we have analyzed the optimal quality level in terms of maintenance and operation cost. In this section we design the tendering process for granting the contract based on both economic and quality criteria. Certain quality criteria have already been incorporated in the regulation of infrastructure management contracts by being linked to bonuses or penalties. However, up to now quality has not been expressly incorporated in the tendering process, nor has the reward been defined so as to maximize "net social benefits." This section offers a new approach to the tender process designed to incorporate these two issues.

The tendering process has to achieve two objectives. First, the contract must be awarded to the most competitive company and second, the potential contractors must have enough incentive to both operate and maintain the infrastructure at the optimal level. One possibility for achieving these two objectives is to establish a procurement process based on both quality and price. Price will be the cost incurred by the contractor, which according to the payment system set up, will be paid either by users or by the public authority. Quality will be measured using an index such as the one shown in Eq. (1).

Therefore, the objective of this process will be to grant the contract to the bidder whose tender offers the best combination of quality and price. To define how the tender process should be designed, we assume that the public authority can approach the WQ curve (the gross social benefit in terms of the quality level provided by the contractor). In practice, it is difficult for the public authority to know the WQ curve in detail. However, the public authority can approach this curve in terms of benefits such as operation benefits, cost derived from maintenance state indicators, time savings derived from avoiding congestion, safety improvements, etc. In this section we demonstrate that, assuming that the public authority is able to at least approach the WQ curve, it is possible to award the contract to the bidder who offers the most effective combination of quality and price in terms of "net social benefit."

To that end, every bidder should declare in the tender both the price required for providing the service (the cost derived from

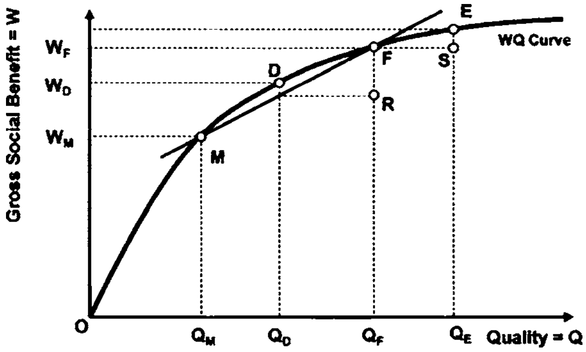

Fig. 3. Incentive mechanism scheme

carrying it out) and the level of quality that the bidder commits itself to achieving during the life of the contract in terms of the quality index defined by the public authority. The contract will be awarded to the company whose combination of quality and price would be the best in terms of "net social benefit." This "net social benefit" will be optimized as the "gross social benefit" produced in attaining the bidder's quality commitment, minus the maintenance and operation cost needed to obtain this quality commitment, would be maximized. With this system, Company B will tend to submit its quotation at Point B in Figs. 1 and 2, where its marginal maintenance and operation cost is equal to the marginal gross social benefit, because if the tender is set up at any other point, there will be less likelihood of it being awarded the contract. Regardless of whether the tender is set at Point B' (Fig. 1), with a higher quality level, or at Point B^* (Fig. 1), with a lower quality level, the inequality described in Eq. (6) will occur and, consequently, the tender coming at Point B will be the most effective. The system encourages every bidder to state, in the procurement process itself, the point at which it can produce, according to its skills, an optimal "net social benefit"

$$W(Q_{B^*}) + C^B_{M\&O}(Q_{B^*}) < W(Q_B) + C^B_{M\&O}(Q_B) > W(Q_{B'}) + C^B_{M\&O}(Q_{B'}) \quad (6)$$

where $W(Q_{B^*})$=gross social benefit linked to Q_{B^*} quality level; $W(Q_{B'})$=gross social benefit linked to $Q_{B'}$ quality level; $W(Q_B)$=gross social benefit welfare linked to Q_B quality level; $C^B_{M\&O}(Q_{B^*})$=maintenance and operation cost of Company B linked to Q_{B^*} quality level; $C^B_{M\&O}(Q_{B'})$=maintenance and operation cost of Company B linked to $Q_{B'}$ quality level; and $C^B_{M\&O}(Q_B)$=maintenance and operation cost of Company B linked to Q_B quality level.

The procurement process should also prevent the company from overestimating the level of quality that it is capable of achieving. To this end, the public authority must include a clause in the contract whereby it would drastically reduce payment for the service in the event that the quality provided by the contractor proved to be lower than the quality stipulated in the contract. One way to achieve this goal could be to increase the penalties imposed on the contractor in proportion to the negative difference between the quality agreed upon in the contract and the quality actually provided. In this respect, Fig. 3 shows an approach which would work to discourage the bidder from submitting unrealistic tenders. In the event that the successful bidder provides a quality level Q_D that is lower than the one agreed upon in the contract (Q_F), the public authority will pay the contractor the price agreed upon in the contract minus the FR segment whose value is calculated using Eq. (7)

$$P = \overline{\mathrm{FR}} = (Q_F - Q_D) \cdot \gamma$$

$$\gamma = \frac{W(Q_F) - W(Q_M)}{Q_F - Q_M} \quad (7)$$

where P=penalty incurred for providing a lower quality than agreed; Q_F=level of quality agreed by the successful bidder; Q_M=minimum quality level admitted by the public authority; Q_D=level of quality actually produced by the contractor; $W(Q_F)$=gross social benefit linked to Q_B quality level; and $W(Q_M)$=gross social benefit linked to Q_M quality level.

Furthermore, regardless of the agreement signed with the public authority in accordance with the bidding terms, the contract must encourage the successful bidder to achieve the highest possible level of service, in such a way that any increase in efficiency will be transferred to the users. To this end, the contract must also include a clause whereby, if Company B is ultimately capable of being more competitive than expected in the bidding process and, as a result, is able to provide the service at the agreed quality level and at a lower cost, the contract terms will contain an incentive for the contractor to produce an even higher level of quality than initially agreed upon because in that case the maximum "net social benefit" will be achieved at a higher quality level.

Fig. 3 shows the incentive effect derived from achieving a quality level higher than agreed upon initially. If the contractor becomes more efficient and the economic optimum would therefore come at Point E instead of Point B, the contract should include a clause to encourage the contractor to move its position to this point. To this end, the contract may provide for payment to the company of the value of the surplus benefits that this increased quality over and above the level agreed on would produce. For instance, if the company reaches Q_E quality level, the public authority will pay to it, above the agreed contract price, for the difference between W_E and W_D, equal to segment SE.

This approach, however, may not be possible since most public authorities have budgetary limits on the financing of quality premiums. In the case in which revenues obtained for payments to the contractor come from the users—a toll highway for instance—the solution to this problem is simple, since the public authority could raise the tolls to compensate the contractor for the increase in gross social benefit produced by raising quality. However, this measure is not easily accepted in the society, and may entail negative effects such as corrupt practices. In the case in which revenues come from the budget, this issue is less susceptible of the solution. One possible reward to the contractor could be an extension of the contract's duration although sometimes this may not be a viable solution for the contractors. In this way, the contractor will increase its profits without forcing the public authority to spend additional public resources.

Limitations of Model

In order to focus on the problem and simplify the model, the approach previously presented has adopted several hypotheses and conceptualizations. Although those hypotheses and conceptualizations affect neither the robustness of the model nor the main conclusions of the paper, it seems adequate to assess the limitations that they impose in the results. The identification of the limitations of the model is a key to proposed future research that might generalize the scope of the model. In this section, we enumerate the main limitations of the model and relate them to future lines of research.

Some issues of the model have been simplified because they are not essential for the main goal of this paper, and its introduction may hinder the correct understanding of the model. For instance, we have not analyzed in detail the contractor's input quality factor. In that respect, we assume that it is equal for all the bidders. In addition we have supposed that the public authority is able to calculate accurately both the *WQ* curve and the *CQ* curve, and we assume that these functions are continuous and consequently fulfill the conditions necessary for them to be integrated.

In order to demonstrate that the *CQ* curve is more convex or less concave than the *WQ* curve, we have adopted the hypothesis that the cost of reaching a certain quality criterion is independent of the other criteria. Although this hypothesis is valid as a first approach to the problem, further research should be conducted to assess whether this condition is valid when the cost of reaching a certain indicator for a specific quality criteria does not depend on the remaining criteria.

The precise definition of the *WQ* curve offers an obstacle to reliance on the use of this mechanism since "gross social benefit" in terms of quality is very difficult to estimate accurately. In spite of this problem, the model will be valid as long as the benefits stemming from quality may be quantified in a certain way. Presently, benefits derived from safety measures and pavement conditions are evaluated with enough precision to correctly approach the *WQ* curve. Moreover, in this paper, we have not conducted a detailed analysis of the implications that the uncertainty in the definition of the *WQ* curve presents for the model. We consider that this is another interesting topic for future research.

Definition of Quality Index: Case of Chilean Highways

In order to be applicable in practice, the theoretical approach described above requires the correct definition of a quality index that should be as complete as possible. This index is essential if the public authority in charge of the infrastructure is to accurately quantify the level of service provided by the contractor. If the cost of applying this index is not high, the quality of the infrastructure could be considered "verifiable" and, consequently, this index could be employed at both the tender stage, and the postawarding stage of the contract, when the successful bidder is fulfilling (adequately or not) its terms.

In order to reinforce the theoretical conclusions of this paper, it seems necessary to show the way in which a quality index may be constructed. To that end this section displays the experience recently implemented in Chile (MOP 1999) that sets up a quality index aimed at measuring quality in road concessions. Although this index has already been designed, it has been implemented as a pilot experiment in only four concessions (Camino de la Madera, Santiago–Talca, Nogales–Puchuncaví, and Temuco–Río Bueno). The government is still deciding when and how to generalize the implementation of this index to all of its highway concessions.

Most of the highway concessions granted in Chile can be considered monopolies because ordinarily there are no alternative roads with which these highways must compete. Moreover, the procurement process carried out has been based mainly on economic criteria, so the concessionaire did not have enough of an incentive to regard the quality of the highway as significant, much less determinative, in awarding of contracts. As a result, lack of maintenance and low levels of quality became frequent on Chilean highways.

For this reason, the government implemented a pilot project, designed to introduce an index for assessing the global quality of roads in order to reward or penalize contractors. This index was divided into three subindexes. The first was defined as the "patrimonial commitment index" and was designed to measure the investment made by the contractor over and above the minimum sum agreed to in the contract. The second was defined as the "road safety index" and was intended to assess the contractor's effort to implement measures to reduce road accidents. The third subindex—defined as the "service quality index"—was aimed at assessing the level of service provided from a double angle: technical perception and users' perception.

The "patrimonial commitment index" is not very relevant for the purpose described in this paper since it evaluates the contractor's effort in terms of investments made to maintain or even improve the road "patrimony" (as it is called) but without considering its direct influence on the quality rendered. The "road safety index" has, however, a significant influence on the quality, and consequently on "gross social benefit." This index is calculated in Chile through a complex procedure based on comparing both the frequency, and the kinds of accidents produced on such roads, with the average index for sections of highway possessing similar characteristics, such as annual average daily traffic (AADT), percentage of heavy vehicles in that traffic, characteristics of the route, etc. To that end the first step in the calculation according to this methodology consists of splitting the road into different sections with similar characteristics with regard to safety. After that, the objective was for every different type of section to record if the accident index was under or below that deemed, on the basis of comparative data from other roads, to be adequate. The indicator is finally obtained as the addition of the lengths of the different sections weighed by their relative accident indexes divided by the total length of the road.

The third subindex (service quality index) is the most complex one. This index is subdivided into two further subindexes: the "technical service quality index" and the "service quality index as perceived by users." The latter was designed to assess users' opinions based on a fixed questionnaire. The former was designed on the basis of a set of indicators defined by road experts. The reason for separating these two indexes is the difficulty users have in making objective perceptions of some of the variables that undoubtedly contribute to the quality provided by the contractor. Experts and ordinary users each have their own, and different, contributions to make concerning the judgment of road quality.

Some of the criteria incorporated to calculate the "technical service quality index" in Chile are: roughness, potholing, skid resistance, road marking, traffic signing, safety measures, lighting, and so on. The stages according to which a "technical service quality index" can be produced include the following:

1. Identification of each criterion affecting quality of service offered to users that might be evaluated through technical analysis;
2. Identification of quality criteria, and classification of them according to their function within the different categories of quality: that of the main trunk road, secondary infrastructures, environment, and services available to users of the road;
3. Definition of indicators, and the way in which those indicators are to be quantified;
4. Definition of a normalized score for each indicator between 0 and 1; and
5. Estimation of the weighting of each criterion that goes into the calculation of the final index.

The calculation of the index is done as arrived at by Eq. (8)

$$\mathrm{TSQI}_t = \sum_i (\theta_i \cdot \beta_i)$$

$$\sum_i \theta_i = 100$$

$$\beta_i = \Phi_i(f_i) \quad 0 \leqslant \beta_i \leqslant 1 \tag{8}$$

where TSQI_t=technical service quality index in year t; θ_i=weight accorded by an expert panel for the i criterion; β_i=homogenized value of the indicator for the i criterion; f_i=value of the indicator for the i criterion according to the original scale on which the i criterion is measured OK; and Φ_i=scale transformation function for the i criterion from its original scale to the [0,1] interval.

Each f_i value is measured according to its original scale. In order to measure each i criterion in a homogeneous scale, it is necessary to transform the original value of each indicator f_i from its original scale into β_i within the [0,1] interval. This transformation is carried out through the Φ_i function which, for most of the indicators, is a linear function.

The index obtained from Eq. (8) can be used to assess the effort of the contractor. According to this index the maintenance and operation contract may set up a system of rewards and penalties in the manner defined in this paper.

This index is complemented according to the methodology carried out in Chile with another index called the "service quality index perceived by users." This index was created to assess those aspects regarding road quality that users and affected people (i.e., people affected by noise, emissions, etc.) are likely to evaluate more correctly than outside experts who know the roads only theoretically. To that end a questionnaire was composed in order to determine the opinions of users on issues such as driving comfort, safety perception, quality of services available along the road, etc. The results of such questionnaires show the quality rendered by the contractor strictly from the viewpoint of the actual user, who may not be aware of the criteria applied by the experts in road safety, or amenities, or "net social benefit," but each user has his own experience, and the totality of those experiences add significantly to determining, not theoretically but actually, the quality of the infrastructure's maintenance.

The implementation of the pilot project produced interesting results, since it demonstrated that the "road safety index," the "technical service quality index," and the "service quality index perceived by users" can all be reasonably measured at a low cost. The experience proved that the scores obtained by the concessions where the results of such indices were to be considered varied from 30 to 70 points (out of 100 points) for the "technical service quality index," and from 35 to 85 points (out of 100) for the "service quality index perceived by users." This experience shows that the range of variation is quite wide, so the index defined is able to evaluate differences in quality among the concessions in which the pilot project was implemented.

Using the predefined subindexes, it is possible to set up a global index, through a weighed sum according to the identified priorities of a given society, that provides both public authorities and users with the tools with which to judge the effort made by the contractor. This experience proves that, in spite of the difficulty of obtaining an accurate measurement, the quality of a highway can be assessed in a reasonably approximate manner in a relatively inexpensive way.

Conclusions

From the analysis carried out in this paper the following conclusions can be drawn:

1. The "infrastructure maintenance and operation contracts by minimum standards" normally employed around the world to regulate infrastructure quality do not create an optimal structure for encouraging contractors to perform to the best of their ability, with the result that they do not achieve an optimal "net social benefit."
2. If infrastructure quality were verifiable (measurable at a low cost) and if the gross social benefit derived from a specific quality level were measurable, it would be possible to carry out a new procurement and regulation process based on both price and quality. This new procurement mechanism, which creates an optimal incentive structure, would grant the contract or franchise to the company that tenders an optimal price/quality ratio, according to its productive capacity.
3. The above mechanism allows an important increase in "net social benefit" to take place compared with the "infrastructure maintenance and operation contracts by minimum standards." Moreover, the greater the competitiveness of the company, the higher the optimal quality level and the "net social benefit" derived from it.
4. The procurement process defined should encourage bidders to submit tenders that are as realistic as possible. To this end, the bidding and contracting terms should include important penalties for the contractor if the level of service actually provided is lower than the agreed upon level. Moreover, the contracting terms must also include mechanisms to encourage the contractor to reach an even higher efficiency level than that contractually agreed upon in the initial commitment.
5. The main problem in putting this mechanism into practice lies in the difficulty of both measuring infrastructure quality inexpensively and of assessing the "gross social benefit" derived from a particular quality level. With respect to the former, it appears that some countries, such as Chile, are having success in defining quite extensive indices measuring infrastructure quality.

Appendix. Glossary of Terms

Bidder: company that competes in a tender process for the award of a contract or concession.

Competitiveness: ability of a firm to provide the same level of quality as other companies at a lower cost.

Concession (or franchise): an agreement between a public authority and a private company whereby the former transfers to the latter the responsibility for the construction and management of an asset, or the responsibility for its management alone, for a term that is often fixed in advance. The public authority generally gives the private company the right to charge a utilization fee to the infrastructure users, so the private company ordinarily bears the demand risk.

Contracting out: agreement between a public authority and a private company whereby the former transfers the infrastructure management responsibility to the latter for a period of time fixed in advance. The private company receives periodic payments from the public authority as compensation for providing that service.

Contractor: company in charge of conducting the maintenance and operation of the infrastructure.

External agents: those nonusers that are affected by the operation and maintenance of the infrastructure. The external agents bear the positive or negative externalities of the infrastructure management.

Gross social benefit: utility experienced by the infrastructure users and external agents, according to a quality level provided by the contractor. The gross social benefit is represented in this paper by the letter W.

Infrastructure maintenance: set of activities devoted to preserving the state of the infrastructure assets.

Infrastructure management: infrastructure maintenance plus infrastructure operation.

Infrastructure operation: set of activities, not related to the preservation of the infrastructure assets, devoted to proper use of the infrastructure.

Infrastructure users: people who directly enjoy the benefits of the infrastructure.

Maintenance and operation cost: cost incurred by the contractor to both maintain and operate the infrastructure plus cost incurred by the public authority to monitor the quality rendered by the contractor. The greater the quality, the greater the maintenance and operation cost will be. The maintenance and operation cost is represented in this paper by the sign $C_{M\&O}$.

Marginal gross social benefit: gross social benefit increase when quality, measured through a specific quality index, increases by one unit ($\partial W/\partial Q$).

Marginal maintenance and operation cost: maintenance and operation cost increase when quality, measured through a specific quality index, increases by one unit ($\partial C_{M\&O}/\partial Q$).

Net social benefit (or social welfare): the utility experienced by the whole society from a quality level provided by the contractor. Net social benefit equals gross social benefit minus maintenance and operation cost.

Public authority: public entity to which the government has entrusted the organization and monitoring of the management of a particular infrastructure (roads, seaports, airports, etc.).

Quality index: weighed sum of quality indicators for several criteria devoted to provide a global outlook of the infrastructure quality ultimately provided by the contractor. The quality index is represented in this paper by the letter Q.

Quality indicator: mechanism for evaluating, in a normalized way, the quality level associated with one specific quality criterion.

Quality premium: incentive introduced in infrastructure management contracts according to which the contractor is rewarded for reaching quality levels higher than expected.

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