APPLICATION OF THE AGENCY THEORY FOR THE ANALYSIS OF PERFORMANCE-BASED MECHANISMS IN ROAD MANAGEMENT

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ABSTRACT

This paper develops a model based on agency theory to analyze road management systems (under the different contract forms available today) that employ a mechanism of performance indicators to establish the payment of the agent. The base assumption is that of asymmetric information between the principal (Public Authorities) and the agent (contractor) and the risk aversion of this latter. It is assumed that the principal may only measure the agent's performance indirectly and by means of certain performance indicators that may be verified by the authorities. In this model there is presumed to be a relation between the efforts made by the agent and the performance level measured by the corresponding indicators, though it is also considered that there may be dispersion between both variables that gives rise to a certain degree of randomness in the contract. An analysis of the optimal contract has been made on the basis of this model and in accordance with a series of parameters that characterize the economic environment and the particular conditions of road infrastructure. As a result of the analysis made, it is considered that an optimal contract should generally combine a fixed component and a payment in accordance with the performance level obtained. The higher the risk aversion of the agent and the greater the marginal cost of public funds, the lower the impact of this performance-based payment. By way of conclusion, the system of performance indicators should be as broad as possible but should not overweight those indicators that encompass greater randomness in their results.

Keywords: road management, performance, public procurement, agency theory

INTRODUCTION

Numerous countries have developed diverse road management systems over recent decades that have gradually replaced direct management by local and central government. The majority of these formulas are based on a contract that establishes the relation between the authorities and a company entrusted with certain aspects of road management. The scope of the services rendered by the contractor varies and may include the maintenance of the asset, traffic and road management and, in some cases, the funding and construction of a new road infrastructure and its ensuing management on completion. The contract formulas employed may also vary from standard maintenance contracts to integral management contracts, concessions or other types of Public-Private Partnerships.

It is increasingly more common to base these different contract formulas on a payment to the agent that is associated with the quality level obtained and which is, in turn, measured by a series of indicators that have become increasingly well-defined over recent years (Delgado Quiralte *et al.*, 2007; Harding *et al.*, 2010; Federal Highway Administration, 2011). This approach acts as an incentive system to ensure the correct performance of the contractor and the optimization of resources employed in road maintenance and operation.

Contract systems of this nature may be analysed within the general framework of agency theory, which has undergone considerable development since it was first established back in the 1970's. This theory attempts to explain the agency relationship whereby one party (the principal) delegates certain tasks to another party (the agent), and where this relation is regulated by a contract or by similar means (Jensen and Meckling, 1976). Agency theory has been applied to many different fields of activity ever since its origins (Harris and Raviv, 1978). Among the first studies applied to the relationship between a public authority and an agent, reference may be made to those of Loeb and Magat (1979) and Baron and Myerson (1982), that focused on the problem of the regulation of a natural monopoly under conditions of asymmetric information between the authorities (principal) and the company providing the asset or service (agent). Reference may similarly be made to the work of Laffont and Tirole (1993) on systematizing this area of economic analysis.

The agency problem arises under conditions of asymmetric information between the principal and the agent when there is a conflict of interest and where it is difficult or expensive for the principal to verify what the agent is actually doing (Eisenhardt, 1989). In these cases, the research conducted into the principal-agent relationship is based on the specification of a series of assumptions regarding the possible means by which the principal may provide incentives to the agent in order to bring their respective objectives into line. On the basis of these assumptions and by a method of deduction, it is then possible to find a solution to the problem of contract optimization.

One of the main aspects to be specified in the agency relationship is the attitude towards risk of the contracting parties. In agency theory, it is generally assumed that the agent is risk-averse and the principal risk-neutral or, at the very least, that the agent is more averse to risk (Eisenhardt, 1989; Dewatripont and Legros, 2005; Sadka, 2007). In the present work, this focus is applied to the case of road management. The model is based on the assumption that the agent (contractor) will normally be averse to risk, though we have also examined the implications in the case that the agent is risk neutral. The incentive provided by a payment system based on performance levels is restricted in the model due to the randomness of the contract. This randomness is due to the fact that the authorities cannot directly measure the effort made by the contractor to render the service and may only do so by means of specific performance indicators that may be observed and verified by the authorities. This may well give rise to a certain discrepancies between the efforts made by the contractor and the effective results obtained from the performance indicators and which, in turn, affects the payment received by the contractor. The problem of information asymmetry then leads to a case of *moral hazard* (Laffont and Tirole, 1993). The main idea behind this focus is that the application of contract incentives to the agent conflicts with their risk aversion and leads to a duality of objectives by, on the one hand, paying the productive work of the agent and, on the other, efficiently assigning the risks, and thereby preventing the optimal outcome obtained in an environment of complete information (Holmström and Milgrom, 1991).

A similar focus has been adopted by Dewatripont and Legos (2005), Martimort and Pouyet (2008) and Iossa and Martimort (2008) in their works, fundamentally geared towards the comparative analysis of public-private partnerships with respect to more traditional public procurement. These authors consider a PPP to be basically defined by the bundling of diverse tasks within one single contract between the public authorities and the agent: and particularly, the design and construction of a certain infrastructure together with its maintenance and the operation of the corresponding service once the infrastructure is up and running. Under traditional procurement, to the contrary, these tasks are separated and assigned to different agents. The most relevant conclusion reached by these authors is that PPP contracts are more efficient than traditional public procurement as the efforts of the agent during the construction stage are positively reflected in the agent's results during the operation stage. As such, it is necessary to design a suitable system of incentives that allow the agent to internalise the benefits derived from the greater build quality of the infrastructure. In an optimal situation this would then lead to the greater allocation of risks to the agent under a PPP than under a traditional contract.

The model considered in the present work is applicable to both a PPP and to any other type of road management contract where the contractor's remuneration is based on the quality level obtained. The incentive system to the contractor should, at the outset, combine payment based on performance levels and payment in accordance with the number of users, as indicated by Sánchez Soliño (2012). However, there has been a shift in attitude in recent years in favour of the retention of the demand risk by the authorities (Abdel Aziz, 2007). This tendency has been very marked in the United Kingdom, where more recent contracts carried out under the PFI framework have all been based on performance-based payment systems (Standard & Poor's, 2003). This method has become even more widespread following the 2008 financial collapse which has led to the reluctance of the majority of financial corporations to fund any project of this nature that incorporates a substantial transfer of the demand risk to the agent.

The following section describes the model employed and the base assumptions of the same. The object of the analysis carried out is to optimize the parameters defining the payment system to the contractor from the perspective of welfare. These parameters depend on a series of factors and the influence of each of these is the subject of detailed study. In section 3 we consider the case of the risk aversion of both the agent and the contracting authority and analyze the implications of the same. Finally, the conclusions contain a summary of the main results obtained and a series of recommendations to be taken into account in the design of the contracts.

PRINCIPAL- AGENT MODEL

We shall presume that a certain authority (the principal) is responsible for the management of a certain road and decides to delegate the corresponding functions by way of contract with a specific company (agent). In most cases, these functions will include the maintenance of the road infrastructure and the corresponding installations, the necessary services for correct traffic operation and, where it be the case, the necessary investment to extend or improve the infrastructure.

In the model developed below, the road is taken to be free for users though the model may readily be applied to the case of toll roads. The objective function of the principal is that of social utility and one the public authority will attempt to maximize through the optimization of the parameters defining the remuneration mechanism of the contract, as described further on.

The social benefits obtained from the operation of the road, including the surplus of users, depend on the quality levels offered and which may, in turn, be measured by a series of indicators. In order to simplify the statement, we shall presume that the social benefits rise lineally with quality, in accordance with the following equation:

$$S = S_0 + a\, q \qquad [1]$$

Where **S** is the total social benefit, **a** a constant greater than zero and **q** a variable that synthetically represents the level obtained by the combination of road quality dimensions. This quality level depends to a certain extent on the efforts made by the contractor, as we shall see below. $\mathbf{S_0}$ represents the minimum social benefit obtained at a quality level that we shall conventionally establish at zero. This aims to reflect the fact that the public authorities generally demand certain minimum conditions in order to place the road at the disposal of users.

As indicated, the quality level **q** may be related to the efforts (referred to as **e**) made by the agent to improve service quality. This effort **e** shall also be a synthetic variable and will be the sum result of the individual efforts made by contractor with regards to each of the quality dimensions.

An essential element of our model is that this relation between the quality obtained and the efforts made by the contractor presents a statistical noise, or random component, to the extent that:

$$q = e + \varepsilon_q \qquad [2]$$

The variable ε_q represents this random component which is taken to have a normal distribution, with a mean equal to zero and a standard deviation equal to $\boldsymbol{\sigma_q}$. This means to say that the public authority cannot directly observe the efforts made by the agent and may only estimate this indirectly by the values obtained for the quality indicators employed. However, these values do not only depend on the effort **e**, but also on other unpredictable factors that are grouped in the said random variable.

As such, in our model the agent acts under risk conditions due to the randomness of the variable **q** and it is similarly assumed that the agent is not neutral to the same. This following the general assumption adopted in agency theory (Eisenhardt, 1989). With regard to the authorities, however, it is possible to assume that this is sufficiently diversified on account of the large number of projects and services for which they are responsible, and which subsequently makes them risk neutral. In the following section we shall relax this assumption and consider the general case in which neither the authorities not the agent are risk neutral.

The agent performs the road management duties and subsequently incurs certain costs that may be expressed as follows:

$$C = C_0 + \Psi(e) \qquad [3]$$

Where C represents the cost of producing the services rendered by the agent and C_0 is a fixed cost term incorporating the cost derived from any necessary initial investment for the rendering of the service. This fixed cost term may be interpreted as the minimum cost necessary to keep the road in operation with a minimum level of quality. The variable cost term is, in turn, a function of the level of effort **e** by the agent, and where $\Psi'(e) > 0$ and $\Psi''(e) > 0$. By this, we are assuming that the variable cost function strictly increases with the effort **e** and that this is also strictly convex.

With regards to remuneration, it is assumed that the agent will receive an amount from the authority which, in accordance with our model, depends on the quality level **q** obtained, as given by the following linear equation:

$$t\,(q) = \alpha + \beta\, q \qquad [4]$$

In this expression, **t** is the amount paid by the authorities to the contractor and **α** and **β** fixed parameters established in the contract. As may be seen, the agent will receive a fixed sum (given by the parameter **α**), regardless of the quality provided, together with a variable amount that depends on the quality verified by the authorities. As the authorities cannot directly observe the efforts made by the agent, an incentive system is then established in this way for this latter. However, the agent's revenue function includes the random variable defined above and the greater the incentives that be established the greater the bearing of this variable. Our problem is then to establish the value of the **α** and **β** parameters, established in the contract, that will maximise the social utility, when taking into account the trade-off between the agent's efforts and their risk aversion

When taking into account the random component of the agent's remuneration, the expected value would be as follows:

$$E\,[t] = \alpha + \beta\, e \qquad [5]$$

While the variance in revenue received by the agent, and specified as $\boldsymbol{\sigma_t^2}$, would be as follows:

$$\sigma_t^2 = \beta^2 \sigma_q^2 \qquad [6]$$

In addition to the social utility function, that is defined further on, it is also necessary to consider the restrictions established on the basis of the agent's utility function. This latter being given by the following equation:

$$Ur = E[t] - C - r\, \sigma_t^2 \qquad [7]$$

In this equation, **Ur** is the utility of the agent, **E[t]** the expected value of the payment made by the principal, and **C** the cost of producing the service. Here, **r** is a parameter that represents the agent's attitude to risk and, when expressed in other terms, **Ur** would then be the certainty equivalent of the returns expected by this latter.

In the case of the risk aversion of the agent, this would imply an **r** value strictly greater than zero, while in the case of risk neutrality this would suppose an **r** equal to zero. In our model it is taken that the agent will normally be risk averse, though we shall also study the implications arising in the case that r = 0. We shall exclude the possibility that the agent be a risk lover, and as result of which it shall always be taken that:

$$r\,\sigma_t^2 \geq 0 \qquad [8]$$

On developing the equation **[7]**, when considering **[3]** and **[5]**, we then obtain:

$$Ur = \alpha + \beta\, e - C_0 - \Psi(e) - r\,\sigma_t^2 \qquad [9]$$

However, in order for the agent to carry out their activity, they will have to obtain a utility greater or equal to the alternative of not carrying out any. If we take this latter alternative to represent a utility equal to zero, the agent's participation is then dependant on the following:

$$Ur \geq 0 \qquad [10]$$

The social utility function which should be maximised to the full shall, in turn, be formed by the benefits produced by the provision of the service for society as a whole minus all costs incurred in making this service available and including, among other factors, the cost derived from the risk aversion of the agent. In this way, the social utility function may be given by:

$$Us = E[S] - C - r\,\sigma_t^2 - \lambda\, E[t] \qquad [11]$$

In this equation Us is the social utility that is to be maximised and the variable S represents the social benefit given by [1], and as such:

$$E[S] = E[S_0 + aq] = E[S_0 + a(e + \varepsilon_q)] = S_0 + a\, e \qquad [12]$$

Equation [11] includes the excess burden of public funds which is given by the term $\lambda E[t]$, where λ is a parameter (attributed with a value greater than zero) that characterises the tax system of the country in question. The value $(1 + \lambda)$ is normally referred to as the marginal cost of public funds, this being a concept that incorporates various aspects and including the distortion introduced by the tax system in the decisions of the economic agents and the cost of tax administration. In other words, we are then supposing that the disutility to taxpayers inflicted by levying an additional monetary unit shall be equivalent to $(1 + \lambda)$ monetary units, where the value of λ depends on the institutional framework of each country and the tax provisions used to obtain additional public funds. This weighting of public funds is not taken into account in the majority of cost-benefit analysis and it is, instead, implicitly established that $\lambda = 0$. However, Laffont and Tirole (1993) considered it reasonable to establish a value $\lambda = 0.3$ for the American economy and Kleven and Kreiner (2003) estimate λ values of between 0.09 and 0.80 for different OECD countries when considering proportional tax increases for the tax system as a whole. In all events, this concerns values that are by no means negligible. A detailed study of the concept of the marginal cost of public funds may be found in Dahlby (2008).

When considering **[3], [5], [6]** and **[12]** and on substituting certain terms by their values, the social utility equation may then be expressed as follows:

$$Us = S_0 + ae - C_0 - \Psi(e) - r\,\beta^2\sigma_q^2 - \lambda\,[\alpha+\beta e] \qquad [13]$$

However, if we take into account **equation [9],** the social utility function can then be written as:

$$Us = S_0 + ae - (1+\lambda)[C_0 + \Psi(e) + r\,\beta^2\sigma_q^2] - \lambda\,Ur \qquad [14]$$

When resolving the problem of maximising this function, it is necessary to take into account, in addition to the restriction **[10],** the restrictions imposed by the maximisation of the objective function of the agent. The agent's efforts **e** should then comply with the following first-order condition:

$$\frac{\partial Ur}{\partial e} = \beta - \psi'(e) = 0$$

That is to say:

$$\psi'(e) = \beta \qquad [15]$$

On introducing this condition in the social utility equation **[14],** the problem may then be laid out in the following terms:

$$Máx_{(Ur,\,e)}\{ S_0 + ae - (1+\lambda)[C_0 + \Psi(e) + r\,(\Psi'(e))^2\,\sigma_q^2\,] - \lambda\,Ur\} \qquad [16]$$

subject to restriction **[10]**

When considering that the social utility function is monotonically decreasing with Ur, the solution to the preceding problem is then as follows:

$$Ur = 0 \qquad [17]$$

$$a - (1+\lambda)[\Psi'(e^*) + r\,\sigma_q^2\,2\,\Psi''(e^*)\,\Psi'(e^*)] = 0 \qquad [18]$$

Where the maximum condition is as follows:

$$-(1+\lambda)[\Psi''(e^*) + 2r\,\sigma_q^2\,(\Psi''(e^*))^2 + 2r\,\sigma_q^2\,\Psi'(e^*)\,\Psi'''(e^*)] < 0 \qquad [19]$$

It should be noted that in accordance with the base assumption of the model and for a risk neutral or risk averse agent (that is to say, with $r \geq 0$), it is sufficient that $\Psi'''(e^*) \geq 0$ in order to comply with the maximum condition.

In order to simplify the exposition, while retaining the general application of the main results of the model, it is possible to consider a specific cost function that satisfies the condition of being strictly positive in its first and second derivatives and greater or equal to zero in its third derivative. In economic literature it is common to take the following type of quadratic cost function:

$$\Psi(e) = e^2/2 \qquad [20]$$

Examples of authors using a quadratic cost function include Arrow and Radner (1979), Gibbons (1998), Rob and Zemsky (2002), Socorro (2007) and Martimort and Pouyet (2008).

The solution obtained with this cost function is then as follows:

$$e^* = \frac{a}{(1+\lambda)(1+2r\sigma_q^2)} = \beta^* \qquad [21]$$

And from which and when taking into account equation **[17]**:

$$\alpha^* = C_0 + (\beta^*)^2 (r\sigma_q^2 - \frac{1}{2}) \qquad [22]$$

In this way we then obtain the values of the parameters of equation **[4]** that optimize the contract in terms of social utility. It may be noted that in an optimal contract it would generally be necessary to include a fixed payment **α***, regardless of the quality of the service and one that would largely depend on the fixed cost term C_0. However, the value of **α*** could, in theory, be negative which would imply the payment of a fixed sum by the agent to the principal.

In this model the value of β*, with a risk neutral or risk averse agent, will always be greater or equal to zero, as will the value of the agent's efforts. The value of β* (and subsequently the effort made by the contractor) will be seen to drop with any increase in the risk aversion of the contractor, the variance σ_q^2 or the marginal cost of public funds.

It may be noted that in a situation of complete information of the authorities and where these may directly observe the efforts made by the contractor, this would then imply that $\sigma_q^2 = 0$ in equation **[21]**. In this case the value of the contractor's efforts would be established as:

$$e^* = \frac{a}{1+\lambda} \qquad [23]$$

When the contractor is risk averse, this value will always be higher than that obtained under the assumption of asymmetric information between principal and agent. However, when the contractor is risk neutral (r=0), the result obtained will always be as that given by equation **[23]**.

RISK AVERSION OF THE PUBLIC AUTHORITIES

In this section the Authorities shall not be considered to be risk neutral, and both the principal and the agent shall be taken to show risk aversion. This new analysis is particularly relevant in those situations where the Government is subject to strong budgetary restrictions due to the need to comply with specific international commitments, as is the current case of member states of the European Union.

In our model the main implication of this new assumption is that a new cost term appears within the social utility function due to the risk aversion of the authorities. If the parameter characterising the risk attitude of the contractor is referred to as $\mathbf{r_F}$ and that corresponding to the government as $\mathbf{r_G}$ (and where $r_F \geq 0$ and $r_G \geq 0$), we then obtain:

$$Us = S_0 + ae - C_0 - \Psi(e) - r_F\, \beta^2\sigma_q^2 - \lambda\, [\alpha+\beta e] - r_G\, \beta^2\sigma_q^2 \qquad [24]$$

When maintaining the same restrictions as in the previous case, the optimization problem may then be established in the following terms:

$$Máx_{(Ur,\, e)}\{ S_0 + ae - r_G\, (\Psi'(e))^2\, \sigma_q^2 - (1+ \lambda)[C_0 + \Psi(e) + r_F\, (\Psi'(e))^2\, \sigma_q^2] - \lambda\, Ur\} \qquad [25]$$

subject to restriction **[10]**.

The resulting first order conditions are as follows:

$$Ur = 0 \qquad [26]$$

$$a - 2r_G\, \sigma_q^2\, \Psi''(e^*)\, \Psi'(e^*) - (1+ \lambda)[\Psi'(e^*) + 2r_F\, \sigma_q^2\, \Psi''(e^*)\, \Psi'(e^*)] = 0 \qquad [27]$$

With the following maximum condition:

$$-2r_G\sigma_q^2(\Psi''(e^*))^2 - 2r_G\sigma_q^2\Psi'(e^*)\Psi'''(e^*) - (1+\lambda)[\Psi''(e^*)+2r_F\, \sigma_q^2(\Psi''(e^*))^2+2r_F\sigma_q^2\Psi'(e^*)\Psi'''(e^*)] < 0 \qquad [28]$$

When taking $\Psi(e) = e^2/2$, we then obtain:

$$e^* = \frac{a}{(1+\lambda)(1+2r_F\sigma_q^2)+2r_G\sigma_q^2} = \beta^* \qquad [29]$$

In this case the maximum condition is always observed, as $\Psi'''(e^*) = 0$.

Furthermore, the equation for parameter **α*** continues to be:

$$\alpha^* = C_0 + (\beta^*)^2 (r_F \sigma_q^{\,2} - \frac{1}{2}) \qquad [30]$$

When making a comparison with the results of the previous section, it may be stated that the risk aversion of the authorities does not substantially change the model. The only aspect of note, in relation to the results obtained under the assumption of the risk neutrality of the authorities, is that the optimal quality and the payment dependent on the quality level obtained are both reduced, while the fixed payment to the contractor may either rise or fall, depending on the result of (r_F σ_q^2 – 1/2).

CONCLUSIONS

As a result of the analysis conducted in this work, an optimal contract for road management should include both a fixed payment to the contractor and a payment established in accordance with the quality levels obtained. The weight of this latter, together with the effort made by the contractor, decreases in an optimal contract with any increase in risk aversion, the σ_q^2 variance or the marginal cost of public funds. The weight of payment for quality is also seen to decrease in the case of the risk aversion of the principal.

The range of performance indicators employed in the contract should be as wide as possible and attempt to include all the quality dimensions that significantly influence the social utility function. In this respect, it is to be expected that the agent will focus all their efforts on those quality dimensions that are specifically regulated. There is subsequently a high risk that certain quality aspects will be neglected merely on account of their omission from the contract.

However, reference should be made to the results obtained in this work with regards to the selection of performance indicators. As may be seen in **equations [21] or [29]** above, the effort made by the agent under an optimal contract depend on a factor, the variance σ_q^2, which in turn depends on the correct design of the quality indicators employed in the contract. In this respect, the selected indicators should attempt to avoid any considerable disparity between the efforts made by the contractor and the quality level measured according to the corresponding indicator. As such, all those indicators providing results with a high random component beyond the control of the contractor should not be overweighted.

In practice, some of the more widely used indicators tend to show a greater variation between the result effectively obtained and the effort made by the concessionaire to improve this quality aspect. This is particularly the case of the road accident and fatality indices that are employed in many road Public-Private Partnerships (Delgado Quiralte et al., 2007; Rangel, T., 2011). The results obtained from these indicators effectively depend on numerous random factors and only to a certain degree on the performance of the contractor. According to the model developed in this work, it would be ineffective to establish the contractor's payment mainly on these types of indicators as this greatly reduces the social utility on account of the risk aversion of the principal or the agent.

The reason behind the generalized use of these types of indicators related to road accidents, is that of the large social repercussions of the same. In this respect, the introduction of accident or fatality indices among the quality indicators of a road management contract may transmit the idea of a public concern for traffic safety, but these are not necessarily the most efficient indicators. The results of this work may serve to revaluate the loss of efficiency resulting from the selection of quality indicators that generally tend to give random results and show that it is preferable to employ other indicators (related, for example, to road maintenance, signs and markings or response to incidents) that also affect safety but whose results depend more on the performance of the contractor.

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