COST-BENEFIT ANALYSIS AND THE OPTIMAL TIMING OF ROAD INFRASTRUCTURES

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ABSTRACT

Standard cost-benefit analysis (CBA) is based on a static setting, allowing one to conclude whether or not a new infrastructure should be built, but not allowing one to conclude if it would be more advantageous to build it right now or in the future. Since the resources available to society are limited, knowing the best timing for such infrastructures is, perhaps, as important as knowing if they should be built. In this paper, we analyze the application of real options analysis within a cost-benefit framework, in order to find the best timing for starting the construction of road infrastructures.

The optimal timing of investments has been, in recent decades, the subject of great interest in the context of corporate finance, leading to the development of real options analysis. There are several applications of real options analysis to transport infrastructures but, despite such contributions, the incorporation of real options analysis in a CBA framework is still in its early stages. This paper provides a contribution to the incorporation of real options analysis into the CBA framework.

We define a model of the expected net present value of a road infrastructure, with two sources of uncertainty: gross domestic product growth and fuel prices. Both these variables are assumed to be stochastic, so we resort to Monte Carlo simulation for the implementation of the model. We also propose a methodology to estimate the thresholds that define the optimal starting time for the infrastructure.

We apply the developed model to a real infrastructure currently under development, and analyse the rules that define the optimal timing for starting its construction.

Keywords: cost-benefit analysis, real options analysis, road infrastructure investments

1. INTRODUCTION

In recent decades, the optimal timing of investments has been the subject of great interest in the context of corporate finance, being linked to the development of real options analysis. McDonald and Siegel (1986) produced the seminal work that provides the basis for several analyses of the optimal timing of investments.

Several authors have applied real options analysis to transport infrastructures. Such applications usually assume that either the project value or the infrastructure demand follow a geometric Brownian motion, and consider a limited range of impacts – financial impacts and, sometimes, the value of time savings. Bowe and Lee (2004) analyse the deferment, expansion and contraction options in a high speed train project, using real data from a project located in Taiwan. The analysis is based on the assumption that the project value follows a geometric Brownian motion. Pimentel *et al.* (2008) study the optimal timing of an investment in high speed rail, assuming that demand follows a geometric Brownian motion. Galera and Solino (2010) value a minimum traffic guarantee in a highway concession, assuming that traffic follows a geometric Brownian motion.

Some authors resort to Monte Carlo simulation to evaluate real options in models that incorporate greater detail. Rose (1998) uses Monte Carlo simulation to estimate the option value of the contractual agreements present in the toll road concession of the Transurban City Link project, in Melbourne. Brandao (2002) uses an approach proposed by Copeland and Antikarov (2001) to analyse the options embedded in building and operating a new road in Brazil. Zhao *et al.* (2004) use a Monte Carlo simulation-based algorithm to evaluate real options in highway development, operation, and rehabilitation.

In this paper, we develop a model for the analysis of the optimal timing of a road infrastructure construction, considering two sources of uncertainty: gross domestic product (GDP) growth and fuel prices. In this model, we include the costs and benefits that are usually considered in CBA. The model intends to be applicable to real projects, without requiring the over-simplifications that are common in real options models, and requiring only the same data that is usually necessary for conventional CBA of road investments. We also present a methodology for choosing the optimal timing for the investment, using the proposed model. This work extends the current literature by explicitly incorporating the timing option in CBA analysis of road infrastructures, without neglecting significant sources of benefits or costs, and without demanding unreasonable data for the analysis. We apply the model to the evaluation of a real infrastructure currently under development – the Douro Interior concession, located in Portugal.

In section 2, we discuss some important methodological issues concerning the choice of the optimal timing of investments within the CBA framework. In section 3 we present a model for road infrastructure investment. Section 4 presents the methodology for determining the optimal timing for the investment, using the proposed model. Section 5 presents an application of the model to the valuation and timing of the Douro Interior concession. Section 6 presents the concluding remarks.

2. METHODOLOGICAL ISSUES IN CHOOSING THE OPTIMAL TIMING

Standard benefit-cost analysis allows the calculation of different measures of the project value: the Net Present Value (NPV), the Internal Rate of Return (IRR) and the benefit-cost ratio. When correctly applied, all these measures lead to the same accept/reject decisions. However, the usual application of different measures may yield different results when ranking alternatives. Particularly, different measures may lead to different choices of project timing. It is accepted that the NPV usually leads to better project ranking decisions (see, for example, Brealey and Myers, 1996), so we will base our analysis on the NPV criterion. We will perform a discrete-time analysis, as usual in CBA.

In a conventional CBA, the NPV can be defined as:

$$NPV = \sum_{t=s}^{H} \frac{E_{T_0}\left(F_t\right)}{\left(1+r\right)^{t-T_0}} \qquad (1)$$

where T_0 is the reference year for the analysis (usually the year the decision is made), s is the year the project is started, H is the last year of the analysis, r is the discount rate and $E_{T_0}\left(F_t\right)$ is expected value of year t's cash flow, estimated with the information that is available at time T_0. In a CBA, the cash flows include the monetized value of the relevant project impacts. In the case of road infrastructures, they usually include the costs of infrastructure investment, maintenance and operation, the value of time savings, the vehicle operating costs, the value of changes in accident risks, the environmental costs, and the additional impacts of tolls and taxes (particularly fuel duty). The year H cash flow also includes the salvage value of the project. All the values are measured at constant prices of a given year (usually the reference year), and the discount rate also assumes constant prices; this way, no assumptions about future inflation rates are required. Following the usual practice in CBA, we will hereafter consider that all the values are measured at constant prices.

The stream of cash flows can be divided into a stream of costs C_t, including the costs of infrastructure investment, maintenance and operation and the salvage value (which is, in fact, a benefit, that is, a negative cost), and a stream of benefits B_t, including the other impacts (some of them may be negative benefits). We will thus have:

$$F_t = B_t - C_t$$

In our model, we will not consider uncertainty in the project costs. We will assume that the costs will grow at the inflation rate – that is, the costs incurred do not change with the year in which construction starts (if the costs are measured at constant prices)[1]. This means that the cost incurred in the n^{th} year of the project is independent of the starting year; we will

[1] It would be easy to allow for a constant annual change in the costs but, for the sake of simplicity of exposition, we will not consider it.

denote it by C'_n. If we consider an evaluation period of *P* years, and a set *S* of possible years for starting the project, we may write:

$$C_{s-1+n} = C'_n, \forall n \in \{1,...,P\}, \forall s \in S$$

2.1. The optimal timing in a deterministic setting

The NPV defined by (1) is the measure of the net society benefits derived from undertaking the project. This means that, when there is no uncertainty, the optimal starting time will be the value of $s \in S$ that maximizes the NPV.

Each possible starting year will be an alternative. The analysis will assume that construction may start at *q* consecutive years:

$$s \in S = \{s_1, s_2 = s_1 + 1, s_3 = s_1 + 2, ..., s_q = s_1 + q - 1\}$$

So, the starting time *s* of expression (1) should take the values of all possible starting years, and the year that yields the largest NPV will be the optimal starting time. To proceed with the analysis, it is necessary to define the last year to include in the analysis.

Pearce *et al.* (2006) suggests a technique that considers a constant evaluation period, and evaluate the project for that period, for all possible starting times. If the final year of analysis is chosen in this way, different years are excluded from the analysis when different starting times are considered. This assumption is suitable for projects in which the flow of benefits cannot be extended beyond the end of the evaluation period – this is, for example, the case of a project for exploring a copper mine that will be depleted by the end of the evaluation period. However, this is not the case for a road infrastructure, because the road may be rehabilitated or rebuilt during its lifetime (assuming the volume of traffic using it is large enough), and so it may still be used after the last year of the analysis. By building the road earlier, society has, in fact, the option of extending its use beyond its normal lifetime, by rehabilitating or rebuilding it. This is why we believe that it does not make sense to use different last years of analysis when evaluating the possibility of starting construction in different years – all alternatives should be evaluated from the corresponding starting year to the same final year.

Extending the analysis to the same final year for all possible starting times raises new questions. First: What should this final year of analysis be ? If the conventional CBA considers an evaluation period *P*, all the alternatives should be evaluated for at least this period. This means choosing a final year that is *P* – 1 years after the latest starting year. If the latest starting year is s_q, the common last year of analysis will be:

$$H = s_q + P - 1 \tag{2}$$

Another question is: For the alternatives that consider more than *P* periods, what costs should be considered after the end of *P* periods ? If we only consider the normal maintenance costs, then we may be biasing the analysis towards starting the project earlier. In fact, a road built later will use new materials and techniques, becoming more valuable to the society; so, if we extend the analysis beyond the normal evaluation period, we should somehow take this into account.

In order to answer this question, we assume that the salvage value is a good proxy for the whole remaining value of the investment that was made to build, operate and maintain the road. So, in order to have an up to date road *P* years after the start of the investment, it will be necessary to perform a new investment, equivalent to incurring in the stream of costs $C'_n, n \in \{1,...,P\}$. In order to allow a fair comparison of all the alternatives, we will resort to the concept of equivalent annual cost. We consider a stream of identical annual cash flows with a length equal to the project operational life, and define the equivalent annual cost as the value, C'', that all the cash flows in that stream must have in order for the stream to have the same NPV as the stream of costs $C'_n, n \in \{1,...,P\}$. If the infrastructure operation begins Δ years after starting construction, then:

$$C'' = \frac{r \cdot \sum_{n=1}^{P} \frac{C'_n}{(1+r)^n}}{\left[\frac{1}{(1+r)^\Delta} - \frac{1}{(1+r)^P}\right]} = \frac{r \cdot NPV_{\text{costs}}}{\left[\frac{1}{(1+r)^\Delta} - \frac{1}{(1+r)^P}\right]} \qquad (3)$$

Concluding, we will extend the analysis of all alternatives to the same final year *H*, defined by (2) and, for those alternatives in which the normal evaluation period ends before *H* (that is, with $s + P - 1 < H$), we lengthen the analysis period by assuming that the stream of benefits extends until year *H* and that, between years $s + P$ and *H*, an annual cost of C'' (defined by (3)) is incurred.

2.2. The optimal timing in a stochastic setting

In a deterministic setting, we may define a priori the optimal moment for starting construction, since we know that the future benefits and costs will not be changed. In a stochastic setting, changes in the stochastic variables may lead to changes in the ranking of the alternative timings.

In this setting, we will use $E_T(NPV_s)$ to represent the expected NPV of starting construction at year *s*, as calculated for year *T* with the information available at that year (for $s \geq T$). The expression for calculating $E_T(NPV_s)$ is similar to (1):

$$E_T(NPV_s) = \sum_{t=s}^{H} \frac{E_T(F_t)}{(1+r)^{t-T}} \qquad (4)$$

Since the conditions may change from period to period in a stochastic setting, we may no longer define a priori the best year for starting construction. What we may do is to determine whether or not the investment should be made right now and, in case it should be postponed, to identify, for every possible moment of decision, rules that define how the decision shall be made at that moment.

So, how should we decide whether or not to start the project ? Let us assume a discount rate *r*, and that a decision to start construction must be made one year in advance. We also define that V_t is the year *t* expected NPV, assuming that a decision to start the project has not been made in a previous year, and that the best decisions are made both at time *t* and in the following years. By using dynamic programming, in a way similar to Dixit and Pyndick (1994), we get:

$$V_t = \max\left[E_t\left(NPV_{t+1}\right);\frac{1}{1+r}\cdot E_t\left(V_{t+1}\right)\right],\text{ for } t < s_q - 1 \qquad (5)$$

Expression (5) defines that, if a decision to start the project has not yet been made, the year *t* NPV will be the maximum of the values of deciding to start ($E_t\left(NPV_{t+1}\right)$) and waiting one more period ($E_t\left(V_{t+1}\right)$ discounted to year *t*). In the last year for which it will be possible to decide to start the project (year $s_q - 1$), we have:

$$V_t = \max\left[E_t\left(NPV_{t+1}\right);0\right],\text{ for } t = s_q - 1 \qquad (6)$$

In year $s_q - 1$, if the project does not start, then it is definitely cancelled. The expressions (5) and (6) define the rules for choosing the optimal moment to start the project. In section 4, we will discuss the implementation of such rules in the context of a simulation model. But before, in section 3, we will discuss the definition of such model.

3. A STOCHASTIC MODEL FOR ROAD INFRASTRUCTURE INVESTMENT

In this section, we will define a stochastic model for CBA of road infrastructures. The model resorts mostly to information already required for a conventional CBA – it was defined in this way in order to be easy to apply. The model is defined for road concessions located outside congested areas, where additional traffic is not expected to have a significant impact in driving speed.

3.1. Base variables

The base variables that are modelled as stochastic are GDP growth and fuel price. These variables were chosen because they are observable variables that have an important effect in the expected NPV, both through their impact in traffic volume (see, for example, Graham and Glaister, 2004) and, in the case of GDP growth, through its impact in several evaluation parameters (unit value of time savings, unit values of casualties avoided, cost factors for transport emissions and noise exposition). Also, their values for the past years are known, so their dynamics can be modelled with some accuracy, and used in the simulation of their future values.

GDP growth

Historical series of GDP growth are available for different countries, and different models are used to model the dynamics of this variable. Autoregressive (AR) or autoregressive moving average (ARMA) models may be estimated from historical data, as well as the residuals' standard deviation, and the estimated model may be used to simulate future GDP growth.

Fuel price

Different types of fuel are used by the vehicles, but petrol and diesel are the most commonly used. So, we have chosen to consider only these two types of fuel. Given the strong correlation between the prices of petrol and diesel, it may suffice, as an approximation, to model one of them, and consider the relation between both prices to be constant.

Mean-reversing stochastic processes have been used to explain the evolution of fuel prices. However, the recent evolution of fuel prices seems to put in check such models for their dynamics. In the absence of further information about the fuel prices, it may be useful to fit both a geometric Brownian motion and a mean-reversion process to the price evolution, and choose the model that better explains it.

3.2. Traffic

Traffic is usually the most important variable determining the benefits in a CBA. Changes in traffic are defined by the modifications in other variables, like population, income, costs of the trips, among others. In this model, we assume that the most relevant variables for explaining changes in traffic are GDP growth (which represents changes in income) and fuel price (an important part of the costs of the trips). Other important variables, like the population in the area, are assumed not to have significant changes during the period of analysis.

A traffic model, forecasting the evolution of traffic in the do-nothing and do-something scenarios, is necessary for a conventional CBA. We propose to use such a forecast as the basis for the stochastic model. In order to do that, we only model changes in the global volume of traffic using the infrastructure, instead of considering detailed changes in its allocation. These global changes in traffic volume can be estimated through the use of traffic demand elasticity estimates. The original traffic model will be based on some assumptions about GDP growth and fuel prices. By considering the difference between the simulated GDP values of these variables and the values assumed by the traffic model, and applying changes in traffic volume according to the demand elasticities, it is possible to calculate updated estimates of traffic, corresponding to the simulated values of the base variables. As usual in CBA, it is necessary to calculate different values of traffic volume for the do-something and do-minimum scenarios, as well as for the relevant classes of traffic (heavy/passenger vehicles, base/generated/diverted traffic).

In case there are elasticity estimates for the area where the infrastructure will be built, these estimates should be used. If no local estimates are available, we may resort to published studies of traffic demand elasticities (for example, Graham and Glaister, 2002, Hanly *et al*., 2002, and Graham and Glaister, 2004).

Notice that this methodology is only directly applicable under the assumption that changes in traffic volume (within a reasonable range) do not have a significant impact in driving speed. If that is not the case with the infrastructure under analysis, then it is necessary to make some adjustments. Mainly, it is necessary to define an equilibrium approach to simultaneously consider the effect of changes in traffic volume on the driving speed, and the effect of driving speed on traffic volume. In this case, if there are sections of the infrastructure with different driving speeds, the equilibrium approach should be applied to each of these sections.

Finally, we must stress that the goal of this traffic estimation is not to get a picture of the traffic as rigorous as the one provided by the original traffic model. The goal is to get an approximate idea of the effect on traffic of changes in the base variables. This way, we will be able to produce an estimate of each year's cash flow for the simulated values of the base variables.

3.3. Components of the simulated cash flows

Using the simulated values of the base variables, and the corresponding traffic volume, it is possible to calculate a simulated cash flow for each year.

Usually the costs related to the infrastructure investment, maintenance and operation are subject to some uncertainty, but that uncertainty is only resolved after the construction is started. In this way, uncertainty about these costs will not be relevant to the timing decisions. Therefore, in the simulation, these values will be considered fixed.

In the model, we incorporate the road impacts that are usually considered in a CBA: value of time savings, vehicle operating costs, casualties due to road accidents, air pollution, global warming emissions, noise costs, fuel duty and tolls. All these costs will depend on traffic volume and, in several cases (time savings, road accidents, air pollution, global warming emissions and noise), the unit costs are assumed to change with GDP growth (Bickel *et al.*, 2006). Since we assume that driving speed does not change with traffic volume, time savings will be proportional to traffic volume.

Some wider economic benefits are also sometimes included in a CBA. Two such benefits, which we included in the model, are improved labour supply and increased output in imperfectly-competitive markets (DfT, 2006). These benefits can be seen as a function of the time savings, so their impacts for the simulated values of the base variables can be easily estimated.

4. APPLYING THE MODEL

The previous section outlined the model, and addressed the simulation of the project cash flows. We will now discuss which cash flows shall be used to calculate the expected NPV, and how to use the simulation model to define the best timing for starting the project.

4.1. Definition of the expected cash flows

The simulated cash flows described in the previous section will not be directly used in the calculation of the expected NPV. Instead, as can be seen in expression (4), the expected cash flows at the time a decision is made should be used in the calculation – that is, the cash flows taking into account the available information at the time of the decision. The simulated cash flows will thus be a means to calculate the expected cash flows.

In a conventional CBA, it is usual to determine the expected cash flows as the cash flows that are calculated by using the expected values of the variables. In a stochastic setting, this will usually lead to biases. To see this, let us examine the value of time savings. The value of time savings is the product of the total time savings by the unit value of time. The value of time will grow with the GDP and, assuming a positive elasticity of traffic demand with GDP, the total time savings will also usually grow with it. This means that the two variables being multiplied are positively correlated, and the expected value of their product will be larger than the product of their expected values, so the use of the latter will lead to a downward bias. Since we are explicitly assuming a stochastic setting, care must be taken to calculate the true expected value of the cash flows with the information available at the moment of the decision, instead of calculating the cash flows by using the expected values of the variables.

4.2. Determining when to start the project

As described in section 2, the optimal rules for starting the project are defined by expressions (5) and (6), and use the expected NPV defined by (4). (6) defines that, at the last decision moment, we should decide to start the project if the expected NPV is positive and not to start it otherwise. In the previous years, the decision is based on the maximum between the value of starting right away and the value of waiting (expression (5)). We will now explain how these expressions will allow us to define the best timing for the project, based on Monte Carlo simulation.

It was assumed that a decision to start the project must be made the year before beginning construction, s_q is the last possible year for starting the project, and V_t is the expected NPV of the project in year *t*, assuming that the decision to start the project was not made before that year and that the best possible decisions will be made thereafter.

We will use backward induction to define the optimal timing for starting the project. We assume that all simulation paths are defined, and $E_{s-1}\left(NPV_s\right)$ is calculated for all these paths and for all possible starting times $s \in S$. We will now show how to build rules for defining the best year to begin the project. Starting with the last year for making a decision, we decide to start the project if the expected NPV is positive and cancel it otherwise. We thus get expression (6):

$$V_{s_q-1} = \max\left[E_{s_q-1}\left(NPV_{s_q}\right);0\right]$$

By using this expression, we can calculate V_{s_q-1} for all the simulation paths.

Considering the decision that will be made at $s_q - 2$, we will start the project if the expected value of starting right away is larger than the value of waiting, and postpone it otherwise. We get:

$$V_{s_q-2} = \max\left[E_{s_q-2}\left(NPV_{s_q-1}\right); \frac{1}{1+r} \cdot E_{s_q-2}\left(V_{s_q-1}\right)\right] \qquad (7)$$

By looking at (7), we can see that, for large values of the expected NPV ($E_{s_q-2}\left(NPV_{s_q-1}\right)$) it will be preferable to start right away, instead a losing one cash flow, and for small or negative values of the expected NPV it will be preferable to wait. This may lead us to think of defining an investment threshold, such that if the expected value of immediately deciding to start construction is larger than this threshold, the road construction should be started, otherwise we should wait. In fact, in several investment timing problems, such a threshold does exist, leading to the optimal decisions (see, for example, McDonald and Siegel, 1986, and Dixit and Pyndick, 1994). However, in this model, since we have multiple state variables, such a threshold will not exist, and the optimal decision rules will be quite complex and hard to understand.

So, we decided to use threshold values based on the expected NPV: the rules thus defined will be easy to understand, and will constitute a good approximation to the optimum. The year $s_q - 2$ investment threshold, τ_{s_q-2}, is defined as:

$$\tau_{s_q-2} = \underset{\upsilon}{\arg\max} \begin{cases} E_{s_q-2}\left(NPV_{s_q-1}\right), E_{s_q-2}\left(NPV_{s_q-1}\right) \geq \upsilon \\ \dfrac{V_{s_q-1}}{1+r}, E_{s_q-2}\left(NPV_{s_q-1}\right) < \upsilon \end{cases} \qquad (8)$$

Notice that (8) simply states that the threshold will be the value that maximizes V_{s_q-2}. Since we already know the value of V_{s_q-1} for all the simulation paths, we can use that value to determine the threshold τ_{s_q-2} defined by (8).

In general, the investment threshold for year *s* – 1 may be defined as:

$$\begin{gathered} \tau_{s-1} = \underset{\upsilon}{\arg\max}\, E_{s_1-1}\left[g_s\left(\upsilon\right)\right], s \in S \setminus \{s_1\} \\ \text{where } g_s\left(\upsilon\right) = \begin{cases} E_{s-1}\left(NPV_s\right), \text{ if } E_{s-1}\left(NPV_s\right) \geq \upsilon \\ \dfrac{V_s}{1+r}, \text{ if } E_{s-1}\left(NPV_s\right) < \upsilon \end{cases} \end{gathered} \qquad (9)$$

Notice that, by starting with the last possible decision moment and going back to the beginning, we can be sure that we know V_s before defining τ_{s-1}.

For $s = s_1$, all paths will lead to the same expected value $E_{s-1}\left(NPV_s\right)$, since this expected NPV does not depend on any simulated values. This means that, for the first period, we may not use (9) to define an investment threshold. For this first period, we may use expression (5) directly: if the expected NPV of deciding to start is larger than the NPV of waiting one year, then we should decide to begin the project. That is, we decide to immediately begin the project if:

$$E_{s_1-1}\left(NPV_{s_1}\right) \geq \frac{E_{s_1-1}\left(V_{s_1}\right)}{1+r}$$

The initial value of the project, assuming that the decisions will be made according to this procedure, will be

$$V_{s_1-1} = \max\left[E_{s_1-1}\left(NPV_{s_1}\right); \frac{E_{s_1-1}\left(V_{s_1}\right)}{1+r}\right]$$

We will now show the results of the application of the model to a real project, and the corresponding investment thresholds.

5. APPLICATION TO A REAL PROJECT

We applied the model to a real infrastructure currently under development – the Douro Interior concession, located in northeast Portugal. This infrastructure will be built and operated as a public-private partnership under a Design-Build-Fund-Operate-Maintain contract, for a 30 year period. The concession will comprise roads with a total extension of about 242 km. It is expected that the construction will take about three years.

The choice of this project was due to the availability of data – KPMG/VTM (2008) and Reis *et al.* (2008) perform cost-benefit analyses of the project for a 30 year horizon, providing most of the relevant data, and allowing us to infer the remaining data; KPMG (2008) includes a 75 year traffic forecast that is useful for the analysis of project timing. Additionally, this project intends to provide better accesses to an area in the interior of the country with limited traffic, where traffic speed is mainly influenced by the quality of the roads, and not so by traffic volume. In fact, the existing CBAs of the project assume that the average driving speed remains constant throughout the 30 years of analysis, both in the do-something and in the do-minimum scenarios, although the traffic increases significantly. So, this project fits nicely into the assumptions of our model.

We must note that this project is integrated into a network of roads that are being built at the same time, and so its deferment would probably cause negative impacts in the remaining network (these impacts are not considered in the CBAs). However, since our goal is not to discuss policy issues, but simply to test the model, this project is adequate for the analysis.

The available studies (KPMG/VTM, 2008 and Reis *et al.*, 2008) used information available in 2008, and assumed construction would start in 2009. So, we also used the information that was available in 2008. In our analysis, we follow closely the methodological choices made by Reis *et al.* (2008).

5.1. Base variables

After analysing some possible ARMA models for real GDP growth, we have chosen an AR(2) model, estimated with annual data from the European Commission – Economic and Financial Affairs[2], starting in 1976. This model is simple, seems to fit adequately the series of GDP growth rates, shows large values for both the Akaike and Schwartz information criteria, and the Durbin-Watson statistic shows no remaining correlation in the residuals from the model. Its R-squared is 0.50. The model equation is:

$$GDPg_t = 0.00570 + 0.829 \cdot GDPg_{t-1} - 0.137 \cdot GDPg_{t-2} + \varepsilon_t \qquad (10)$$

In (10), $GDPg_t$ denotes the growth in per capita GDP in year t, at constant prices, and ε_t is the error term, assumed to be normally distributed with zero mean. According to this model the long-term GDP growth will be about 1.85%. This value is somewhat lower than the long-term growth rates of 2.2% and 2.0% used by KPMG/VTM (2008) and Reis *et al*. (2008), respectively.

For the fuel price, Reis *et al.* (2008) assume constant prices during the period of analysis, estimated by using the average costs between October 2007 and September 2008, as reported by *Direcção Geral de Energia e Geologia*[3]. KPMG/VTM (2008) do not report the assumed fuel cost, but they use constant vehicle operation costs per unit of distance, leading us to think that constant fuel prices were assumed.

We assumed fuel prices to have a constant expected value, but changing according to a geometric Brownian motion. Also, we have chosen to model the resource costs instead of the market prices. The decision was made based on the fact that, in Portugal, fuel duty represents a constant term in the cost of fuel (instead of a constant percentage of the market price). Models with a geometric dynamics are unsuitable to model the dynamics of prices that exhibit such constant terms, so we considered that it would be better to model the resource costs.

We modelled the diesel costs, assuming that the ratio between petrol and diesel costs is constant. Both the ratio between petrol and diesel costs, the expected cost of diesel and the cost volatility were estimated by using weekly data from the year 2008, provided by the *Direcção Geral de Energia e Geologia* (the same source that was used by Reis *et al.*, 2008).

5.2. Traffic

In order to estimate changes in traffic, we used demand elasticities reported by Graham and Glaister (2002) and Hanly *et al*. (2002). The assumed traffic elasticity with respect to income was 0.30 in the short run and 0.73 in the long run, both for passenger cars and heavy vehicles (based on Hanly *et al*., 2002). The assumed traffic elasticity with respect to fuel price was -0.15 in the short run and -0.31 in the long run for passenger cars (based on Graham and Glaister, 2002). Heavy traffic demand was assumed to be inelastic with respect

[2] http://ec.europa.eu/economy_finance/ameco
[3] http://www.dgge.pt

to fuel price. Short run elasticities were assumed to have an effect in the same year, while the effect of long run elasticities was assumed to build up over 5 years.

To assess how the traffic volume would change with the simulated values of the base variables, we assumed that the traffic model was based on the GDP growth rates reported by KPMG/VTM (2008), and on the average price of fuel of 2008. With the demand elasticities and the traffic forecast, it was possible to determine the traffic volume implied by the simulated values of the GDP *per capita* and the fuel price, both for the do-nothing and the do-something scenarios.

5.3. Results

In order to apply the model, we used Microsoft Excel with the simulation add-in @Risk. All our simulations were based on 10 000 iterations.

Both KPMG/VTM (2008) and Reis *et al.* (2008) perform static CBAs for a 30 year horizon, using slightly different assumptions (for example, Reis *et al.*, 2008, assume a smaller long-term rate of GDP growth). KPMG/VTM (2008) calculate an expected NPV of 261 million euros, and Reis *et al.* (2008) present an expected NPV of 225 million euros. We also performed a static CBA for the same period, based on the expected values of the base variables, and using the traffic volumes that were defined by these expected values. We reached an expected NPV of 173 million euros. It is not surprising that we get a smaller NPV than the other analyses, since we are using a GDP model that leads to a lower growth, and we re-estimate the traffic according to this smaller GDP.

We stated in 4.1 that the cash flows calculated with the expected values of the variables will usually underestimate the true expected cash flows, due to the correlations among variables. In fact, by using expected cash flows (estimated with the simulation model), we reach a larger expected NPV of 232 million euros, clearly showing that the correlations have a significant impact on the expected cash flows.

For the analysis of the best time to start the project, we considered the postponement for a maximum of 30 years, that is, we considered postponing the decision until 2038. This means that the period of analysis was extended until 2068. The expected NPV for this extended period of analysis (calculated with the true expected cash flows) is 628 million euros. This increase in the expected NPV is the result of the extension of the period of analysis – we are, in fact, considering that the period of road operation will more than double (taking into account the construction time).

We started by analysing the optimal timing assuming that the moment to start construction must be chosen in 2008, and that it is not possible to change it, even if the conditions change. By being able to choose the optimal timing (even if we have to define it in advance), it is possible to increase the project NPV by 3 million euros, to 631 million euros. Figure 1 shows the NPVs for each possible starting year.

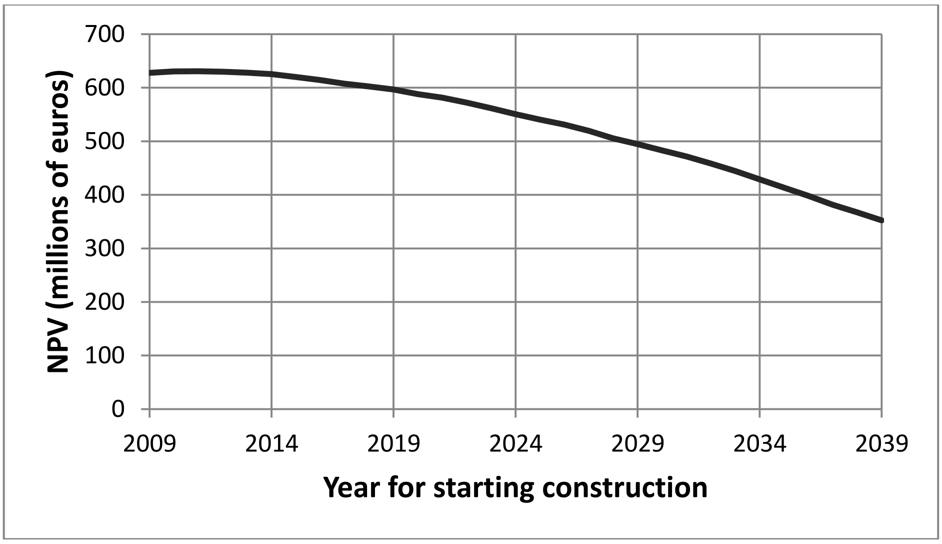

Figure 1 – Project NPV in 2008, when we commit to start construction in different years.

Then, we assumed that a decision to start the project can be made one year in advance, and so that we do not have to commit to a year for starting the project – every year we can choose whether or not we will start it in the next year. We started by estimating the thresholds for deciding to start construction, based on expression (9). Using these thresholds on the same data that was used to estimate them, we get an expected NPV of 645 million euros if we delay the beginning of the project.

By using the thresholds on the same data that was used to estimate them, we may be biasing the results towards a larger NPV. So, we decided to use the estimated thresholds to calculate the NPV with an independent simulation. We now got an NPV of 644 million euros. This means that a decision to immediately start the project should be made in 2008 if the NPV, calculated for a period extending to 2068, was larger or equal to 644 million euros: in fact, it is 628 million euros. So, the option to wait increases the project value in 16 million euros.

6. CONCLUDING REMARKS

In this paper, we addressed the optimal timing of road infrastructures, in the framework of a CBA. We presented a methodology for choosing the best moment to start construction, and we proposed a stochastic model for the NPV of road infrastructures. The model considers two sources of uncertainty – GDP growth and fuel prices – and incorporates the sources of benefits and costs that are usually considered in a CBA.

The model was applied to the evaluation of a real infrastructure currently under development – the Douro Interior concession, located in Portugal. We were able to apply the model by using the data on which the conventional CBAs of the infrastructure were based. The results we obtained show that the deferment option may be an important source of value in the CBA framework, even if the expected NPV of starting right away is clearly positive. We also showed that, by estimating the project cash flows with the expected values of the variables, we may be biasing the NPV downwards, due to the correlations among variables.

We will now discuss some lines of future research that should follow this work.

In most road infrastructures, there will be some level of congestions, and therefore driving speed will depend on traffic volume. Therefore, it is important to extend the model, in order to explicitly consider the relation between these variables.

An increase in GDP will usually lead to an increase in oil demand and, since oil extraction capacity is fixed in the short run and extraction is near or at full capacity, any increase in demand leads to an increase in price[4]. So, it is expected that there will be a positive correlation between GDP growth and fuel price. In a future version of the model, such relation should be explicitly considered.

The model we presented here requires a traffic forecast for a longer period than a conventional CBA. The uncertainty of traffic forecasts increases with the forecasting period, so the model may be using values subject to a large degree of uncertainty. Therefore, it will be important to check the sensitivity of the investment thresholds to the traffic volume in the middle and latest years of analysis.

It is usually possible to postpone the construction of a road infrastructure indefinitely. However, our model assumes that the deferment is limited to a pre-defined number of years. By performing a sensitivity analysis of the results to this pre-defined number of years, we may find out whether this assumption significantly influences the results.

Finally, we note that it was assumed that the infrastructure would operate until the last year of the analysis, even if that would require significant rehabilitation costs. If the traffic volume is lower than expected, it may not make sense to continue investing in the infrastructure. This means that we may also have an option to "abandon" the infrastructure. It would also be interesting to incorporate this option in the model.

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