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ACCOMMODATING ENERGY PRICE VOLATILITY IN LIFE CYCLE COST ANALYSIS OF ASPHALT PAVEMENTS

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Abstract. Energy price is related to more than half of the total life cycle cost of asphalt pavements. Furthermore, the fluctuation related to price of energy has been much higher than the general inflation and interest rate. This makes the energy price inflation an important variable that should be addressed when performing life cycle cost (LCC) studies regarding asphalt pavements. The present value of future costs is highly sensitive to the selected discount rate. Therefore, the choice of the discount rate is the most critical element in LCC analysis during the life time of a project. The objective of the paper is to present a discount rate for asphalt pavement projects as a function of interest rate, general inflation and energy price inflation. The discount rate is defined based on the portion of the energy related costs during the life time of the pavement. Consequently, it can reflect the financial risks related to the energy price in asphalt pavement projects. It is suggested that a discount rate sensitivity analysis for asphalt pavements in Sweden should range between –20 and 30%.

Keywords: road & highways, life cycle cost, pavement design, discount rate.

Introduction

The price of energy has been identified as one of the most important factors affecting the cost of construction projects (Hastak, Shaked 2000; Baloi, Price 2003; Jaafari 2001). Furthermore, the increase in cost of oil products has been the main cause of rise in highway construction cost (Wilmot, Cheng 2003). In the mid-2000 highway construction showed a sharp increase in prices (Zhou, Damnjanovic 2011). Consequently, construction projects in 2006 were valued two times more than similar projects in 1997 (Pandit *et al.* 2009). This was believed to be related to the dramatic increase in the price of crude oil and its products such as bitumen, fuel oil and transportation fuel. Evidently, a direct correlation between the oil price and the cost of asphalt pavement projects exists (Gallagher, Riggs 2006; Damnjanovic, Zhou 2009). In a recent study conducted by the authors the crude oil price was closely related to more than 50% of the cost of asphalt pavement during its life time (Mirzadeh *et al.* 2013). Different approaches such as real option models (e.g. Garvin, Cheah 2004; Zhao *et al.* 2004; Chiara *et al.* 2007; Brandao, Saraiva 2008; Cui *et al.* 2004; Vassallo 2006), the neural network modelling (e.g. Sonmez, Ontepeli 2009; Baalousha, Çelik 2011; Wilmot, Mei 2005; Hegazy, Ayed 1998; Sodikov 2005) and discounted cash flow (DCF) are used for cost evaluation of infrastructure projects. Due to its simplicity, DCF analysis which provides net present value (NPV) of a project is the most common approach among the practitioners (Yeo, Qiu 2003). Moreover, it has been used by the Swedish transport administration for evaluating the infrastructure projects. The present value of future costs and benefits are highly sensitive to discount rate. Therefore, the choice of the discount rate is the most critical element in any evaluation of costs and benefits during the life time of a project. Often, decision makers are faced with the problem of either investing more initially or saving money for maintenance and rehabilitation. The extent to which discounted future costs exceed the initial costs depends directly on the discount rate. The social discount rate is used for public infrastructure projects. Different approaches such as social rate of time preferences (SRTP), marginal social opportunity cost of capital (SOC), weight average (WA) and shadow price of capital (SPC) have been applied for selecting the social discount rate. Evans and Sezer (2005) estimated discount rates, based on the social rate of time preferences, for countries such as USA, UK, Germany, Japan, France and Australia. Their results ranged between 3–5% which clearly contradicted with the official discount rate at the time. Azar (2007) suggested that the social discount rate for the US is 5.66%, with a 95% confidence interval ranging from 5.62 to 5.71%. However, Lally (2008)

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argued that this underestimates the confidence interval on the discount rate primarily through ignoring uncertainty surrounding the expected return on risky assets. Percoco (2008) suggested a discount rate for Italy which was 1.2 to 1.3% lower than the official discount rate (5%). Due to the lack of an agreed approach for selecting the discount rate for the evaluation of the public projects, many transport agencies across and within countries have used different discount rates for their public projects (e.g. Ferreira, Santos 2013). Moreover, the social discount rate reflects the general inflation in each country. However, due to high amount of energy related costs in asphalt pavement projects, the inflation regarding this sector is usually different from the rest of economy. Therefore, the use of social discount rate for asphalt pavements can be questioned. The other common method which calculates the discount rate for a specific project is capital asset pricing model (CAPM). The CAPM is widely used in calculating the discount rate regarding public private partnership (PPP) or built operate transfer (BOT) projects (e.g. Yeo, Qiu 2003; Lee *et al.* 2009; Fama, French 2004; Campbell 1993). The CAPM is based on the modern portfolio theory developed by Markowitz (1952). In the CAPM model the expected return is presented in terms of the risk free rate, e.g. interest rate arising from government bonds, plus a risk premium. Therefore, the calculation of the discount rate is a qualitative assessment of how much to increase the discount rate over the risk free rate to account for the projects' risk (Baker, Fox 2003). As a result, a higher risk gives a higher discount rate. Consequently, the NPV decreases due to a higher discount rate. A lower NPV regarding revenues due to a higher risk is reasonable. However, a lower NPV regarding cost due to higher risk is not relevant. In order to deal with this problem, the authors used an approach based on the modern portfolio theory to calculate the discount rate. In modern portfolio theory the return on a portfolio is the proportion-weighted combination of the constituent assets' returns (e.g. Sharpe 1964; Elton *et al.* 2007; Melicher, Norton 2010). It was shown that more than 50% of the total LCC of asphalt pavement is related to oil products (Mirzadeh *et al.* 2013). Additionally, the fluctuation related to oil price has been more than the general inflation and interest rate (Fig. 1). Consequently, calculation of the discount rate cannot be done based on a homogeneous inflation. However, based on the modern portfolio theory an equivalent discount rate for asphalt pavement projects can be defined as the sum of two separate discount rates.

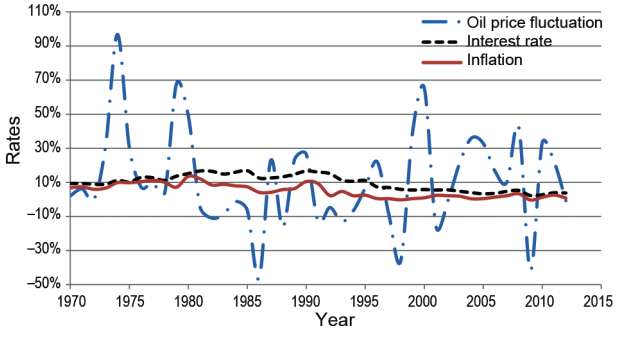

Fig. 1. The yearly average crude inflation, lending interest rate (World Bank 2012) and inflation for Sweden

The objective of the paper is to present a discount rate for asphalt pavement costs as a function of interest rate, general inflation and oil price inflation. The discount rate is defined based on the portion of the energy related costs during the life time of the pavement. It reflects the financial risks related to the costs asphalt pavement projects. Furthermore, it can be applied for costs calculation regarding both public and PPP projects.

1. Methodology

In traditional LCC of asphalt pavements the calculation of the discount rate has generally been based on the interest rate and inflation. However, the fluctuation regarding the energy price has been more than the general inflation. The price of oil products was shown to be related to more than half of the costs related to asphalt pavement life cycle. In order to capture the financial risk related to cost of oil products, the cost items were divided into energy and time related items. Energy related items are those affected by the crude oil price such as bitumen, modifier, fuel oil and transportation fuel (Table 1). The price of bitumen and modifiers is calculated as the sum of the costs related to crude oil and production in the refinery. The amount of energy for the transportation was related to the required material distribution from the refinery to the construction site. The agency-related expended energy was attributed to laying, compacting, milling and resurfacing. Furthermore, the user-related expended energy was defined for the extra amount of fuel used by the vehicles in the work zone. The unit cost of energy for each activity can be calculated via Eqn (1). Time related costs are defined as those affected by the general inflation such as labor and equipment costs (Table 2) (Eqn (2)). The value of time

Table 1. Energy related variables

	Crude oil (MJ)	Energy source A (MJ)	Energy source B (MJ)	Cost of Energy (€)
Bitumen	qc_1	–	–	CE_1
Modifier	qc_2	–	–	CE_2
Aggregate production	–	qa_3	qb_3	CE_3
Bitumen production	–	qa_4	qb_4	CE_4
Modifier production	–	qa_5	qb_5	CE_5
Asphalt production	–	qa_6	qb_6	CE_6
Transportation	–	qa_7	qb_7	CE_7
Laying asphalt	–	qa_8	qb_8	CE_8
Compacting asphalt	–	qa_9	qb_9	CE_9
User's energy loss	–	qa_{10}	qb_{10}	CE_{10}

Table 2. Time related variables

Item		Time Spent (Hr.)	Value of time (€/Hr.)	Cost of time (€)
Labor & equipment	Transportation	t_1	V_1	CT_1
	Laying asphalt	t_2	V_2	CT_2
	Compacting asphalt	t_3	V_3	CT_3
	Milling and resurfacing	t_4	V_4	CT_4
Road users	User's delay cost	t_5	V_u	CT_5

included the hourly wage of the labors together with the amount of hourly depreciation regarding the equipment. The hourly depreciation was defined as the initial price of the equipment divided by the useful life of the equipment (hours). The calculation regarding the user delay cost has to be done separately for the personal cars and heavy vehicles, since they should be treated with different values of time. The road user costs are defined as those related to energy loss and delay for the road users during maintenance and rehabilitation activities. The amount of energy spent (MJ/tonne), time spent (hr/km), unit price of energy (€/MJ) and unit value of time (€/hr) for different Swedish mixes are presented by Mirzadeh *et al.* (2013).

$$CE = \sum_{k=1}^{n} (qc_k \times P_c + qa_k \times P_a + qb_k \times P_b + ...), \quad (1)$$

where: CE is the unit cost of energy related items for a construction/rehabilitation activity; qc_k, qa_k and qb_k are the quantities (MJ) regarding crude oil, energy source A and B; P_c, P_a and P_b are the unit prices (€/MJ) regarding crude oil, energy source A and B at the base year;

$$CT = \sum_{k=1}^{n} V_k \times t_k , \quad (2)$$

where: CT is the unit cost of time related items for a construction/rehabilitation activity; t_k is the amount of time spent for each item; V_k is the value of time for each item.

The most common method used to compare past and future cash flow with those of today is NPV method. Costs regarding initial construction, maintenance and rehabilitation occur at different times. Therefore, it is essential to use a discount rate in order to reflect the time value of money. The time value of money results from inflation and opportunity cost. Inflation is the rise in the general level of prices of goods and services in an economy over a period of time. Opportunity cost is equivalent to the benefit, the cash could have achieved, had it been spent differently or invested. The *NPV* for a construction/rehabilitation cost (C) at the yth year can be calculated form Eqn (3) based on the discount rate (FHWA 2002):

$$NPV = C \times \left(\frac{1}{1+r}\right)^{y} . \quad (3)$$

The traditional discount rate (r) is calculated according to Churchill and Panesar (2013):

$$r = \frac{1+i}{1+j} - 1 , \quad (4)$$

where: i and j are the rate of interest and inflation. Since C consists of energy related costs (CE) and time related costs (CT), the discount rate should reflect inflations both regarding CE and CT. The inflation regarding CE and CT are defined as crude inflation and general inflation respectively.

For a portfolio consisting of investments a and b where portion α of the wealth is placed in a and (1–α) in b the equivalent rate of return and its standard deviation are expressed in Eqns (5)–(6) (Strong 2008):

$$r = \alpha \cdot r_a + (1-\alpha) \cdot r_b ; \quad (5)$$

$$\sigma = \sqrt{\alpha^2 \sigma_a^2 + (1-\alpha)^2 \sigma_b^2 + 2\beta\alpha(1-\alpha)\sigma_a \sigma_b} , \quad (6)$$

where: r_a and r_b are the return on investments and σ_a, σ_b are their standard deviations. β is the correlation coefficient between the rates of return of the two investments. A positive value for β indicates that there is a positive correlation between r_a and r_b. A zero value would indicate that r_a and r_b are completely independent. Furthermore, a negative value indicates that there is an inverse relationship between them.

It was shown by Mirzadeh *et al.* (2013) that crude oil inflation can be used as the inflation index for the energy related items. Consequently, the crude oil discount rate (r_1) can be used as the discount rate for the energy related costs. The traditional discount rate is the discount rate for the time related items (r_0). Assuming α as the portion of the energy related costs Eqns (5)–(6) can be rewritten as:

$$r = \alpha \cdot r_1 + (1-\alpha) \cdot r_0 ; \quad (7)$$

$$\sigma = \sqrt{\alpha^2 \sigma_1^2 + (1-\alpha)^2 \sigma_0^2 + 2\beta\alpha(1-\alpha)\sigma_1 \sigma_0} , \quad (8)$$

where: r is defined as the equivalent discount rate. r_1 is the discount rate for energy related items based on the interest rate and the crude oil inflation. Moreover, σ_1 is its standard deviation. r_0 is the traditional discount rate based on interest rate and general inflation and σ_0 is its corresponding standard deviation. The portion of energy related costs (α) can vary between zero to one. In this context β is chosen to describe the correlated volatility of r_1 in relation to r_0 (Eqn (9)):

$$\beta = \frac{Cov(r_1, r_0)}{Var(r_0)} . \quad (9)$$

By inserting the interest rate, the general inflation and the crude oil inflation Eqn (7) can be rewritten as:

$$r = \alpha \times (1+i) \times \left(\frac{1}{1+j_c} - \frac{1}{1+j}\right) + \frac{1+i}{1+j} - 1 . \quad (10)$$

The *NPV* based on the equivalent discount rate can be obtained by Eqn (3).

The NPV of the alternatives are only comparable if they have the same life span. In the case of comparing alternatives with different life span, equivalent annual cost (*EAC*) is often used as a decision support tool. The *EAC* is the cost per year of owing an asset over its defined life span. The *EAC* is calculated by multiplying the total net present value (*TNPV*) by the annuity factor ($A_{t,r}$) (Mirzadeh *et al.* 2013):

$$EAC = TNPV \times A_{t,r} = TNPV \times \frac{r}{1-(1+r)^{-d}}, \quad (11)$$

where: *TNPV* is the sum of all the *NPV*s regarding construction, maintenance and rehabilitation activities during the life span and d is the design life of the asphalt pavement.

The portion of energy related cost regarding each project may vary for the initial construction and future maintenance and rehabilitation. Therefore, α should be calculated based on the discounted energy and time related cost. However, the equivalent discount rate itself is a function of α. In order to solve this problem a flowchart for evaluating the discount rate for asphalt pavements is presented in Figure 2. The design inputs such as the thickness of the asphalt layer for construction can be obtained from the Calibrated Mechanics based model (MC). The MC model is based on the mechanistic empirical pavement design model developed by Birgisson *et al.* (2006) which is calibrated by Gullberg *et al.* (2012) for the Swedish conditions. The initial α is calculated based on undiscounted energy related and time related costs. The equivalent discount rate is evaluated as a function of α, general inflation, oil price inflation and interest rate. The new α is then calculated based on *NPV* for energy related and time related items by substituting *r* into Eqn (9). The iteration continues as long as the difference between $\alpha_i + 1$ and α is larger than 1%. Once α satisfied the required condition, *r* can be used as the discount rate for the asphalt pavement project. A sensitivity analysis is to be performed in order to assess the effect of the expected variation of the discount rate on the life cycle cost of the project. The sensitivity analysis should be done based on the historical values of interest rate, general inflation and oil price inflation.

2. Results and discussion

The variation of the discount rates for different assumed values for α based on the historical data regarding interest rate, inflation and crude oil price inflation for Sweden is presented in Figure 3. Expected range of change regarding the equivalent discount rates, has been higher than

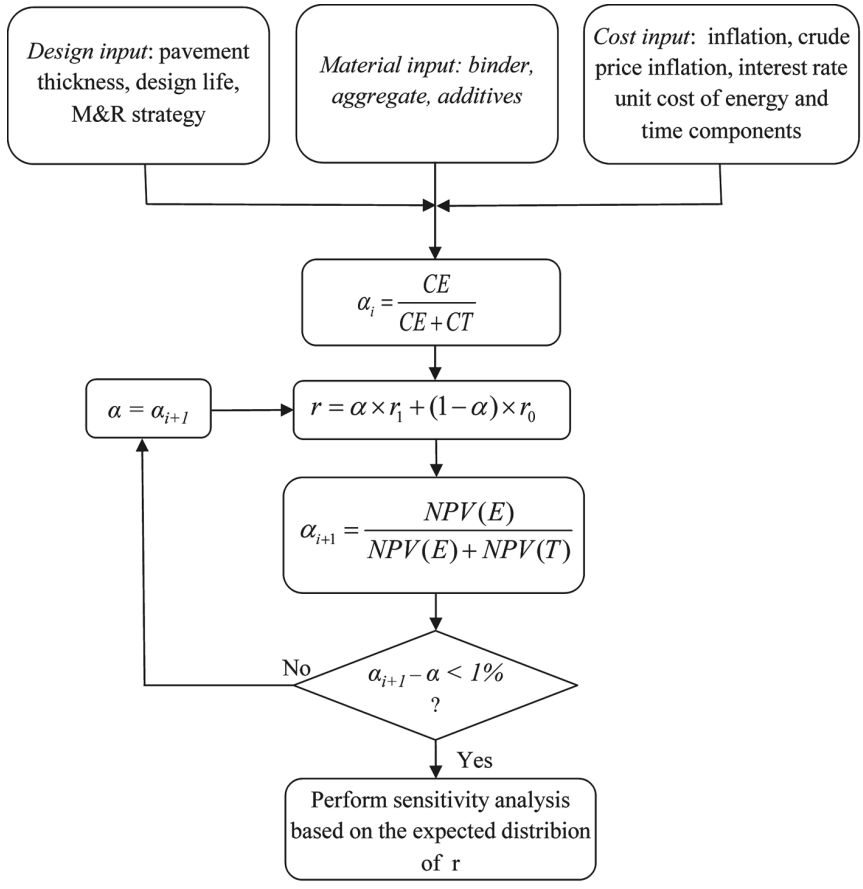

Fig. 2. The flowchart to calculate the equivalent discount rate

the traditional discount rate. Depending on the portion of energy related items, volatility of the discount rate has excessively increased. It was observed that during 1981–1994 the Swedish economy faced a relatively high interest rate, inflation and an overall deflation in the oil price. This situation caused the equivalent discount rates to be higher than the traditional discount rate (Fig. 4) and beta in this period was 0.2. The beta coefficient in this period was positive which means r_1 and r_0 changed in the same direction. However, during 1970–1980 and 1999–2012 the high crude inflation caused the equivalent discount rate to be negative and beta coefficients were –2.3 and –3.7. The negative beta coefficients indicate that r_1 was moving in the opposite direction of r_0. The discount rate in these periods implied a rapid increase in the cost of asphalt pavement construction and rehabilitation which did not correspond to the general inflation.

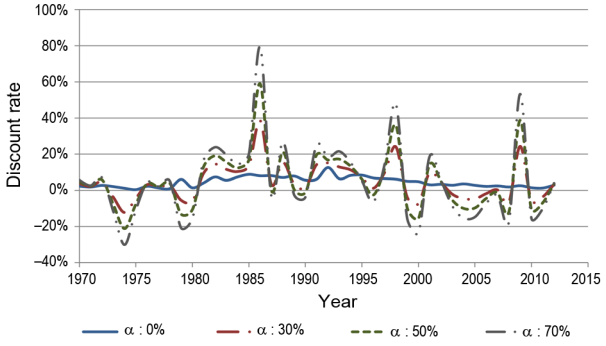

Fig. 3. The average equivalent discount rates based on the historical data for Sweden

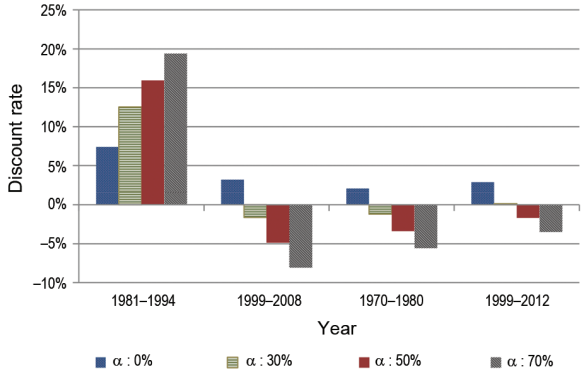

Fig. 4. The average equivalent discount rates in different time periods

The empirical cumulative distribution function (*CDF*) of discount rates regarding energy related items (r_1) and time related items (r_0) during 1970–2012 in Sweden was plotted against the normal *CDF* in order to test if they follow a normal distribution (Fig. 5). The midpoint probability plotting positions was used where the i^{th} sorted values were plotted against the midpoint in the jump of the empirical cumulative distribution function (*CDF*) on the *y* axis. It was observed that the historical values regarding the both discount rates have followed normal distributions.

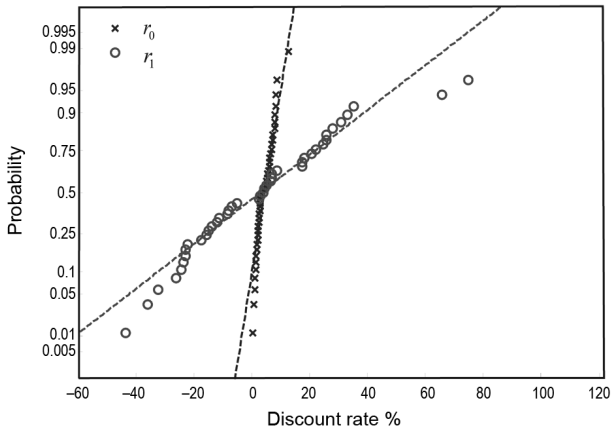

Fig. 5. Normal probability distribution plot test for discount rates regarding energy related items (r_1) and time related items (r_0) for Sweden during 1970–2012

The *NPV* for the future cost items is the multiplication of their current cost by the discount factor. The discount factor is a function of the discount rate and the year of the analysis (Eqn (11)). In sensitivity analysis regarding the current LCC studies, the discount rate usually is assumed to be positive (e.g. Ferreira, Santos 2013; Christensen 2009; Vacheyroux, Corotis 2013; Zhou *et al.* 2010; Churchill, Panesar 2013). However, if the inflation is higher than the interest rate from the Eqn (4) the discount rate should be negative. This behavior was observed for the equivalent discount rate in certain time periods such as 1970–1980 and 1999–2012 in Sweden (Fig. 4). The high amount of oil price inflation caused a negative equivalent discount rate in these periods. The effect of the discount rate on the discount factor is presented in Figure 6.

A positive discount rate causes the discounted value for the future costs to be lower. However, a negative discount rate makes the value of the discounted costs to be higher. This causes different interpretations of a LCC study. Having a positive value for the discount rate may imply that it is worth to invest less for the initial con-

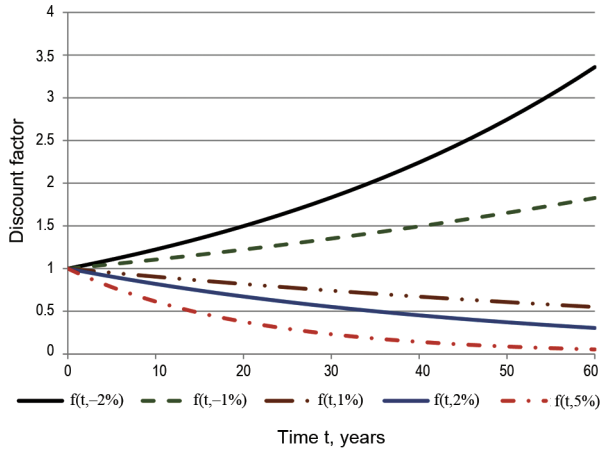

Fig. 6. Discount factor as a function of time and discount rate

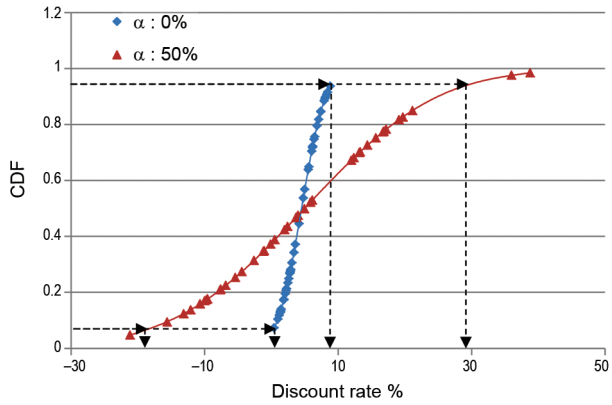

Fig. 7. Normal cumulative distributions for discount rates regarding energy related items (r_1) and time related items (r_0) for Sweden during 1970–2012

struction and have a higher level of maintenance and rehabilitation in the future. However, a negative discount rate supports the argument to invest more in the initial construction to lower the amount of the future costs. The cumulative probability distribution function for discount rates with α equal to 0 and 50% based on a Swedish data regarding 1970–2012 is plotted in Figure 7. It was observed that the common range, that is widely used in sensitivity analysis regarding discount rate for infrastructure projects (i.e. 0–8%), is relevant for traditional discount rate (α = 0). However, the same probability requires a range between –20 and 30% for α equal to 50%.

The normal probability Distribution Function (PDF) for discount rates with different portion of energy related items during 1970–2012 in Sweden is depicted in Figure 8. The probability distribution regarding r_1 with a standard deviation equal to 0.3 was shown to be a wide distribution compare to r_0 with a standard deviation equal to 0.03. The standard deviation for the equivalent discount rate, which is a combination of energy and time related discount rates, has changed depending on its α.

Furthermore, the shape of the probability distribution for the equivalent discount rate has been more similar to re for a higher α and more similar to r for a lower α. This volatility has imposed a high level of financial risk to the highway projects. This financial risk is primarily

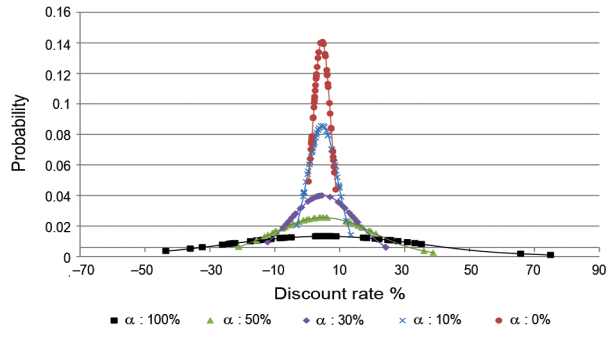

Fig. 8. Normal distributions for discount rates with different portions of energy related items during 1970–2012

subjected to the longer projects. On the other hand, it also exists during the contract time for construction contracts. The length of the contract highly affects this risk. The longer the contract the more significant the risk becomes. If the contract duration is short the high volatility should not affect the prices as the contractor has the material/fuel available before the beginning of the contract. However, the impact of volatility can be significant even for modest volatility measures for long duration contracts. The sharp increase in the level of material and fuel prices has been experienced during the last years. Consequently, a large number of contractors in the USA were affected by escalating material prices (bitumen, fuel) (Gallagher, Riggs 2006). According to the results of a survey conducted by AASHTO in 2008 (AASHTO 2009), 40 states used fuel price adjustment clauses, and 42 states used bitumen price adjustment clauses.

However, even when transportation agencies use price adjustments, the trigger levels are only arbitrarily defined and are not considered from the risk analysis perspective. For example, the Washington state department of transportation (DOT) applied the trigger value of 10% for fuel and bitumen cost adjustments (AASHTO 2009). By considering the high level of risks (Fig. 8) the amount of the adjustments might not be sufficient.

To hedge against this risk, especially for contracts without price adjustment clauses, contractors usually have incorporated a premium in the bid price (Damnjanovic, Zhou 2009). Contractors can allocate this risk in four following ways: (1) adding the risk to the price of individual items in the contract, (2) adding the risk to the overall estimated price of the project, (3) dividing the risk and spreading it on some particular items in a bid and (4) spreading the risk on a portfolio of projects. Contractors in longer contracts are more concerned about the future prices. Therefore, they usually get engaged in hedging against commodity (material/fuel) risk with suppliers. The contractor risk premium, especially for smaller contractors, might be larger than the suppliers' premium. In this case the transportation agencies could consider including the price adjustment clauses to cover the risk of the future price increases. This can be done by hedging with purchasing options for the future consumption of the fuel and material at the predetermined fixed prices. Furthermore, this will encourage more contractors to take part in the bidding and consequently could result in overall lower bidding prices.

The equivalent discount rate reflected the risk of the change of prices and volatility regarding the crude oil. This information can be used by the road authorities in the context of managing risks on an individual project level as well as the network level. At the project level, results provide a basis for making decisions to either retain or transfer the commodity (material/fuel) price risk. For example having high values regarding α and the expected change in the oil price the road agency should consider price adjustment clauses. On the network level,

the results provide a measure for minimizing portfolio risks by diversifying risk retention and transfer policies. For example, exposing only a portion of projects to risk by implementing price adjustment clauses, the portfolio risk can be minimized. For instance, an increase in the energy related prices causes only a part of the projects to be subjected to losses that are compensated by gains on the rest of the portfolio.

Summary and conclusions

This paper presented a discount rate for asphalt pavement projects as a function of interest rate, general inflation and oil price inflation which can be defined for each project based on the portion of the energy related items during the defined life time. This so called "equivalent discount rate (r)" reflected the impact of energy price fluctuation on the costs and the associated financial risks related to asphalt pavement works. A flowchart was suggested for calculating r for asphalt pavement projects. The equivalent discount rate was studied by analyzing the historical values regarding the interest rate, general inflation and oil price inflation in Sweden during 1970–2012. The range of α was assumed to be between 50–70%. In periods between 1970–1980 and 1999–2012 the average value for r has been –4 and –3%, respectively. The beta coefficients in these periods have been –2.3 and –3.6. The negative beta was related to high oil price inflation which changed the behavior of the equivalent discount rate. The standard deviation of the equivalent discount rate was 0.15 and 0.20 for α equal to 50 and 70%, respectively. This was much higher than the standard deviation for the traditional discount rate in the same period. The high volatility for the r was mainly caused by the high volatility in the oil price.

The following conclusions are drawn from this study:

- By evaluating the historical values regarding inflation, oil price inflation and interest rate, during specific time periods, the r was shown to be much lower than the traditional discount rate ($\alpha = 0$). Therefore, applying an average traditional discount rate may lead to an under-estimation of the project costs.
- The lower discount rate, specially the negative discount rate in the recent years, implies that the future costs can be more expensive than projected due to discounting. This highlights the importance of lowering the amount of required maintenance and rehabilitation by increasing the initial construction quality.
- It was observed that the common range (i.e. 0–8%) for discount rate sensitivity analysis regarding infrastructure projects is not suitable for highway projects. By assuming 50% of the costs related to the energy related items, the discount rate sensitivity analysis should cover a range between –20% and +30%.
- Both the equivalent discount rate and its volatility are dependent on the amount of contribution of the energy related costs. Therefore, the discount rate should be defined based on α for each highway project.
- The high amount of volatility in the oil price imposed increased financial risk to the highway projects. This financial risk may highly affect the fixed-price unit-based contracts with longer time period which the owner transferred the risk to the contractor.
- By incorporating the financial risks imposed by the oil price, this paper helps the contractors and road authorities with a more transparent estimation of the total LCC cost and the associated risks related to asphalt pavement projects.

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References

AASHTO. 2009. *Survey on the use of price adjustment clauses*. AASHTO Subcommittee on Construction [online], [cited 12 December 2013]. Available from Internet: http://fhwic-sint01.fhwa.dot.gov/programadmin/contracts/aashto.cfm

Azar, S. A. 2007. Measuring the US social discount rate, *Applied Financial Economics Letters* 3(1): 63–66. http://dx.doi.org/10.1080/17446540600771068

Baalousha, Y.; Çelik, T. 2011. An integrated web-based data warehouse and artificial neural networks system for unit price analysis with inflation adjustment, *Journal of Civil Engineering and Management* 17(2): 157–167. http://dx.doi.org/10.3846/13923730.2011.576806

Baker, R.; Fox, R. 2003. Capital investment appraisal: a new risk premium model, *International Transactions in Operational Research* 10: 115–126. http://dx.doi.org/10.1111/1475-3995.00398

Baloi, D.; Price, A. D. 2003. Modelling global risk factors affecting construction cost performance, *International Journal of Project Management* 21(4): 261–269. http://dx.doi.org/10.1016/S0263-7863(02)00017-0

Birgisson, B.; Wang, J.; Roque, R. 2006. *Implementation of the Florida cracking model into the mechanistic-empirical pavement design*: monograph. Transportation Research Board, USA. 103 p.

Brandao, L. E. T.; Saraiva, E. 2008. The option value of government guarantees in infrastructure projects, *Construction Management and Economics* 26(11): 1171–1180. http://dx.doi.org/10.1080/01446190802428051

Campbell, J. Y. 1993. Intertemporal asset pricing without consumption data, *American Economic Review* 83(3): 487–512.

Chiara, N.; Garvin, M.; Vecer, J. 2007. Valuing simple multiple-exercise real options in infrastructure projects, *Journal of Infrastructure Systems* 13(2): 97–104. http://dx.doi.org/10.1061/(ASCE)1076-0342(2007)13:2(97)

Christensen, P. 2009. Life-cycle cost-benefit (LCCB) analysis of bridges from a user and social point of view, *Structure and Infrastructure Engineering* 5(1): 49–57. http://dx.doi.org/10.1080/15732470701322818

Churchill, C.; Panesar, D. 2013. Life-cycle cost analysis of highway noise barriers designed with photocatalytic cement, *Structure and Infrastructure Engineering* 9(10): 983–998. http://dx.doi.org/10.1080/15732479.2011.653574

Cui, Q.; Bayraktar, M.; Hastak, M.; Minkarah, I. 2004. Use of warranties on highway projects: a real option perspective, *Journal of Management in Engineering* 20(3): 118–125. http://dx.doi.org/10.1061/(ASCE)0742-597X(2004)20:3(118)

Damnjanovic, I.; Zhou, X. 2009. Impact of crude oil market behavior on unit bid prices: the evidence from the highway construction sector, *Construction Management and*

Economics 27(9): 881–890. http://dx.doi.org/10.1080/01446190903171204

Elton, E. J.; Gruber, M. J.; Brown, S. J.; Goetzmann, W. N. 2007. *Modern portfolio theory and investment analysis*. 7th ed. New York: John Wiley & Sons. 752 p.

Evans, D. J.; Sezer, H. 2005. Social discount rates for member countries of the European Union, *Journal of Economic Studies* 32(1): 47–59. http://dx.doi.org/10.1108/01443580510574832

Fama, E. F.; French, K. R. 2004. The capital asset pricing model: Theory and evidence, *Journal of Economic Perspectives* 18(3): 25–46. http://dx.doi.org/10.1257/0895330042162430

Federal Highway Administration (FHWA). 2002. *Life-cycle cost analysis primer*. Washington, DC: US Department of Transportation. 26 p.

Ferreira, A.; Santos, J. 2013. Life-cycle cost analysis system for pavement management at project level: sensitivity analysis to the discount rate, *International Journal of Pavement Engineering* 14(7): 655–673. http://dx.doi.org/10.1080/10298436.2012.719618

Gallagher, J.; Riggs, F. 2006. *Material price escalation: allocating the risks*. Construction Briefings, Thomson/West, Eagan. 28 p.

Garvin, M. J.; Cheah, C. Y. J. 2004. Valuation technics for infrastructure investment decisions, *Construction Management and Economics* 22(4): 373–383. http://dx.doi.org/10.1080/0144619032000164901O

Gullberg, D.; Birgisson, B.; Jelagin, D. 2012. Evaluation of a novel calibrated-mechanistic model to design against fracture under Swedish condition, *International Journal on Road Material and Pavement Design* 13(1): 49–66. http://dx.doi.org/10.1080/14680629.2011.651838

Hastak, M.; Shaked, A. 2000. ICRAM-1: Model for international construction risk assessment, *Journal of Management in Engineering* 16(1): 59–69. http://dx.doi.org/10.1061/(ASCE)0742-597X(2000)16:1(59)

Hegazy, T.; Ayed, A. 1998. Neural network model for parametric cost estimation of highway projects, *Journal of Construction Engineering and Management* 124(3): 210–218. http://dx.doi.org/10.1061/(ASCE)0733-9364(1998)124:3(210)

Jaafari, A. 2001. Management of risks, uncertainties and opportunities on projects: time for a fundamental shift, *International Journal of Project Management* 19(2): 89–101. http://dx.doi.org/10.1016/S0263-7863(99)00047-2

Lally, M. 2008. Measuring the US social discount rate: reply to Azar, *Applied Financial Economics Letters* 4(4): 283–285. http://dx.doi.org/10.1080/17446540701720543

Lee, H.; Lee, S.; Lee, J.; Chon, K. 2009. The revenue-beta model for private participation in infrastructure, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 8. 13 p.

Markowitz, H. 1952. Portfolio selection, *Journal of Finance* 7(1): 77–99.

Melicher, R. W.; Norton, E. A. 2010. *Introduction to finance: Markets, investments, and financial management*. 14th ed. Danvers: John Wiley & Sons. 624 p.

Mirzadeh, I.; Butt, A.; Toller, S.; Birgisson, B. 2013. Life cycle cost analysis based on the fundamental cost contributors for asphalt pavements, *Structure and Infrastructure Engineering*. 11 p. http://dx.doi.org/10.1080/15732479.2013.837494

Pandit, D.; Anderson, S.; Damnjanovic, I.; Nejat, A. 2009. Assessment of strategies and methods to reduce construction costs while maintaining quality. Presentation at *The 1st International Conference on Transportation Construction Management*, 11 February 2009, Orlando, FL.

Percoco, M. 2008. A social discount rate for Italy, *Applied Economics Letters* 15(1): 73–77. http://dx.doi.org/10.1080/13504850600706537

Sharpe, W. 1964. Capital asset prices: a theory of market equilibrium under conditions of risk, *The Journal of Finance* 3(8): 425–442.

Sodikov, J. 2005. Cost estimation of highway projects in developing countries: artificial neural network approach, *Journal of the Eastern Asia Society for Transportation Studies* 6: 1036–1047.

Sonmez, R.; Ontepeli, B. 2009. Predesign cost estimation of urban railway projects with parametric modeling, *Journal of Civil Engineering and Management* 15(4): 405–409. http://dx.doi.org/10.3846/1392-3730.2009.15.405-409

Strong, R. A. 2008. *Portfolio construction, management, and protection* [With Stock-Trak]. London: Cengage Learning. 688 p.

Vacheyroux, G.; Corotis, R. 2013. Strategies of investment in the management of urban bridges: a life-cycle approach illustrated for Paris, *Structure and Infrastructure Engineering* 9(11): 1080–1093. http://dx.doi.org/10.1080/15732479.2012.665464

Vassallo, J. 2006. Traffic risk mitigation in highway concession projects, *Journal of Transport Economics and Policy* 40(3): 359–381.

Wilmot, C. G.; Cheng, G. 2003. Estimating future highway construction costs, *Journal of Construction Engineering and Management* 129(3): 272–279. http://dx.doi.org/10.1061/(ASCE)0733-9364(2003)129:3(272)

Wilmot, C. G.; Mei, B. 2005. Neural network modeling of highway construction costs, *Journal of Construction Engineering and Management* 131(7): 765–771. http://dx.doi.org/10.1061/(ASCE)0733-9364(2005)131:7(765)

World Bank. 2012. *World development indicators 2012*. World Bank. 248 p.

Yeo, K.; Qiu, F. 2003. The value of management flexibility – a real option approach to investment evaluation, *International Journal of Project Management* 21(4): 243–250. http://dx.doi.org/10.1016/S0263-7863(02)00025-X

Zhao, T.; Sundararajan, S.; Tseng, C. 2004. Highway development decision-making under uncertainty: a real options approach, *Journal of Infrastructure Systems* 10(1): 23–32. http://dx.doi.org/10.1061/(ASCE)1076-0342(2004)10:1(23)

Zhou, X.; Damnjanovic, I. D. 2011. Optimal hedging of commodity price risks in highway contracts, *Transportation Research Record: Journal of the Transportation Research Board* 2228(1): 19–25. http://dx.doi.org/10.3141/2228-03

Zhou, Y.; Banerjee, S.; Shinozuka, M. 2010. Socio-economic effect of seismic retrofit of bridges for highway transportation networks: a pilot study, *Structure and Infrastructure Engineering* 6(1–2): 145–157. http://dx.doi.org/10.1080/15732470802663862

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