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Research Article

Mean-Reverting Valuation of Real Options for International Railway Construction Projects

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Abstract: This study proposes to employ a mean-reverting model to evaluate the real options embedded in international railway construction projects. The application of mean-reverting models has usually had the difficulty of defining suitable mean-reverting variables for evaluating railway construction projects. The innovative aspect in this research is the formation and calibration of the mean-reverting models we have proposed, in which underlying variables related to the present value of a railway project normalized by either the length of a railway track or the construction time are assumed to follow stochastic mean-reversion processes. Through an example, we show that this assumption enabled us to have evaluated the abandonment option embedded in the construction project by calibrating the parameters with Euler's estimation and maximum likelihood estimation.

Keywords: Investment under uncertainty, mean reverting process, railway construction projects, real option valuation

INTRODUCTION

In the past three decades, valuations of capital investment opportunities using real option valuation methods have seen a wide range of developments in areas such as natural resources investments (Tourinho, 1979; Titman, 1985; Brennan and Schwartz, 1985), IT investments (Chen *et al*., 2007), Capital budgeting (Kensinger, 1987; Trigeorgis, 1986), Agriculture venture investment (Wang and Tang, 2010) and many other fields as such. The theoretical foundations underpinning real options valuation methods is now well developed (Brennan and Schwartz, 1985; Copeland and Antikarov, 2002; Trigeorgis, 1996; Mun, 2002; Trigeorgis, 2000). There are many real option articles on infrastructure transportation such as (Rose, 1998; Chiara *et al*., 2007; Cheah and Liu, 2006; Chi and Amy, 2011; Huang and Chou, 2006; Bowe and Lee, 2004) and many others. International railway construction project could involve huge risks. Uncertainties aroused by non-standardized contracts, cultural differences and political influences may result in wrong decision making, the consequence of which can be disastrous. The traditional discounted cash flow analysis and Net Present Value (NPV) method can be much restricted for such complex international construction cases because the decision-making process is non-flexible. Therefore, real option approach for such projects could be beneficial and would accommodate the managerial flexibilities.

With regard to the methods for evaluating real options, the application of the Mean-reverting method for real options is seldom seen for railway construction project evaluation whilst it has been often adopted for valuing commodity prices (such as oil prices) (Pindyck, 1999; Schwartz, 1997; Schwartz and Smith, 2000). In this study, we will attempt to examine the effectiveness of the mean-reverting method for real options for railway construction projects. Innovatively, we propose to adopt underlying variables related to the normalized present value of a railway project as dynamic factors which follow mean-reverting processes. The objective of this study is to show that the proposed idea allows us to calibrate the mean-reverting models by using past available construction projects and employing the Euler's estimations and maximum likelihood estimations. It is shown that this approach is applicable and can give many insights in the real option evaluations.

MEAN-REVERTING PROCESS FOR REAL OPTIONS

It is commonly known that the mean-reverting models accurately account for historical commodity prices such as oil prices or electricity prices (Schwartz, 1997; Bessembinder *et al*., 1995; Hjalmarsson, 2003; Laughton and Jacoby, 1993).

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The Ornstein-Uhlenbeck (O-U) process (Gillespie, 1996), in particular, is widely used for modelling a mean-reverting process:

$$ds = \lambda(\mu - s)dt + \sigma dW \quad (1)$$

where,

W = A Brownian motion, $W \sim N(0, \sqrt{dt})$
s = The underlying asset
λ = The mean-reverting rate, or the speed of the mean reverting
μ = The mean, where the process is modeled to revert
σ = The volatility of the process

The return of s follows a normal distribution with:

$$E(s) = \mu + (s_0 - \mu)e^{-\mu T} \quad (2)$$

$$Var(s) = \frac{\sigma^2}{2\lambda}(1 - e^{-2\mu T}) \quad (3)$$

Another possible mean reverting model is Stochastic Logistic or Pearl-Verhulst equation (Gershenfeld, 1999):

$$d(s) = \lambda(\mu - s)sdt + \sigma sdW \quad (4)$$

The problem of the traditional Ornstein-Uhlenbeck (O-U) process and Pearl-Verhulst equation is that the returns can take negative results and the drift and diffusion term are not homogenous with degree one.

The third possible mean-revering process is the Inhomogeneous Geometric Brownian Motion (IGBM) (Robel, 2001):

$$d(s) = \lambda(\mu - s)dt + \sigma sdW \quad (5)$$

This model does not violate the homogeneity conditions and has a closed-form solution that produces positive results. The explicit solution is:

$$s = e^{-\left(\lambda + \frac{\sigma^2}{2}\right)t + \sigma W)}(s_0 + \lambda\mu \int_0^t e^{\left(\lambda + \frac{\sigma^2}{2}\right)x - \sigma W} dx) \quad (6)$$

Many commodity researches rely on the mean-reverting Ornstein-Uhlenbeck process, for example Gibson and Schwartz (1990) uses a mean-reverting model for estimating commodity convenience yield. Also, O-U process generally produces positive results, which is suitable for modeling construction projects. Therefore, our research will adopt the mean-reverting Ornstein-Uhlenbeck process for evaluating the real options.

Using the Euler's method, we can first discretize the OU process and then use the Maximum Likelihood Estimation method (MLE) to obtain the parameters μ, λ, σ. According to Euler's discretization method, we can have (assuming time-step Δ):

$$s_{i+\Delta} - s_i = \lambda(\mu - s_i)\Delta + \sigma\sqrt{\Delta}\emptyset_{t+\Delta} \quad (7)$$

The probability density function is:

$$P(N_{0,1} = x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2} \quad (8)$$

And the conditional probability density of an observation s_{i+1} on the condition given previous observation s_i is presented:

$$f(s_{i+1}|s_i; \mu, \lambda, \hat{\sigma}) = \frac{1}{\sqrt{2\pi\hat{\sigma}^2}} exp\left[-\frac{(s_i - s_{i-1}e^{-\lambda\Delta} - \mu(1 - e^{-\lambda\Delta}))^2}{2\hat{\sigma}^2}\right] \quad (9)$$

where,

$$\hat{\sigma} = \sigma^2 \frac{1 - e^{-2\lambda\Delta}}{2\lambda}$$

The log-likelihood function of the set of data $s_0, s_1, \ldots, s_n$ can be obtained from the following function:

$$L(\mu, \lambda, \hat{\sigma}) = \sum_{i=1}^{n} lnf(s_i s_{i-1}; \mu, \lambda, \hat{\sigma}) = \frac{n}{2}\ln(2\pi) - nln(\hat{\sigma}) - \frac{1}{2\hat{\sigma}^2}\sum_{i=1}^{n} [s_i - s_{i-1} e^{-\lambda\Delta} - \mu(1 - e^{-\lambda\Delta})]^2 \quad (10)$$

In order to derive the maximum likelihood, we set all the partial derivatives equal to zero:

$$\frac{\partial L(\mu, \lambda, \sigma)}{\partial \mu} = 0 \quad (11)$$

$$\frac{1}{\hat{\sigma}^2}\sum_{i=1}^{n}\left[s_i - s_{i-1}e^{-\lambda\Delta} - \mu\left(1 - e^{-\lambda\Delta}\right)\right] = 0$$

The mean is given by:

$$\mu = \frac{\sum(s_i - s_{i-1}e^{-\lambda\Delta})}{n(1 - e^{-\lambda\Delta})}$$

$$\frac{\partial L(\mu, \lambda, \hat{\sigma})}{\partial \lambda} = 0 \quad (12)$$

$$-\frac{\Delta e^{-\lambda\Delta}}{\hat{\sigma}^2}\sum_{i=1}^{n}[(s_i - \mu)(s_{i-1} - \mu) - e^{-\lambda\Delta}(s_{i-1} - \mu 2 = 0$$

The mean reversion rate is given by:

$$\lambda = -\frac{1}{\Delta} ln \frac{\sum(s_i - \mu)(s_{i-1} - \mu)}{\sum(s_{i-1} - \mu)^2} \quad \frac{\partial L(\mu, \lambda, \hat{\sigma})}{\partial \hat{\sigma}} = 0 \quad (13)$$

$$\frac{n}{\hat{\sigma}} - \frac{1}{\hat{\sigma}^3}\sum_{i=1}^{n}\left[\left(s_i - \mu - e^{-\lambda\Delta}(s_{i-1} - \mu)\right]^2 = 0$$

The volatility can be calculated as:

$$\hat{\sigma}^2 = \frac{1}{n}\sum_{i=1}^{n}\left[\left(s_i - \mu - e^{-\lambda\Delta}(s_{i-1} - \mu)\right]^2$$

To solve these equations for μ, λ. Denote the data as follows:

$$s_x = \sum_{i=1}^{n} s_{i-1}$$
$$s_y = \sum_{i=1}^{n} s_i$$
$$s_{xx} = \sum_{i=1}^{n} {s_{i-1}}^2$$
$$s_{xy} = \sum_{i=1}^{n} s_{i-1}\, s_i$$
$$s_{yy} = \sum_{i=1}^{n} {s_i}^2 \quad (14)$$

Thus, the Eq. (12) and (13) give:

$$\mu = \frac{s_y - e^{-\lambda\Delta} s_x}{n(1-e^{-\lambda\Delta})} \quad (15)$$

$$\lambda = -\frac{1}{\Delta} ln \frac{s_{xy} - \mu s_x - \mu s_y + n\mu^2}{s_{xx} - 2\mu s_x + n\mu^2} \quad (16)$$

Substituting (16) into (15) gives:

$$n\mu(s_{xx} - s_{xy}) - \mu({s_x}^2 - s_x s_y) = s_y s_{xx} - s_x s_{xy} \quad (17)$$

The mean is calculated as:

$$\mu = \frac{s_y s_{xx} - s_x s_{xy}}{n(s_{xx} - s_{xy}) - ({s_x}^2 - s_x s_y)} \quad (18)$$

The mean reversion rate is given by:

$$\lambda = -\frac{1}{\Delta} ln \frac{s_{xy} - \mu s_x - \mu s_y + n\mu^2}{s_{xx} - 2\mu s_x + n\mu^2} \quad (19)$$

The volatility can be given by:

$$\widehat{\sigma}^2 = \frac{1}{n}[s_{yy} - 2\alpha s_{xy} + \alpha^2 s_{xx} - 2\mu(1-\alpha)(s_y - \alpha s_x) + n\mu^2(1-\alpha)^2]$$
$$\sigma^2 = \widehat{\sigma}^2 \frac{2\lambda}{1-\alpha^2} \quad (20)$$

where, $\alpha = e^{-\lambda\Delta}$ (Van den Berg, 2011).

THE PROPOSED UNDERLYING VARIABLES (ASSETS)

The intrinsic mechanism of using the mean-reversion in construction projects can be controversial. But compared with standardized shipping projects, which is securitized and traded as options between major banks, we could assume that similarly two-track railway construction projects can be standardized and therefore, follow mean reverting processes. However, identification of a sensible variable following Mean-Reverting Process (MRP) in the railway construction projects may seem not to be straightforward. In order to analyze and determine the parameters for the O-U mean reverting model, we assume that the parameters defined in Table 1 might be all relevant to the mean-reverting process.

In this study, we will focus on 'the option to abandon' (or abandonment option) in order to examine the proposed models for real options. An option to abandon is similar to the long put option. If the value of the underlying asset does not decrease overtime, the maximum loss incurred of this option will be the cost of setting (Mun, 2002). On the other hand, Trigeorgis (2000) suggested that the NPV under the concept of real options or managerial adaptability should be called 'expanded NPV', reflecting both components: the traditional NPV of direct cash flows and the option value of operating and strategic adaptability. The expanded NPV stands for the real value of a project:

Expanded (strategic) NPV = traditional NPV + value of options from active management (real options) meanwhile, in the mean reverting process:

$$ds = \lambda(\mu - s)dt + \sigma dW \quad (21)$$

dW is a Wiener process:

$$dW = \emptyset\sqrt{dt} \quad (22)$$

And $\emptyset$ is a random variable that follows standard normal distribution. In this study, we use Monte Carlo method to simulate this process. The value of an abandon option is therefore calculated as follows due to Feynman-Kac:

$$v = e^{-r\Delta t} Max[residual - the\ value\ of\ underlying\ at\ time\ t, 0] \quad (23)$$

where,

$$Residual = Present\ value\ of\ the\ contract * (1 - stage\ of\ completion) * salvage\ rate$$

where, t is the time elapsed by which the option is exercised and r is the risk-free rate. Owing to the fact

Table 1: Possible MRP variables defined for railway construction projects

Variable symbols	Definitions	Units	s (underlying)
PVL	Project present value/total length of the rail tracks	Billion USD/Km	PV/L
VL	Total contract value/total length of the rail tracks	Billion USD/Km	V/L
PVLT	Project present value/total length of the rail tracks/construction period	Billion USD/Km/year	PV/L/T
VLT	Total contract value/total length of the rail tracks/construction period	Billion USD/Km/year	V/L/T
PVT	Project present value/construction period	Billion USD/year	PV/T
VT	Total contract value/construction period	Billion USD/year	V/T

Table 2: Option values corresponding to different underlying variables

Variable symbols	Option value formulas
PVL VL	$v = e^{-r\Delta t}\text{Max}[\text{residual} - s * L, 0]$
PVLT VLT	$v = e^{-r\Delta t}\text{Max}[\text{residual} - s * L * T, 0]$
PVT VT	$v = e^{-r\Delta t}\text{Max}[\text{residual} - s * T, 0]$

L: The length of a railway; T: The construction period

we have supposed several different underlying assets which may follow mean-reverting processes; the option value can be computed by using (23) in which the value of underlying needs to represent for each individual variable listed in Table 1, therefore, we have different option value formulas corresponding to these variables (Table 2).

PRICING THE REAL OPTION TO ABANDON-AN EXAMPLE

Models calibration using CRCC railway construction projects: In order to give an example of the application of the proposed framework, we now gather information of several railway construction projects conducted by China Railway Construction Corporation (CRCC) during 2009-2012 as shown in Table 3. We acknowledge that the sample size at present is small in this research due to the restrictions of finding suitable data. But for demonstration purpose, the data is deemed as appropriate.

We now regard the variables shown in Table 1 as the underlying s respectively; we can then compute the samples listed in Table 4.

We can then obtain the parameters (Table 5) by using the calibration method above for the O-U mean reverting model. Consequently, we now have the following possible O-U mean reverting processes corresponding respectively to the parameters estimated in Table 4:

$$\begin{aligned} ds &= 0.6165(0.0776 - s)dt + 0.0561dW \\ ds &= 0.6165(0.3222 - s)dt + 0.2329dW \\ ds &= 0.2115(0.0459 - s)dt + 0.0124dW \\ ds &= 0.2115(0.1906 - s)dt + 0.0514dW \\ ds &= 0.7212(0.3859 - s)dt + 0.2715dW \\ ds &= 0.7245(1.6004 - s)dt + 1.1293dW \end{aligned} \tag{24}$$

Models applications to another CRCC railway construction project: In order to show the way of using these models, we now try to value the abandonment option embedded in another railway project carried out by CRCC. We assume the following parameters showed in Table 6 are valid for the project by taking reference to the Mecca Light Railway project in Mecca, Saudi Arabia conducted by CRCC (2009). Information on this project is readily available on the company's official website. (As this part is for demonstration purpose, whether the estimated parameters in Table 6 are strictly correct is out of the scope of this study).

If CRCC chose to abandon the contract and sold it to another contractor when the stage of completion was around 40%, the residual value of the contract:

$$\begin{aligned} Residual\ Value &= Present\ value\ of\ the\ contract \\ &\quad * (1 - stage\ of\ completion) \\ &\quad * salvage\ rate \\ &= 2.91\ billion * (1 - 40\%) * 0.6 = 1.05\ billion \end{aligned}$$

Let us take the mean-reverting model for the underlying asset PVT (see Table 1 for its definition) as an example. Monte Carlo simulations of project value

Table 3: Samples of two tracks railways construction projects

Year	Project	Length (Km)	Period (years)	Present value (billion)	Contract value (billion)
2009	Libyan Arab to RasAjdir line	172.00	3	1.27248	5.28
2009	The Algerian EL AFFROUN to KHEMIS	55.00	3	0.83386	3.46
2009	The Algerian B.B.A. to THENI	175.00	5	3.34990	13.90
2011	Mi'eso-Darwanle railway	15.00	4	1.81232	7.52
2012	Nigeria to Djibouti railway projects	14.80	3	1.40985	5.85

(Available at CRCC published investor's reports: http://www.crcc.cn/g345.aspx)

Table 4: Values of the underlying variables as samples

	PVL	VL	PVLT	VLT	PVT	VT
s_1	0.007398	0.030698	0.002466	0.010233	0.42416	1.76
s_2	0.015161	0.062909	0.005054	0.020970	0.27795	1.15
s_3	0.019142	0.079429	0.003828	0.015886	0.66998	2.78
s_4	0.120821	0.501333	0.030205	0.125333	0.45308	1.88
s_5	0.095260	0.395270	0.031753	0.131757	0.46995	1.95

Table 5: Calculated parameters of OU processes

Parameters	Values (PVL)	Values (VL)	Values (PVLT)	Values (VLT)	Values (PVT)	Values (VT)
μ	0.0776	0.3222	0.0459	0.1906	0.3859	1.6004
σ	0.0561	0.2329	0.0124	0.0514	0.2715	1.1293
λ	0.6165	0.6165	0.2115	0.2115	0.7212	0.7245

Table 6: Parameters obtained from the Mecca light railway project

	Notation	Value
Risk free rate (estimated)	r	2.3%
Present value of the project	S	2.91 billion
Stage of completion (estimated)	C	40%
Construction period elapsed	T	10 months
Salvage rate (estimated)	SR	60%
Total length of the railway	L	18.06 km

are displayed in Fig. 1, which shows that s converges to 0.3802.

On this date, the stage of completion is 40% and with a total length of 18.06 km, the length till then would be 18.06*0.4 = 7.2240 km. The time period elapsed is 10 months, or 0.8333 years. Therefore, the real option value can be calculated as:

$$v = e^{-0.023*0.83333}$$
$$Max[1.05 - 0.8333 * 0.3802, 0] = 0.719$$

Similarly, we can obtain the option values corresponding to each of the models Eq. (24) and results are shown in Table 7 including the option values for the case of s = PVT.

Interestingly, we find from Table 7 that the option values corresponding to the underlying VL, VLT and VT are all zeros, which implies these variables are unlikely following the mean-reverting process, since the embedded abandonment option must be of positive value. It also indicates that the total contract value of the railway construction project normalized either by time or by the length of the railway unlikely follows the mean-reverting process. On the other hand, the present value of the project normalized by time or the length of the railway or both can be promising. Further validation research would be conducted on this aspect by interested researchers with large sample sizes.

COMPARING THE MEAN-REVERTING WITH BLACK-SCHOLES MODEL

Although an abandonment option is usually treated as American put option when exercise time is unknown (Hull, 2007), we could regard the option as a European option when the exercise time is fixed in advance. The Black-Scholes Model (Hull, 2007) can provide robust approximations for real options. The option to abandon is intuitively compared with put option since it offers option holders to sell or abandon the project at a specific price. However, the parameters of the real options and financial options are similar but need a transformation of the underlying instruments. The parameters for the inputs of BS formula are shown in Table 8.

In BS model:

$$d_1 = \frac{ln\left(\frac{S}{E}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = \frac{ln\left(\frac{2.91}{1.05}\right) + \left(2.3\% + \frac{35\%^2}{2}\right)*0.8333}{35\%*\sqrt{0.8333}} = 3.57$$

$$d_2 = \frac{ln\left(\frac{S}{E}\right) + \left(r - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = 3.26$$
$$N(-d_1) = 0.0$$
$$N(-d_2) = 0.0006$$

The value of the put option:

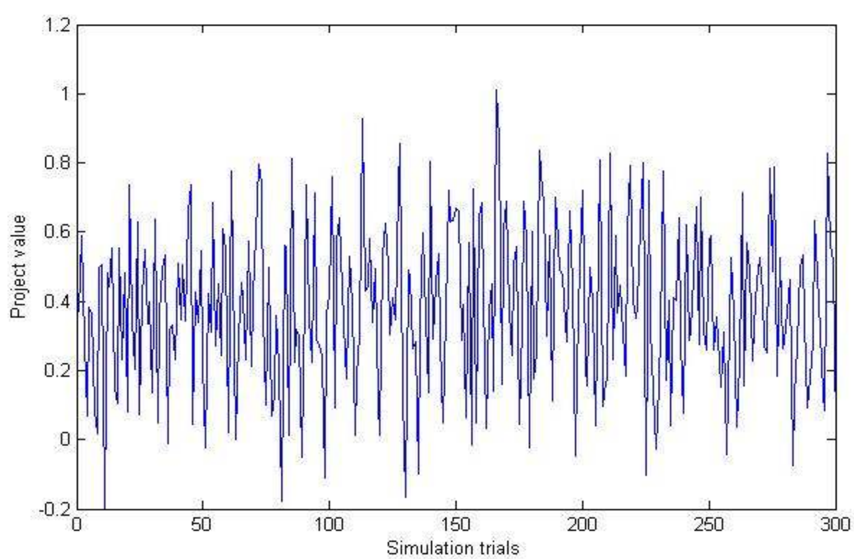

Fig. 1: Project value simulation

Table 7: Option prices obtained by different mean-reverting models

	Values (PVL)	Values (VL)	Values (PVLT)	Values (VLT)	Values (PVT)	Values (VT)
Real option prices	0.1692	0.0	0.5158	0.0	0.719	0.0

Table 8: Parameters comparisons between real and financial options

Real options	Parameter	Financial options
Present value of project	S	Stock price
Residual value if sold (liquidation value)	X	Strike price
Time until investment opportunity	T	Time until expiry
Volatility of the value of project	σ	Volatility of the stock price
Risk free rate	r	Risk free rate

$$P(S,t) = Ee^{-rT}N(-d_2) - SN(-d_1)$$
$$= 1.05e^{-2.3\%*0.75} * 0.0006 - 2.91 * 0.0$$
$$= 0.000619$$

The value of the put option given by BS is much less than that given by the mean-reverting model. This result somewhat indicates the limitation of the BS model for real options due to the model's assumptions upon which it was developed. This is a well-known issue therefore we would have expected that it could be such a case. In this case, it is due to the fact that the residual of the project (strike price) is lower than the present value of the project (underlying price) in the example project being examined. On the other hand, it has shown the advantage of the proposed methodology.

CONCLUSION AND DISCUSSION

Valuing real options in railway construction projects with mean reverting models has little previous evidence. This study however employs the mean-reverting model to evaluate the real option in the railway construction project. This research allows the commodity characteristics by defining several underlying variables and therefore allowing the mean reversion of the real option price for railway construction projects. Although the effectiveness of such a model can be disputed on this occasion, it was shown that the present value of the construction project normalized by time or railway length or both could be promising and the adopted approach was feasible for real option pricing for railway construction projects. Further, it shows some advantages over the traditional BS model in this case. However, the proposed idea is preliminary and must be subject to future investigations with larger sample size by collecting more data on the past railway construction projects.

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