Improving the Assessment of Economic Foreign Exchange Exposure in Public–Private Partnership Infrastructure Projects

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Abstract: Unexpected foreign exchange (FX) rate changes represent an important risk factor, especially in public-private partnership (PPP) infrastructure projects in developing countries. The risk exists because PPP projects typically sell their outputs domestically and generate revenues in local currency, whereas their financing costs and operating and maintenance costs are denominated in major currencies. Multidisciplinary experience and engineering judgment are needed to control and manage FX exposure during construction, operation, and maintenance of infrastructure. In this context the paper aims to establish a quantitative model that is linked to engineering parameters and cost assumptions to quantify economic FX exposure in PPP infrastructure projects. First, the FX index terminology will be introduced, based on a first-order second-moment reliability method. Second, the methodology is illustrated on a PPP coal-fired power project in Southeast Asia. It is also shown that the proposed dispersion ellipsoid implementation is much faster in computation time compared with commonly used Monte Carlo simulations in PPP infrastructure projects. **DOI: 10.1061/(ASCE)IS.1943-555X.0000069.**

CE Database subject headings: Financial factors; Risk management; Partnerships; Private sector; Infrastructure.

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Introduction

In the past, many countries have made serious efforts to improve infrastructure. Even though infrastructure will always be ultimately paid for by government, the users, or a mix of both, countries embarking on massive construction programs are unlikely to find the required funds from their national budget. In such cases the private sector can contribute to advance the necessary capital. In a typical public-private partnership (PPP) infrastructure project, the functions of construction, operation, maintenance, and finance are transferred to a special-purpose company (SPC) that is formed for this purpose for a period of, for example, 30 years. The SPC operates under the terms of an agreement with the characteristics of a contract for work and services, with ownership returning to the public sector principal at the end of the contractual term. The concessionaire receives in return either a regular payment as availability fee or revenues based on user fees. Infrastructure procurement methods vary from infrastructure procurement by public agencies, state-owned corporations, up to functional outsourcing or material privatization. However, within the privatization path several contracts are available such as service contracts, management contracts, concessions, or joint ventures (Alfen and Weber 2010; Schaufelberger and Wipadapisut 2003; Shen et al. 1996).

The complexity and long-term focus of infrastructure projects include several risks during the construction and operation phases. It requires a multidisciplinary approach to design a project with the objective to minimize risks and to optimize costs and it requires engineering input to control and manage the risks. In this context, Kakimoto and Seneviratne (2000) provided an investment risk analysis framework. Saleh and Marais (2006) used the reliability concept to model reliability of the project present value. Pantelias and Zhang (2010) presented a methodological framework for the probabilistic evaluation of the financial viability of transportation infrastructure projects procured as PPPs. Their methodology is based on the reliability concept by considering all project-related risks under the limit state function of the net present value. Another approach to assess financial viability and investment risk by Monte Carlo simulation has been shown by Seneviratne and Ranasinghe (1997). Ye (2001) and Ye and Tiong (2000) contributed with a net present value (NPV) at-risk model by combining the weighted average cost of capital and dual risk-return methods. All of the models try to assess financial viability and default probabilities. However, one of the significant risk factors in PPP infrastructure projects is economic foreign exchange (FX) exposure. This is the extent to which future earning power is affected by changes in relevant exchange rates. The risk often has a high impact on default probabilities and the desired project outcome. As long as the risk cannot be quantified appropriately or as long as mitigation of FX risk is not possible, investors are unable and unwilling to carry the risk at a competitive price level (Gray and Irwin 2003; Matsukawa et al. 2003). In many cases projects will most probably not be procured at all if expectations of return on investment are too high as compensation for bearing FX risk. The significance of FX risk compared with other risk factors depends on the nature of the project and its procurement method, user or taxpayer revenues,

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J. Infrastruct. Syst. 2012.18:57-67.

contractual arrangements, and many other factors. Furthermore, the significance of FX exposure varies with respect to the life cycle of the project. For example, engineers, quantity surveyors, and facility management can apply different strategies to use materials and major equipment depending on the structural design and life cycles of the components. The cost of major components might be lower in foreign markets, but they could involve FX exposure compared with local options. The same applies to the cost of local financing compared with financing by foreign loans. The underlying assumptions to optimize the cost structure reflect the choice of construction components as well as maintenance and replacements during the life cycle. Subsequently, quantifying FX exposure and efficient controlling constitute a multidisciplinary approach.

Exchange rate risk management in international construction companies on borrowing and FX future hedging is presented by Kapila and Hendrickson (2001). Besides FX management, a suitable methodology to quantify FX exposure in PPP infrastructure projects could help construction managers, engineers, and quantity surveyors to formulate their decisions despite the increasing complexity and dynamism of infrastructure projects. The quantitative measures of FX exposure are generally calculated in practice on the basis of the project's cash flow. The calculations are based on forecasts of cash flows, which are based on a set of uncertain assumptions. Common practice to test FX exposure in PPP projects is through the use of risk factors on revenue and cost positions or by adopting conservative assumptions in the cash flow. However, ratios such as debt service cover ratio (DSCR) or loan life cover ratio (LLCR) do not explicitly reflect the uncertain effects of economic FX exposure on revenue and cost positions in the project. The approach does not include the logical basis for addressing uncertainties. Other methods, such as Monte Carlo simulations, are quite complex to implement in determining project cash flow, and the simulation process is often time-consuming.

The methodology developed in this paper aims to establish an extra tool that is linked to the project's cash flow. The proposed method of feasibility analysis via expanding dispersion ellipsoid, derived in this research, is simple in terms of modeling methodology and faster in simulation time compared with Monte Carlo simulations. The proposed foreign exchange exposure (FEE) model is developed with the purpose of quantifying economic FX exposure in the cash flow of the SPC. The FEE model will show the expected economic FX exposure related to alternatives and measures costs related to quantities in relation to timely implications on the cash flow of the infrastructure project. Quantity surveyors and facility managers can monitor FX exposure with the FEE model during construction and operational phases. It is a decision support tool to structure and evaluate operation and maintenance (O&M) alternatives as well as a tool to control FX exposure.

Objectives and Scope

The FEE model considers probability density functions (PDFs) and correlations of market variables, which are linked to the cash flow of the project. Historical cycles are applied to estimate the future economic FX exposure. The model acts as an assessment system to evaluate economic FX exposure by monitoring changes in market conditions. Feasibility is ensured in terms of probability that a defined investability grade will be adequate to withstand economic FX exposure. Therefore, the FX index is modeled as a system of market variables including inflation rates, interest rates, and FX rates. All the variables are fitted to PDFs during a defined time period and correlations between the variables are aggregated on defined economic cycles. All variables form an ellipsoid in the n-dimensional shape. It is a first-order second-moment reliability method that is adjusted to the characteristics of project finance with the purpose of analyzing economic FX exposure in PPP infrastructure projects. The FX index is modeled via an expanding dispersion ellipsoid. A defined surface divides the n-dimensional space of variables into two sets: an investability domain and a noninvestability domain. The limit is described in terms of a minimum DSCR requirement defined by the feasibility function $g(x)$. One set contains points in the model that are below a certain minimum DSCR requirement, and one set contains points that behave above a DSCR requirement. The derived FX index is equivalent to the distance from the ellipsoidal center to the most probable point of noninvestability grade. The index illustrates how well the project is able to absorb FX fluctuations. The more the ellipsoid can disperse without exceeding the non investability surface, the more FX exposure can be absorbed by the project. The impact on the cash flow is measured on net operating revenue, free cash flow, and dividends.

All components of the quantitative model developed in this paper, and their interconnections, are explained in detail. First, the concept of project feasibility modeling and the implementation of the methodology into project finance modality are introduced. Second, the proposed FEE model is tested against the commonly used Monte Carlo simulation and applied to an independent power producer (IPP) project. Last, the conclusions from this research are presented.

Project Feasibility Modeling

A first-order second-moment reliability method based on the Hasofer-Lind reliability index is undertaken to model the uncertainties of FX risk in PPP infrastructure projects. This terminology is borrowed from the engineering field of load-carrying structures and adapted to the characteristics of project finance. The second-moment reliability index was first defined by Hasofer and Lind (1974). The index has been further refined by Rackwitz and Fiessler (1978), Ditlevsen (1981), Shinozuka (1983), Ang and Tang (1984), Madsen et al. (1986), and Tichy (1993). Low and Tang (1997, 2004, 2007) presented a practical procedure of efficient feasibility evaluation for correlated non normal variables with respect to the Hasofer-Lind index and first-order reliability method.

The application of second-moment reliability methodology in quantifying FX exposure in project finance has several advantages compared with the commonly used Monte Carlo simulation. The FEE methodology is designed as an extra tool that can be linked to any kind of financial model that includes the detailed costs and revenues of the project. The methodology is able to consider PDFs, correlations between the variables, and the computation of an FX index.

The following section focuses on the implementation of the model framework in PPP procurement. The computation of the FX index is derived from the FEE model. It is linked to the cash flow of the project by defined market variables. This allows the FX model to consider project specifics such as different institutional arrangements and payment structures. All variables influence the cost and revenue structure and therefore the noninvestability domain from the FEE model. Each project has different output quantity, technical requirements, different cost positions, and financial assumptions. These details are modeled in financial models with input sheets and computation sheets. Input sheets include details such as output quantity, involved costs, and revenues. Computation sheets include modeling of income tax, profit and loss statement, balance sheet, and the cash flow as well as detailed modeling of funding drawdown, sources and uses of funds, and debt repayment.

J. Infrastruct. Syst. 2012.18:57-67.

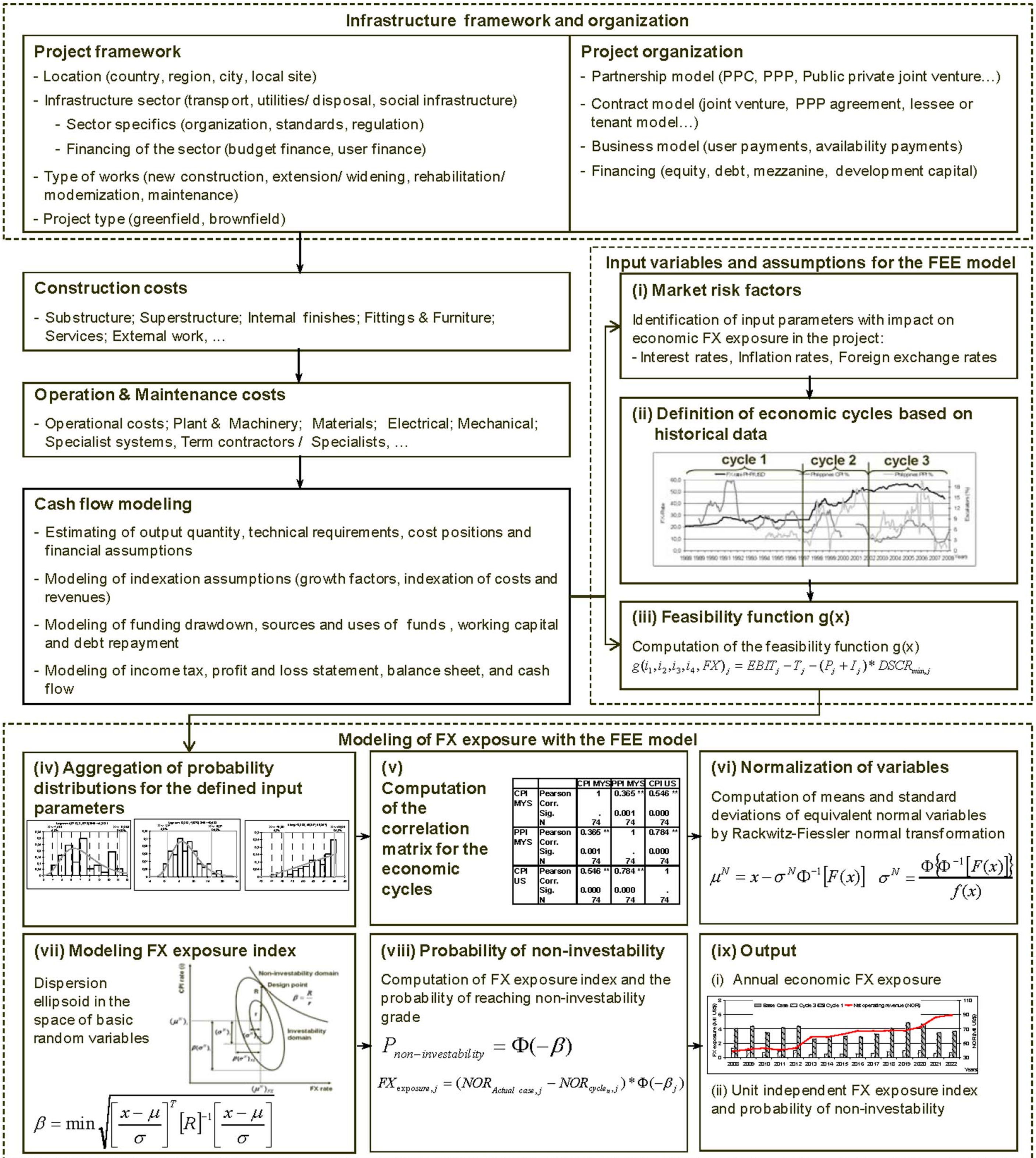

Fig. 1. Methodological framework to quantify FX exposure with the FEE model

Fig. 1 illustrates the process to develop the cash flow modeling characteristics and the FX index computation in the FEE model. The aim is to develop an extra tool that is linked to the financial models to achieve a high level of practicality.

Engineering parameters in the categories of local characteristics, design criteria, and design parameters will fit into the FEE methodology in terms of quantities, time, and costs. The future construction, operating, and maintenance costs depend on factors such as engineering design, construction quality, utilization, and external factors. On the basis of the engineering and financial structuring the construction, operation, and maintenance costs will vary in magnitude and frequency. All engineering parameters will be

J. Infrastruct. Syst. 2012.18:57-67.

considered in the feasibility function, which is based on the DSCR. The parameters are fitted into the FEE methodology in terms of quantity and costs and are not defined as random variables. Market variables are defined as functions of correlated random variables and described in a random vector. The random variables are linked to the corresponding cost positions within the cash flow of the project. In this formulation, the nonlinearity between the random vector of market variables and the engineering parameters expressed in the limit state function as DSCR is limited.

The combination of engineering and financial structuring influences not only the success of a PPP project; it is also the main driver to realize innovations in the project. Therefore parties involved in the negotiation of the final engineering can address the engineering parameters into the FEE methodology during the planning phase. After the planning phase the FEE model becomes a decision support and controlling instrument with the objective to investigate the best options with lowest economic FX exposure in terms of the engineering life cycle design. A company might set a target level of acceptance for a maximum FX exposure under a defined confidence interval.

All boxes in Fig. 1 are described in greater detail in the following sections.

Methodological Framework of the FEE Model

The aim of the FEE model is to reflect the uncertainties of market risks that impact on the FX exposure and the cash flow of the PPP project. The FX index is modeled in terms of n variables $x_1, x_2, \ldots, x_n$ representing market risks (Fig. 1, box i). The input variables describe inflation, interest, and FX rates.

The definition of the economic cycles (Fig. 1, box ii) is based on historical data. Each cycle will be replicated in the future. Because the methodology is applied in Asia the analysis is based on three economic cycles indicating, respectively, the period of growth in Asian markets (1989—1997), the Asian financial crisis (1997—2002), and the post-Asian financial crisis (2002—2008).

Alternatively, the variables can be fitted to the whole cycle from 1989 to 2008. In this case, the distributions generally fit very well to normal or log-normal distributions because of the large amount of data. Instead of specific economic cycles, the variables will be set to upper and lower boundary conditions. However, the disadvantage of this method is higher standard deviations and correlations, which cannot reflect the behavior between the different cycles. In general, accuracy will increase by minimizing the time duration.

The third box in Fig. 1 represents the link between the cash flow of the project and the FEE model. The corresponding dividing surface on the debt perspective is called the limit-investability surface. The DSCR for the limit-investability surface is computed as follows:

$$\mathrm{DSCR}_t = \frac{\mathrm{EBIT}_t + R_{t-1} - T_t}{P_t + I_t} \tag{1}$$

where EBIT_t = earnings before interest and tax, R_{t-1} = reserves, T_t = tax, $P_t + I_t$ = principal and interest, and DSCR_t = the minimum DSCR requirement in year t. The feasibility function $g(x)$ is set to zero and defined as follows (Fig. 1, box iii):

$$g(x)_t = \mathrm{EBIT}_t + R_{t-1} - T_t - (P_t + I_t) \times \mathrm{DSCR}_t \tag{2}$$

Consequently, the computation on annual values would be a 1-year FX index. Alternatively, a 3-year FX index might be necessary to relocate assets or to refinance or to renegotiate the concessionaire contract. The FEE model is therefore designed to compute a 1-year and a 3-year FX index. The feasibility function $g(x)$ for the 3-year FX index in year t can be described as dependent on the annual inflation rates f_{it}, f_{it+1}, and f_{it+2} and the annual FX rates S_{it}, S_{it+1}, and S_{it+2}. The feasibility function $g(x)_{t+2}$ is written as follows:

$$g(x)_{t+2} = \mathrm{EBIT}_{t+2} + R_{t+1} - T_{t+2} - (P_{t+2} + I_{t+2}) \times \mathrm{DSCR} \quad t = C+1, \ldots, N \tag{3}$$

Equivalently, the limit-investability surface can be formulated in the equity perspective. In this case, the feasibility function would be defined as minimum return on equity (ROE). The FX index would then show how prepared the project is to cover FX fluctuations by maintaining a minimum ROE. Nevertheless, both definitions make it possible to compute the FX exposure on the net operating revenue (NOR) and dividends as important figures for project managers and quantity surveyors in PPP projects.

Quantifying FX Exposure with the FEE Model

First, each of the market variables will be fitted to PDFs during the defined time periods (Fig. 1, box iv).

The bivariate correlations (Fig. 1, box v) between all input variables are obtained with SPSS software. Pearson's correlation coefficient measures the significance levels of the linear association between the variables. Variables should be approximately normally distributed and have no outliers because the Pearson correlation coefficient measures the linear association between the variables.

A normalization process in box vi (Fig. 1) of variables is necessary to apply the fitted PDFs to first-order reliability method (FORM) modeling. The means and standard deviations of equivalent normal variables are computed by Rackwitz-Fiessler normal transformation with equivalent normal standard deviation

$$\sigma^N = \frac{\Phi\{\Phi^{-1}[F(x)]\}}{f(x)} \tag{4}$$

and equivalent normal mean

$$\mu^N = x - \sigma^N \Phi^{-1}[F(x)] \tag{5}$$

where x is the original nonnormal variable, $\Phi^{-1}[\,]$ is the inverse of the cumulative density function (CDF) of a standard normal distribution, $F(x)$ is the original nonnormal CDF evaluated at x, $\Phi\{\}$ is the PDF of the standard normal distribution, and $f(x)$ is the original nonnormal probability density ordinate at x.

Most of the market risk variables follow either log-normal or normal distributions. The transformation of log-normal μ and σ to μ^N and σ^N is derived by applying Rackwitz-Fiessler normal transformation as follows:

$$\mu^N = x\left\{1 - \ln(x) + \ln(\mu) - \frac{1}{2}\ln\left[1 + \left(\frac{\sigma}{\mu}\right)^2\right]\right\} \tag{6}$$

$$\sigma^N = x^* \sqrt{\ln\left[1 + \left(\frac{\sigma}{\mu}\right)^2\right]} \tag{7}$$

All further types of probability distributions are normalized by applying Rackwitz-Fiessler Eqs. (4) and (5).

After the normalization all variables are applied to the FORM methodology of an ellipsoid in the n-dimensional shape (Fig. 1, box vii).

J. Infrastruct. Syst. 2012.18:57-67.

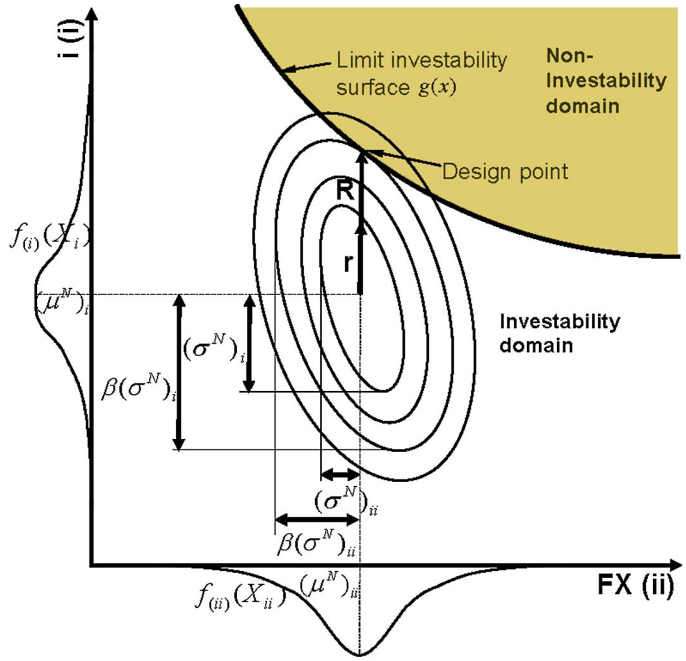

Fig. 2. Equivalent dispersion ellipses in the original space of the basic random variables

A defined surface divides the n-dimensional space of variables into two sets, an investability domain and noninvestability domain, as shown in Fig. 2. The limit is described in terms of a minimum DSCR requirement defined by the feasibility function $g(x)$. One set contains points in the model that are below a certain minimum DSCR requirement; the other set contains points that are above a DSCR requirement.

Fig. 2 shows a two-dimensional case of FX risk and inflation risk i. The FX index is the axis ratio (R/r) of the ellipse that touches the limit state surface of the noninvestability surface and the 1-standard deviation dispersion ellipse. The ratio is the same along any direction because of the geometrical properties of the ellipsoid. The corresponding dividing surface of investability and noninvestability is called the limit-investability surface. Investability is defined as the minimum DSCR necessary to perform its operation and maintenance, principal and interest payments, tax, and expected dividend payments during the predetermined lifetime.

Each axis of the ellipsoid is parallel to a corresponding coordinate axis in the 1-standard deviation dispersion ellipsoid if the variables are uncorrelated. The dispersion ellipsoid is tilted by consideration of correlation assumptions between the escalators.

The computation of the FX index involves eigenvalues and eigenvectors, rotation of the reference frame, and transformed space for the random variables. The second-moment representation of the mean vector $E[X]$ position on input parameters is judged within the set above the investability surface with respect to the covariance matrix C_x. However, the variables x must be normalized into one unit that applies irrespective of the direction in the space. This transformation of the x space in a normalized u space is done by

$$u = C_x^{-1/2}(x - E[X]) \tag{8}$$

The FX index can then be measured by the distance from the origin to any specific point of the limit-investability surface L_x. The distance is the number of standard deviations from the mean value to the critical point of the limit-investability surface. The squared length of any vector u in the normalized space is defined by Hasofer and Lind (1974) as

$$u'u = (x - E[x])'C_x^{-1}(x - E[X]) \tag{9}$$

Any point x of the limit-investability surface L_x can be computed by the formula of Veneziano (1974)

$$x \epsilon L_x = \sqrt{(x - E[x])'C_x^{-1}(x - E[X])} \tag{10a}$$

The Hasofer-Lind index is defined by the smallest value of this function. The matrix formulation of the Hasofer-Lind index for correlated normal random variables is

$$\beta_0 = \min \sqrt{(x - E[x])'C_x^{-1}(x - E[X])} \tag{10b}$$

or equivalently

$$\beta = \min \sqrt{\left[\frac{x-\mu}{\sigma}\right]^T [R]^{-1} \left[\frac{x-\mu}{\sigma}\right]} \tag{10c}$$

where x represents the set of random variables, μ represents the mean value, R represents the correlation matrix, and σ represents the standard deviation. The procedure to compute β is to vary x_i to minimize the quadratic form of the ellipsoid subject to the constraint that the ellipsoid just touches the surface of the noninvestability domain. The smallest ellipse or hyperellipsoid that is tangent to the noninvestability domain is then equivalent to the most probable design point. Therefore, the index is equivalent to the distance from the ellipsoidal center to the most probable point of noninvestability grade (design point). The ellipsoidal center is described by the distributions of inflation and FX, whereas the distance is measured in units of directional standard deviation. Low and Tang (2004) expanded the Hasofer-Lind ellipsoid perspective as shown in Fig. 2 for correlated nonnormal distributions by applying the Rackwith-Fiessler equivalent normal transformation. The normal distributions are replaced by an equivalent normal ellipsoid, centered not at the original mean values of the nonnormal distribution but at the equivalent normal mean μ^N.

The FX index β is the axis ratio (R/r) of the ellipse that touches the limit state surface of the noninvestability domain and the 1-standard deviation dispersion ellipse. The FX index therefore illustrates how well the project is prepared to cover foreign exchange fluctuations. The more the ellipsoid can disperse without exceeding the non investability surface, the more FX exposure can be absorbed by the project. On the basis of the derived FX index β the probability of noninvestability $P_{\text{noninvestability}}$ is computed from the normal distribution of the FX index as follows (Fig. 1, box viii):

$$P_{\text{noninvestability}} = \Phi(-\beta) \tag{11}$$

The economic FX exposure is computed by the most likely case based on a minimum DSCR of defined economic cycles (Fig. 1, box ix). All annual FX indexes are computed with a probability of reaching noninvestability. The most likely exposure is computed by the following equation:

$$FX_{\text{exposure},j} = (x_{\text{Actualcase},j} - x_{\text{cycle}_n,j}) \times \Phi(-\beta_j) \tag{12}$$

where x represents the NOR, net cash flow, or dividends, respectively. The maximum loss within the investability surface is adjusted to minimum $\text{DSCR}_j = 45\%$ of reaching noninvestability.

J. Infrastruct. Syst. 2012.18:57-67.

Table 1. Cash Flow for Case Study A

	Year																		
	1997	1998	1999	…	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Capital expenditure	54.01	213.61	47.78																
Interest and fees	21.06	23.66	41.49																
Capital recovery fee (A)	0.00	0.00	1.25	…	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03	10.03
Fixed operating fee (B)	0.00	0.00	1.81	…	26.38	28.32	29.63	32.93	35.43	38.14	41.09	44.29	47.77	51.55	55.66	60.14	65.01	70.30	76.07
Service fee (C)	0.00	0.00	4.05	…	32.41	32.41	31.75	32.41	32.41	32.41	32.41	32.41	32.41	32.41	32.41	32.41	32.41	32.41	32.41
Infrastructure fee (D)	0.00	0.00	0.00	…	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy fee (E)	0.00	0.00	4.06	…	103.30	106.39	105.17	113.23	116.68	120.26	123.99	127.86	131.89	136.09	140.46	145.01	149.77	154.73	159.92
Total revenue	0.00	0.00	11.17	…	172.12	177.14	176.58	188.60	194.55	200.84	207.51	214.59	222.10	230.08	238.56	247.59	257.21	267.47	278.42
VAT receivable	0.00	0.00	1.12	…	17.21	17.71	17.66	18.86	19.45	20.08	20.75	21.46	22.21	23.01	23.86	24.76	25.72	26.75	27.84
Interest on reserves	0.00	0.00	0.00	…	1.40	1.34	1.26	1.23	1.17	1.11	1.06	1.00	0.94	0.89	0.83	0.77	0.71	0.66	0.60
Passthrough fixed costs	0.00	0.00	1.41	…	22.80	31.94	34.59	46.05	49.02	35.42	41.04	43.61	44.69	56.69	61.06	72.49	74.99	69.00	73.21
Passthrough variable costs	0.00	0.00	4.01	…	102.55	101.66	104.81	105.71	106.69	105.85	108.93	110.20	111.58	110.80	114.73	116.52	118.48	117.88	122.94
Non passthrough fixed and variable costs	0.00	0.00	0.00	…	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAT payable	0.00	0.00	0.00	…	17.21	17.71	17.66	18.86	19.45	20.08	20.75	21.46	22.21	23.01	23.86	24.76	25.72	26.75	27.84
Increase/(decrease) in W/C	0.00	0.00	0.00	…	4.29	0.02	(0.44)	0.98	0.67	2.10	0.56	0.87	1.06	0.22	0.92	0.42	1.24	2.04	1.29
Net operating revenue	0.00	0.00	6.87	…	43.88	44.86	38.88	37.08	39.33	58.58	58.05	60.91	65.71	63.26	62.67	58.94	63.22	79.20	81.58
Equity drawing	38.54	28.21	26.25	…															
USD debt drawing T1	34.06	121.42	39.78	…															
Local currency debt drawing	0.50	29.50	0.00	…															
USD debt drawing T2	1.97	58.14	23.24	…															
Local currency debt interest	0.00	0.00	0.00	…	2.95	2.75	2.21	2.35	2.15	1.95	1.75	1.55	1.35	1.15	0.95	0.75	0.55	0.35	0.15
USD bank debt T2 interest	0.00	0.00	0.00	…	5.75	5.36	4.97	4.58	4.19	3.80	3.41	3.02	2.63	2.24	1.85	1.46	1.07	0.68	0.29
USD bank debt T1 interest	0.00	0.00	0.00	…	11.66	10.87	10.08	9.29	8.50	7.71	6.92	6.13	5.34	4.55	3.76	2.97	2.17	1.38	0.59
Local currency debt principal	0.00	0.00	0.00	…	1.40	1.40	1.22	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
USD debt T2 principal	0.00	0.00	0.00	…	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62	3.62
USD debt T1 principal	0.00	0.00	0.00	…	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49	8.49
Total debt interest and principal	0.00	0.00	0.00	…	33.88	32.50	30.60	29.74	28.36	26.98	25.60	24.22	22.84	21.46	20.08	18.69	17.31	15.93	14.55
Income tax	0.00	0.00	0.00	…	3.20	2.91	3.90	4.13	5.30	13.02	12.77	14.37	16.60	15.93	16.45	15.45	17.72	24.08	25.13
Net cash flow	0.00	0.00	6.87	…	6.79	9.45	4.37	3.21	5.68	18.59	19.68	22.33	26.28	25.88	26.14	24.79	28.18	39.19	41.90
Cash available	0.00	0.00	6.87	…	32.20	33.82	27.33	25.51	26.95	38.82	38.88	40.49	43.41	41.97	41.20	38.81	41.17	51.14	52.81
Distributions	0.00	0.00	0.00	…	7.83	10.87	5.02	4.24	6.71	19.62	20.71	23.36	27.31	26.91	27.18	25.83	29.22	40.23	52.81
Reserve account	0.00	0.00	6.87	…	24.38	22.95	22.30	21.27	20.23	19.20	18.16	17.13	16.09	15.06	14.02	12.99	11.95	10.91	0.00
Cash amount available and paid as dividends	0.00	0.00	0.00	…	7.83	10.87	5.02	4.24	6.71	19.62	20.71	23.36	27.31	26.91	27.18	25.83	29.22	40.23	52.81
W/H tax on dividends	0.00	0.00	0.00	…	0.35	0.49	0.23	0.19	0.30	0.88	0.93	1.05	1.23	1.21	1.22	1.16	1.31	1.81	2.38
Dividends paid	0.00	0.00	0.00	…	7.48	10.38	4.80	4.05	6.41	18.74	19.78	22.31	26.08	25.70	25.96	24.67	27.90	38.42	50.43

Note: All figures in U.S. dollars (millions); Tranche 1 (T1), XXX; Tranche 2 (T2), XXX; USD, U.S. dollars; VAT, value-added tax; W/C, working capital; W/H, withholding.

J. Infrastruct. Syst. 2012.18:57-67.

The conditional probability of not reaching noninvestability has a maximum of 50%.

$$FX_{\text{exposure},j} = (x_{\text{Actualcase},j} - x_{\min \text{DSCR},j}) \times 45\% \tag{13}$$

The following section focuses on the implementation of the model framework in a coal-fired power plant under PPP procurement in the Philippines. The case study, called case study A, has been conducted under a confidentiality agreement, and therefore the project and the parties involved are not identified. The objective of case study A is to quantify economic FX exposure and to show the additional information generated by the model.

FEE Model Application in an IPP Project

Case study A is a coal-fired power plant developed in the 1990s. The project has a concession period of 25 years, including a 3-year construction period. The project has a capacity of 200 MW (gross) with a total estimated construction cost of about US$400 million. The debt-to-equity ratio of the project is assumed to be 75%:25%. Financing is separated into local and foreign lending; local lending is equal to US$30 million, and foreign lending is equal to US $370 million including equity. The foreign lenders have senior status to the local lenders. Both loans have a maturity of 17 years. The first loan repayment is due in year 5. Because of forecasted stable demand, a grace period is not required. A subordinated working capital will be drawn in case of shortcomings in interest rate payments and principal repayments. Table 1 illustrates the cash flow of case study A.

Market Risk Factors

The tariff TAR_{tj} is indexed on the revenue positions by including an allowable maximum adjustment. The concessionaire contract of the case study allows a maximum 10% annual change on tariff indexation.

The variables with exposure to market risks and impact on cost and revenue positions in the case study are (1) the consumer price index (CPI) of the Philippines, (2) the producer price index (PPI) of the Philippines, (3) the CPI of the United States, (4) the wholesale price index (WPI) of the United States, and (5) FX rates of the United States and the Philippines. Interest rates are fixed over the whole concession period and therefore are not relevant in the model. All variables are fitted to probability density functions based on monthly rates. Each variable covers 250 data points from 1989 to 2008. The data were obtained of the international financial statistics database of the International Monetary Fund.

The analysis is based on three economic cycles: (1) 1989—1997, (2) 1997—2002, and (3) 2002—2008, indicating the period of growth in Asian markets, the Asian financial crisis, and the post-Asian financial crisis, respectively (Table 2).

Table 2. Fitted Probability Density Functions—Philippines

	Market risk variables	Cycle 1: 1989—1997			Cycle 2: 1997—2002		
		Distributions	μ	σ	Distributions	μ	σ
i_1	CPI PHL	Log-normal	10.45	4.74	Log-normal	7.28	2.10
i_2	WPI PHL	Triangular	4.20	0.67	Triangular	9.79	4.39
i_3	CPI US	Log-normal	3.62	1.36	Uniform	2.57	0.71
i_4	PPI US	Normal	2.26	2.02	Log-normal	1.06	3.60
FX	FX rate	Normal	54.70	3.21	Normal	57.29	3.21
		Cycle 3: 2002—2008			Base case		
		Distributions	μ	σ	Distributions	μ	σ
i_1	CPI PHL	Log-normal	4.76	1.82	Log-normal	10.00	2.88
i_2	WPI PHL	Log-normal	7.73	4.69	Log-normal	9.32	4.69
i_3	CPI US	Triangular	2.65	0.86	Log-normal	2.85	0.91
i_4	PPI US	Normal	4.52	4.04	Normal	4.82	4.04
FX	FX rate	Normal	50.77	3.21	Normal	43.84	3.21

Note: CPI, consumer price index; FX, foreign exchange; PHL, the Philippines; US, United States.

All inflation variables applied in the case study are modeled on the basis of the fitted distributions in the specific cycles as illustrated in Table 2. In contrast, the FX rates are modeled on the maximum change during a 3-year cycle. The current spot price is increased by the percentage maximum change during the specific cycle. This is the time during which the project is tested for feasibility and the probability to reach non investability grade. Furthermore, the Asian financial crisis, in cycle 2, is only modeled by 30% of the actual hyper devaluation during that time. Under this assumption the cycle illustrates the worst case assumption in FX exposure. Table 3 shows the adjusted probability density functions for the economic FX exposure modeling.

Computation of Feasibility Function *g(x)*

The feasibility function $g(x)$ of the 1-year FX index is calibrated to a minimum DSCR of cycle 1, cycle 3, and the base case. The minimum DSCR assumption is generated from the cash flow. The feasibility function $g(x)$ for the 1-year FX index is therefore computed as follows:

$$g(i_1, i_2, i_3, i_4, FX)_t = \text{EBIT}_t - T_t - (P_t + I_t) \times \text{DSCR}_{\min,t}$$
$$t = C + 1, \dots, N$$

Reserves are excluded in the 1-year FX index in order to measure FX exposure on the NOR. In the case of currency devaluation reserves would offset FX exposure without being counted in the NOR on a 1-year basis. However, the 3-year FX index includes reserves because of accumulation of changes in the reserve account

Table 3. Foerign Exchange Rate Modeling

	Period	3-year change in FX rate		% change	FX rate modelling		
		Minimum	Maximum		Distributions	μ	σ
Base case	2008				Normal	43.8	3.21
Cycle 1	1989—1997	22.4	28.0	25	Normal	54.7	3.21
Cycle 2	1997—2002	26.3	42.4	61	Normal	70.6	3.21
Cycle 3	2002—2008	46.3	53.6	16	Normal	50.8	3.21

J. Infrastruct. Syst. 2012.18:57-67.

during the following years. The 3-year FX index in dependency of the annual inflation rates f_{it}, f_{it+1}, and f_{it+2} and the annual FX rates S_{it}, S_{it+1}, and S_{it+2} is written as follows:

$$g(i_1, i_2, i_3, i_4, FX)_{t+2} = \mathrm{EBIT}_{t+2} + R_{t+1} - T_{t+2} - (P_{t+2} + I_{t+2}) \times \mathrm{DSCR}_{\min,t+2}$$

$$t = C + 1, \ldots, N$$

To compare all three cycles, it is important to include minimum boundaries instead of maximum boundaries on the inflation and FX variables. The minimum boundary is set at the original mean value in each cycle. The model will have a setting-up problem when there is no possible combination that will reach the noninvestability surface.

Computation of the Correlation Matrix

The bivariate correlations and the Pearson's correlation coefficient between the variables and the P values of the CPI of the Philippines, the PPI of the Philippines, the CPI of the United States, and the WPI of the United States are listed in Table 4.

All correlations until the 0.05 significance level are included in the FX index computation.

Results

Fig. 3 illustrates the output of the feasibility analysis, with the FX indexes based on the defined economic cycles. The FX index therefore illustrates how well the project is prepared to cover FX fluctuations. Each combination fulfills the constraint of feasibility function $g(x) = 0$ and a minimum FX index. It is therefore a forward-looking approach searching for the combination of the possible maximum market variables with the shortest distance to the noninvestability surface without exceeding the noninvestability domain. The possible combinations of the inflation and FX rates are based on the fitted distributions and the correlation assumptions. The FX index is unit independent and allows for comparison of different projects in different markets.

Fig. 3 shows the FX index compared with the base case DSCR during the defined cycles. The input parameters are linked to the cash flow and reflect the different life cycle cost and revenue structures. Higher x values compared with the original μvalue illustrate the potential of increased inflation rates or FX rates without reaching the noninvestability domain. Therefore, the higher the FX index, the more feasible it is that the project will absorb FX fluctuations. The upper line in Fig. 3 represents the base case. All other cycles have FX indexes with a distance of about two units to the base case. Cycle 3 is the bottom line in Fig. 3, with a maximum FX index equal to 0.8. Fig. 3 illustrates that the DSCR cannot reflect the uncertainties of economic FX exposure. The DSCR increases constantly until the end of the concession period. In this case, the DSCR could mislead one to the interpretation that the project becomes increasingly resistant to market risk during the concession period. The FX index shows by how many standard deviations of the feasibility function the expected condition reaches the defined investability grade. Each standard deviation can be expressed in nominal absolute values.

The FX index is approximately constant over the whole period while the DSCR is increasing. The only increase in the FX index, by 0.3 units in all cycles, is from 2012 to 2013. This increase reflects a change in replacement costs during the year 2013.

Table 4. Correlation Matrix for the Philippines

Variables		Philippines (1989—1997)					Philippines (1997—2002)					Philippines (2002—2008)				
		CPI PHL	PPI PHL	CPI US	WPI US	FX rate	CPI PHL	PPI PHL	CPI US	WPI US	FX rate	CPI PHL	PPI PHL	CPI US	WPI US	FX rate
CPI PHL	Pearson correlation	1	0.415[a]	0.514[b]	−0.178	0.117	1	0.552	−0.778[b]	−0.721[b]	0.852[b]	1	0.697[b]	0.632[b]	0.515[b]	0.515[b]
	Sig. (2-tailed)	—	0.012	0.000	0.083	0.257	—	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000
	N	96	36	96	96	96	25	25	25	25	25	70	70	70	70	70
PPI PHL	Pearson correlation	0.415[a]	1	−0.287	0.056	0.002	0.552[b]	1	−0.704[b]	−0.613[b]	0.793[b]	0.697[b]	1	0.642[b]	0.499[b]	0.44[b]
	Sig. (2-tailed)	0.012	—	0.090	0.744	0.991	0.004	—	0.000	0.001	0.000	0.000	—	0.000	0.000	0.000
	N	36	36	36	36	36	25	25	25	25	25	70	70	70	70	70
CPI US	Pearson correlation	0.514[b]	−0.287	1	0.556[b]	−0.390[b]	−0.777[b]	−0.704[b]	1	0.9162	−0.891[b]	0.632[b]	0.642[b]	1	0.833[b]	0.174
	Sig. (2-tailed)	0.000	0.090	—	0.000	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	—	0.000	0.149
	N	96	36	96	96	96	25	25	25	25	25	70	70	70	70	70
WPI US	Pearson correlation	−0.178	0.056	0.556[b].	1	−0.477[b]	−0.721[b]	−0.613[b]	0.916[b]	1	−0.815[b]	0.515[b]	0.499[b]	0.833[b]	1	0.354[b]
	Sig. (2-tailed)	0.083	0.744	0.000	—	0.000	0.000	0.001	0.000	—	0.000	0.000	0.000	0.000	—	0.003
	N	96	36	96	96	96	25	25	25	25	25	70	70	70	70	70
FX rate	Pearson correlation	0.117	0.002	−0.390[b]	−0.477[b]	1	0.852[b]	0.793[b]	−0.891[b]	−0.815[b]	1	0.515[b]	0.44[b]	0.174	0.354[b]	1
	Sig. (2-tailed)	0.257	0.991	0.000	0.000	—	0.000	0.000	0.000	0.000	—	0.000	0.000	0.149	0.003	—
	N	96	36	96	96	96	25	25	25	25	25	70	70	70	70	70

[a]CPI, consumer price index; FX, foreign exchange; PHL, the Philippines; PPI, producer price index; Sig. (2-tailed), two-tailed significance P value; US, United States; WPI, wholesale price index. Correlation is significant at the 0.05 level (two-tailed).
[b]Correlation is significant at the 0.01 level (two-tailed).

J. Infrastruct. Syst. 2012.18:57-67.

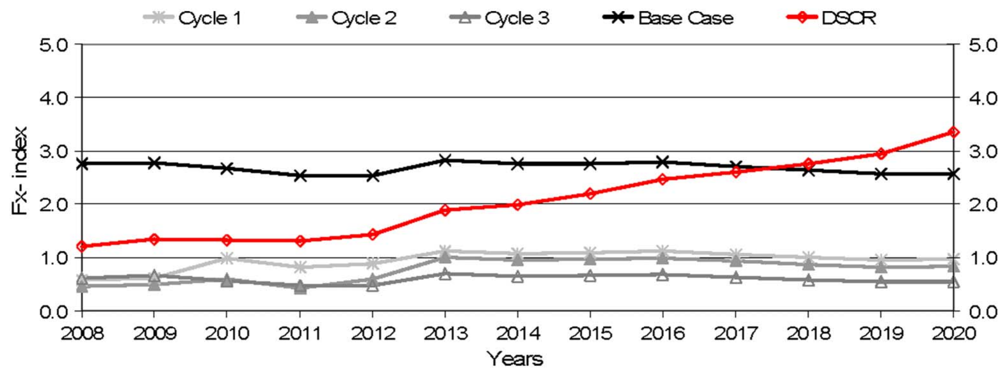

Fig. 3. FX index for the defined cycles compared with DSCR

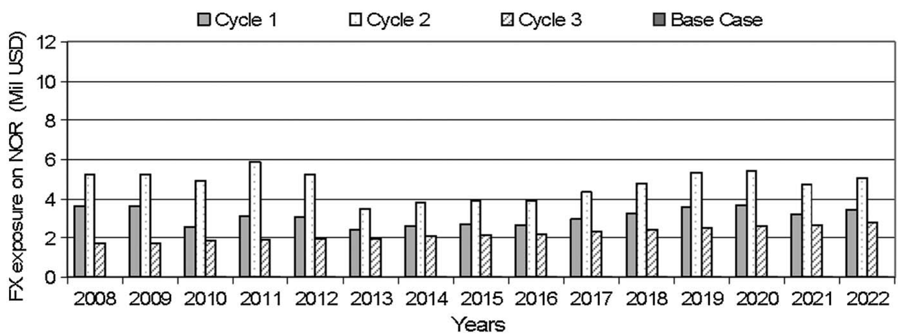

Fig. 4. Economic FX exposure on net operating revenue

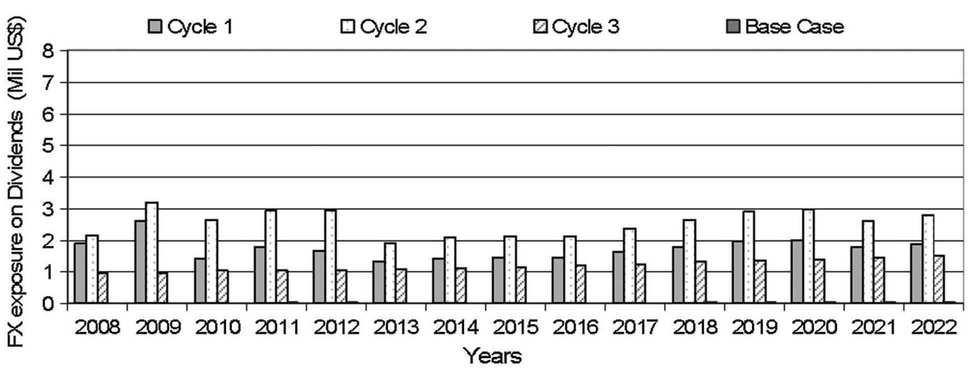

Fig. 5. Economic FX exposure on dividends

From 2013 to 2020 the FX indexes are decreasing back to the value of 2012. The index illustrates very low feasibility to cover FX exposure by applying cycle 1, cycle 2, and cycle 3. The lowest values can be seen in the years 2008 to 2012.

Figs. 4 and 5 illustrate the market risk exposure on NOR and dividends. The market exposure is calculated on the basis of the change in the variables in each applied cycle compared with the actual case. Each annual combination of inflation rates and FX rates fulfills the constraint of just touching the noninvestability surface and reaching a minimum FX index. The escalators and FX rates are changed randomly under the constraint of the fitted PDFs and the correlations between the variables. The economic FX exposure is computed by a most likely case based on a minimum DSCR from cycle 1, cycle 3, and the base case. All annual FX indexes are computed with a probability of reaching noninvestability. The annual most likely and maximum FX exposures are computed as stated in Eqs. (12) and (13), respectively. Fig. 4 illustrates that the FX exposure on NOR varies from US$ 1.8 to 3.9 million in cycle 1, from US$ 3.9 to 5.9 million in cycle 2, and from US$ 1.9 to 2.8 million in cycle 3. FX exposure on dividends varies from US$ 1.5 to 2.6 million in cycle 1, from US$ 2.0 to 3.1 million in cycle 2, and from US$ 1.0 to 1.5 million in cycle 3 as shown in Fig. 5. The most likely case is based on the minimum DSCR of the base case, cycle 3, and cycle 1. The base case has zero probability of reaching non investability and therefore no FX exposure.

J. Infrastruct. Syst. 2012.18:57-67.

Table 5. β Dispersion Ellipsoid versus Monte Carlo Simulation

	Cycle 1						Cycle 3						Base case					
	Feasibility index β			Monte carlo (10000 trials)			Feasibility index β			Monte carlo (10000 trials)			Feasibility index β			Monte carlo (10000 trials)		
	β	$\phi(-\beta)$	Time	$\phi(-\beta)$	Time		β	$\phi(-\beta)$	Time	$\phi(-\beta)$	Time		β	$\phi(-\beta)$	Time	$\phi(-\beta)$	Time	
Years			s		min	s			s		min	s			s		min	s
2008	0.57	0.28	23	0.32	1	54	0.61	0.27	23	0.29	2	2	2.75	0.00	21	0.00	1	46
2009	0.61	0.27	23	0.29	1	35	0.66	0.26	23	0.26	1	53	2.78	0.00	21	0.00	2	3
2010	0.98	0.16	23	0.18	2	5	0.56	0.29	23	0.29	2	7	2.67	0.00	21	0.00	1	45
2011	0.82	0.21	23	0.22	1	56	0.47	0.32	23	0.31	2	7	2.54	0.01	21	0.01	2	3
2012	0.88	0.19	23	0.18	1	45	0.47	0.32	23	0.32	2	7	2.53	0.01	21	0.01	1	45
2013	1.11	0.13	24	0.13	1	47	0.69	0.24	23	0.25	1	53	2.82	0.00	22	0.00	2	3
2014	1.08	0.14	25	0.13	1	56	0.65	0.26	23	0.27	1	45	2.75	0.00	21	0.00	1	48
2015	1.09	0.14	25	0.15	2	6	0.66	0.25	25	0.24	1	65	2.76	0.00	21	0.00	2	6
2016	1.11	0.13	25	0.14	2	9	0.69	0.25	25	0.23	1	53	2.79	0.00	21	0.00	1	48
2017	1.06	0.14	25	0.18	2	14	0.64	0.26	25	0.26	1	43	2.71	0.00	21	0.00	1	39
2018	1.01	0.16	25	0.18	1	58	0.59	0.28	25	0.28	1	54	2.64	0.00	21	0.00	2	9
2019	0.95	0.17	25	0.19	2	3	0.54	0.30	25	0.30	2	34	2.56	0.01	21	0.01	2	2
2020	0.97	0.17	25	0.17	2	12	0.55	0.29	25	0.29	2	23	2.58	0.00	21	0.01	1	47
2021	1.11	0.13	25	0.13	2	10	0.68	0.25	25	0.26	2	12	2.74	0.00	21	0.00	1	45
2022	1.09	0.14	25	0.15	2	1	0.67	0.25	25	0.25	2	23	2.70	0.00	21	0.00	1	12
Computation time (min)			6		30				6		31				5		28	

Validation of the FEE model with Monte Carlo Simulation

Table 5 illustrates a comparison between the FEE methodology and Monte Carlo simulations in case study A. The computation times required by the two methods show a significant advantage of about 6 min for the FEE methodology, compared with 30 min for the Monte Carlo simulation. Both probabilities are computed with 1.8 GHz CPU and 10,000 simulation trials in the Monte Carlo simulation and a maximum of 300 iterations with a minimum precision of 0.01% in the FEE methodology. The computation time depends on the complexity of the financial model. The trend shows that the Monte Carlo simulation takes much more computation time if the dependencies between the variables increase. The computational time advantage becomes important as soon as the analysis is required to compare several economic cycles. Consequently, the aggregated time advantage of three cycles in the case study is 17 min for the FEE methodology and 89 min for the Monte Carlo simulation. Because of the stochastic character of both methods, the probability of reaching non investability grade depends on the numbers of simulation trials with the Monte Carlo simulation. Under the assumptions of the case study, both methods show a maximum variation of 4% in the results of the probability of noninvestability.

Advantages of the Developed FEE Model

The FX exposure index derived from the FEE model is unit independent and allows comparisons of different projects in different markets. It is an FX assessment and monitoring tool for performing FX exposure and return analysis. It accounts for the particular features of a project through adjustments to input data based on the specific project variables.

The FEE model's contribution to research is a consistent process to evaluate FX exposure in PPP infrastructure projects. The developed FEE model is a new, structured approach to estimate the FX exposure in PPP projects. This research work contributes to the field of risk analysis and management due to enhanced FX risk impact analysis. It provides a methodology for better understanding as well as responding to FX risk.

Furthermore, the FEE methodology is an extra tool that can be linked directly to financial models by connecting the market variables to the cost and revenue positions of the project. Because the methodology needs to be developed just once, the whole modeling process becomes much simpler compared with Monte Carlo simulation. A Monte Carlo simulation is normally built up and integrated into financial models. It has been shown that the FEE methodology has an additional computation time advantage. The time advantage between the FEE methodology and Monte Carlo simulation increases if the dependencies between the variables increase, depending as well on the simulation trials, due to the stochastic character of both methods.

Conclusion

The FEE model represents an important component in the set of quantitative tools. The model has been designed to act as an assessment system to evaluate economic FX exposure by monitoring changes in market conditions. The developed FX index indicates whether the project is able to absorb historical market fluctuations during 1- and 3-year cycles. The model is directly linked to the cost and revenue structure of the project. The model can be applied to infrastructure projects such as transportation, utilities, and disposal or social infrastructure. It will also assist in evaluating critical variables that need to be controlled in order to secure favorable loan terms, minimize the probability of reaching noninvestability grade, and improving the structure of a project. Furthermore, the proposed dispersion ellipsoid methodology has a significant timely computational advantage compared with Monte Carlo simulations, commonly used in structured finance. Both the FX index and the probability of noninvestability are not unit dependent; hence, different projects in different markets are comparable. The proposed model is therefore a contribution to the traditional risk modeling

J. Infrastruct. Syst. 2012.18:57-67.

framework and a possible way to determine the economic FX risk exposure in PPP infrastructure projects.

Notation

The following symbols are used in this paper:

C^{-1} = inverse of the covariance matrix;
C_x = covariance matrix;
CDF = cumulative density function;
CPI = consumer price index;
DSCR = debt service cover ratio;
$E[X]$ = mean vector;
EBIT_t = earnings before interest and tax in year t;
$F(x)$ = original non normal CDF evaluated at x;
$f(x)$ = non normal probability density ordinate at x;
$g(x)$ = feasibility function;
L_x = limit-investability surface;
NOR_t = net operating revenue at year t;
$P_{\mathrm{noninvestability}}$ = probability of noninvestability;
R = correlation matrix;
S_i = foreign exchange rate i in domestic currency per unit of foreign currency;
T_t = Tax;
β = FX index;
$\Phi^{-1}[\,]$ = inverse of the cumulative density function of a standard normal distribution;
$\Phi\{\}$ = probability density function of the standard normal distribution;
μ = mean value;
μ^N = normalized mean;
σ = standard deviation; and
σ^N = normalized standard deviation.

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J. Infrastruct. Syst. 2012.18:57-67.