Available online at www.sciencedirect.com
ScienceDirect
Int. J. Production Economics 104 (2006) 62–73
international journal of production economics
www.elsevier.com/locate/ijpe

Uncertainty and global sensitivity analysis in the evaluation of investment projects

E. Borgonovo*, L. Peccati

Istituto di Metodi Quantitativi, Bocconi University, 20135 Milano, Viale Isonzo 25, Italy

Received 8 April 2004; accepted 11 May 2005
Available online 13 October 2005

Abstract

This paper discusses the use of global sensitivity analysis (SA) techniques in investment decisions. Global SA complements and improves uncertainty analysis (UA) providing the analyst/decision- maker with information on how uncertainty is apportioned by the uncertain factors. In this work, we introduce global SA in the investment project evaluation realm. We then need to deal with two aspects: (1) the identification of the appropriate global SA method to be used and (2) the interpretation of the results from the decision maker point of view. For task 1, we compare the performance of two family of techniques: non-parametric and variance decomposition based. For task 2, we explore the determination of the cash flow global importance (GI) for valuation criteria utilized in investment project evaluation. For the net present value (NPV), we show that it is possible to derive an analytical expression of the cash flow GI, which is the same for all the techniques. This knowledge enables us to: (1) offer a direct way to compute cash flow GI; (2) illustrate the practical impact of global SA on the information collection process. For the internal rate of return (IRR), we show that the same conclusions cannot be driven. In particular, (a) one has to utilize a numerical approach for the computation of the cash flow influence, since an analytical expression cannot be found and (b) different techniques can produce different ranking. These observations are illustrated by means of the application to a model utilized in the energy sector for the evaluation of projects under survival risk. The quantitative comparison of cash flow ranking with respect to the NPV and IRR concludes the paper, illustrating that information obtained from the SA of the NPV cannot be transferred to the IRR.

Keywords: Uncertainty analysis; Investment evaluation; Sensitivity analysis; Discounted cash flow

1. Introduction

This paper introduces the use of global sensitivity analysis (SA) techniques in investment valuation. When firms deal with investment projects, many factors are uncertain. Uncertainty analysis (UA) is performed as part of the decision-making (DM) process to enable the decision maker (DMr) to understand the degree of confidence in the decision (Apostolakis, 1995), and to assess the project risk (Winston, 1998; Bodie and Kane, 2001; Helton, 1993; Borgonovo et al., 2003; Hofer, 1999). Dedicated subroutines are nowadays included in the most diffuse business software (Excel or Lotus) or in dedicated software packages (Winston, 1998). UA results alone, however, do not provide information on how uncertainty is apportioned by uncertainty in the input factors, and, therefore, on which

*Corresponding author.
E-mail address: emanuele.borgonovo@uni-bocconi.it (E. Borgonovo).

0925-5273/$ - see front matter
doi:10.1016/j.ijpe.2005.05.024

Table 1
Acronyms used in this work

Acronyms	Name
UA	Uncertainty Analysis
SA	Sensitivity Analysis
VDB	Variance Decomposition Based
DM	Decision-Making
DMr	Decision-Maker
NP	Non-Parametric
GI	Global Importance
PEAR	Pearson correlation coefficient
SRC	Standardized regression coefficient
$S_r(x_i)$	Sobol' Global Sensitivity Indices of order r
$S_T(x_i)$	Sobol' total indices
FAST	Fourier Amplitude Sensitivity Test

factors to devote data collection resources so as to reduce uncertainty most effectively/rapidly (Saltelli, 1999). This is, however, the information one obtains from global SA. Several SA methods have been recently developed in the literature, outside the investment project valuation realm (Archer et al., 1997; Borgonovo 2001; Campolongo and Saltelli, 1997; Downing et al., 1985; Hamby, 1994; Hamby and Tarantola, 1999; Helton, 1993; Hofer, 1999; Homma and Saltelli, 1996; McKay, 1996; Saltelli, 1997, 1999; Saltelli and Bolado, 1998; Saltelli and Marivoet, 1990; Saltelli et al., 1999, 2000; Sobol', 1967, 1990, 1993, 2001; Saltelli and Sobol', 1995).

It is the purpose of this paper to illustrate the utilization and meaning of global SA in the uncertainty management of investment project evaluation. We undertake the analysis in two steps. The first step is the identification of the appropriate techniques to be applied to discounted cash flow (DCF) valuation models (Borgonovo and Peccati, 2005; Bodie and Kane, 2001; Beccacece et al., 2000; Koltai and Terlaky, 2000; Taggart, 1996). The second step is the analysis of the application of cash flow GI and of its role in the DM process.

For the first step, we examine the following global SA techniques: Sobol' global sensitivity indices $[S_r(x_i)]$[1] (Table 1) (Sobol', 1993, 2001; Saltelli and Sobol', 1995; Saltelli et al., 1999), the Pearson correlation coefficients (PEAR) and the standardized regression coefficients (SRC) (Saltelli and Marivoet, 1990). $S_r(x_i)$ belong to the family of variance decomposition-based (VDB) techniques and estimate the GI of a parameter by means of the complete decomposition of the model variance. PEAR and SRC are non-parametric (NP) global SA techniques and compute the GI by means of a regression of the output on the uncertain parameters.

We show that, if the DMr selects as a valuation criterion a net present value (NPV) or one of its generalized forms, then the GI of cash flows: (a) can be computed analytically; (b) coincides with the fraction of the NPV variance associated with the cash flow; is equivalently estimated by all the techniques; (c) depends only on the cash flow standard deviation and not on the type of cash flow distribution; (d) has a straightforward interpretation in terms of uncertainty management. Thanks to these properties, it is then possible to study the relationship between GI, timing and uncertainty of a cash flow. We show that, if the DMr selects an internal rate of return IRR to value the investment, an analytical approach is not feasible. As a consequence, not all the techniques can be equivalently used to estimate cash flow GI. In particular, NP techniques should not be utilized since their ability to correctly estimate GI declines as the model becomes non-linear.

For the second step, we show that these results have a direct impact on the information collection process. To do so, we illustrate the global SA of a sample model utilized in the energy sector for the evaluation of projects under survival risk (Beccacece et al., 2000). The model estimates three investment criteria: NPV, value at any time $t(V_t)$, and IRR. For the project NPV and V_t the computation of the cash flow GI is direct thanks to the analytical results mentioned above. In particular, it is enough that the DMr has assesses the cash flow standard deviation, which is a direct output of a standard UA. We show that collecting information on the cash flows associated to the highest values of GI provides the most effective way to reduce the valuation criterion variance. We also illustrate that the DMr has immediate information on the amount of the decrease. For the project IRR estimated via the same model, we compute the cash flow GI numerically, comparing the performance of $S_T(x_i)$, PEAR and SRC. We show that if one relied upon PEAR and SRC to rank cash flows based on their GI, then incorrect conclusions could be drawn. We then compare the cash flow ranking w.r.t. the NPV and to the IRR, obtaining quantitative information through Savage Scores (Borgonovo et al., 2003; Campolongo and Saltelli, 1997). The little agreement between the ranking shows that a cash flow

[1] Table 1 summarizes the acronyms used in this work