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Credit Risk Monte Carlo Simulation Using Simplified Creditmetrics' Model: the joint use of importance sampling and descriptive sampling

Jaqueline Terra Moura Marins *
Eduardo Saliby **

Abstract

Monte Carlo simulation is implemented in some of the main models for estimating portfolio credit risk, such as CreditMetrics, developed by Gupton, Finger and Bhatia (1997). As in any Monte Carlo application, credit risk simulation according to this model produces imprecise estimates. In order to improve precision, simulation sampling techniques other than traditional Simple Random Sampling become indispensable. Importance Sampling (IS) has already been successfully implemented by Glasserman and Li (2005) on a simplified version of CreditMetrics, in which only default risk is considered. This paper tries to improve even more the precision gains obtained by IS over the same simplified CreditMetrics' model. For this purpose, IS is here combined with Descriptive Sampling (DS), another simulation technique which has proved to be a powerful variance reduction procedure. IS combined with DS was successful in obtaining more precise results for credit risk estimates than its standard form.

Keywords: Monte Carlo simulation, credit risk, Importance Sampling and Descriptive Sampling.

JEL Classification: C15.

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1 Introduction

In this paper it is developed a simulation experiment related to credit risk. International financial literature devoted great part of its attention in the last decade to creating methodologies to evaluate portfolio credit risk of financial institutions, in response to the effects of the new Basel Accord over banks capital requirements, known as Basel II. According to Basel II, banks must have enough capital to cover not only market risk but also credit risk of their portfolios. KMV´s approach from KMV Corporation, CreditRisk+ from Credit Suisse First Boston Institution, CreditPortfolio View from McKinsey Consulting and CreditMetrics from JPMorgan Bank are portfolio credit VaR (Value at Risk) methodologies developed by financial industry in the last years[1]. Some of these models give analytical solutions while others elaborate simulation-based solutions. The present paper does not intend to judge the presented credit risk models, instead, it elects CreditMetrics as the simulation methodology to be implemented here[2]. Variance reduction techniques will be applied over CreditMetrics' simulation model and a comparative analysis among their performances will be made.

A simplified version of CreditMetrics, as presented in Glasserman (2004) and Glasserman and Li (2005), is used in this paper, where only the default risk is considered. As in Glasserman and Li (2005), the instrument under analysis is a theoretical portfolio of bonds and loans issued by different firms. This portfolio is only subject to default risk, so that no other kind of credit deterioration but default generates portfolio losses. Importance Sampling is the variance reduction technique applied here, once its use is indicated in rare events simulation, such as the events of default. Importance Sampling is also used in association with other variance reduction technique named Descriptive Sampling. This last technique has already generated interesting results in previous papers.[3] Efficiency of the techniques is measured by the ratio between the standard error of the estimates obtained when a technique is used and the standard error of the estimates obtained when the standard

[1] Crouhy (2000) and Gordy (2000) make a comparative analysis of these methodologies.

[2] Gupton, Finger and Bhatia (1997).

[3] Marins, Santos and Saliby (2003) and Saliby, Marins and Santos (2005).

simulation method (Simple Random Sampling) is used. The lesser this ratio, the greater the precision gain obtained by the technique over the standard method.

In section 2, the credit risk simulation model used here is described, which is based on a simplified version of CreditMetrics' model. Importance Sampling methodology, in its pure version and in association with Descriptive Sampling, is also presented in this section. Main simulation results and conclusions are described in sections 3 and 4, respectively.

2 Methodology

2.1 Monte Carlo Simulation Credit Risk Model

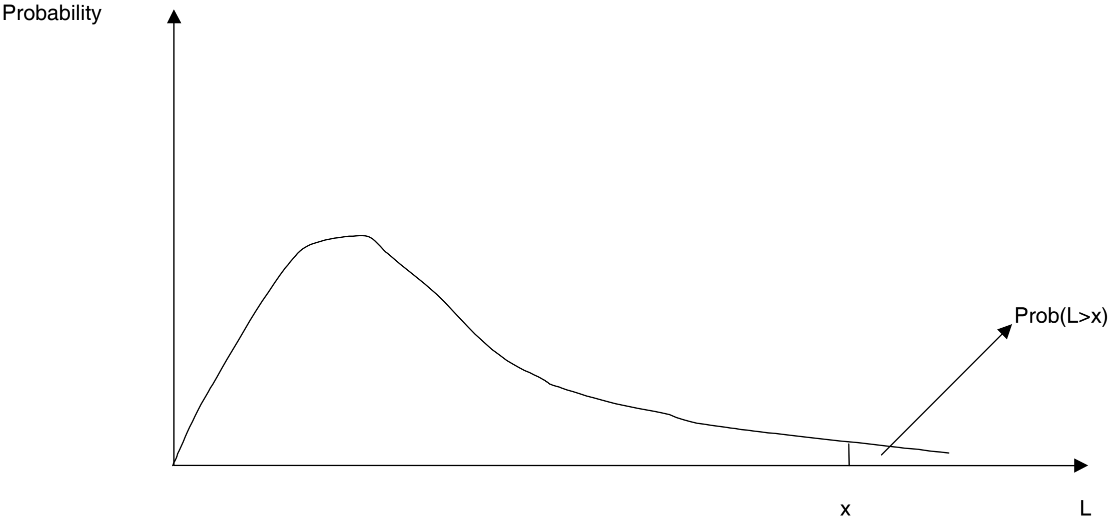
The simulation model implemented in this paper is a simplified version of CreditMetrics and is described in Glasserman (2004) and Glasserman and Li (2005). The goal of the original CreditMetrics' version is to simulate the probability distribution of changes in portfolio future value from changes in the credit rating of their issuers. In its simplified version, the focus is the distribution of future losses arising from default of the issuers. In other words, in the original CreditMetrics, default is one of the many possible credit ratings, while, in its simplified approach, the only possible events are default and non-default.

Besides, the simplified approach admits full loss in case of default, equivalently to 100% of the exposure, while the percentage of loss in the original model depends on the recovery rate of the exposure in the occurrence of default.

Finally, according to the original CreditMetrics, the rating scenarios for each issuer are sampled from a Normal distribution, while, in the simplified model, the scenarios for each issuer are sampled from Bernoulli distributions, each one with one specific probability of default.

The Monte Carlo model studied here intends to simulate the sampling distribution of future portfolio losses arising from default of their issuers over a fixed time horizon (one year) and, then, to estimate tail probabilities of this simulated distribution. Figure 1 below illustrates this idea.

Figure 1: Distribution of losses from default of a theoretical portfolio composed by bonds and loans issued by *m* different firms.



Where:

m = total of issuers to which the portfolio is exposed;

Y_k = default indicator for the k^{th} issuer over the time horizon (k = 1, …, m);

c_k = loss resulting from default of the k^{th} issuer;

p_k = Prob(Y_k=1) = individual probability that the k^{th} issuer defaults;

L = total loss from defaults = $\sum_{k=1}^{m} c_k * Y_k$;

x = loss threshold;

Y_k ~ Bernoulli(p_k).

As suggested in Glasserman and Li (2005), c_k and p_k will be considered constants to simplify the model's implementation. They will be deterministically given by:

$$c_k = \left(5k/m\right)^2, \text{ (1)}^4$$

$$p_k = 0.01 * \left(1 + sin\left(\frac{16\, pi\, k}{m}\right)\right). \text{ (2)}^5$$

[4] This formula splits the total number of issuers in groups of the same size and value.

[5] According to this formula, the (small) default probabilities vary between 0% and 2%, no matter is the number of issuers.

The dependence among the issuers in this simulation model is introduced by the Normal Copula model, which is widely used in association with CreditMetrics[6].

In Normal Copula, the events of default ($Y_k = 1$) are associated to latent variables X_k as indicated below:

$$Y_k = 1\,\{X_k > x_k\},\ (3)$$

where each x_k is chosen to match the individual default probabilites p_k.

The latent variables X_k have standard Normal distribution and they are related to systematic risk factors (Z) common to all the issuers, as indicated below:

$$X_k = a_{k1} * Z_1 + ... + a_{kd} * Z_d + b_k * \varepsilon_k\ ,\ (4)$$

where:

$a_{k,i}$ = factor loadings for the k^{th} issuer, with i = 1,...,d and k = 1,...m;

Z_i (i^{th} common systematic risk factor) ~ N(0,1);

ε_k (idiosyncratic risk factor associated with the k^{th} issuer) ~ N(0,1);

$0 \le a_{k1}^2 + ... + a_{kd}^2 \le 1$;

$b_k = \sqrt{1 - \left(a_{k1}^2 + ... + a_{kd}^2\right)}$, so that X_k is N(0,1).

The systematic risk factors, as they are common to all the issuers, introduce a correlation among the latent variables X_k, which create the dependence among Y_k and, consequently, among the default of the issuers. These risk factors may represent specific risks of an industry or a geographic region.

The simulation routines of this paper are developed in MatLab 6.1. The executed experiment has 40 simulation runs, with 1000 observations of losses in each run. The portfolio analyzed is composed by theoretical bonds and loans issued by 20 different firms (m=20). Each issuer is subject to 10 different risk factors (d=10), common to all the 20 issuers. The threshold loss (x) is $35, corresponding to 20% of possible total loss, resulting in a very low probability of the event L>x.

[6] Kang and Shahabuddin (2005) uses a t-copula model to apply Importance Sampling to the simulation of Prob(L>x). In the t-copula model, the latent variables X_k have multivariate t-student distribution instead of having Normal distribution.

2.2 Variance Reduction Techniques

According to the methodology described above, Prob(L>x) is the output variable of the simulation model. It is not an easy task to obtain a precise measure of this probability, when dealing with low probabilities of default of the issuers and with high levels of threshold loss. It happens because the problem becomes a rare-event simulation. In this context, Importance Sampling (IS), which basically turns rare events into less rare ones, fits well into the simulation problem studied here.

The use of IS in the simulation model considered would require an increase in the original probabilities of default (p_k) in a way to make the events L>x more frequents. The return to the original simulation problem would require the use of the likelihood ratio on every new generated observation of the event L>x. In general, the idea behind IS on Monte Carlo simulation and its likelihood ratio can be presented as:

$$E\big(h(x)\big) = \int h(x) f(x) dx = \int h(x) \frac{f(x)}{g(x)} g(x) dx = E\left(h(y) \frac{f(y)}{g(y)} \right), \ (5)$$

where: E(.) = Expected Value, to be obtained through Monte Carlo simulation; h(.) = any function of the random variable x; f(.) = original density probability function of x; and g(.) = shifted density probability function of x.

Beside the standard form of IS, it is also analyzed here its combined form with Descriptive Sampling (DS), in order to try to obtain more precise estimates. The use of IS also depends on the level of default correlation among the issuers. In this sense, two cases were considered here: independent issuers and strongly dependent issuers. The two forms of IS were implemented in both cases of dependence.

2.2.1 Importance Sampling in the case of Independent Issuers

In this case, the standard IS approach is well known. The risk factor loadings, $a_{k,i}$, are zero because the issuers are independent in terms of the events of default. Standard IS idea consists on exchanging the individual default probabilities, p_k, for higher probabilities, q_k, and randomly sampling default events from these new probabilities. Because these new default events will be randomly sampled, standard IS will be named here IS+SRS (Importance Sampling plus Simple Random Sampling) from now on. Then the events L>x would be easier obtained from these new higher default probabilities. In order to return to the original problem, these L>x events would have to be corrected by the likelihood ratio, which relates the original distribution of the default events (Bernoulli(p_k)) to the new distribution (Bernoulli(q_k)). The IS estimation of Prob(L>x) would then be obtained from two expressions:

$$E(L > x) = 1 * \Pr ob(L > x) + 0 * \Pr ob(L < x) \Rightarrow \Pr ob(L > x) = E(L > x), \ (6)$$

$$E(L > x) = \tilde{E}\left[1\{L > x\} \prod_{k=1}^{m} \left(\frac{p_k}{q_k} \right)^{Y_k} \left(\frac{1 - p_k}{1 - q_k} \right)^{1 - Y_k} \right]. \ (7)$$

Where:

$1\{...\}$ = indicator of the event in braces;

$\tilde{E}$ (...) = expected value under the new default probabilities q_k;

$\prod_{k=1}^{m}(...)$ = likelihood ratio.

The idea behind Equation 6 is that L>x is also a Bernoulli-type random variable. Equation 7 results from IS main idea, expressed in Equation 5.

Therefore,

$$\Pr ob(L > x) = \tilde{E}\left[1\{L > x\} \prod_{k=1}^{m} \left(\frac{p_k}{q_k} \right)^{Y_k} \left(\frac{1 - p_k}{1 - q_k} \right)^{1 - Y_k} \right], \ (8)$$

As a result of this construction and if the default indicators are to be sampled from the new default probabilities q_k, it can be said that:

Unbiased IS Estimator of Prob(L>x) $= 1\{L > x\} \prod_{k=1}^{m} \left(\frac{p_k}{q_k} \right)^{Y_k} \left(\frac{1 - p_k}{1 - q_k} \right)^{1 - Y_k}$. (9)

Glasserman and Li (2005) do not choose the new probabilities q_k in a arbitrarily way; instead, they use the named *exponential twisting* mechanism to optimize the choice of these new probabilities. According to this mechanism, a non-negative value for θ parameter is chosen and the new probabilities are evaluated from:

$$p_k(\theta) = \frac{p_k e^{\theta c_k}}{1 + p_k (e^{\theta c_k} - 1)}. \ (10)$$

The value of θ must be such that minimizes the variance of the unbiased estimator of Prob(L>x). Glasserman and Li (2005) evaluate the optimum level of θ analytically. They prove that this optimum-θ makes the IS estimator of Equation 9 asymptotically optimal, and therefore it is more efficient than the traditional estimator using SRS. Optimum-θ value is[7]:

$$\text{Optimum-}\theta = \begin{cases} \text{Unique solution of } \varphi'(\theta) = x, & x > \varphi'(0); \\ 0, & x \le \varphi'(0); \end{cases}$$

where:

$$\varphi(\theta) = \sum_{k=1}^{m} \log\left(1 + p_k\left(\exp(\theta c_k) - 1\right)\right). \quad (11)$$

The incorporation of DS to IS procedure presented above results in a combined technique, named from now on IS+DS. This incorporation basically involves choosing deterministically instead of randomly the values of Y_k. This same set of values for Y_k is used in all simulation runs, but of course its elements are randomly permutated in each run to generate different samples[8].

2.2.2 Importance Sampling in the case of Strongly Dependent Issuers

As proposed in Glasserman and Li (2005), the IS approach in this case is a two-step procedure: 1) apply conditional IS, where Y_k variables will be conditional on a z set of values for the Z common risk factors, and 2) apply standard IS on the Z factors themselves.

On the first step, IS procedure is conditioned to a set of values for the common risk factors (Z=z), randomly chosen from standard Normal distribution. When this is done, variables Y_k are obtained from the same set of z values for the risk factors, no matter who the issuer is, and then the default indicators become independent again. Therefore, it is possible to proceed exactly as in the case of independent issuers presented in the last section. The only difference is that it will be necessary to evaluate conditional default probabilities, $p_k/Z=z$, for each issuer, instead of considering given default probabilities p_k. This conditional probability is:

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[7] See Glasserman (2004), pgs. 498 and 530.

[8] A full description of Descriptive Sampling is found in Saliby (1990) and Saliby (1997).

$$p_k /(Z = z) = \Pr ob(Y_k = 1/Z) = \Pr ob(X_k > x_k / Z) =$$

$$= \Pr ob(a_k Z + b_k * \varepsilon_k > \Phi^{-1}(1 - p_k)/Z) = \Phi \left(\frac{a_k Z + \Phi^{-1}(p_k)}{b_k}\right). \quad (12)$$

According to Glasserman and Li (2005), the second step becomes necessary when there is strong default correlation among the issuers. In order to obtain this strong correlation, the factor loadings $a_{k,i}$ are generated independently and uniformly from the interval $(0;1/\sqrt{d})$. This second step is justified because when the correlation is strong, greats losses arises firstly from great values of Z, which indicates that IS must be applied to the distribution of Z as well.[9]

Therefore, in this second step, instead of dealing with a z-set of values sampled from a standard Normal distribution, it is used a new set sampled from the Normal shifted distribution $N(\mu,1)$. From there on, it is only required to implement conditional IS already described. The only thing new is the likelihood ratio formula presented in Equation 7, which will have an additional term, $\exp((-\mu'Z+\mu'\mu)/2)$, relating $N(0,1)$ density to $N(\mu,1)$ density.

Glasserman and Li (2005) determines analytically the optimum value for μ, the shift parameter, that will minimize the variance for the estimator of Prob(L>x). In this paper, the optimum value for μ was empirically chosen to simplify the IS procedure.

The incorporation of DS to IS procedure in this case involves not only the deterministic selection of the Y_k values, but also of the Z values. These two sets of values deterministically chosen are used in all simulation runs, but off course their elements are randomly permutated in each run to generate different samples.

3 Results

Figure 2 below presents the main simulation results of the experiment executed in this paper. There are estimates of Prob(L>x) for the three different simulation methods here applied: the traditional one (SRS), the standard IS (IS+SRS) and the combined IS (IS+DS). The performance of each method was analyzed for independent issuers and for strongly dependent issuers. Estimates' precision, measured by its standard errors, is presented as well.

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[9] The analytical proof is found in Glasserman and Li (2005), pg. 8.

The chosen loss threshold (x = \$35) defines a convenient region to implement IS, as the probability of superior losses is really low for two of the cases of dependence considered. To get an idea of the magnitude of this probability, a simulation of 10000 runs was executed, using the traditional sampling method (SRS). The resulting estimates of Prob(L>x) were 0.13% for independent issuers case and 0.34% for dependent issuers case. These low percentages characterize a rare event situation in both cases of dependence.

The relevance of IS for the experiment in study can also be understood when probabilities of losses even superior than x are estimated. There is a threshold level x' (equal to \$52 in the studied model, or equivalently to 30% of possible total loss) from which the simple occurrence of the event L>x' is no longer observed, no matter the number of observations generated by the traditional method. It simply makes impossible to evaluate estimates for Prob(L>x').

Both variance reduction techniques here used (IS+SRS and IS+DS) generated similar and unbiased estimates in relation to the ones obtained within the huge simulation.

As expected, under the two cases of dependence considered, IS improved well the estimates precision in relation to SRS estimates. The precision gain of IS+SRS, or equivalently its standard error reduction, is about 88% for independent issuers and 40% for dependent issuers.

The combined technique IS+DS was also efficient in obtaining precision gains in relation to traditional SRS method, resulting in a gain of 88% for both cases of dependence. However, DS contribution was more relevant in the dependent issuers' case, generating a precision improvement of 81% in relation to IS+SRS, against only 3% in the case of independent issuers. The greater DS' contribution to IS in the dependent case is associated to the fact that DS needs to be applied twice when there are dependence among the issuers, as mentioned in section 2.2.2.

Figure 2: Estimates for Prob(L>x) according to different simulation methods (SRS, IS+SRS, IS+DS). Two cases of default dependence among the issuers were considered. The mean and the standard error of the estimates were calculated for 40 simulation runs, each one containing 1000 observations of losses.

Independent Issuers	SRS	Mean	0,1125
		Standard Error	0,0791
	IS+SRS	Mean	0,1279
		Standard Error	0,0091
	IS+DS	Mean	0,1256
		Standard Error	0,0088
Dependent Issuers	SRS	Mean	0,3250
		Standard Error	0,9388
	IS+SRS	Mean	0,3363
		Standard Error	0,5649
	IS+DS	Mean	0,3364
		Standard Error	0,1099

4 Conclusion

Importance Sampling is a variance reduction technique well suited to rare event simulation problems, because its main idea is to make the rare events less rare. This is done when the original probability distribution of the input variable is shifted to the right. Therefore, Importance Sampling technique is useful when dealing with portfolio credit risk simulation, once this kind of risk is associated to the occurrence of rare events of default by the issuers in a period of time.

This paper applied Importance Sampling as a variance reduction technique to improve Monte Carlo simulation of the loss distribution of a theoretical portfolio of bonds and loans subject to default risk of their issuers. Importance Sampling has proved to be an indispensable simulation tool to generate observations for the experiment under study, as the events of default considered here were rare. Besides, Importance Sampling, in its standard shape or in association with Descriptive Sampling, has proved to be useful in obtaining more precise estimates than the ones that would be obtained in the traditional way.

Importance Sampling precision gains has extend themselves to the more complex case of strong default correlation among the issuers of the portfolio under analysis.

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