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Research Notes in Economics

Modelling Sovereign Credit Risk: Binomial Approach

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Abstract

The global financial crisis has demonstrated the importance of measurement and monitoring of credit risk due to close links between financial instruments and economic agents. In this regard, the most popular pure credit risk derivative is credit default swap, which allows timely and up-to-date assessment of creditworthiness of reference entities. This study presents an approach to obtain practical and reliable market based credit risk indicators based on the observed prices of credit default swaps for Turkish hard currency sovereign bonds through binomial modelling. Model outputs in terms of default probabilities enable market participants to track the changes in market view of creditworthiness of Turkey across different maturities on a daily basis in response to global and local macroeconomic developments. The empirical findings show that conditional default probabilities are higher in general for longer maturities as compared to probabilities belonging to shorter maturities. However, it has been observed that the relation might be reversed during periods of high volatility in financial markets such as August 2018. This is the period where CDS curve was inverted and the likelihood of default was deemed to be more probable in the short run as compared to longer maturities. However, the inversion of implied conditional default probabilities tended to be short lived and with the normalization of market conditions, the risks receded across all maturities, most notably in the short term.

Özet

Küresel finansal kriz, finansal ürünler ve ekonomik birimler arasındaki yakın ilişki dolayısıyla kredi riskinin ölçümü ve takibinin önemini ortaya koymuştur. Bu bağlamda, kredi temerrüt takası referans kurumların kredi değerliliğine dair zamanlı ve piyasa bazlı değerlendirmeleri yansıtması açısından en popüler türev ürün olarak ön plana çıkmaktadır. Bu çalışma, binom modeli ile Türkiye'nin yabancı para cinsi tahvilleri üzerine yazılan kredi temerrüt takası primlerini kullanarak piyasa bazlı pratik ve güvenilir kredi risk göstergeleri elde edilmesine yönelik bir yaklaşım sunmaktadır. Temerrüt olasılıkları şeklinde elde edilen model sonuçları piyasa katılımcılarının günlük bazda Türkiye'nin yerel ve küresel makroekonomik gelişmeler neticesinde kredi değerliliğindeki değişimleri farklı vadeler için takip etmesini mümkün kılmaktadır. Ampirik bulgular koşullu kredi temerrüt olasılıklarının genel olarak uzun vadelerde kısa vadelere kıyasla yüksek seyrettiğine işaret etmektedir. Ancak, söz konusu durum finansal piyasalarda yüksek oynaklığın gözlendiği 2018 Ağustos ayında olduğu gibi bazı dönemlerde gelişmelere bağlı olarak değişebilmektedir. Bu dönemde, kredi temerrüt eğrisi ters eğime sahip bir seyir izlerken, temerrüt gerçekleşme ihtimali kısa vadelerde uzun vadelere kıyasla daha yüksek olarak değerlendirilmektedir. Öte yandan, ima edilen koşullu temerrüt olasılıklarındaki terse dönme hareketinin kısa süreli olduğu ve izleyen dönemde piyasa koşullarındaki normalleşmeyle beraber risklerin kısa vadelerde daha belirgin olmak üzere tüm vadelerde gerilediği gözlenmiştir.

Introduction

Credit risk is defined as the risk that a debtor may not be able or eager to make its repayments (principal or interest payments) to the creditor. Countries, financial entities, non-financial firms and households, all economic agents, and financial products are linked to each other more than before in the ongoing realm of globalization, which leads to contagion effects across the entities upon a negative shock. As an evidence, the global financial crisis has shown that the default events might produce spillover effects between indirectly related entities and raise systemic risk. In this regard, in the aftermath of the crisis, financial stability has been the main focus of the policy makers and there have been several steps taken to overcome credit risk related issues. Besides, accurate measurement of credit risk in the post-crisis period has tempted attention. In this regard, obtaining default probabilities which constitute a major ingredient in the credit risk modelling, is pivotal. In addition to being an input for credit risk modelling, knowledge of default probabilities enable regulators and risk managers to establish risk indicators and to contribute the stress testing of financial system while enabling the pricing of risk-bearing assets.

The measurement of credit risk is not straightforward as default is a rare event such that there does not exist a sufficient number of realizations for each country/corporate enabling market participants/academicians to fully characterize the process in terms of likelihood, timing and size of exposure. There have been many studies that aim to measure credit risk accurately, especially for developed markets. The most commonly used approaches for obtaining the likelihood of default can be broadly classified under two groups: structural and reduced form models.

Structural models aim to characterize the event of default as an internal process. Basically, default risk is modeled by a stochastic process standing for total value of assets of a reference entity such that default happens to be contingent upon the case that total value of entity's assets falls below its liabilities. These models establish a link between the firm's financial status and its credit quality in such a way that the credit event is generated endogenously. These models, which are based on the studies of Black & Scholes (1973) and Merton (1974), are more appropriate for modelling credit risk of firms as the value of firms' assets can be identified through data sources such as balance sheets. On the other hand, the sovereigns' value of assets is a vaguer concept, although there are attempts in the literature, such as Lehrbass (2000), to approximate it with stock market value. Additionally, a structural model might become complex for a portfolio including many entities since it requires identifying the linkages among the entities in terms of their exposure to different risk factors.

Reduced form models, on the other hand, do not investigate the causes of default as in the case of structural approaches. These approaches directly model the likelihood of default by using the information conveyed by observable market prices of defaultable securities and corresponding pricing models. As prices of marketable securities are forward looking and contain all the publicly available information under the assumption of market efficiency, they reflect the market view regarding the credit risk of an entity without resorting to any assumption for the financial structure of the obligor. The most widely used form of reduced models is presented by Jarrow and Turnbull (1995) who characterized default as the first event of a Poisson process.

There are also econometric models adopting logistic regression with a set of explanatory variables for modelling the default probability. In particular, macroeconomic variables are used as regressors for the estimation of the ability of the obligor to pay its liabilities. Kutty (1990) and Kalliomäki (2012) are examples of these studies aiming to determine the default probabilities of developing countries and their causes. However, the willingness of the obligor to meet its obligations is not generally incorporated in these models. Furthermore, empirical analysis of the default event is hampered by the fact that they are very rare events. In this regard, by using the observable market prices which are thought to involve the premium markets participants attributing to the morality of the obligor among other things, reduced form models do not exclude any information that is deemed to be important for the financial markets.

The most commonly used financial instruments that can be utilized to infer the probability of default are corporate or sovereign bonds and credit default swaps (CDS). Credit default swaps can be considered as pure indicators of credit risk. As compared to sovereign bonds, they provide a direct measure of spread that makes defining a risk-free interest rate obsolete and they also do not involve any complexities regarding taxation or early redemption optionality. Since CDS contracts allow buyers to hedge against credit risk, investors transacting in various markets such as bond, loan, equity and foreign exchange markets use CDS contracts for hedging or speculation purposes. Thanks to this comprehensive nature of CDS markets, liquidity in this market is ample and CDS spreads adjust quickly to developments affecting credit risk. In this regard, several studies point out the efficiency of CDS markets for incorporating any development related with the creditworthiness of the obligor. Hull et al. (2004b) found that credit rating announcements are anticipated in the CDS market as Blanco et al. (2004) emphasized that the CDS market leads the bond market in determination of the price of credit risk. For these reasons, CDS derivatives are commonly used to infer creditworthiness of entities.

There exist studies in the literature examining the creditworthiness of Turkey in terms of external debt repayments. As an example to reduced form models, Berardi et al. (2004) used a logit type of econometric model to estimate default probabilities for US Dollar denominated bonds of twelve countries including Turkey. For structural models, Maltritz et al. (2006) applied a Merton-type model to a sample of emerging countries covering Turkey and Keller et al. (2007) adopted contingent claims approach to quantify the evolution of Turkey's sovereign risk. This study aims to obtain a term structure of implied survival and default probabilities using CDS spreads for Turkish sovereign bonds denominated in hard currency through an iterative process of bootstrapping. To the best of our knowledge, it is the first attempt to obtain default probabilities from CDS spreads relying on reverse engineering procedure with asset pricing formulas for Turkish case. Its merits come from its 'easy to implement' and tractable properties while providing a market based reliable source of information on a daily basis regarding the creditworthiness of Turkey.

Data and Methodology

In order to obtain default probability of Turkish sovereign bonds based on market prices of credit default swaps, this study presents a valuation framework using binomial model. As the event of default is binomial in nature, cash flow structure of the credit default swaps can be demonstrated in two legs. One is the premium leg at which CDS buyers make periodic payments (premium)[1] either until the maturity of the contract or until the occurrence of default event[2], whichever comes first. The other is the protection leg at which CDS buyer is entitled to receive the par amount less recovery rate of the reference obligation when reference entity fails to meet its obligations specified in the contract[3]. The mechanics of credit default swap is illustrated below in Figure 1. As the payments at each leg are contingent upon the occurrence of the default, survival and default probabilities are required to compute the expected present values of cash flows at each leg. Using the fact that the value of the swap contract must be zero

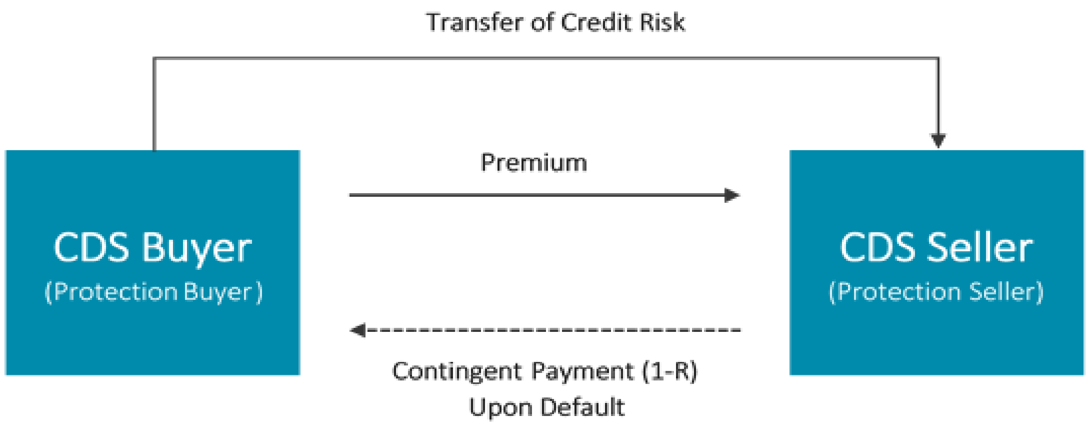
[1] As part of standardisation attempts by International Swaps and Derivatives Association (ISDA), CDSs are decided to be traded with standard spreads which are 100 bps or 500 bps per annum for sovereign reference entities whichever is closer to the market quoted spread. Upfront payments need to be made to equalise the actual spread with the standard one. This is just a change in the quotation and does not alter the calculations. Since premium only version of CDS spread data is available in Bloomberg, it is used for the valuation of CDS.

[2] Credit events for sovereign CDS are listed as failure to pay, obligation acceleration, obligation default, repudiation/moratorium and restructuring. Standardisation of CDS contracts with respect to these and other parameters are conducted by ISDA.

[3] In the event of default, settlement can be accomplished in two ways which are cash settlement and physical settlement. In a physical settlement CDS holder brings the reference entity's obligation to the protection seller and receive the par value of the obligation whereas CDS holder receives the cash payment equivalent of the fall in the price of the obligation after the credit event.

at the initiation, equating the present values of expected cash flows at each leg yields implied survival and default probabilities through market quoted CDS spreads.

Figure 1 – Mechanics of Credit Default Swap



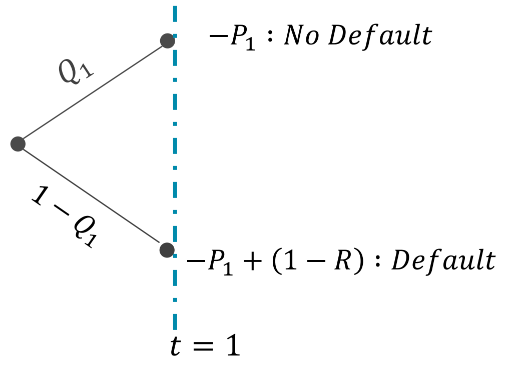
Before proceeding into valuation of a credit default swap contract, it would be insightful to introduce certain assumptions in an attempt to simplify the valuation process. The first one is that defaults are assumed to occur only at premium payment dates. With this assumption, accrued premium can be ignored as regards the present value calculation of the cash flows in the premium leg. Otherwise, the timing of default would need to be modeled in higher frequency in discrete time setting or for a continuum of time in a certain period. Secondly, default events are assumed to be independent of interest rate movements. Assuming otherwise, a framework which models the dynamics of the relationship between interest rates and default incidences, would be needed, which is out of the scope of this study. One other assumption is the constant recovery rate, whose value is approximated and published by credit rating agencies and is based on past default events. In order to illustrate the impact of the recovery rate assumption on implied default probabilities, calculations at different levels of recovery rate are examined in the empirical findings section.

The main theme in the approach adopted in this study is the arbitrage free valuation of payoffs contingent on the event of default[4]. While doing this, the study obtains the risk-neutral implied default probabilities. To illustrate the basics of deriving survival probabilities from credit default swaps, valuation formulas are demonstrated on a sequential basis starting with a single period discrete time setting. As seen in Figure 2, reference entity either survives with probability Q_1 or defaults with probability $(1 - Q_1)$. Since default is assumed to occur only at the end of each period, CDS buyer pays the premium in either case but receives the par less recovery rate (R) of the reference obligation only when default event occurs (see equation 1). Cash flows in each leg are discounted back to today using the risk free interest rate (r) with the same maturity[5].

[4] A long position in credit default swap (buying CDS contract) can be considered as the portfolio consisting of a long position in risk-free US floating rate note and a short position in a defaultable USD denominated floating note at the same maturity. Therefore, it is possible to obtain nearly the same payoff of a CDS contract through the synthetic portfolio mentioned above.

[5] For illustrative purposes, discrete compounding is assumed for the valuation of cash flows. However, continuously compounded interest rates are used for the calculation of survival and default probabilities in the other sections of the study.

Figure 2 – Extraction of Risk-Neutral Default Probabilities: 1-Period Example



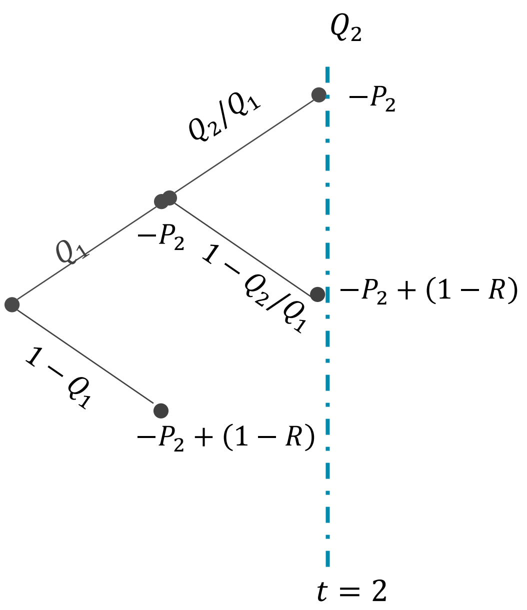
Nonexistence of arbitrage opportunities in line with the market efficiency assumption requires the payoff from protection and premium legs to be equal as it is presented in equation (1). By equating the payoffs from these two legs, implied survival probability Q_1 can be found as shown in equation (2). Therefore, the risk-neutral survival probability is a function of recovery rate and the premium paid for one single period.

$$Q_1 \frac{P_1}{1+r} = (1 - Q_1) \frac{-P_1 + (1-R)}{1+r} \tag{1}$$

$$Q_1 = 1 - \frac{P_1}{(1-R)} \tag{2}$$

The same reasoning applies to a two-period CDS contract whose payoff structure is illustrated with the help of a binomial tree below (Figure 3). If the reference entity defaults in period 1, then the CDS contract is settled and CDS holder receives the par amount less recovery. If the entity does not default and survives in period 1, there are two possibilities again: i) reference entity survives to period 2 or ii) the entity defaults.

Figure 3 – Extraction of Risk-Neutral Default Probabilities: 2-Period Example



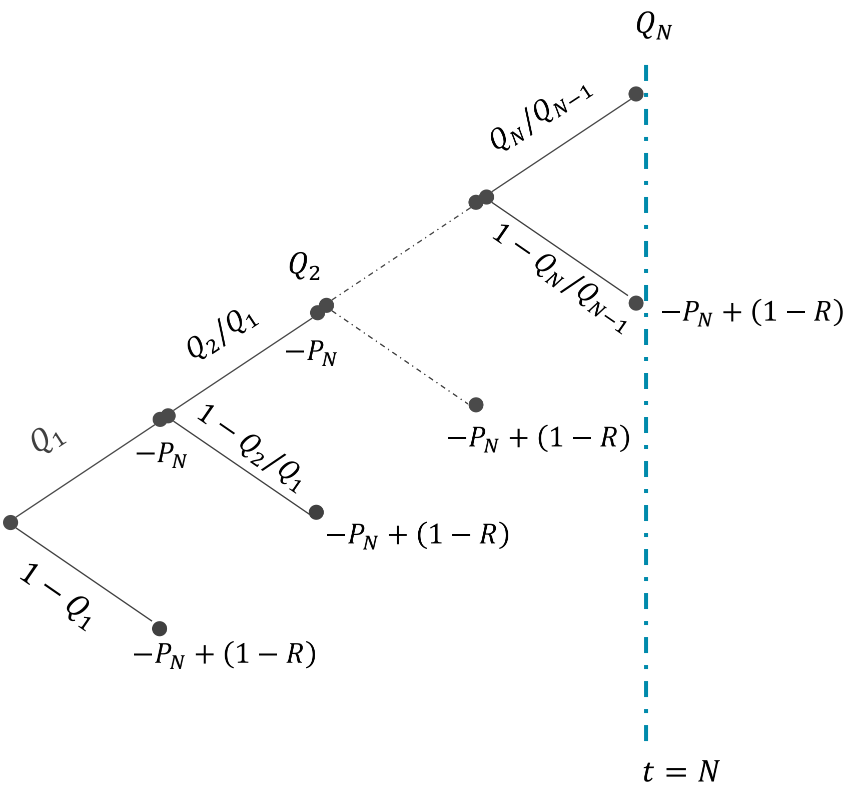
The expected discounted stream of cash flows for the premium leg is given in the left hand side of equation (3) whereas that of the contingent leg is given on the right side of the equality. As the unconditional survival probability of the entity at period 1 is known by the previous calculations given above, unconditional probability of default in period 2, Q_2 is the only unknown in the expression. Breakeven condition enables to obtain Q_2 in terms of other parameters as the expression for the unconditional survival probability is given in (4).

$$Q_1 \frac{P_2}{1+r} + Q_2 \frac{P_2}{(1+r)^2} = (1 - Q_1) \frac{-P_2+(1-R)}{1+r} + (Q_1 - Q_2) \frac{-P_2+(1-R)}{(1+r)^2} \quad (3)$$

$$Q_2 = Q_1 - \frac{P_2}{(1-R)} [(1 + r) + Q_1] + (1 - Q_1)(1 + r) \quad (4)$$

Proceeding this way, it is possible to derive the risk neutral survival and default probabilities sequentially for longer maturities using breakeven conditions as long as CDS spread quotations are available for those maturities. As shown in Figure 4, the cash flow structure of a credit default swap can be depicted with a one sided tree for N period case.

Figure 4 - Extraction of Risk-Neutral Default Probabilities: N-Period Example



That is to say, given a term structure of credit default swaps with maximum maturity N, it is possible to formulate the procedure of bootstrapping the CDS curve for obtaining risk neutral survival probabilities from CDS spreads.

Defining:

$$M_N = \sum_{t=1}^{N} D_t Q_{t-1}, \ \widehat{M_N} = \sum_{t=1}^{N} D_t Q_t \ and \ \alpha_N = \frac{P_N}{(1-R)} \quad (5)$$

where Q_i, D_i and P_i stands for unconditional survival probability, riskless discount factor and CDS premium for period i respectively. Unconditional default probabilities for the N^{th} period can be written as:

$$Q_N = \left(\frac{1}{D_N}\right)\left[M_N(1-\alpha_N) - \widehat{M_{N-1}}\right] \text{ where } Q_0 = 1 \text{ and } \widehat{M_N} = 0. \qquad (6)$$

Q_N denotes the unconditional survival probability of the reference entity up to the N^{th} period. Having found unconditional survival probabilities, it is straightforward to obtain unconditional and conditional default probabilities (PD) for each period n by using the expressions given in (7) and (8) respectively.

$$PD(t=n) = Q_{n-1} - Q_n \qquad (7)$$

$$PD(t=n \mid t=n-1) = 1 - \frac{Q_n}{Q_{n-1}} \qquad (8)$$

Unconditional default probability $PD(t=n)$ expresses the entitiy's probability of default at period $t=n$, whereas conditional default probability $PD(t=n \mid t=n-1)$ states the probability of defaulting in the next period $t=n$ conditional on having survived to time $t=n-1$.

It is also possible to derive cumulative default probability of an entity at time $t=n$ by summing the unconditional default probabilities starting from time $t=1$ to $t=n$ which can be demonstrated as in equation (9):

$$Cumulative\ PD(t=n) = \sum_{i=1}^{n} PD(t=n) = 1 - Q_n \qquad (9)$$

Binomial modelling framework is adopted using the data for CDS contracts written on Turkish sovereign debt denominated in hard currency to obtain default probabilities implied by CDS spreads. The mid-point market quotes for all available CDS spreads with 1, 2, 3, 4, 5, 7 and 10 years maturities are obtained from Bloomberg for the period between January 2017 and January 2020. Missing observations have been interpolated from adjacent maturities. Additionally, overnight index swap (OIS) rates with maturities of 1 year to 10 years are used as US dollar risk-free rates. However, as overnight index swap rates are quoted as par rate, zero-rates are obtained using Nelson-Siegel methodology. Another input for the reverse-engineering process is the recovery rate of the reference obligation after the default of the entity. Recovery rate is defined as the proportion of the par value of a bond that investors receive in case the reference entity fails to meet its obligations. The recovery rate is deemed to be a key ingredient for default probability estimation. The market standard source of recovery rates for bonds is the study of historical default rates published by Moody's regularly. For the period across 1995-2018, recovery rate of emerging market bonds is announced to be around 40 % which is taken as an input in this study.

To illustrate the methodology, risk neutral survival and default probabilities fitted to a market CDS curve of maturities from 1 year to 10 years for an arbitrarily chosen date, are demonstrated in Table 1 below. Recovery rate is assumed to be 40 % as stated previously.

Table 1: Calculation of Survival and Default Probabilities Implied By Market CDS Curve

Maturity	OIS (%)	Discount Factor	CDS (Bps)	Conditional Default Probability (%)	Unconditional Default Probability (%)
1	1,45	0,99	63	1,05	1,05
2	1,31	0,97	133	3,40	3,36
3	1,16	0,96	180	4,64	4,44
4	1,25	0,95	212	5,30	4,83
5	1,26	0,94	238	5,98	5,16
6	1,28	0,93	259	6,49	5,27
7	1,30	0,91	275	6,52	4,95
8	1,33	0,90	286	6,61	4,69
9	1,35	0,89	295	6,64	4,40
10	1,38	0,87	303	6,64	4,11

Empirical Findings

Default probabilities implied by market prices of credit default swaps for Turkish sovereign bonds can be used in a variety of forms[6]. Initially, the results are presented in the form of conditional default probabilities at various maturities for the period between January 2017 and January 2020. Conditional default probabilities are frequently labelled as forward default probabilities for they express the n-period ahead likelihood of default of the reference entity in one year. Since unconditional default probabilities are scaled versions of their conditional counterparts, they are not examined separately. As seen in Figure 5a, the implied default probability that market participants priced for all maturities tend to oscillate in an interval for the sample period until May 2018. From then onward, market implied forward default probabilities across all maturities increased sharply during the Turkish lira sell-off period between August-September 2018. Since then, default expectations have receded back and stabilized at a level seen in the pre-August 2018 period.

In order to monitor the dynamics of forward default probabilities more closely, current 1-year, 1 year forward 1 year and 4 years forward 1 year default probabilities are illustrated below in Figure 5b. Except the financial stress episode experienced in the beginning of the second half of 2018, forward default probabilities line up in an ascending order with respect to maturity since CDS curve is positively sloped. During months of August and September in 2018, conditional default probabilities for shorter maturities rose to levels exceeding their longer maturity counterparts. Market perceived default probability in 1 year reached 11.8 %. This is the case where the CDS curve is inverted (short term CDS spreads higher than long term CDS spreads) which reflects the incidence that the likelihood of default of the reference entity is higher in the immediate future; but, once the challenges causing the market sentiment to deteriorate are over in the short term, the odds that the entity will survive in the medium and long term increase. In the

[6] CDS spreads incorporate risk premium other than pure credit risk that market participants attribute to reference entity such as risk aversity nature of investors, counterparty risk, varying liquidity among different maturities pointed out by Jarrow in depth (2012). However, it is rather difficult to disentangle the impact of these factors separately and there is no consensus view reached for isolating their true time varying effect in the literature.

latter period, the inverted shape of the CDS curve normalized where default probabilities adjusted accordingly. Furthermore, short end of the curve demonstrates a higher variability than the front end reflecting the case that investor's expectations for shorter maturities are subject to higher fluctuations against financial market developments.

Figure 5a - Conditional Default Probabilities
(Forward Probabilities)

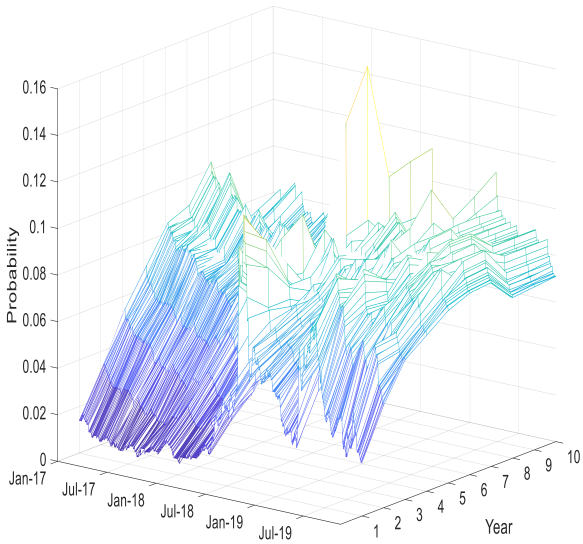
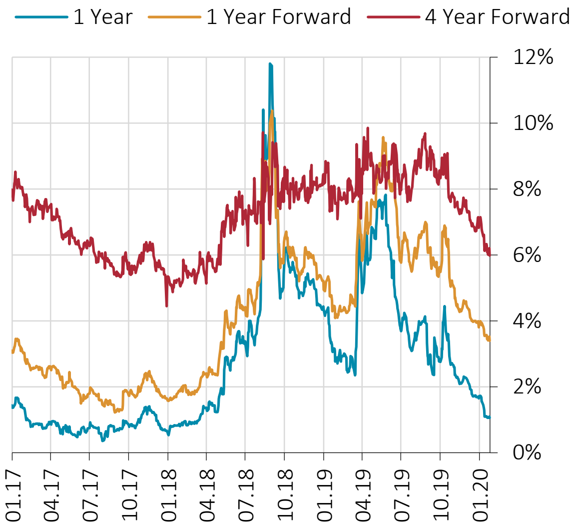


Figure 5b - Conditional Default Probabilities
(Forward Probabilities)



Under the model used in this study, recovery rate is assumed to be fixed at 40 % based on the historical calculations collected and shared by Moody's for EM sovereign hard currency bonds. This is also the market practice so that the valuation of credit default swaps on Turkey's foreign currency denominated sovereign bonds and extraction of default probabilities can be obtained accordingly. However, it could also be meaningful to see the impact of the changes in recovery rate on implied default probabilities. Figure 6a presents the sensitivity of conditional default probabilities for all maturities (1 year-10 year) with respect to a range of recovery rates lying between [5 % - 75 %] for an arbitrary day. The shaded region shows the default probabilities corresponding to a range of recovery rates for interim maturities. As the recovery rate increases, given that CDS spreads and other parameters stay constant, market implied default probabilities have to rise to satisfy the equality between premium and protection legs for all maturities. This is because an increase in recovery rate leads the CDS holder to incur a smaller amount of loss in the event of default. Therefore, for the CDS buyer to pay the same amount of premium as in previous case, credit event needs to have a higher probability than before. Furthermore, the marginal increase in the conditional probability with respect to an increase in the recovery rate is higher for longer maturity default probabilities. In addition to the maturity, the level of spreads also plays a role in the magnitude of marginal impact of recovery rate on market implied default probabilities. Figure 6b shows that during stressful episodes in financial markets, a unit change in the recovery rate has a much larger impact on default probabilities than during periods of tranquility.

Figure 6.a Sensitivity Analysis of Default Probabilities with respect to Recovery Rates

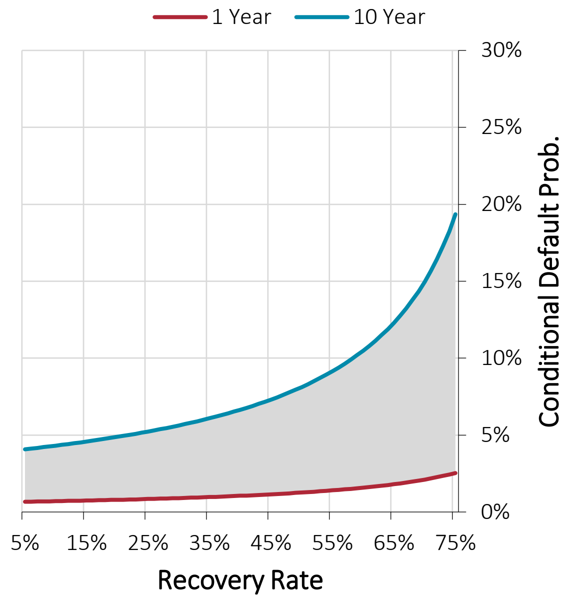
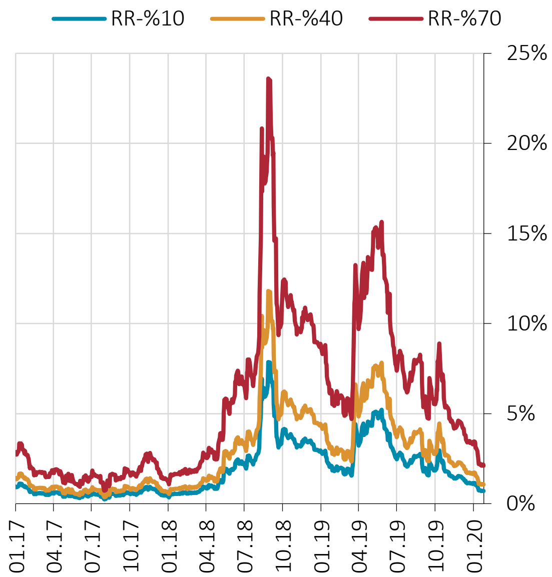


Figure 6.b Sensitivity of Default Probabilities with respect to Recovery Rates



Conclusion

The importance of accurate measurement of credit risk has been understood by market participants and policy makers especially after the global financial crisis. Given the complexity of financial markets and the dynamic interaction between financial instruments and economic agents, it is vital to monitor credit risk with high frequency market based indicators. In this regard, the most popular and liquid credit risk instrument is CDS, which is a pure measure of credit risk. CDSs for sovereign hard currency debts have been closely monitored and traded by economic agents for the purposes of speculation and hedging among other things. In this study, practical and comprehensible market based credit risk indicators are obtained by using the information conveyed by credit default swaps on hard currency bonds issued by Ministry of Treasury and Finance of Turkey. These indicators are helpful to monitor the changes in the market view of riskiness of the country in response to local or global macroeconomic and political developments.

As credit is a two-state event, survival and default probabilities are computed by using binomial model under certain assumptions across different maturities. This study outlines the technical background for the computation of default probabilities through an iterative process of bootstrapping the CDS curve and outlines the results of the model for the recent period. Furthermore, as recovery rate is one of the most important determinants of credit risk, sensitivity analysis of default probabilities under different levels of recovery rate is performed and corresponding findings are presented.

When the empirical findings are reviewed, conditional default probabilities in the short term are observed to be smaller than the conditional default probabilities corresponding to longer maturities in compliance with the upward sloping nature of CDS curve in most of the cases for the period of January 2017 and afterwards. The exception is the high volatility period of August 2018 where CDS curve was inverted and the likelihood of default was priced to be more probable in the short run as compared to longer maturities. This situation reflected rising concerns towards the state of the economy in the immediate future. However, these concerns turned out to be short-lived and the deterioration in the risk perception of market participants were reversed in the following period.

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