# CONTINGENT CLAIMS ANALYSIS AS A CREDIT RISK METRIC: EVIDENCE FROM TURKEY

Burcu Bahcecı Baskurt
Department of Business Administration; Faculty of Business and Economics; Izmir Kâtip Celebi University, Turkey
burcu.baskurt@ikcu.edu.tr

Şaban Çelik
Department of Business Administration; Faculty of Business and Economics; Izmir Kâtip Celebi University, Turkey
saban.celik@ikcu.edu.tr

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**Abstract**

Credit ratings have become open to dispute in recent years regarding their objectivity, timeliness, and the criteria considered in the assignment process, which resulted in an inclination toward other methods to measure credit risk. This study applies contingent claims analysis, a novel risk analysis technique, in Turkey to assess their credit risk appropriately and investigate the determinants of the sovereign credit risk correctly. While the technique has been applied in Turkey before, the study contributes to the results of the preceding literature by applying the technique at a wider spectrum in terms of regarding the assessed risk indicators, time horizon considered, diagnosis tests, and sensitivity analyses. Risk indicators are calculated by applying this method to Turkey between July 2009 and December 2020. Results highlight that the movements in the risk indicators reflect the market. To ensure robustness, the Spearman rank-order correlations of the model risk measures with three market indicators are calculated, and sensitivity analyses are done. The credit default swaps are found to be correlated with all of the model risk measures, while the distance to distress is correlated with sovereign bond spreads, affirming model robustness. Analysis results highlight that among the variables for which sensitivities are assessed, changes occurring in the volatility of local currency liabilities heavily impact the risk indicators. Hence, the contingent claims approach model is robust in considering the correlations of model risk indicators with actual market data. Therefore, the model can be used in policymaking for realistic results.

JEL: G13, G17, G24
Keywords: Contingent claims analysis, Credit rating, Credit risk.

## 1. Introduction

Sovereign credit risk is a distinguished issue of international finance as it indicates the vulnerability of a sovereign. To handle the credit risk correctly, analyzing the weak links in the chain appropriately is required.

Following the contingent claims approach (CCA, hereafter) pioneered by Fisher Black and Myron Scholes (1973) and Robert C. Merton (1973), the risk-adjusted balance sheet of Turkey is constructed to evaluate the credit risk correctly initially. For convenience, it is suggested to apply the CCA technique to emerging market economies as the model necessitates differentiating between the local and foreign currency liabilities, and the probability of having foreign currency liabilities is higher for the emerging economies than for the advanced ones (Rahmi E. Aktug 2014, p. 295). Considering Turkey's swinging credit ratings in recent years, Turkey found appropriate to apply the technique for illustration purposes. Second, the research subject investigates the relations between the model risk indicators and several traditionally accepted risk indicators by calculating the Spearman correlation coefficients to make robust interpretations. Lastly, the study aims to make wide-ranging sensitivity analyses by considering diversified scenarios.

To date, this paper is a pioneer in intricately analyzing Turkey’s credit risk stance by assessing three risk indicators of the CCA model. Even though Keller, Kunzel, and Souto (2007) and Aktug (2014) applied the CCA technique to Turkey, the former considered only the risk-neutral probability of default, while the risk-neutral default probability, the distance to distress and implied CDS spreads are calculated in the latter. However, as the risk-neutral probability of default, the distance to distress, and the implied credit spreads are computed as the proposed risk indicators in this study, it is possible to evaluate the results from a broad perspective.

The Spearman rank-order correlations between the model and traditional risk indicators are calculated and found to be parallel with the traditional market-based risk indicators, supporting the robustness of the model. As this study examines a larger time window than others focusing on Turkey, evaluating the credit risk for a long period is possible. In contrast to the other studies examining the credit risk of Turkey, sensitivity analyses are done after applying the model to understand the main determinants of model risk measures. While Aktug (2014) applied sensitivity analysis and changed the volatility of national markets only, monetary bases, external debts, local currency liabilities, and spot exchange rates are changed to examine the sensitivity of the risk indicators following the study of Marie Briere, Benno Ferrarini, and Arief Ramayandi (2016). The volatility of local currency liabilities is found to be an important determinant of model risk indicators. Considering the volatile conjuncture of the sovereign, sensitivity analyses might be significantly useful in tailoring policies to mitigate the risk.

Section 2 includes the examination of relevant literature. The theoretical framework and background are introduced in Section 3. Section 4 discusses the data and methodology. The empirical results and robustness tests are shown in Section 4, and the study concludes in Section 5.

## 2. Literature review

The first sovereign application of the approach was made by Michael T. Gapen et al. (2005) on twelve emerging market economies. The study's results, in which robustness tests, regressions, and scenario analyses on the CCA risk indicators were applied, showed that the risk indicators of the CCA model were more robust and significant than the market-based ones. Dale F. Gray, Robert C. Merton, and Zvi Bodie (2007) worked on Brazil and proved that the risk-neutral probability of default strongly correlates to CDS spreads, highlighting that the CCA approach is better at forecasting non-linear movements in the market. Keller, Kunzel, and Souto (2007) investigated Turkey's risk profile changes by adopting the CCA approach. Considering the distance to distress and the risk-neutral probability of default, improvements were found in the credit risk profile of Turkey, and the latter was strongly correlated with CDS spreads. Another study applying the model to emerging markets was made by Johan G. Duyvesteyn and Martin P.E. Martens (2012), which examined the sovereign credit risk of eight emerging market economies. The study concluded that the risk indicators of the model strongly correlate to CDS spreads. Hence, the model indicators were found to be robust. As another example of studies on emerging market economies, Aktug (2014) worked on Brazil, Mexico, and Turkey by applying the CCA technique. He found that the model calculates risk indicators significantly smaller than the credit ratings, highlighting the need to recalibrate the model calculations.

South-eastern Asia countries are often the subjects under the model. Wan-Ni Lai (2016) examined the credit risk at household and sovereign levels in Singapore and concluded that the distance to distress and the risk-neutral probability of default indicators are relatively high and low, respectively, while the indicators worsen during crisis. Briere, Ferrarini, and Ramayandi (2016) and Ho Hong Hai and Tran Duy Long (2017) investigated credit risk in Southeast Asia countries using the CCA model. The former proved a negative correlation between distance to distress and CDS spreads, while the latter confirmed a positive correlation between the risk-neutral probability of default, the risk-neutral credit spreads, and sovereign bond spreads, including the negative correlation between distance to distress and sovereign bond spreads, affirming the robustness of the indicators. Devendra K. Jain, Rup Singh, and Arvind Patel (2020) examined the sovereign credit risk of Fiji and proved that the distance to distress and the risk-neutral probability of default values showed the positive circumstance of the country regarding credit risk.

Even though it is difficult to implement the model in advanced economies due to the probable inadequacy of foreign currency debt, European countries are employed in CCA studies. Moisa Altar, Adam-Nelu Altar-samuel, and Ioana Marcu (2014) and Dale F. Gray and Andreas A. Jobst (2011) investigated the credit risk of four European countries and Sweden, respectively. The result that the risk-neutral probability of default was significantly different from zero only during a crisis was reached by the former, while Gray and Jobst (2011) applied scenario analyses and stress tests after calculating expected losses and implied credit spreads for Sweden. Manish K. Singh, Marta Gomez-Puig, and Simon Sosvilla-Rimero

(2021) affirmed that for eleven European countries, the distance to distress indicator was correlated with market-based indicators, including CDS spreads, sovereign bond spreads, and credit ratings, providing evidence for the robustness of the indicator. Dennis Kahlert, Niklas F. Wagner, and Ludwig Weipert (2017) and Manish K. Singh, Marta Gomez-Puig, and Simon Sosvilla-Rimero (2019) studied Eurozone countries and included some modifications to the model in their studies. The former one extended the model by including jump-diffusion process properties, while the latter considered detailed prioritization of the lenders. Kahlert, Wagner, and Weipert (2017) found that the modified model could calculate the probability of default, credit contagion, and systemic risks, while the modified distance to distress was better at forecasting actual value, as confirmed by correlations with market-based indicators according to Singh, Puig, and Sosvilla-Rimero (2019). Dale F. Gray et al. (2013) applied CCA Global VAR on fifteen European countries, the United States at the sovereign level, and the banking and corporate sectors of the United States with the simulation of various shock scenarios. Dale F. Gray (2014) worked on fifteen European countries, Japan, and the United States to examine interactions causing crises to spread between banks, insurance firms, various sectors, and sovereigns using the CCA-network model. He found evidence that interactions increasing during a crisis go down asymmetrically from sovereign to sectoral risks.

## 3. Background and theoretical framework

Contingent claims are the financial assets whose payoff devolved on another financial asset value (Marie Briere, Benno Ferrarini, and Arief Ramayandi 2016, p. 2). In applying the CCA, the value and the volatility of the sovereign assets are derived from the liability part of the risk-adjusted sovereign balance sheet, which reflects the volatility in the market and internalizes the non-linear movements (Christian Keller, Peter Kunzel, and Marcos Souto 2007, pp. 9-10). The model requires certain adaptations for sovereign applications.

The touchstone of the CCA approach is the risk-adjusted balance sheet concept in which liabilities derive their values from assumed assets to follow a stochastic process. This risk-neutral balance sheet is formed by consolidating basic government and monetary authority balance sheets into which current market prices are incorporated to ensure risk-adjusted results (Ho Hong Hai and Tran Duy Long 2017, p. 24). In this way, better credit risk forecasts are possible as the current dynamic market information is considered instead of static financial ratios.

In the context of Turkey, which faced a volatile conjuncture created by highly unstable exchange rates and the ongoing impacts of the COVID-19 pandemic on the domestic markets, grasping the vulnerability of the sovereign balance sheet properly becomes critical. Risk indicators of traditional models usually focus on debt sustainability. Although financial ratios are calculated using stocks, flow of funds, and debt information provided in the financial tables to measure credit risk have been used prominently, the results of these analyses may be significantly lagged. As the financial tables are prepared periodically, risk indicators calculated using them cannot reflect the continuous changes in sovereign vulnerability. Additionally, these traditional approaches are mainly based on macro fundamentals and cannot internalize non-linear changes in measuring credit risk (Aktug 2014, p. 294; Devendra K. Jain, Rup Singh, and Arvind Patel 2020, p. 2).

To perceive the credibility of a sovereign, sovereign credit ratings reflecting experts' opinions about the creditworthiness of a government have been used since the early twentieth century (Aktug 2014, p. 294). Sovereign credit risk valuation is done by credit rating agencies. Among those, Fitch, Moody's, and Standard & Poor's (S&P, hereafter) are the most prominently known ones. Assigning credit ratings is convenient for companies and countries, and the same measurement scale is employed globally. However, the ratings are argued to reflect the policies and political stance, competitiveness, and regulatory quality instead of economic fundamentals (Dimitrios Soudis 2017, p. 174; Periklis Boumparis, Costas Milas, and Theodore Panagiotidis 2017, p. 58). Additionally, credit ratings agencies are paid by the issuers of the securities that are to be evaluated, not by the investors, which may result in high ratings to ensure ongoing business relationships (Miloš Bozovic, Branko Urosevic, and Boško Zivkovic 2011, p. 222). Thus, other studies' results reflect the procyclical nature of the ratings, which means that during downgrading periods, the rating agencies become oversensitive to the fundamentals, resulting in excessive downgrading (Giovanni Ferri, L-G Liu, and Joseph E. Stiglitz 1999, p. 347; Brieuc Monfort and Christian B. Mulder 2000, p. 25; Carmen Broto and Luis Molina 2016, p. 222). Additionally, sovereign credit ratings are claimed to be sticky, so they require an adequately large divergence between predicted and actual ratings for rating upgrades and are found to be affected by the sovereign's default history (Nada Mora 2006, p. 2061). Stickiness of the ratings also stems from different credit rating agencies wanting to have relatively stable ratings across time and countries to ensure consistency, resulting in unpractical ratings for signaling during sudden changes (Bozovic, Urosevic, and Zivkovic 2011, p. 222).

The economic uncertainty heavily affects the low-rated countries more, causing bigger downgrades and possibly increased stickiness (Boumparis, Milas, and Panagiotidis 2017, p. 58). Hami Saka and Mehmet Orhan (2018) proved that for most countries they had evaluated, well-known credit rating agencies assign significantly different ratings, causing these ratings to be approached with suspicion. It is claimed that the rates these agencies give to developed countries better than those are given to the developing ones regardless of the macroeconomic fundamentals (Derya Gultekin-Karakas, Mehtap Hisarciklilar, and Huseyin Ozturk 2011, p. 81). Considering the bottom line of relevant literature and the fact that even though various factors underlying the ratings are revealed, the relative weights of these factors and other details of the sovereign rating assessment procedures are not revealed elaborately (Helmut Reisen 2002, p. 2; Mora 2006, p. 2043; Manish K. Singh, Marta Gómez-Puig, and Simón Sosvilla-Rivero 2019, p. 6). This caution in assessing the credit ratings is suggested.

Instead of depending only on the traditional methods to assess sovereign credit risk, CCA is formed by synthesizing the traditional approach with up-to-date market information and modern finance theory (Aktug 2014, p. 294). The initial milepost of the approach is found in the study of Black and Scholes (1973) and

Merton (1973), who were defending that corporate liabilities could be evaluated by option pricing methods. Finally, four years later, Robert C. Merton (1977) published his study on measuring the risk exposure of the finance sector and claimed that, considering the correspondence between a bank and deposits with a firm and its liabilities; deposit insurance might have a "isomorphic correspondence" with common stock put options.

CCA approach internalizes market prices constituted by the collective ideas and expectations of the market participants, making the model results more realistic and foreseeing in credit risk assessment than the traditional methods. Considering the deep fluctuations in the value of the Turkish Lira, decreased interest rates, and one of the highest annual inflation rates of the sovereign history (48.69% as of January 2022[1]), internalizing the current market prices in the process of credit risk measurement becomes critical to assess the vulnerability of the sovereign balance sheet properly. Moreover, the seniority structure of the liabilities is incorporated into the credit risk assessment process. Since the future value of the sovereign assets is uncertain, they are derived from the value of sovereign liabilities calculated using the Black–Scholes option pricing formula in creating the risk-adjusted balance sheet.

In Table 1, the consolidated balance sheet is shown. On the assets side, the first component is the foreign reserves, which include gold and foreign exchange reserves and the special drawing rights given by international organizations. The second part of the assets is the net fiscal assets, which show the present value of future taxes and revenues after deducting the present value of future non-discretionary expenses, including education, welfare, core infrastructure, and defense expenditures (Wan-Ni Lai 2016, p. 446). Other assets comprise the last part of the assets section, which includes the value of the public sector's monopoly in issuing money, sovereigns' equity in public enterprises (Dale F. Gray, Robert C. Merton, and Zvi Bodie 2007, p. 10), unrealized liabilities, obligations of pension and healthcare systems, other sovereigns' contingent financial supports (Dale F. Gray and Andreas A. Jobst 2011, p. 38), and other financial and non-financial assets.

Table 1
Risk-adjusted balance sheet.

| **Assets** | **Liabilities** |
|---|---|
| Foreign reserves<br>Net fiscal assets<br>Other sovereign assets (Guarantees) | Local currency liabilities (Monetary base + Local currency debt)<br>Risky debt (Foreign currency debt) |

In the consolidated balance sheet, the liabilities section must comprise items in observable quantities and market values. That is why guarantees given to too-big-to-fail entities are subtracted both from liabilities and assets sections to ensure

[1] https://tradingeconomics.com/turkey/inflation-cpi. Retrieved on 18th of February 2022.

consistency (Moisa Altar, Adam-Nelu Altar-samuel, and Ioana Marcu 2014, p. 26). The first item in the liabilities part is the monetary base, which includes currency in circulation, required and excess bank reserves, and vault cash. Local currency debt is another item in the liabilities. Lenders of the local currency debt get their interest payments. However, the government can restructure or postpone the payments to these lenders. Furthermore, besides the inflationary results, the government may issue money to pay off local currency debts (D. F. Gray, Merton, and Bodie 2007, p. 11). In the risk-adjusted balance sheet, monetary base and local currency debt are rearranged as local currency liabilities (LCL).

Foreign currency liabilities constitute the other part of the liabilities section, formed by the sovereign debt denominated in foreign currency usually held by foreigners. Emerging market economies are found to be borrowing in foreign currencies often, called an “original sin” (Barry Eichengreen, Ricardo Hausmann, and Ugo Panizza 2005, p. 235). As this kind of debt cannot be paid by issuing money, and governments cannot provide flexibility by restructuring or postponing the payments related to these debts. Foreign currency debts are found to be riskier than LCL. Additionally, this kind of borrowing causes an aggregate currency mismatch on the borrowers’ balance sheets, which may result in higher volatilities of output and capital flow, decreased credit ratings, and increased financial vulnerability. That is why even though it is important to examine sovereign behaviors, especially in financial distress periods to understand their prioritization pattern (Dennis Kahlert, Niklas F. Wagner, and Ludwig Weipert 2017, p. 12), LCL have a subordinate stance vis-à-vis foreign currency debts, and the latter is found to be senior to the former one, considering the re-adjustment options for local currency liabilities (Eichengreen, Hausmann, and Panizza 2005, p. 243; International Monetary Fund [IMF, hereafter] 2002). As an important example of the prioritization pattern, Russia decided on the compulsory extension of terms on local currency debts, while the foreign currency debts were to be paid on time (Akira Ariyoshi et al. 2000, pp. 60-61).

Merton (1973) assumed that a firm's assets are financed by two types of liabilities: Equity and debt. For sovereign applications, equity and debt are replaced by local currency liabilities and risky debt, respectively.

Local currency liabilities are contingent on the company's debt because the shareholders get their payoff only after commitments are honored. At this point, uncertainty must be considered as the assets move in a stochastic manner, so the value of the sovereign assets is uncertain. That is why both LCL and risky debt derive their values from the stochastic asset values and considering Black–Scholes–Merton (BSM, hereafter) option pricing theory would be appropriate in assessing the balance sheet relations in such an uncertain conjuncture. LCL may be modeled as an implicit call option on the value of the sovereign assets for why the holders of the option get paid only when the underlying assets’ value is over the strike price, which is analogous with the promised payments in this approach. Hence, if the assets are adequate to cover the promised payments, the residual value of the assets would be left to LCL, and whole assets would be sold to pay off the promised payments.

Even though the risky debts are prioritized among the payments, there exists the possibility of inadequate assets to pay the debt, as the value of the assets moves stochastically. Thus, the value of risky debt is also contingent on the sovereign assets. For risky debt lenders, the value of default-free (riskless) debt equals the summation of the value of risky debt and the guarantee on the debt, which gives lenders the right to liquidate the borrowers' assets in the case of default to receive their payments at least partially (Gray, Merton, and Bodie 2007, p. 11). This right to sell is modeled as an implicit put option in the CCA approach that may be exercised if the promised payments exceed the value of the borrower's assets. This put option represents the debt guarantee or expected loss in the case of default (Jain, Singh, and Patel 2020, p. 5).

In the CCA model, promised payments at a certain maturity date are defined as a distress barrier (DB, hereafter). In assessing the sovereign credit risk, the value of the assets revolves around this barrier due to the stochastic movements. If the implied value of assets is inadequate to pay the promised payments, sovereign distress appears.

Figure 1 shows the basic reasoning underlying the CCA approach.

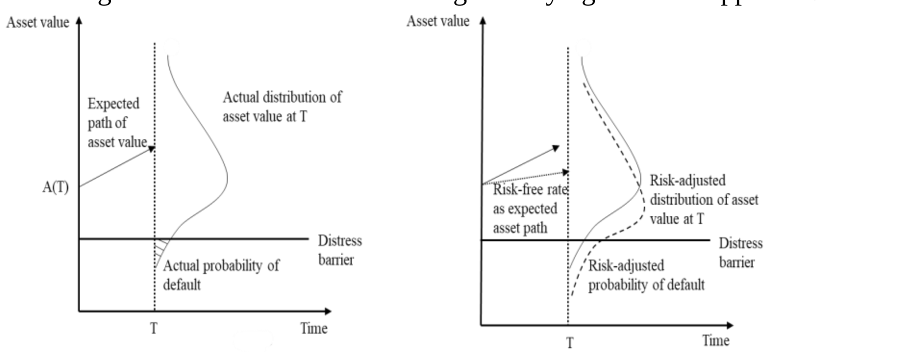


**Figure 1** Probability distribution of asset value regarding the DB (Adapted from Gray, Merton, and Bodie 2007, Figure 1)

In Figure 1, the value of assets starts from A(0) and reaches A(t) at time t. The expected path of asset value is shown. Due to the stochasticity in the asset return pattern, assets' value at time *t* is uncertain and can be any value in the distribution range, as shown in (a). Asset values are distributed in a log-normal pattern (Michael T. Gapen et al. 2005, p. 15). If the asset value falls below the DB shown in the figure, default occurs (Gray, Merton, and Bodie 2007, p. 7). Thus, the probability of default can be calculated as the distribution area under the barrier. In the model, asset drift is equal to the risk-free rate, resulting in a lower asset value at time *t*, as shown in (b). Consequently, the distribution of the asset value changes, and the distribution area under the barrier gets larger. Thus, the probability that the asset value falls below the DB at time *t* increases, and the risk-adjusted default probability is calculated by this area. Since the model uses risk-free interest rates instead of the expected return of the assets, the risk-neutral probability of default would be higher than the actual one (Gapen et al. 2005, p. 8). The asset value decreases or becomes volatile if the DB increases, and the risk-adjusted default probability increases. Default occurs at the end of the period.

The assets move in a stochastic manner, so the value of the sovereign assets is uncertain. Some sovereign assets, including the right to issue money and those not traded in the market, cannot be valued properly. For this reason, to estimate uncertain and unobservable asset values indirectly, benefiting from the liability side of the risk-adjusted balance sheet, which comprises the claims on the assets, is required in the CCA approach.

For the sovereign applications of the CCA model, choosing the sovereign wisely to evaluate the credit risk is important. As the model requires differentiation of the local and foreign currency debts, applying the model to emerging market economies is appropriate because advanced economies with strong local currencies usually have extremely limited foreign currency debt. Consequently, the calculated DB is usually zero or near zero. Similarly, as the DB calculation is impossible without foreign currency debt, the volatility of the LCL, implied value of the sovereign assets, and consequent risk indicators could not be computed for these countries. For this reason, it is more convenient to select emerging market economies with significant foreign currency debt and reachable CDS spread data.

In applying the CCA approach, all items in the risk-adjusted balance sheet must be in the same currency. Usually, prominently used currencies are chosen. If the sovereign has foreign currency debts in different currencies, all foreign currency debts must be converted into the chosen currency and summed to get the total risky debt amount. The European Union Economic and Monetary Union member countries cannot issue money for which the European Central Bank is authorized. Hence, practicing the model in these countries is inappropriate (Johan G. Duyvesteyn and Martin P.E. Martens 2012, p. 2).

## 4. Data and methodology

### *4.1. Data*

It is very important to measure the credibility of emerging markets, in Turkey in particular, because these markets are the target of many direct and/or indirect foreign investments. In this context, Turkey was chosen to illustrate the analysis, considering the recent changes in its credit ratings and data availability.

In the study, the model requires balance sheet data and market information to construct the consolidated balance sheet and calculate credit risk indicators. Data in daily frequency is used for the period covering from the 31$^{st}$ of July, 2009, to the 31$^{st}$ of December, 2020. Balance sheet items are converted into the United States dollars before calculations.

Data is mainly collected from six sources:

i. The Ministry of Treasury and Finance of Turkey: Quarterly series of the domestic currency and foreign currency debt.

ii. The Central Bank of the Republic of Turkey: Weekly series of the monetary base, spot exchange rate of Turkish Lira versus United States dollar on a daily frequency.

iii. Investing: Turkey sovereign bond spreads with 1- and 5-year maturities on daily frequency.

iv. Yahoo Finance: United States sovereign bond spreads with 1- and 5-year maturities on daily frequency.

v. Bloomberg: Daily series of 1- and 5-year CDS spreads for Turkey.

vi. Trading Economics: Credit ratings assigned to Turkey by three credit rating agencies.

The monetary base is the sum of currency in circulation and bank reserves (Kahlert et al., 2017: 9). Regarding the foreign debt data, the model requires the data to differentiate between short- and long-term foreign debts. In this way, computing the DB is possible.

To ensure consistency, for the analyses considering maturities of 1- and 5-year, respectively, CDS and sovereign bond spreads are included in the calculations with the relevant maturity. Following Jeffrey R. Bohn (2000), Gray et al. (2013), and Briere, Ferrarini, and Ramayandi (2016), the LCL and foreign debt variables are linearly interpolated to get series in daily frequencies to make them consistent with the other series used in analyses.

Considering that the dataset is not distributed normally and by following Gapen et. Al. (2005), Aktug (2014), and Hai and Long (2017), the Spearman rank-order correlations between the CCA approach credit risk indicators and market-based measures are checked to ensure the model's robustness. The three market-based measures considered in the empirical analyses are the CDS spreads, sovereign bond spreads, and the borrowing costs following the credit ratings assigned to Turkey by Fitch, Moody's, and the S&P. These ratings are numbered in Table 2 to show the increasing borrowing costs of the sovereigns following the lower credit ratings to compensate for high credit risks. It is shown that even though Moody's uses a different rating scale than the other two agencies, after lining the ratings up hierarchically, ratings with the same rank are considered equal. For the period covering from July 2009 to December 2020, credit ratings given by the mentioned credit rating agencies are included in the study to compute mean borrowing costs related to the ratings as a market-based indicator.

Table 2
Credit ratings scale.

| **Definition** | **Fitch** | **Moody's** | **S&P** | **Borrowing Cost** |
|---|---|---|---|---|
| Prime | AAA | Aaa | AAA | 1 |
| High Grade | AA+ | Aa1 | AA+ | 2 |
| | AA | Aa2 | AA | 3 |
| | AA- | Aa3 | AA- | 4 |
| Upper-Medium Grade | A+ | A1 | A+ | 5 |
| | A | A2 | A | 6 |
| | A- | A3 | A- | 7 |
| | BBB+ | Baa1 | BBB+ | 8 |

| | | | | |
|---|---|---|---|---|
| Lower-Medium Grade | BBB | Baa2 | BBB | 9 |
| | BBB- | Baa3 | BBB- | 10 |
| Speculative | BB+ | Ba1 | BB+ | 11 |
| | BB | Ba2 | BB | 12 |
| | BB- | Ba3 | BB- | 13 |
| Highly Speculative | B+ | B1 | B+ | 14 |
| | B | B2 | B | 15 |
| | B- | B3 | B- | 16 |
| Substantial Risk | CCC+ | Caa1 | CCC+ | 17 |
| | CCC | Caa2 | CCC | 18 |
| | CCC- | Caa3 | CCC- | 19 |
| Extremely Speculative | CC | Ca | CC | 20 |
| | C | Ca | C | 21 |
| In Default | RD | C | RD | 22 |
| | SD | - | SD | 23 |
| | D | - | D | 24 |

Source: https://www.moneyland.ch/en/rating-agencies.

*4.2. Methodology*

The methodology of the CCA approach is well constituted in the relevant literature (Fisher Black and Myron Scholes 1973; Robert C. Merton 1973; Robert C. Merton 1977; Gapen et al. 2005; Gray and Jobst 2011). Merton (1973) focused on the analogy between the shareholders' equity of a company and a call option, considering that the equity is contingent on the value of the debts taken by the company. For this reason, the probability of default for a company was modeled by applying the BSM option pricing model, which was later extended to an application on sovereigns by Gapen et al. (2005).

In the CCA approach, a sovereign balance sheet is constructed, making sovereign assets financed by two types of liabilities: LCL and risky debts, where the former is calculated by summing up the monetary base and the local currency debt of the sovereign that is converted into the foreign currency by using forward exchange rate (Hai and Long 2017, p. 26; Jain, Singh, and Patel 2020, p. 9).

Following Gray, Merton, and Bodie (2007), basic balance sheet relations can be summarized as follows.

$$\mathrm{A}_{\$} = \mathrm{D}_{\$} + \mathrm{LCL}_{\$} \tag{1}$$

$$\mathrm{LCL}_{\$} = \mathrm{MB}_{\$} + \mathrm{DD}_{\$} = \frac{(\mathrm{MB}e^{r_d t} + \mathrm{DD})e^{-r_f t}}{\mathrm{X_F}} \tag{2}$$

Here, $r_d$ and $r_f$ represent the domestic and foreign risk-free interest rates, respectively. $X_F$ is the forward exchange rate.

Since the LCL are analogous to an implied call option, contingent on the assets with strike prices equal to the DB (Gray, Merton, and Bodie 2007, p. 14; Lai 2016, p. 439), the value of the item could be calculated by using option pricing formula. Using the Black–Scholes option pricing equation as in Merton (1977), the value of $LCL_{\$}$ could be shown as:

$$LCL_{\$} = A_{\$}N(d_1) - DB_{\$}e^{-r_f T}N(d_2) \tag{3}$$

Where,

$$d_1 = \frac{\ln\left(\frac{A_{\$}}{DB}\right)+\left(r_f+\frac{\sigma^2_{A_{\$}}}{2}\right)t}{\sigma_{A_{\$}}\sqrt{t}} \tag{4}$$

$$d_2 = d_1 - \sigma_{A_{\$}}\sqrt{t} \tag{5}$$

$\sigma_{A_{\$}}$ is the volatility of the asset value, N(.) is the cumulative standard normal distribution function (Gapen et al. 2005, p. 14), and *t* is the time to maturity.

The last variable required to be calculated is the volatility of the local currency liabilities, which can be computed as below.

$$\sigma_{LCL_{\$}} = \sqrt{\left(\frac{MB_{\$}}{MB_{\$}+DD_{\$}}\right)^2 \sigma^2_{MB_{\$}} + \left(\frac{DD_{\$}}{MB_{\$}+DD_{\$}}\right)^2 \sigma^2_{DD_{\$}} + 2\rho_{MB_{\$},DD_{\$}}\left(\frac{MB_{\$}}{MB_{\$}+DD_{\$}}\right)\sigma_{MB_{\$}}\left(\frac{DD_{\$}}{MB_{\$}+DD_{\$}}\right)\sigma_{DD_{\$}}} \tag{6}$$

Where,

$$\sigma_{DD_{\$}} = \sqrt{\left(\sigma^2_{DD} + \sigma^2_{X_F}\right) - \left(2\rho_{DD,X_F}\sigma_{X_F}\sigma_{DD}\right)} \tag{7}$$

and

$$\sigma_{MB_{\$}} = \sqrt{\left(\sigma^2_{MB} + \sigma^2_{X_F}\right) - \left(2\rho_{MB,X_F}\sigma_{X_F}\sigma_{MB}\right)} \tag{8}$$

Here, $\sigma_{X_F}$, $\sigma_{MB_{\$}}$, and $\sigma_{DD_{\$}}$ represent the volatility of the forward exchange rate, monetary base, and the local currency debt in foreign currency values, respectively. $P_{DD,X_F}$, $\rho_{MB,X_F}$, and $p_{MB_{\$}DD_{\$}}$ show relevant correlation coefficients. The volatility of the monetary base and the local currency debt in local currency values are shown as $\sigma_{MB}$ and $\sigma_{DD}$, respectively. The volatility of the forward exchange rate, monetary base, and local currency debt in local currency are calculated as the annualized standard deviations of their values over the past rolling three months. If the weights of the monetary base and the local currency debt in the LCL are replaced into the equation, it becomes;

$$\sigma_{LCL_{\$}} = \sqrt{w_1^2\sigma^2_{MB_{\$}} + w_2^2\sigma^2_{DD_{\$}} + 2\rho_{MB_{\$},DD_{\$}}w_1 w_2\sigma_{DD_{\$}}\sigma_{MB_{\$}}} \tag{9}$$

Where,

$$w_1 = \frac{MB_{\$}}{MB_{\$}+DD_{\$}} \tag{10}$$

and

$$w_2 = 1 - w_1 \tag{11}$$

Since the market value of the sovereign assets could not be observed, the risk-adjusted balance sheet may be used to estimate implied values. If the assumptions made by Black and Scholes are binding, then the following equation holds.

$$LCL_{\$}\sigma_{LCL_{\$}} = A_{\$}\sigma_{A_{\$}}N(d_1) \tag{12}$$

Here, $N(d_1)$ represents the delta of the call option with respect to the assets of the sovereign. As the value and the volatility of the LCL can be observed, they can be employed to solve for the implied value and the volatility of the assets.

On the other part of the liabilities section, risky debts can be directly observed on the balance sheet. However, considering the risk born by the lender, it can be calculated as the default-free value of the debt minus the debt guarantee, which equals the expected loss in the model. The guarantee is modeled as a put option contingent on the assets with a strike price equal to the DB.

$$D_{\$} = DBe^{-r_f t} - ELV \tag{13}$$

$$ELV = DBe^{-r_f t}N(-d_2) - A_{\$}N(-d_1) \tag{14}$$

If the ratio of the assets to the default-free debt increases or the volatility of the assets decreases, the value of the risky debt would increase directly and via $d_1$, respectively. Hence, if a sovereign gets rich or the stream of income flow of the sovereign becomes certain, the market value of its debt gets high (Hai and Long 2017, p. 23).

*4.2.1. Calculation of the implied asset values*

In the model, the assumptions made by Black and Scholes (1973) are assumed to be true, which include constant short-term interest rates, no dividend policy, and European options which can be exercised only at maturity and no transaction costs in buying/selling options. It is assumed that the assets follow a random walk, and they are distributed log-normally at the end of any period. Thus, the assets move stochastically following geometric Brownian motion, where the randomness in the asset returns is described by the Wiener process (Lai 2016, p. 439).

As the liabilities in the risk-adjusted balance sheet are validated by the Black–Scholes option pricing method, Equations (3) and (12) would be used to reach implied values for asset and asset volatility (Gapen et al. 2005, p. 12; Gray, Merton, and Bodie 2007; Altăr, Altăr-samuel, and Marcu 2014; Aktug 2014; Hai and Long 2017, p. 22). Hence, if the data for LCL and risky debt are reachable, then the implied values of assets and their volatilities could be calculated by the model. However, both equations are non-linear because both must benefit from a numerical method to find the mutual solution. In the study, solving simultaneous equations technique is employed to find the implied values of the assets and their volatility.

*4.2.2. Risk indicators*

After calculating the implied values of assets and their volatility, computing quantitative risk indicators of the model for credit risk assessment becomes possible. These risk measures include the risk-neutral probability of default, the distance to distress, and the risk-neutral credit spreads.

Nevertheless, the initial step is to compute the DB as it is required to calculate the indicators. The distress can occur when the sovereign assets are inadequate to pay the promised payments. For this reason, it depends on the value of the assets, asset volatility, and the value of the DB (Singh, Gómez-Puig, and Sosvilla-Rivero 2019; Jain, Singh, and Patel 2020, p. 9).

DB is calculated as the summation of short-term debts, interest to be paid in the short-term, and a proportion of the long-term debts, which usually changes between 0.5 and 0.8 (Gapen et al. 2005, p. 7; Gray, Merton, and Bodie 2007, p. 10).

$$\mathrm{DB} = \mathrm{D}_{\$\mathrm{ST}} + 0{,}5\ \mathrm{D}_{\$\mathrm{LT}} + \text{Short} - \text{term interest payments} \tag{15}$$

Hence, its value is between the book value of the short-term debts and the value of the total debts. Hence, as the proportion of short-term debts increases in the total debts, the DB will also increase. From this point of view, even though the model is primarily used to assess credit risk, it points out the liquidity risk indirectly by examining the term structure of the debts (Keller, Kunzel, and Souto 2007, pp. 9–10). Considering the application of the model on the sovereigns, DB is calculated by examining its risky debt in a foreign currency. As the proportion of risky debt in whole debts increases or the term structure of the risky debt shortens, the probability of distress occurrence increases.

*4.2.2.1 Risk-neutral probability of default*

The risk-neutral default probability (RNDP, hereafter) is the risk indicator measuring the risk-adjusted probability of sovereign assets' value being lower than the DB at maturity. For this reason, incorporating the uncertainties into the model is critical as the future value of assets may fall below the barrier due to the unforeseen occurrences causing default (D. Gray et al. 2013, p. 28)

The probability that the assets will be under the DB can be calculated by Black–Scholes option pricing model as below:

$$\mathrm{Prob}\left(\mathrm{A}_{\$,} \leq \mathrm{DB}\right) = 1 - \mathrm{N}(\ln\left({}^{\mathrm{A}_{\$,}}/_{\mathrm{DB}}\right) + \left(\mathrm{r} - \frac{\sigma^2_{\mathrm{A}_{\$,}}}{2}\right)\mathrm{t}\sigma_{\mathrm{A}_{\$,}}\sqrt{\mathrm{t}}) \tag{16}$$

Gapen et al. (2005) showed that the RNDP can be computed as below by replacing the Equations (4) and (5).

$$\mathrm{RNPD} = \mathrm{N}(-\mathrm{d}_2) \tag{17}$$

A decrease in the asset value or a higher asset volatility highlights an increase in the probability of default as the probability distribution in Figure 1 Part (b) would widen, leading to a high area under the DB (Gapen et al. 2005, p. 8).

*4.2.2.2. Distance to distress*

The distance to distress (DtD, hereafter), shown as $d_2$, is a risk measure showing the distance between the value of the sovereign assets and the DB, which provides a normalized measure of the risk as it is measured by the standard deviations (Lai 2016, p. 439). As the distress occurrence increases in probability when the value of the assets falls, the volatility of the assets (Singh, Gómez-Puig, and Sosvilla–Rivero 2021, p. 78) or the DB increases. It is expected that these occurrences also decrease the DtD indicator (Hai and Long 2017, p. 23) which can be calculated as below:

$$\mathrm{DtD} = \frac{\mathrm{A}_\$ - \mathrm{DB}}{\mathrm{A}_\$\sigma_{\mathrm{A}_\$}} \tag{18}$$

*4.2.2.3. Risk-neutral credit spread*

Credit spread is the difference between the yields of a risky and a risk-free bond with similar characteristics, highlighting the security's default probability. If the credit spread is considered for sovereigns, then the spread reflects the sovereign risk (Ajax Moreira and Katia Rocha 2004, p. 48). The model calculates the risk-neutral credit spread (RNS, hereafter), constituting a significant part of the interests sovereigns pay to compensate for the default risk. The RNS is mainly affected by the risk-free interest rate, volatility of the sovereign assets, and the ratio of sovereign assets to the DB (Gray, Merton, and Bodie 2007, p. 15).

The RNS can be calculated by deducting the risk-free interest rate from the yield to maturity of the risky debt as below.

$$\mathrm{RNS} = \mathrm{y} - \mathrm{r_f} = \frac{\ln\left(\frac{\mathrm{DB}}{\mathrm{D_\$}}\right)}{\mathrm{t}} - \mathrm{r} = -\frac{1}{\mathrm{t}}\ln(1-\mathrm{EL}) = -\frac{1}{\mathrm{t}}\ln\left(1-\frac{\mathrm{ELV}}{\mathrm{DBe^{-r_f t}}}\right) = -\frac{1}{\mathrm{t}}\ln\left(1-\frac{\mathrm{DBe^{-r_f t}N(-d_2)+A_\$N(-d_1)}}{\mathrm{DBe^{-r_f t}}}\right) = -\frac{1}{\mathrm{t}}\ln\left(\frac{\mathrm{A_\$}}{\mathrm{DBe^{-r_f t}}}\mathrm{N(-d_1)} + \mathrm{N(d_2)}\right) \quad (19)$$

## 5. Results and discussions

After calculating the LCL, the volatility of the LCL, and the DB by benefiting from the methodology discussed in Section 4, the value and the volatility of sovereign assets are calculated in daily frequency. Table 3 shows the mean values of these model inputs on a yearly basis for the maturity of 1 year.

Table 3

Descriptive statistics – Model inputs.

| Year | $LCL_\$$ (In billion U.S. dollars) | $\sigma_{LCL\$}$ | $A_\$$ (In billion U.S. dollars) | $\sigma_{A\$}$ |
|---|---|---|---|---|
| 2009 | 232.70 | 0.61 | 276.72 | 0.51 |
| 2010 | 266.13 | 1.13 | 311.53 | 1.00 |
| 2011 | 273.05 | 2.87 | 297.05 | 2.74 |
| 2012 | 251.04 | 1.64 | 302.56 | 1.44 |
| 2013 | 250.26 | 2.52 | 286.97 | 2.33 |
| 2014 | 225.38 | 2.80 | 257.61 | 2.62 |
| 2015 | 195.25 | 1.46 | 260.07 | 1.17 |
| 2016 | 196.45 | 2.02 | 247.63 | 1.76 |
| 2017 | 180.92 | 1.37 | 258.66 | 1.02 |
| 2018 | 153.39 | 2.98 | 184.32 | 2.75 |
| 2019 | 151.39 | 2.01 | 209.61 | 1.67 |
| 2020 | 189.75 | 5.81 | 216.03 | 5.63 |

Note: $LCL_\$$: Local currency liabilities in billion U.S. dollars; $\sigma_{LCL\$}$: The volatility of the local currency liabilities; $A_\$$: Sovereign assets in billion U.S. dollars; $\sigma_{A\$}$: The volatility of the sovereign assets.

Even though the fluctuations draw attention in all series, overall tendencies of $LCL_\$$ and $A_\$$ are to decrease while volatilities generally increase. Additionally, it is seen that the volatilities of the LCL and assets are significantly parallel.

Since the risk indicators are calculated by using the value and the volatility of the assets, it is important to understand the potential influencers of these items. LCL may affect the volatility of the assets according to Equation (12), where the former is an important determinant of the latter as found in the study of Lai (2016).

After getting the implied values and volatilities of the sovereign assets, risk indicators are calculated by using these inputs. In Table 4, mean values of the credit risk measures are shown on a yearly basis as model outputs.

Table 4
Risk indicators (2009–2020).

| Year | DtD | RNDP | RNS |
|---|---|---|---|
| 2009 | 2.11 | 1.65% | 0.47% |
| 2010 | 1.06 | 13.19% | 11.49% |
| 2011 | 0.36 | 68.07% | 122.30% |
| 2012 | 0.66 | 33.94% | 29.88% |
| 2013 | 0.37 | 64.66% | 96.36% |
| 2014 | 0.31 | 72.88% | 127.82% |
| 2015 | 0.69 | 31.87% | 20.87% |
| 2016 | 0.50 | 51.58% | 62.93% |
| 2017 | 0.66 | 29.33% | 13.98% |
| 2018 | 0.22 | 78.22% | 163.95% |
| 2019 | 0.40 | 58.11% | 64.95% |
| 2020 | 0.16 | 85.72% | 749.33% |

Note: DtD: Distance to distress; RNDP: Risk neutral default probability; RNS: Risk neutral spreads.

In the table, the DtD column is calculated in the units of standard deviations, while the RNDP and RNS are measured in percentages. Substantial alteration can be seen in all of the three series over time. It is found that the DtD series has a decreasing trend generally, while it is in the opposite way for the RNDP, both pointing out the deterioration of credit risk over time.

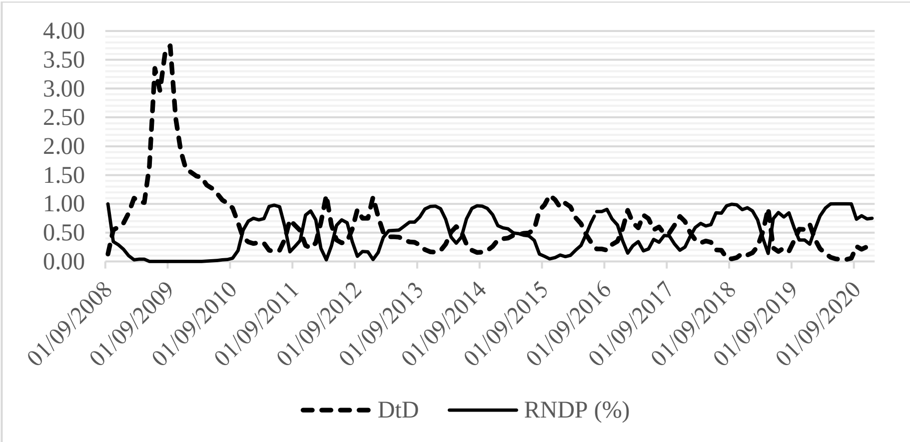


**Figure 2** Distance to distress and risk neutral default probability

These two indicators are plotted in Figure 2 to observe their trends clearly. Suppose the distance between the value of the sovereign assets and the DB is used as a base to calculate the DtD indicator. In that case, when this distance increases, a decrease in the risk-neutral probability of default is expected. As shown in the figure, these indicators move in opposite directions, matching up to the expectations.

As shown in Table 4, the value of the DtD changes between 0.16 and 2.11, where the lowest and the highest values are seen in 2009 and 2020, respectively. Concordantly, the RNDP has the lowest value of 1.65% in 2009 and the highest value of 85.72% in 2020. Lastly, the fluctuations in the RNS series are more prominent than that in others. The indicator takes the lowest value of 0.47% in 2009 and the peak value of 749.33% in 2020.

As the RNS reflects the sovereign credit risk directly on the borrowing rate, it is accepted as one of the most critical risk indicators. In Figure 3, the 1-year CDS spreads of Turkey, the volatility of the USD/TRY exchange rate, and the RNSs are plotted. To make them visible, the volatility of the USD/TRY exchange rate and the risk-neutral credit spreads are multiplied by 1000 and 100, respectively. The volatility of the exchange rate is seen as one of the most critical model inputs in the dynamics of the sovereign structural models (Duyvesteyn and Martens 2012, p. 11), thus it is included in the model.

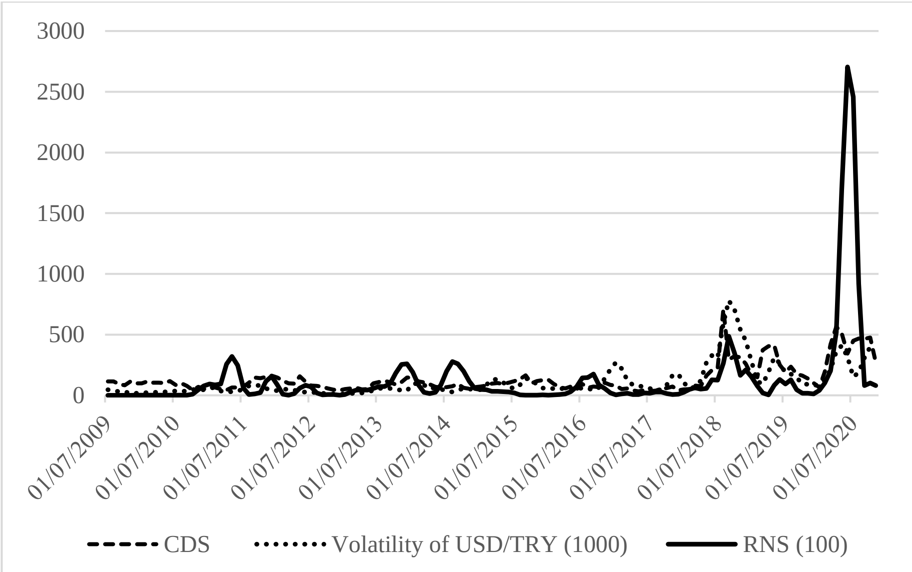


**Figure 3** Risk neutral spreads, CDS spreads, and the volatility of the USD/TRY exchange rate

The figure shows these three items show similar trends, especially during more volatile periods. Their peak points are coherent, and the data point with the highest RNS has significantly high CDS spread and exchange rate volatility values.

*5.1. Robustness checks*

Even though all indicators highlight an increase in the sovereign credit risk for Turkey, it is important to analyze the results by comparing them to the real market data to ensure their robustness (Gapen et al. 2005, p. 15).

In this study, the Spearman rank-order correlations between the model risk measures and traditional market indicators are calculated for robustness purposes. CDS spreads, sovereign bond spreads, and borrowing rates related to the credit ratings assigned to Turkey are included in the correlation computations as actual market data.

Gray, Merton, and Bodie (2007) claimed that because the non-linearity of macroeconomic variables may affect correlations significantly, these calculations should be done by considering possible non-linearities. Additionally, the normality of the variables is critical in choosing the right correlation type to make insightful analyses. For this reason, Skewness–Kurtosis, Shapiro–Wilk, and Shapiro–Francia normality tests are employed to understand normality of the variables.

Shapiro–Wilk test statistics is calculated as below:

$$W = \frac{(\sum_{i=1}^{n} a_i x_{(i)})^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{20}$$

In Equation (20) $x_{(i)}$, $\bar{x}$ and $a_i$ represent the i$^{th}$ order statistic, sample mean and coefficients, respectively. Shapiro–Francia normality test statistic is calculated as:

$$W' = \frac{\sum_{i=1}^{n}\left(x_{(i)}-\bar{x}\right)^2(m_i-\bar{m})}{\sqrt{\left(\sum_{i=1}^{n}\left(x_{(i)}-\bar{x}\right)^2\right)\left(\sum_{i=1}^{n}(m_i-\bar{m})^2\right)}} \tag{21}$$

Here, $m_i$ shows the mean of the i^th order statistic as the result of $n$ independent draws from a normal distribution, while $\bar{m}$ is representing the mean value of all $m_i$.

In Table 5, the results of the normality tests are shown for all related variables. The tests are done for 1- and 5-year maturity terms as the comparisons with the market indicators are done for both maturities. Null hypotheses of all the three tests are the normality of the series. It is shown in the Table 5 that the results of the normality tests highlight the non-normality where majority of the test results are significant at 1% level.

Table 5
Normality tests.

| 1 year | Skewness-kurtosis | | Shapiro-Wilk | | Shapiro-Francia | |
|---|---|---|---|---|---|---|
| | Chi2 | p-value | z | p-value | z | p-value |
| DB | 7.32 | 0.03 | 3.51 | 0.00 | 3.05 | 0.00 |
| RNDP | 7.13 | 0.00 | 3.78 | 0.00 | 3.30 | 0.00 |
| DtD | . | 0.00 | 7.90 | 0.00 | 7.27 | 0.00 |
| RNS | . | 0.00 | 9.67 | 0.00 | 8.83 | 0.00 |
| CDS | 58.44 | 0.00 | 7.85 | 0.00 | 7.23 | 0.00 |
| Bond spread | 22.86 | 0.00 | 7.56 | 0.00 | 6.91 | 0.00 |
| Credit rating | 11.83 | 0.00 | 3.98 | 0.00 | 3.51 | 0.00 |
| **5 years** | **Skewness-kurtosis** | | **Shapiro-Wilk** | | **Shapiro-Francia** | |
| | Chi2 | p-value | z | p-value | z | p-value |
| DB | 18.23 | 0.00 | 4.16 | 0.00 | 3.68 | 0.00 |
| RNDP | 57.87 | 0.00 | 8.32 | 0.00 | 7.12 | 0.00 |
| DtD | 73.47 | 0.00 | 7.91 | 0.00 | 7.29 | 0.00 |
| RNS | 60.82 | 0.00 | 7.34 | 0.00 | 6.70 | 0.00 |
| CDS | 26.61 | 0.00 | 6.20 | 0.00 | 5.70 | 0.00 |
| Bond spread | 32.67 | 0.00 | 6.24 | 0.00 | 5.66 | 0.00 |
| Credit rating | 37.83 | 0.00 | 2.14 | 0.02 | 2.05 | 0.02 |

Note: DB: Distress barrier; RNDP: Risk neutral default probability; DtD: Distance to distress; RNS: Risk neutral spreads; CDS: Credit default swap.

Considering the non-normality of the variables evaluated and the probable non-linearity, applying the Spearman rank-order correlation test looks suitable. Since none of the CDS spreads, sovereign bond spreads and credit ratings are placed in the CCA model. The correlations between them and the model risk indicators are found appropriate to reflect the robustness and the explanatory power of the model. The Spearman rank-order correlation coefficient is calculated without any linearity assumption as below:

$$r_s = \rho_{rg_x rg_y} = \frac{cov(rg_x rg_y)}{\sigma_{rg_x}\sigma_{rg_y}} \tag{22}$$

Here, $rg_x$ and $rg_y$ represent the correlation coefficients between the rank variables. The covariance between the rank variables is shown as $cov(rg_x rg_y)$, while the standard deviations of the correlation coefficients are indicated as $\sigma_{rg_x}$ and $\sigma_{rg_y}$.

The Spearman correlation coefficients between the model risk indicators and the actual market data are shown in Tables 6–8. All correlation analyses include the correlations between the actual market data and DB in addition to the indicators. The calculations are made for 1- and 5- years of maturities. Additionally, different time lags (changing from −4 to +4) are considered in the correlation calculations to grasp the leading, synchronous, and/or lagging impacts of the variables.

*5.1.1. CDS spreads*

In Table 6, the Spearman rank-order correlation coefficients between the model risk indicators and CDS spreads are shown for 1- and 5-year terms.

Table 6

Spearman rank-order correlations: CDS spreads.

| 1 Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 |
| DB | 0.34*** | 0.33*** | 0.33*** | 0.32*** | 0.32*** | 0.32*** | 0.32*** | 0.32*** | 0.32*** |
| RNDP | 0.35*** | 0.36*** | 0.36*** | 0.33*** | 0.28*** | 0.20*** | 0.15* | 0.09 | 0.06 |
| DtD | -0.38*** | -0.39*** | -0.39*** | -0.37*** | -0.32*** | -0.24*** | -0.18** | -0.13 | -0.09 |
| RNS | 0.34*** | 0.35*** | 0.35*** | 0.32*** | 0.27*** | 0.19** | 0.13 | 0.08 | 0.04 |
| 5 Years | | | | | | | | | |
| | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 |
| DB | 0.34*** | 0.33*** | 0.31*** | 0.30*** | 0.30*** | 0.30*** | 0.31*** | 0.32*** | 0.32*** |
| RNDP | 0.31*** | 0.29*** | 0.27*** | 0.23*** | 0.19** | 0.12 | 0.06 | 0.01 | -0.05 |
| DtD | -0.49*** | -0.43*** | -0.40*** | -0.38*** | -0.35*** | -0.29*** | -0.25*** | -0.21** | -0.17** |
| RNS | 0.30*** | 0.28*** | 0.26*** | 0.23*** | 0.18** | 0.11 | 0.05 | 0.00 | -0.05 |

Note: *: 10% significance level **:5% significance level ***:1% significance level. DB: Distress barrier; RNDP: Risk neutral default probability; DtD: Distance to distress; RNS: Risk neutral spreads.

For all of the time lags, there exist positive correlations between the DB and CDS spreads, which are significant at 1% level. In cases where the DB increases, the risky debt of sovereign and/or the short-term portion of the risky debt would also increase. An increase in the CDS spreads is an expected consequence. The positive correlation found between the DB and CDS spreads is parallel to the result found by Aktug (2014) for Turkey in 2001–2010 period by using the Pearson and Spearman correlation tests.

Evidence exists regarding a significant positive relationship between the RNDP and the CDS spreads, including the lagged relations where CDS spreads lead the indicator. Considering that an increasing risk-neutral probability of default is a sign of an increase in the sovereign credit risk which would be accompanied with an increase in the CDS spreads, the result is parallel to the expectations. Keller (2007) and Gray, Merton, and Bodie (2007) plotted the correlation between the RNDP and the CDS spreads of Turkey and six countries (including Turkey), respectively. They both concluded that these two indicators usually move together. Gapen et al. (2005) and Duyvesteyn and Martens (2012) calculated the correlation coefficients between the RNDP and CDS spreads for twelve and eight emerging market economies (including Turkey), respectively. They both found evidence of a positive association between these two variables, affirming the analysis results shown above.

Between the DtD and CDS spreads, significant negative correlation is found, confirming the expectations as a decrease in the DtD would be a sign of an increased sovereign credit risk reflected by high CDS spreads. Gapen et al. (2005) and Gray, Merton, and Bodie (2007) investigated this relationship for twelve countries (including Turkey) and a cumulative of eleven countries (including Turkey), respectively. The observation of a negative relationship between the model indicator and CDS spreads was common in both studies. Duyvesteyn and Martens (2012) calculated the correlation between these two variables for eight emerging market economies (including Turkey) and proved the existence of a negative significant correlation between them. All of these results are parallel to the findings above about this relationship.

There are other studies analyzing this relationship for other countries. Briere, Ferrarini, and Ramayandi (2016); Singh, Gomez-Puig, and Sosvilla-Rivero (2019); and Singh, Gomez-Puig, and Sosvilla-Rivero (2021) worked on five East Asia sovereigns and five and eleven Europe countries, respectively. Their conclusions affirm the findings above, and these studies confirm the existence of a negative association between DtD and CDS spreads.

In the last part of Table 6, the correlation coefficients are calculated for the RNS and the CDS spreads. It is found that there exist leading impacts of the CDS spreads on the indicator in addition to the positive synchronous correlations which are both significant at 1% and 5% levels. As the credit risk level increases, both CDS and RNS are expected to rise. Hence, the result of the study is parallel to the expectations. Duyvesteyn and Martens (2012) examined this relationship and concluded that a positive significant association exists between the indicator and the CDS spreads.

#### *5.1.2. Sovereign bond spreads*

Table 7 shows the Spearman rank-order correlation coefficients between the model risk indicators and sovereign bond spreads.

It is found that there exists a positive correlation between the DB and sovereign bond spreads, which is significant at a 1% level. Considering that an increase in the DB highlights a higher credit risk. Then, it is required to provide the potential investors with a higher pay off to compensate for the larger risk. For this reason, this result follows the expectations.

Table 7

Spearman rank-order correlations: Sovereign bond spreads.

| 1 Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 |
| DB | 0.38*** | 0.37*** | 0.37*** | 0.37*** | 0.37*** | 0.39*** | 0.42*** | 0.45*** | 0.48*** |
| RNDP | -0.12 | -0.13 | -0.15* | -0.15* | -0.15* | -0.13 | -0.09 | -0.06 | -0.01 |
| DtD | 0.09 | 0.10 | 0.12 | 0.12 | 0.12 | 0.09 | 0.05 | 0.02 | -0.03 |
| RNS | -0.14 | -0.15* | -0.17* | -0.17** | -0.17** | -0.15* | -0.11 | -0.07 | -0.03 |
| **5 Years** | | | | | | | | | |
| | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 |
| DB | 0.28*** | 0.26*** | 0.25*** | 0.24*** | 0.23*** | 0.23*** | 0.23*** | 0.23*** | 0.23*** |
| RNDP | 0.09 | 0.06 | 0.06 | 0.04 | 0.01 | -0.04 | -0.09 | -0.12 | -0.13 |
| DtD | -0.30*** | -0.28*** | -0.28*** | -0.27*** | -0.25*** | -0.21** | -0.17** | -0.14* | -0.13 |
| RNS | 0.08 | 0.06 | 0.05 | 0.03 | 0.00 | -0.05 | -0.10 | -0.12 | -0.13 |

Note: *: 10% significance level **:5% significance level ***:1% significance level. DB: Distress barrier; RNDP: Risk neutral default probability; DtD: Distance to distress; RNS: Risk neutral spreads.

When the relation between the risk-neutral probability of default and sovereign bond spreads is examined, a positive synchronous correlation is expected as an increased credit risk would cause the RNDP and sovereign credit spreads to rise. However, there is no correlation coefficient, which is significant at 1% or 5% levels, seen for these two variables in any lags. Considering other sovereigns, periods, or data frequencies may give different results. Hai and Long (2017) examined four East Asia sovereigns and concluded the existence of a positive significant association between these two variables.

A negative correlation is found between the DtD and sovereign credit spreads, which is significant at 1% level considering a 5-year maturity term. A decrease in the DtD highlights a bigger sovereign credit risk, which must be compensated with higher payoffs for investors. For this reason, a negative correlation between this indicator and the sovereign credit spreads is an expected result. Additionally, results stress out the leading effect of sovereign credit spreads on the DtD. Hai and Long (2017) and Singh, Gomez-Puig, and Sosvilla-Rivero (2019) investigated the same relation for four East Asia and five European countries, respectively. The former found negative significant correlations between these two variables in three out of four countries, while the latter detected negative leading or synchronous associations in all examined countries.

The last part of Table 7 indicates the correlation coefficients calculated for the RNS and sovereign credit spreads. As the coefficients lose their significance when the lags are included and most of the coefficients are not significant even at a 10% level, no consequential relationship exists between these variables. Hai and Long (2017) calculated the Pearson correlation coefficients of four East Asia countries and proved strong positive associations. The correlation tests, sovereigns examined, time frame considered, and other analysis details may affect analysis results.

*5.1.3. Credit ratings*

Table 8 shows the Spearman rank-order correlation coefficients between the borrowing rates assigned according to the credit ratings and risk indicators. Regarding the relation between the DB and credit ratings, it is proved that there exists a positive correlation that is significant at 1% and 5% levels between them. When the DB increases, the borrowing rate assigned in relation to the credit ratings is expected to rise accordingly, parallel to the correlation analysis results above.

Table 8

Spearman rank-order correlations: Credit ratings.

| 1 Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 3 | 2 | 1 | 0 | 1 | 2 | 3 | 4 |
| DB | 0.29*** | 0.28*** | 0.27*** | 0.26*** | 0.25*** | 0.24*** | 0.22** | 0.21** | 0.19** |
| RNDP | 0.10 | 0.09 | 0.08 | 0.07 | 0,.08 | 0.09 | 0.10 | 0.10 | 0.10 |
| DtD | -0.14 | -0.12 | -0.12 | -0.12 | -0.12 | -0.13 | -0.14 | -0.14 | -0.14 |
| RNS | 0.09 | 0.08 | 0.07 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.10 |
| 5 Years | | | | | | | | | |
| | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 |
| DB | 0.01 | 0.01 | 0.00 | 0.00 | -0.01 | -0.03 | -0.05 | -0.07 | -0.09 |
| RNDP | -0.09 | -0.11 | -0.12 | -0.13 | -0.13 | -0.14* | -0.14* | -0.14* | -0.15* |
| DtD | -0.12 | -0.11 | -0.09 | -0.08 | -0.07 | -0.06 | -0.05 | -0.04 | -0.02 |
| RNS | -0.05 | -0.05 | -0.07 | -0.07 | -0.07 | -0.08 | -0.08 | -0.08 | -0.09 |

Note: *: 10% significance level **:5% significance level ***:1% significance level. DB: Distress barrier; RNDP: Risk neutral default probability; DtD: Distance to distress; RNS: Risk neutral spreads.

Considering the correlation coefficients calculated between the risk-neutral probability of default and credit ratings, there is no significant result other than four negative coefficients that are significant at 10% level, showing the leading impact of the indicator on the borrowing rates. Even though the significance level is moderate, results show that an increase in the RNDP brings a decrease in the borrowing rates in forthcoming months, which means an improved stance in credit risk. This can be explained by the claim of Giovanni Ferri, L-G Liu, and Joseph E. Stiglitz (1999) that the credit rating agencies could not foresee the approaching crisis and rate sovereigns as investible before the crisis. When the investible sovereigns get hit by a crisis, the credit rating agencies may lower their grades excessively during the crisis to save their reputation, as explained by Ferri, Liu, and Stiglitz (1999). Additionally, the sticky ratings notion defended by Nada Mora (2006) may also explain the result above.

Table 8 shows the correlation coefficients between the credit ratings and DtD, which are not significant. Singh, Gomez-Puig, and Sosvilla-Rivero (2019) and Singh, Gómez-Puig, and Sosvilla-Rivero (2021) studied five Europe and eleven European Union sovereigns, respectively, where they both evidenced negative correlations between the DtD and the credit ratings. Every aspect of the analysis, including the data frequency, chosen sovereigns, and analysis methods, may affect the conclusions considerably.

The last part of Table 8 shows the relation between the RNS and the credit ratings. As no significant coefficient is found, no significant relationship is evidenced between these variables.

*5.2 Sensitivity analysis*

Considering the financial, political, and economic stance of Turkey, especially in the last few years, the unpredictability of market trends and changes in the conjuncture in direction and severity draw attention. For this reason, observing the potential impacts of changes in the economic conditions on the sovereign's balance sheet and credit risk might be insightful. With this aim, after confirming the robustness, sensitivity analyses are done to evaluate the potential effects of various shocks on the sovereign credit risk using the CCA model.

To start with, baseline balance sheet items are shown for the 31$^{st}$ of 2020. Risk indicators are calculated for the baseline scenario, where the RNDP, DtD, and RNS are calculated as 68.49%, 0.30 standard deviations, and 67 basis points, respectively. Afterward, sixteen alternative shock scenarios are considered: Increases and decreases of 1% and 5%, respectively, in the values of the monetary base, risky debt, volatility of the LCL, and the USD/TRY exchange rate. Table 9 summarizes the effects of these shocks on the model risk indicators.

Table 9

Sensitivity analysis.

| **CCA sovereign balance sheet** | **Baseline** | **Scenario 1: 1% increase in monetary base** | **Scenario 2: 1% increase in the risky debt** | **Scenario 3: 1% increase in the volatility of LCL** | **Scenario 4: 1% increase in the exchange rate** |
|---|---|---|---|---|---|
| RNDP | 8.49% | 68.46% | 68.60% | 69.23% | 68.60% |
| Change RNDP | | -0.03% | 0.11% | 0.73% | 0.11% |
| DtD | 0.30 | 30.02% | 29.81% | 29.47% | 29.81% |
| Change DtD | | 0.00 | 0.00 | -0.01 | 0.00 |
| RNS | 0.67 | 0.67 | 0.67 | 0.69 | 0.67 |
| Change RNS | | 0.00 | 0.00 | 0.02 | 0.00 |
| **CCA sovereign** | **Baseline** | **Scenario 5: 5% increase** | **Scenario 6: 5% increase** | **Scenario 7: 5% increase in the** | **Scenario 8: 5% increase in the** |

| balance sheet | | in monetary base | in the risky debt | volatility of LCL | exchange rate |
|---|---|---|---|---|---|
| RNDP | 8.49% | 68.35% | 69.02% | 72.02% | 69.02% |
| Change RNDP | | -0.14% | 0.52% | 3.53% | 0.52% |
| DtD | 0.30 | 30.20% | 29.14% | 27.55% | 29.14% |
| Change DtD | | 0.00 | -0.01 | -0.02 | -0.01 |
| RNS | 0.67 | 0.67 | 0.68 | 0.77 | 0.68 |
| Change RNS | | 0.00 | 0.01 | 0.10 | 0.01 |

| CCA sovereign balance sheet | Baseline | Scenario 9: 1% decrease in monetary base | Scenario 10: 1% decrease in the risky debt | Scenario 11: 1% decrease in the volatility of LCL | Scenario 12: 1% decrease in the exchange rate |
|---|---|---|---|---|---|
| RNDP | 8.49% | 68.52% | 68.38% | 67.74% | 68.38% |
| Change RNDP | | 0.03% | -0.11% | -0.75% | -0.11% |
| DtD | 0.30 | 0.30 | 0.30 | 0.31 | 0.30 |
| Change DtD | | 0.00 | 0.00 | 0.01 | 0.00 |
| RNS | 0.67 | 0.67 | 0.67 | 0.65 | 0.67 |
| Change RNS | | 0.00 | 0.00 | -0.02 | 0.00 |

| CCA sovereign balance sheet | Baseline | Scenario 13: 5% decrease in monetary base | Scenario 14: 5% decrease in the risky debt | Scenario 15: 5% decrease in the volatility of LCL | Scenario 16: 5% decrease in the exchange rate |
|---|---|---|---|---|---|
| RNDP | 8.49% | 68.64% | 67.93% | 64.60% | 67.93% |
| Change RNDP | | 0.14% | -0.56% | -3.89% | 0.56% |
| DtD | 0.30 | 0.30 | 0.31 | 0.33 | 0.31 |
| Change DtD | | 0.00 | 0.01 | 0.03 | 0.01 |
| RNS | 0.67 | 0.67 | 0.66 | 0.58 | 0.66 |
| Change RNS | | 0.00 | -0.01 | -0.09 | -0.01 |

Note: RNDP: Risk neutral default probability; DtD: Distance to distress; RNS: Risk neutral spreads.

For example, an increase of 1% in the monetary base results in a decrease of 0.03% in the RNDP. Regarding the changes in the RNDP, it is seen that the most significant impact on the indicator is caused by the changes in the volatility of the LCL, while the monetary base change caused the least significant effect. When the monetary base increases, the expectation is a decreased sovereign credit risk due to a more powerful monetary base, creating a lower RNDP.

Meanwhile, the increases in the risky debt, volatility of the LCL, and the exchange rate highlight a higher burden on the sovereign in terms of credit risk, which means a higher RNDP. For this reason, regarding the sixteen scenarios, the results of the changes above are parallel to the expectations.

After examining the table, the insensitivity of the DtD in almost all scenarios draws attention. There exist only slight changes between 0.01 and 0.03 standard deviations in this indicator, where the highest impact stemmed from the changes in the volatility of the LCL. While the monetary base changes do not create any significant reaction in the indicators at either 1% or 5% change levels, the exchange rate and risky debt changes of 5% level create an alteration of 0.01 in the indicator. As the increase in the risky debt, volatility of LCL, and/or the exchange rate probably result in higher sovereign credit risk levels, the results follow the expectations. Briere, Ferrarini, and Ramayandi (2016) studied five East Asia countries and evidenced that the volatility of LCL has the most prominent impact among all effectors of the distance to distress.

Considering the impacts of the scenarios, the RNS is mostly affected by the alteration in the volatility of the LCL, while it is almost insensitive to the other scenarios. The indicator changes by 9–10 points in the same direction when the volatility of the LCL is altered by 5%. The increase in the risky debt, the volatility of the LCL, and/or the exchange rate has an increasing impact on the indicator. As the RNS shows the spread required to compensate for the extra risk burden for investors, the results parallel the expectations.

After examining Table 9, it is seen that the volatility of the LCL is among the most powerful triggers of the alterations in the risk indicators. The risk exposure increases as the value of the LCL becomes uncertain, which provides a buffering effect against the risky debts. In addition, the proportions of items constituting the LCL also matter. To exemplify, if the growth rate of the monetary base becomes exceeds the growth rate of GDP, this may result in local currency depreciation, inflation, and a rise in the sovereign credit risk (Hai and Long 2017).

## 6. Conclusion and policy implications

Regarding Turkey’s vulnerability to the macroeconomic conjuncture, including the changes in the sovereign credit risk, which led to the significant changes in the economic risk in Turkey, the importance of assessing Turkey’s credit risk correctly becomes apparent. Evaluating the sensitivity of the sovereign’s credit risk correctly is critical in designating the economic policy appropriately. In this study, the CCA approach is employed considering the probable inadequacy of the financial ratio-based traditional models in assessing the credit risk in such an active market, which experiences fluctuations often. To perform a risk-neutral analysis, financial data taken from the sovereign balance sheet is synthesized with the actual market data.

The study concluded that the CCA model is appropriate to investigate the credit risk of Turkey comprehensively as the CCA model risk indicators successfully reflect market movements correctly. Moreover, the depreciation of Turkish Lira, which has affected the market since its initiation around the summer of 2018, is reflected in the risk indicators with a rise in the risk-neutral probability of default and a decrease in the DtD despite the fluctuations.

The correlation analysis which ensures the robustness of the model evidenced the existence of significant correlations between CDS spreads and all of the model risk indicators parallel to the expectations. Sovereign bond spreads have a negative leading impact on the DtD as expected, while the risk-neutral probability of default have a negative leading relationship with the variable constituted by mean borrowing rates assigned according to the credit ratings of Turkey. This result can be explained by credit rating agencies' inability to foresee the crisis beforehand, as defended by Ferri, Liu, and Stiglitz (1999) or by the sticky credit ratings notion, as explained by Mora (2006). Particularly, the downgradings made by Moody's and S&P in August of 2018 when the exchange rate depreciation had just started exemplify the claim made by Ferri, Liu, and Stiglitz (1999).

The CDS spread of Turkey had 432 points on 29th of September 2021, which rose to 489 on 24th of November 2021[2]. In this period, the volatility of the exchange rates has affected the whole market, which testified to the sovereign's vulnerability. In this respect, sensitivity analyses made within the frame of the CCA approach are valuable to policymaking. The results of the analyses examining influences of 1% and 5% increases and decreases in the monetary base, risky debt, volatility of the LCL, and the USD/TRY spot exchange rates indicate that all of the credit risk indicators give the strongest response to the changes in the volatility of the LCL among all the scenarios examined. Indeed, the volatility of the LCL is a critical part of an important macroeconomic story for Turkey as an emerging market country. The dynamic exchange rates, the case of twin crises showing the existence of fiscal and trade deficits, and ascensive inflation rates may impinge on the volatility of the LCL potentially.

In light of the analysis results, the CCA model is found to be robust, considering the correlations of model outputs with the actual market data. Hence, the model can be employed in policymaking to reach realistic results.

Although the study's results are empirically robust in the framework of the CCA, the study's limitations should be emphasized for future research. Other countries/country groups may be evaluated for larger data windows in the CCA framework. Furthermore, assumptions made by Black and Scholes (1973), including the constant short-term interest rates, no dividend policy, European options, and no transaction costs in buying/selling options, may be relaxed to construct a more down-to-earth model.

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[2] The mentioned CDS spreads and the interpretations are limited by the data window analyzed in the study.

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