Exchange Rate Determinants & Exchange Rate Risk Hedging: An Empirical Study Applied on the Case of a Tunisian Company

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Abstract: The aim of this paper is to propose an appropriate method that could assist decision-makers in the finance department responsible for hedging against the exchange risk yielding a better strategy to shield the company from the undesired scenarios of loss. Our research interrogation related to an intelligent solution devoted to the minimization of the currency risk incurred by our Tunisian studied Holding when trading on the foreign exchange market. The study focused on the four most involved currencies in the Tunisian and Foreign trading market: USD, EUR, GBP, and JPY. Our sampling period runs from January 03, 2011 to June 30, 2021. First, the results suggest that the key interest rate and the foreign exchange reserves are most determinant variables compared to the other variables. Second, we present a feasible procedure to hedge against currency risk consisting of five steps, through a developed Artificial Intelligence based program, a correlation analysis and the Temporal Causality Model. Finally, we create our different hedging scenarios and the desired exchange rate is forecasted for a period (from 1 month to 12 months). Based on the forecasted exchange rate values, the studied Holding is able to conclude the most advantageous forward hedging contract by choosing the term of the contract at which the exchange rate level is the most profitable rate according to its position in the market.

Key words: Artificial Intelligence, Exchange rate, Forecasting, Risk hedging, Temporal Causality Model, VaR model.
JEL classification: C15; C30; C53; C55; E17; E47; F31.

INTRODUCTION

Foreign Exchange (Forex) markets are deemed as one of the very volatile markets worldwide. This fluctuation stems from a plethora of determinants. Among the factors residing behind maintaining this liability to change is the existence of threefold types of market actors. The first ones are the investors who are endeavoring to invest in a currency for long-run gains. The second ones are the arbitrators who opt for making risk-free benefits by taking advantage of any price mismatch due to market incoherence. The last actors are the speculators whose principal mission is to take bets in hope that price movements draw up in their favor. Broadly, monetary and financial organizations would engage in all three main activities discussed earlier (investment, arbitration, and speculation). Even though the rate of price movements and consequently marginal gains in Forex markets is regarded particularly low, the principal amount (also known as the nominal value) of trading streams is accounted in trillions of dollars, therefore, causing either high absolute profits or losses. Under these circumstances governing the market, the profitability and earning of the traders are intrinsically reliant upon the predictions capability of the upcoming rate flows.

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For large firms, especially those who exert a substantial trade's volume on the foreign market referring to import and export operations, translated into noteworthy currency transfers in the course of business, being able to accurately forecast movements of currency exchange rates can warrant the upper hand for the company and results in valuable enhancements for its profitability. In this context, the exchange rate can be viewed as the main measure that has a direct impact on the relationship between local and foreign prices and is often the most effective indicator when it is necessary to promote exports and imports simultaneously and directly. International economic relations must use the exchange rate in these streams of goods and services, in which case the local currency is converted into foreign currencies, and the free exchange rate is determined in the market through mechanisms that are considered exchange rate regimes.

For instance, a case of a leading Tunisian multi-national company (MNC) working in the agri-food sector sheds light on the risk that could be incurred in the market and more specifically on the international trading market. Indeed, the potential risk has been identified and falls into two principal types. The first one concerns the exchange risk caused by the volatility of the exchange rate on the market during imports. The second risk relates to interest rates and the increase in financial charges. As a matter of fact, according to this company's data, the overall trade value of this corporate group

amounts to 152680 thousand Tunisian dinars in 2020 of which more than 70% constitute imports rendering an offset or compensation strategy inadequate due to the inequality between imports and exports volumes. This prominent number enforces harnessing a rigorous policy that targets the exchange rate regimes and opts for a proactive decision regarding the repercussions of the unexpected evolution of the exchange rate. Undoubtedly, numerous factors influence this rate to various extents. Accordingly, the present research consists in capturing the most substantial macroeconomic variables that intervene in quantifying the relation between the Tunisian national currency and the other currencies. Once the variables and their contribution are settled, the focus will be directed towards the determination of the most effective and cautious alternative of hedging or not against depreciation or appreciation of the currency. Eventually, a subsequent decision has to be made concerning which hedging alternative to lean toward among the existing ones in the Tunisian bank system.

In this sense, hedging in companies operating on the Forex trading market is affiliated with a wide range of benefits. It plays a crucial role in decreasing the exposure risk of traders in a volatile-driven market. On the one hand, bearish market times and economic recessions are inevitably market traits that can be overcome or significantly by passed thanks to the hedging strategy. Indeed, this market peculiarity poses a threat to a company exerting exportation. Unlike the bearish trend, the other side of the coin involves the bullish market aspect, which embodies an unfavorable situation for the importers. Generally, establishing a successful hedging plan can contribute to an efficient protection against inflation, prices variations, exchange rates fluctuations, as well as being sheltered against changes in central bank interest rate policies.

Notwithstanding that hedging currency risk is intended to reduce overall risk for a trader, hedging itself can be a risky endeavor since it is not a risk-free strategy. Undoubtedly, aside from its potential benefits, forex hedging likewise holds some cons. A solid experience is a requirement when it comes to guaranteeing a successful hedging strategy. Additionally, it is also wise to highlight that a hedging strategy could harness one of the options' alternatives to exert the protection which can turn out to have greedy costs rendering the desired gain to a loss.

Over the last decades, a plethora of models have been conceived, developed, and employed aiming to comprehend the numerous properties characterizing the market and its peculiarities (e.g. volatility, fluctuation of the exchange rate, behavioral changes, etc). Recently, we have witnessed a phenomenal growth of the application of computational intelligence methodologies in the financial field proving that the old workhorses' models originating from the Autoregressive Integrated Moving Average (ARIMA) linear models are not able to capture the exigencies of the real-world nonlinear features. It should be pointed out that these breakthrough models possess the ability to manage specific characteristics of economics and finance forecasting problems such as nonlinear relationships, behavioral changes, or knowledge-based domain segmentation. All these motives exhort us to adopt one of this landscape of methods.

Accordingly, in the first place, we aim at studying a wide variety of computationally intelligent methods for Forex market prediction. In the second place, a selection of the outperforming ones will be conducted to ensure an efficient result and an eventual accurate forecast for the particular situation of the examined company concerning hedging against variations of the exchange rate between the Tunisian Dinar and the most involved currencies in the Tunisian and Foreign trading market.

The main contribution of this research is that it proposes an appropriate method that could assist decision-makers in the finance department responsible for hedging against the exchange risk yielding a better strategy to shield the company from the undesired scenarios of loss. To our knowledge, this is the first paper to address such issue.

The rest of the paper is organized as follows. Section 1 briefly reviews existing research. Section 2 describes the data and explains the choice of variables and the methods employed in the empirical analysis. Section 3 presents the results. The final section summarizes the main conclusions and preconizes.

1. LITERATURE AND EMPIRICAL REVIEW

1.1. Exchange Rate Determinants

Several researchers have studied the exchange rate and tried to define the main determinants of its fluctuations. A study conducted by Fuchs (2020) has examined the macroeconomic determinants of foreign exchange rate exposure on the United States economy. An analysis that reveals strong evidence that the after exposures of potential exporters are affected by their expectations of foreign market Gross Domestic Product GDP, Current Account Balance CAB, Consumer Price Index CPI, Term Spreads TS, Unit Labor Costs ULC as well as government expenditures. Findings indicate that there is an effect of the forecasted macroeconomic variables on the expected exchange rate and companies' adjustment of their hedge ratio to benefit from the change in the expected exchange rates. Also, results show a significant impact on the positive exposures for the foreign GDP, CAB, CPI, TS, ULC and government expenditures forecasts, and a no significant impact of the foreign macroeconomic variables for more stable negative exposures. In addition, only a negative effect concerning foreign government expenditures forecasts for potential (net) United States importers is observed. Taking positive and negative exposures that qualify as such for a longer period together, all forecasted macroeconomic variables show the expected positive impact with a significant effect of CAB, CPI, TS, and ULC. The major findings indicate strong evidence that foreign macroeconomic determinants influence the foreign exchange rate exposure of United States companies.

On the other hand, some decades before and studying the case of the New York foreign exchange market, Meese and Singleton (1982) have studied the volatility of exchange rates in a stationary world and non-stationary world with both sticky and flexible price models. They found that the variations in the exchange rate are resulted from the fluctuations in fundamental economic conditions in the first place and by speculations secondly. They noticed a difference in

the determinants of the exchange rate between the stationary world and the non-stationary one. In the stationary world, the exchange rate elasticity about its determinants is greater than unity. It means that a magnification effect is observed. In this case, the real income and the money stock are considered the most important determinants that influence the value of exchange rates. However, in the non-stationary world, the variations in exchange rates are not directly justified by variations in its determinants.

Analyzing the case of the exchange rate determinants of the four most important economies in the world for the period 1979-2008 (the United States, the United Kingdom, Sweden, and Australia), Wang et al. (2019) have manipulated a set of variables and arrived at different results. They found that the interest rate differential has to be an important source of nonlinearities in exchange rates for all countries studied.

As a literature summary, Nandrajog (2019) has presented descriptive research in which he tried to recapitulate the previous literature and get out of it a conclusion. In the case of monetary models, the exchange rate is indirectly affected by the factors that influence the demand for and supply of a currency. In addition, he added that inflation, interest rates, money supply, CAB, equity and bond prices, foreign direct investment, oil prices, credit default, swap premium, and macro news announcements have a significant impact on exchange rate movements.

In conclusion, macroeconomic variables are considered able to explain the exchange rate movements in the long run but it is not the case for the short run, whereas the microstructure variables such as currency order flow are considered able to explain the exchange rate movements in the short run. Despite the fact that the field of exchange rate and its determinants is one of the most well researched ones in the discipline, the concluded results differ with the studied context and economy.

1.2. Exchange Rate Forecasting and its Risk Hedging

Diverse determinants models have been affirmed as facilitators to forecast exchange rates by several studies (Meese & Singleton, 1982; Wang et al., 2019; Nandrajog, 2019; Harun & Zeynep, 2020; Chen et al., 2021). As confirmed by Nandrajog (2019), the models for forecasting exchange rates are different from a country to another because of the uniqueness of every country in terms of the market environment and macro conditions affect the reliability and the accuracy of the model. We can classify these models into two sets: a set of classic models and a second of advanced ones.

Beginning with the first set, we note that the forecasting of exchange rates is regarded as a fundamental step notably for companies that are trading internationally, as in the case of the studied Tunisian multi-national company. These corporations are targeting to minimize the risk of unfavorable fluctuations of exchange rates converted into substantial costs in certain scenarios. This subject was variously investigated for a long period by numerous researchers through applying assorted models on multiple exchange rates. Several models dedicated to the determination of the exchange rate have been proposed by economists, which assist in predicting exchange rates and endeavoring to forecast their fluctuations. Each model can explain the evolution of the exchange rate by using macroeconomic variables. The Purchasing Power Parity model (PPP) considers the price levels of two countries to predict the exchange rate between them. With absolute PPP, exchange rates are established as the difference between real and foreign prices. Whereas, in relative PPP, the ratio of domestic to foreign prices is useful for anticipating exchange rates. The relative PPP is more preferred and appropriate to the absolute form as confirmed by Krueger (1983).

Multiple statistical models such as the Autoregressive Integrated Moving Average (ARIMA), Generalized AutoRegressive Conditional Heteroskedasticity (GARCH), and exponentially weighted Moving-Average models are the most commonly used analytical tools to forecast exchange rate for different currencies such as Bitcoin, Gold, USD, and the Association of South East Asian Nation exchange rates (Dirk et al., 2017; Ender et al., 2018; Mohd et al. 2019). These approaches have been largely the forecasting workhorses nevertheless they can treat only linear problems and the variables must follow a normal distribution (Ching-Hsue et al., 2010).

To overcome these limits, the Artificial Intelligence based models and methodologies, as the second set, such as Bayesian Neural Networks (BNNs), Artificial Neural Networks (ANNs), and Support Vector Regression (SVR) have been adopted to forecast myriad exchange rates. These approaches can extract hidden, new, extraordinary patterns, and information from big data without the requirement for any prior knowledge about the data. Accordingly, we will develop literature on the advanced models based on machine learning employed to prognosticate exchange rates. Exchange rate series are typically dynamic and nonlinear and thus, forecasting exchange rates is a challenging endeavor. The range of forecasting methods that has been considered is particularly broad since it involves econometric models such as ARIMA, GARCH, and their derivatives, as well as various machine learning and computational intelligence approaches such as support vector machines, ensemble models, and fuzzy system (Dautel et al., 2020).

Furthermore, Deep-learning-based forecasting models and their applications in finance have gripped a lot of attention in recent research (Fischer & Krauss, 2018; Maté & Jimeńez 2021) though only a humble number of studies are devoted to examining the Forex market. This is surprising for several reasons. On the one hand, investigating the extent to which market evolving can be forecasted with high accuracy implies academic and practical relevance. Moreover, exchange rates have been characterized as non-linear, stochastic, and highly non-stationary financial time series (Kayacan et al., 2010), which makes them particularly tricky to predict and thus an interesting subject for forecasting research (Wu & Chen, 1998; Czech & Waszkowski, 2012).

Although the properties of the exchange rate time series, ANNs comprise the most prominent modeling family, and on account of their learning, adaptability, and flexibility qualities, they are capable of forecasting exchange rates. On the other hand, Deep Learning (DL) models such as Convolutional Neural Networks (CNNs), Deep Belief Networks (DBNs), Long Short Term Memory (LSTM), and Gated Re-

current Unit (GRU), inter alia, have started to emerge in the field, and each has been found to significantly outperform traditional ANN counterparts in terms of successful forecasting performance.

Shen et al. (2015) and Zheng et al. (2019) reported that, compared to the Feed-Forward Neural Network model (FFNN), the DBNs model could more accurately forecast an exchange rate. Galeshchuk & Mukherjee (2017) successfully employed CNNs to predict changes in the direction of foreign exchange rates. Among DL models, LSTM is the preferred choice of most researchers in financial time-series forecasting (Sezer et al., 2020; Wu & Gao, 2018). LSTM models constitute a special type of RNN that learns long-term dependencies. In a related context, Qu & Zhao (2019) compared the performance of LSTM and RNN models for the forecasting of EUR/USD series. They indicated that LSTM has a lower Root Mean-Square Error (RMSE) and Mean Absolute Error (MAE) than does the RNN model. Other researchers such as Ranjit et al. (2018), Dodevski et al. (2018) and Ito et al. (2022) reported similar results in favor of LSTM. Along the same lines, Zhang (2018) combined an empirical mode decomposition model and LSTM to predict the USD/Chinese Yuan (CNY), EUR/CNY, and USD/EUR series, while Sun et al. (2018) proposed the AdaBoost-LSTM ensemble learning approach to forecast USD/CNY and USD/EUR exchange rates. Focusing on Deep learning, it is lumped under the machine learning umbrella domain, which is, in turn, the most prevailing subset of the Artificial Intelligence realm defined as a myriad of tools destined to render computers behaving more intelligently. Its distinguishing aspect resides in relying on numerous processing layers that allow computational models to learn data representations at different levels of abstraction (Le Cun et al., 2015).

Unquestionably, these approaches have participated considerably in boo sting the AI breakthroughs (e.g. speech recognition, objects identification, etc.). In reliance on the back-propagation mechanism, deep learning networks shed light on the sophisticated patterns existing within massive datasets without requiring explicit knowledge about the inner operations or the intermediate stages. This process is adopted to guide and train the machine to an optimal tuning of its interior parameters inherent to each layer of its network. Indeed, there are multiple subcategories gathered under the deep learning label.

1.3. Exchange Rate Risk Hedging Tools

Based on the researches' set consulted on the financial strategies adopted for the exchange risk hedging, we found that divers' internal and external instruments are used. As developed by Hrifa & Bamousse (2018), these different instruments will be described in details in the following.

1.3.1. Internal Instruments

The four most popular internal tools for exchange risk hedging are as follows:

The Choice of the Billing Currency: The billing currency is the one in which the international purchase or sale contract will be expressed. The parties of the contract, who have the flexibility to choose this billing currency, may opt for one currency rather than another to minimize the exchange rate risk. Two options are considered: either billing by the national currency TND or by another currency like EUR, USD, GBP or other. The choice of this currency is mainly based on the fact that it is easily transferable and used in a usual way for international payments as for the latter. Adopting this strategy to the Tunisian context and specifically on our Tunisian Holding case, cannot lead to good exchange risk hedging results since the TND is considered a weak currency compared to others with which it has the most transactions.

The Termalization: This technique aims to vary the terms of the payments in order to take advantage of favorable exchange rate evolution. This strategy consists in accelerating or retarding the inflow or outflow of foreign currencies according to the anticipated evolution of these latter as mentioned by Hrifa & Bamousse (2018). Although this instrument appears to be easy to apply, in the reality it is based on a process of exchange rate evolution estimation. The latter is only useful if the export turnover and the potential losses due to exchange rate fluctuations support the establishment of such a structure referring to Hrifa & Bamousse (2018). This strategy is still limited to be adopted by the studied Holding caused of the possibility of its refusal by the latter's partners. In other words, the adoption of this strategy for our case can be refused by its second part with which it makes its international transactions.

The Indexation Clauses in Contracts: The aim of indexation clauses in international purchase or sale contracts is to contractually provide for the sharing of the transaction exchange rate risk between the buyer and the seller, in the event of a variation in the exchange rate of the currency chosen by the two contracting parties. The content of an indexation clause, as with termalization, is often difficult to negotiate because such clauses usually transfer all or part of the risk to the other contracting part.

The Compensation: The offsetting or the compensation is a hedging technique by which a company limits its foreign exchange risk by balancing cash inflows and outflows in the same currency. Thus, the regulation of a debt in a foreign currency will be allocated to the payment of a debt denominated in the same monetary unit. With this in sight, a company tries to limit the number of invoicing currencies, so as to be able to offset as many inflows and outflows of money as possible. In our Holding case, this approach cannot be adopted considering that the value of its imports is much higher than that of its exports, as it will be explained better numerically.

As these internal instruments were not relevant for our case Holding, the next part will be reserved to present the external ones and detecting the best to be explored for our hedging exchange risk case.

1.3.2. External Instruments

The external exchange risk hedging strategies commonly followed internationally and partially used in the Tunisian context will be presented in this section.

Exchange Insurance: The company can hedge against the exchange risk through insurance offered by external organizations. The purpose of this insurance is to allow exporting

companies to establish their sales prices and to conclude contracts in foreign currencies without incurring the risk of exchange rate fluctuations. This strategy has the most hated disadvantage by any company which is its prepaid price that presents a high cost for the insured company and that this cost can in some cases be more reduced if no insurance occurred, which justify its uselessness for our case.

Swaps: A currency swap is an agreement between two parties to exchange a specified amount of foreign currency to make regular interest payments to each other and to return the exchanged amount at a specified time. In most cases, a bank acts as an intermediary for the transaction. In simple terms, this strategy is presented by one spot and one forward transaction between a bank and its exporting client. The parallel lending, as a second form of swaps, allows two companies located in different countries to agree to lend to each other in the currencies they need for a specified period. At the end of the term, both companies repay the loans they owe each other in their respective currencies. The swaps as an exchange risk hedging strategy can be carried out on the interbank market and is entitled by the Tunisian legal framework since 2001, but it is still rarely used by companies.

Options: The holder of an option can freely decide to exercise it, i.e. to buy or sell the currency at the strike price. But he can also renounce to use this right if the price he can obtain on the foreign exchange market is more advantageous for him. The currency option therefore allows its holder to hedge his exchange risk while keeping the possibility of making a profit in the event of a favorable evolution of the exchange rate. In the face of the service and the risks incurred by the seller of the option (generally a bank), a price premium, more or less important depending on the conditions (currencies, duration of the hedge, guaranteed prices), is requested from the buyer of the option. The option buyer's risk is thus limited to the amount of this premium. The latter justifies the scarcity of this hedging instrument use. The implementation of this strategy is allowed by the legal framework of Tunisia since 2007 on the interbank market and not allowed on the organized market.

Futures and Forwards: These two exchange rate risk hedging tools present a form of a term hedge. Hedging on the term market is one of the most commonly employed techniques by companies due to its simplicity of use. The term hedging is based on an exchange of one currency against another, based on a fixed spot price with reciprocal delivery on an agreed date. There are two possible transactions: forward buying (import hedging) and forward selling (export hedging), as mentioned by Desbriéres & Poincelot (1999). The forward exchange allows establishing today a buying or selling rate of currencies for future maturity. The exporter, to hedge against the exchange rate risk linked to the possible depreciation of a currency, sells the amount of his claim to his bank on a forward basis. In this way, the exporter determines the precise amount of national currency he will receive at maturity. The importer, for his part, to hedge against the exchange rate risk linked to the possible appreciation of a currency, buys forward the currencies corresponding to the amount of his debt. He thus knows precisely the amount in national currency that he will have to pay. The forward hedging technique enables the banker to know in advance the rate at which he will buy the currency from the exporter at maturity and sell the currency to the importer at maturity. This step will require, therefore, a whole calculation and forecast on the part of the banker as well as his customers (importer and exporter) to fix the most profitable price for each of his position. The forwards and the futures are two term hedging tools that are presented both by term hedging contracts that are different in terms of their conditions and flexibility. On the one hand, the forward hedging by "Forward" contracts is a hedging technique that is traded on the interbank markets. It is an over-the-counter contract, either between two banks or between a company and its bank. A forward contract is a derivative product that most often deals with currencies. In other words, a forward contract is a definitive commitment to buy or sell a certain quantity of a currency, at a given future date, for a previously agreed price. Simply, this contract allows a company (importer/exporter) to hedge against the exchange rate risk by establishing today the exchange rate to be respected at a future date. On the other hand, the futures contracts for exchange risk rate hedging are negotiated on the organized markets and are considered as standardized contracts. The contract's term, the amount, sometimes the quality and the location (raw materials) are specified by the market on which the contract is traded. The most specificity of these contracts is that the buyers and the sellers do not know each other. The term's hedging through Forwards contracts in the Tunisian context has been possible since 1997, the date of the creation of the forward foreign exchange market (BCT circular 97/07) but it is not the case for hedging the foreign exchange risk using futures contracts which is not yet eligible by the Tunisian legislation.

2. EMPIRICAL METHODOLOGY

Throughout this section, we will conduct a methodological study targeting to respond to our research interrogation related to an intelligent solution devoted to the minimization of the currency risk incurred by our Tunisian studied Holding when trading on the foreign exchange market. To do such, we will present below our data, the different variables used in our study, the followed process as well as the adopted model, and the different results we will reach.

2.1. Data Description

To conduct our study, two types of variables are employed: the financial variables as the historical exchange rates and the nominal effective exchange rate, and the real variables such as the Inflation Rate, the GDP Growth Rate, and others. We have selected many foreign currencies based on the available data from the list published by the Tunisian Central Bank BCT official site and decided to analyze only the four most involved currencies in the Tunisian and Foreign trading market (United States Dollar USD, the EURO EUR, the British Pound GBP, and the Japanese Yen JPY) based on the graphical analysis of the different exchange rates (reported later). In detail, these historical rates are adopted to quantify the weights of these foreign currencies on the determination of the Tunisian Dinar TND value. We decide to pick several variables deemed weightily determinant of the exchange rate, (justified in the following) to specify the most contributing macroeconomic variables in the measurement of the TND value, namely the Inflation Rate (InfR), the Remainder

Payments Balance Indicator (RPB), the GDP Growth Rate (GDPGR), the Key Interest Rate (KIR), the Money Supply Indicator (MSI), the Net Foreign Claims (NFC), and the Foreign Exchange Reserves (FER). Our sampling period runs from January 03, 2011 to June 30, 2021, duration of about 10 years, and is twofold: the first data set is daily and comprises 2510 daily observations for each selected exchange rate. The second data set is monthly, covers 126 monthly observations for the selected macroeconomic variables and the four exchange rates deemed as the most important accompanied by the effective nominal exchange rate and the effective real one. The choice of this study period is justified, on the one hand, by the availability of data and on the other hand by the specificity of this period which begins with the Tunisian revolution and which takes into account global crises such as the health crisis of the Covid-19 pandemic that has affected the whole world. We collected our initial database consisting of the set of exchange rates of the Tunisian Dinar TND against the selected currencies for our sampling period from the official website of the BCT for the USD/TND, the EUR/TND, the JPY/TND, and the GBP/TND, and not for the others since their data were not available. To overcome this limit, we computed these exchange rates by a cross-calculation where the necessary data were subtracted from the site *excelrates.com*. The monthly exchange rates were deduced from the daily ones by computing simply the monthly mean for each exchange rate. The monthly macroeconomic variables series for the same period were collected, according to their availability, from the BCT official site and directly from the BCT followed by a specific treatment for one of these variables. Assuredly, the gathering process of these data records was a challenging mission to achieve because of the scarcity of their sources. In the following, we will present, respectively, the procedure followed for collecting and processing exchange rates, then that for macroeconomic variables.

2.2. Variables Presentation

The variables on which we will base our analysis are exchange rates and macroeconomics variables. The first set is presented by the four most important exchange rates in terms of their presence on the Tunisian foreign exchange market and which have available data for our entire sample period running from January 03, 2011 to June 30, 2021, namely USD/TND, EUR/TND, GBP/TND, and JPY/TND. All exchange rates selected were graphically and statically analyzed (not reported) but not explored in our hedging solution creation process. The second set of data is shown by InfR, RPB, GDPGR, KIR, MSI, NFC, and FER macroeconomic available data variables.

In the following, we will present in detail, firstly, our exchange rates variables on the basis of their transformation process from historical exchange rate series of the form Foreign currency/TND, to series of Currency/Referential Currency form, then to series of the logarithm of the just preceding series and finally to series of the first difference of those above. Secondly, we will present and define the macroeconomic variables that we decided to study and justify our choice.

2.2.1. Exchange Rates Variables

Exchange rates are considered as the organizer of the foreign exchange market, which justifies the importance of these indicators when studying this specific market. In our case, we will initially deal with the exchange rates linking between the national currency TND and the four most involving foreign currencies on the Tunisian foreign exchange market. These exchange rates are available on the BCT site in the indirect quotation; it means that for every rate the level of the foreign currency is expressed in terms of the local currency TND. In simple terms, all exchange rates take the form 1 Foreign Currency = XTND. In our study, the foreign currencies considered are the USD, EUR, GBP, and JPY, then the examined exchange rates are USD/TND, EUR/TND, GBP/TND, and JPY/TND. To conduct our study and establish our intelligent solution to hedge the foreign exchange risk, a whole process must be followed upstream. The latter is to identify the currencies that are included in the TND basket of currencies and that affect directly its evolution. As stated by Charfi (2009), the Tunisian authorities have adopted the basket system on the determination of TND value since 1978. The adoption of a basket as an anchor and not of a single currency makes it possible to avoid suffering the floating of the latter. The process, that we have just pointed, involves several data transformations, the first of which is the calculation of the new exchange rates of the different currencies expressed in a new referential one.

The calculation of the weighting of each foreign currency on the local currency TND is a crucial step to detect the foreign currencies' level of impact on every fluctuation of the TND. This stage involves the introduction of a referential currency on the different selected exchange rates with the aim of neutralizing the latter for more accurate results. In our case and inspired by Charfi (2009), we choose to introduce the referential currency named Special Drawing Rights and noted SDR or XDR. This currency is an international monetary instrument created by the International Monetary Fund (IMF) in 1969 to complement the existing official reserves of member countries. Throughout our study, this referential currency will be noted as XDR. Because of the unavailability of Foreign Currency/Foreign Currency exchange rates on the official site of the BCT, we used the site excelrates.com to extract these latter. We used these exchange rates for a cross-calculation to find exchange rates of the form Currency/Referential Currency. Our calculation was based on the exchange rate historical data of USD/XDR available on the IMF official site. In other simpler words, we calculated all Currency/XDR rates by multiplying the exchange rate Currency/USD extracted from excelrates.com site by the USD/XDR one excerpt from the IMF official site. Mathematically, the formula applied is:

$$Currency/XDR = Currency/USD * USD/XDR \quad (1)$$

The obtained exchange rates series are presented by 2510 daily observations for the period from January 03, 2011 to June 30, 2021 of TND/XDR, USD/XDR, EUR/XDR, GBP/XDR, and JPY/XDR exchange rates.

As mentioned by Charfi (2009), the study of exchange rates in terms of variations and not in terms of levels makes it

possible to consider certain floating exchange rate regimes as the nominal one to a currency or a basket. In other terms, the study of exchange rate variations makes it possible to consider certain crawling peg regimes as pegging to a currency or a basket, which is the case of the exchange rate policy followed by the BCT since the devaluation of August 1986, as it declares that it is following a rule of targeting of the constant real exchange rate. Based on this statement, we decide to calculate the series of the Neperian Logarithm (Ln) on our initial exchange rates historical data. This calculation is considered as a way to quantify the movement of the different studied exchange rates. With this calculation, we obtained five series composed of 2510 observations each. These series are named ln(TND/XDR), ln(USD/XDR), ln(EUR/XDR), ln(GBP/XDR), and ln(JPY/XDR) having the same order of the initial exchange rate historical series. Like any econometric procedure, a crucial starting step must be established. This step is presented by a set of tests on the data to be exploited. The main of these tests are: the test of normality that can be produced by Jarque-Bera test, the test of stationarity that can be determined by Augmented Dickey-Fuller also known as ADF test, the test of autocorrelation that can be drawn by the statistical Ljung Box-Q LB-Q test, and the test of heteroscedasticity that can be performed by the AutoRegressive Conditional Heteroskedasticity Lagrange Multiplier ARCH LM test. Following the elaboration of the tests already mentioned, we obtained that for all the studied series, we reject the null hypotheses of normality for the J-B test, the absence of an ARCH effect for the ARCH LM test, and non-autocorrelation for the LB-Q statistical test for different significance levels and we accept the null hypothesis of the unit root for the ADF test. The results are summarized in Table 1 reported in the statistical analysis part of the Descriptive Statistics section. On the basis of the results of the stationarity test, we tried to correct the presence of the unit root on our data by calculating the first difference of ln(Currency/XDR) for all currencies exchange rate time series.

By reapplying all tests including that of ADF, on the resulting new series, results show that series are co-integrated in level and stationary in first difference. All results are summarized in the same table. The obtained series are named Δln(TND/XDR), Δln(USD/XDR), Δln(EUR/XDR), Δln(GBP/XDR), and Δln(JPY/XDR) and composed each of 2509 observations. The corrected time series presenting the first difference of the ln(Currency/XDR) series can be considered as the return in its continuous formula for Currency/XDR exchange rate series. As mentioned by Majdoub & Ben Sassi (2017) and using the model of the form:

$$y_t = y_{t\text{-}1} * \exp(\mathrm{Rt}) \tag{2}$$

and not

$$y_t = y_{t\text{-}1} * (1 - \exp(\mathrm{Rt})) \tag{3}$$

Where Rt is the return of the y_t series, the first difference of the ln of the exchange rate parities series is considered as the return of the considered series. In other terms, the first difference that we calculated on ln(Currency/XDR) as:

$$\Delta\ln(Currency/XDR) = \ln(Currency/XDR)_t - \ln(Currency/XDR)_{t\text{-}1} \tag{4}$$

Where t indicates the present date and t-1 indicates a just previous date, can be transformed mathematically to:

$$Rt_{it} = \ln(X_{it}/X_{i(t\text{-}1)}) \tag{5}$$

as a return calculation of the exchange rate Currency/XDR i presented by its value X in the date t in a continuous case.

The new time series just calculated will be used to estimate our linear regression model to find the weights of the foreign currencies components of the currency basket of the local currency TND on the latter.

2.2.2. Macroeconomic Variables

Concerning the estimation of the exchange rate by employing macroeconomic determinants for the Tunisian case, we have two groups of macroeconomic variables: financial variables and real variables. The choice of these variables is justified by several important considerations. For the real variables, we have the foreign exchange reserves which are considered as a major variable to determine the stability of exchange rates and the level of domestic prices. Simply, strong currencies are generally in high demand and covered by substantial reserves as well as overall economic strength, while weak currencies do not benefit from the same advantages. Second, we find the money supply M2 indicator that informs us about the adequacy and credibility of an exchange rate policy. The inflation rate, on its part, is considered as an indicator of economic uncertainty. In other words, an economic instability is often characterized by high inflation rates that negatively affect expected profits. In addition, net foreign claims have a role to play in the valuation of reserve stocks where it reinforces the search for monetary stability. The growth GDP rate is one of the most important exchange rate determinants. A positive growth rate leads to higher incomes and therefore the well-being of the Tunisian citizen. The remainder of the payments balance is considered as an important indicator for the determination of the exchange rate evolution. In other words, this indicator makes it possible to highlight various significant balances whose analysis is important to reflect the macroeconomic situation of a country. For the financial variables, we have chosen to introduce the key interest rate as an indicator in this class. The interest rate is considered as the most important variable explained, as the most important determinant to attract FDI (Foreign Direct Investment), thus contributing to an increase in national income that increases the value of the investment, including the overall development of the country. In other words, this refinancing rate of commercial banks from the Tunisian central bank is very decisive in overall monetary policy. Two exchange rate types are also selected as macroeconomic variables namely the nominal effective exchange rate and the real effective exchange rate. The first one is considered generally as a synthetic rate describing the average evolution of bilateral exchange rates of a country's currency against the currencies of its main trading partners or competitors, and the second one is defined as the nominal exchange rate index adjusted by the inflation differential. These macroeconomic

variables can be classified differently according to their importance in determining the exchange rate evolution. The first set of the most important indicators is composed of the remainder of the payment balance, the GDP growth rate, and the inflation rate. The second set of the less important variables is formed of the key interest rate, the net foreign claims indicator, the foreign exchange reserves variable, and the money supply indicator. Since we did not find monthly data for the GDB Growth Rate we tried to proceed to have it. We were able to find only its annual and quarterly data on the official website of the BCT. Based on the later, we tried to apply the actuarial rate calculation procedure. This rate series treatment allows us to extract the monthly growth rate from the quarterly ones under the hypothesis that it takes the same value for every 3 successive monthly observations. The calculation equation that we have used is the following:

$$AR_m = (1 + R_t)^{1/3} - 1 \quad (6)$$

Under the assumption that the monthly AR_m is constant for each 3 successive months. AR_m is the Actuarial Rate presenting the monthly one and R_t is the initial subtracted quarterly rate.

Following this calculation, we complete our monthly database of macroeconomic variables to use in the following on the evaluation of the TND by macroeconomic variables to help us to establish our intelligent solution to hedge the foreign exchange risk in a later step. Thus, the next section will be reserved to better explain our econometric process explored on the just presented variables.

2.3. Econometric Process Explanation

2.3.1. Process of Weightings Determination

The construction of the effective multilateral real exchange rate to be stabilized raises the question of the weights chosen for the different currencies that make up the anchor basket TND (Rhomberg, 1976). It is in this context that the theory of Optimal Monetary Area OMA (ZMO in French) can be used to determine which currency or currencies are best suited for an anchoring strategy. To do so, we will follow Charfi (2009) and calculate the relative volatility for each currency. The results of the latter will be discussed in the empirical results section. It is to be noted that an OMA is a geographical area characterized by a fixed exchange rate regime for trade within the area and floating for outdoor exchanges. In other words, within the zone, either there is only one currency circulating, or several currencies are circulating in the zone but the exchange rates between the different currencies are fixed, while parities with currencies belonging outside the zone are floating. The anchoring is not necessarily a fixed parity, insofar as it may be a simple regularity of nominal exchange rate variations against the anchor currency and, in this case, it would be a rolling parity regime or a managed floating regime. It can coincide with a fixed exchange rate regime when changes are zero as stated by Benassy & Lahrèche-Révil (1999).

Following Charfi (2009) and knowing that since 1978 Tunisia has been pegged to a basket of currencies and that the weighting of currencies is not officially announced, we have found it useful to estimate econometrically the weights attributed to the different currencies. The basket is supposed to consist mainly of American Dollar, European Euro, Britain Livre Sterling, and Japanese Yen, which are the main currencies of settlement of the operations with the outside. The anchoring concept on a basket of currencies is to keep fixed the value of the currency in question. In this case, it is a question of fixing the value of the Tunisian dinar in relation to the basket of currencies when they change in value. The value of the TND is represented by the effective nominal exchange rate (SE) index, which is a geometric average of the bilateral nominal exchange rates (S) weighted by their weights in the dinar's anchor basket.

$$SE_t = S_t\,(TND/EUR)^{\alpha 1} * S_t\,(TND/USD)^{\alpha 2} * S_t\,(TND/GBP)^{\alpha 3} * S_t\,(TND/JPY)^{\alpha 4} \quad (7)$$

Considering XDR as the reference currency, this equation will be transformed as:

$$\log[S_t(TND/XDR)] = \alpha_0 + \sum_{i=1}^{4} \alpha_i * \log(S_t\,(i/XDR)] \quad (8)$$

Where i represents the four foreign currencies EUR, USD, GBP, and JPY, respectively by taking values from 1 to 4 in the same order. The constraint of the composition of the anchor basket requires that the sum of the weights of the four currencies be equal to the unit. By introducing this constraint into the last equation, the equation to be estimated becomes:

$$\log[(S_t(TND/XDR))/(S_t(USD/(XDR))] = \alpha_0 + \sum_{i=1}^{3} \alpha_i * \log[(S_t(i/XDR))/(S_t(USD/XDR))] \quad (9)$$

Under the constraint:

$$\alpha_2 = 1 - \alpha_1 - \alpha_3 - \alpha_4 \quad (10)$$

2.3.2. Process of TND Determination using Macroeconomic Variables

At this level, it is important to carefully specify the model to be tested before implementing the estimation of the exchange rate equation. To do so, we started with a descriptive study of our macroeconomic database, which will be reported in detail in a following part. The fact that we have several variables for time observations, does not affect their nature as time series, i.e. our whole database is considered as time-series data too. Moreover, since we aim to describe an endogenous variable (Exchange Rate) as a function of other exogenous variables (Macroeconomic variables), does not need to involve the notion of time. Therefore, the non-stationarity, the autocorrelation and the presence of the ARCH effect on our series, as found by the descriptive analysis of our macroeconomic variables, will no longer be a problem to be solved. For those reasons, the statistical model to apply to our data will be simply the multiple linear regression implemented on our original database. To better organize our study, we will estimate four regression equations for the four exchange rate parities previously chosen which are USD/TND, EUR/TND, GBP/TND, and JPY/TND. The estimated equations are the following:

$$USD/TND = \alpha_0 + \alpha_1 RPB + \alpha_2 GDPGR + \alpha_3 InfR + \alpha_4 KIR + \alpha_5 MSI + \alpha_6 FER + \alpha_7 NFC + \varepsilon_t \quad (11)$$

$$EUR/TND = \alpha_0 + \alpha_1 RPB + \alpha_2 GDPGR + \alpha_3 InfR + \alpha_4 KIR + \alpha_5 MSI + \alpha_6 FER + \alpha_7 NFC + \varepsilon_t \quad (12)$$

$$GBP/TND = \alpha_0 + \alpha_1 RPB + \alpha_2 GDPGR + \alpha_3 InfR + \alpha_4 KIR + \alpha_5 MSI + \alpha_6 FER + \alpha_7 NFC + \varepsilon_t \quad (13)$$

$$JPY/TND = \alpha_0 + \alpha_1 RPB + \alpha_2 GDPGR + \alpha_3 InfR + \alpha_4 KIR + \alpha_5 MSI + \alpha_6 FER + \alpha_7 NFC + \varepsilon_t \quad (14)$$

Where: *RPB* is the payment balance indicator, *GDPGR* is the growth GDP rate, *InfR* is the inflation rate, *KIR* is the key interest rate, *MSI* is the money supply M2 indicator, *FER* is the foreign exchange reserves and *NFC* is the net foreign claims. Then For a visualization of the general state of the market, we will try to describe the two nominal and real effective exchange rates according to the different macroeconomic determinants selected in order to deduce which one best reflects the general evolution of the Tunisian exchange market. Based on the latter, we will establish our hedging scenarios. The two equations added to estimate are the following:

$$NEER = \alpha_0 + \alpha_1 RPB + \alpha_2 GDPGR + \alpha_3 InfR + \alpha_4 KIR + \alpha_5 MSI + \alpha_6 FER + \alpha_7 NFC + \varepsilon_t \quad (15)$$

$$REER = \alpha_0 + \alpha_1 RPB + \alpha_2 GDPGR + \alpha_3 InfR + \alpha_4 KIR + \alpha_5 MSI + \alpha_6 FER + \alpha_7 NFC + \varepsilon_t \quad (16)$$

Where: the independent macroeconomic variables are respectively the same as for the previous equations and the dependent ones *NEER* and *REER* represent respectively the effective nominal exchange rate and the effective real exchange rate. By the estimation of the just presented equations, we will be able to identify the macroeconomic determinants of the TND evolution.

Following this step and based on the different internal and external exchange rate risk hedging possible strategies presented above and based on their usefulness, their likely costs, and the related Tunisian legislation, we decide to implement a forward hedging strategy using forward contracts negotiated on the interbank market and eligible by the Tunisian legal framework since 1997. Therefore, the main component of the "forward" contract that we can manipulate to have the most profitable exchange rate risk hedging contract to our Holding case is the terms of this signed contract. In other words, before concluding a forward contract, a process must be established in order to choose the contract term at which the exchange rate or rather the return on this rate, the reason for choosing the return rather than the rate value itself is already mentioned, will be the most advantageous in reducing losses caused by the exchange rate risk. To do this, a whole mathematical and statistical process was followed. Following the established exploratory study, covering the different selected exchange rates and the various sampled macroeconomic variables, a cross-correlation study controlled by a causality analysis by means of multivariate causality model examining all the possible cause-effect relationships between the main selected exchange rates with the real and nominal effective ones presenting the market in general, was carried out. Then, several scenarios were created based on the forecasts made by taking into account the position of our Holding on the foreign exchange market, which can be importing or exporting, as well as the global market situation presented by the nominal effective exchange rate. The choice of the latter rather than the real effective rate is justified by the results we have been able to achieve. The nominal effective exchange rate is translated in our scenarios by its Value at Risk VaR. This VaR, presenting the global situation of the Tunisian exchange market, is compared each time by the returns forecasted of the exchange rates and considering the position of the Holding on the exchange market. According to the forecasts resulting from these scenarios, the term of the contract producing the minimum of losses for our Holding will be fixed. And thus, the most advantageous forward contract hedging of the exchange risk for it will be concluded. In the aim to establish all this econometric processing, we have used different IBM products i.e. the statistical tool SPSS Statistics and the modeling one SPSS Modeler. The latter is a leading visual data science and machine learning (ML) solution designed to accelerate time to value by speeding up operational tasks for data scientists. The following part will be reserved to present and interpret our results to be able to deploy our strategy of hedging the exchange rate risk for the benefit of our Tunisian Holding towards its end.

3. RESULTS AND DISCUSSION

3.1. Descriptive Analysis

3.1.1. Graphical Analysis

Beginning with a graphical analysis for the Exchange Rates Historical Data, our data are presented by four sets: Foreign Currency/TND exchange rates, Currency/XDR exchange rates, ln(Currency/XDR) time series, and Δln(Currency/XDR) series for the period from January 03, 2011 to June 30, 2021 presented by 2510 observations for the three first sets and only 2509 observations for the last one. In the Fig. (**1**), the daily evolution of the exchange rates of the four most involving foreign currencies on the Tunisian market expressed in TND has been presented. It is to be noticed that the monthly evolution of these four parities of Foreign Currency/TND presents the same curve pace as the daily one (Figure not reported). This graph allows us to visualize the series of our exchange rates data and deduce that the four exchange rate series are not stationary and fluctuate arbitrarily. They do not have a trend and do not move seasonally or cyclically. Also, the different exchange rate series have started to appreciate remarkably since 2015 and take their maximum value towards the end of 2019. This evolution can probably be explained by the two successive terrorist attacks on the Bardo museum, Tunisia and in Sousse, Tunisia, respectively, on March 18, 2015, and June 26, 2015. The maximum value of 2019 is likely due to the start of the spread of the Covid-19 pandemic in the world. This finding is reflected financially by the depreciation of the national currency TND

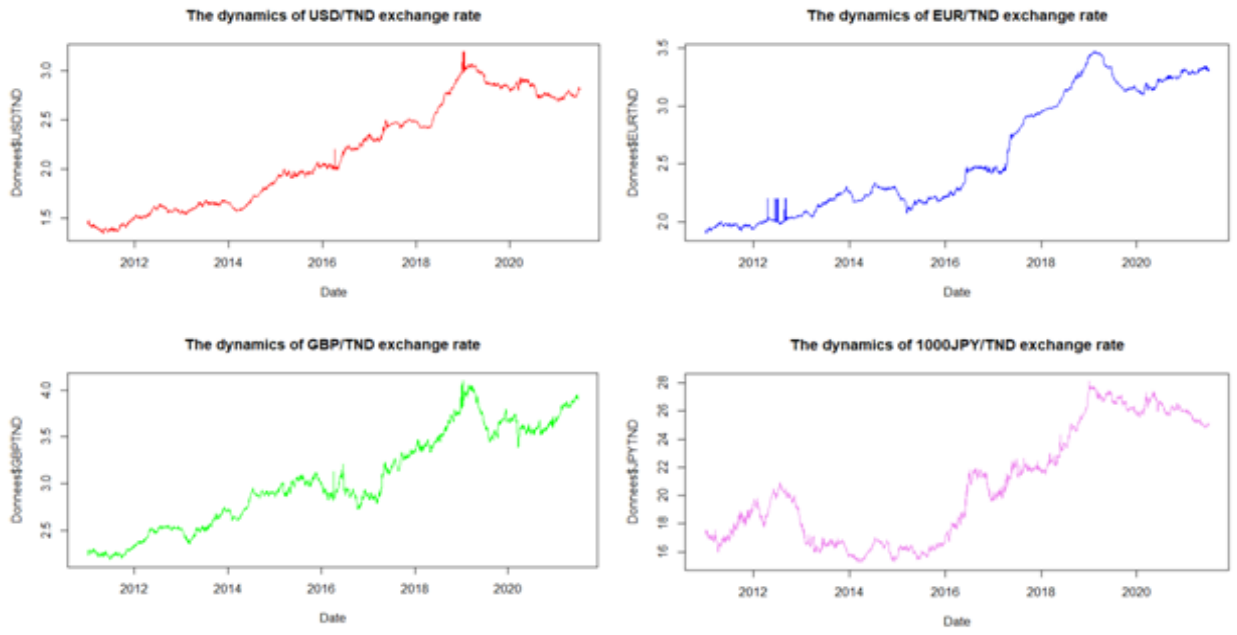


Fig. (1). The Dynamics of the Foreign Currency/TND Exchange Rates.

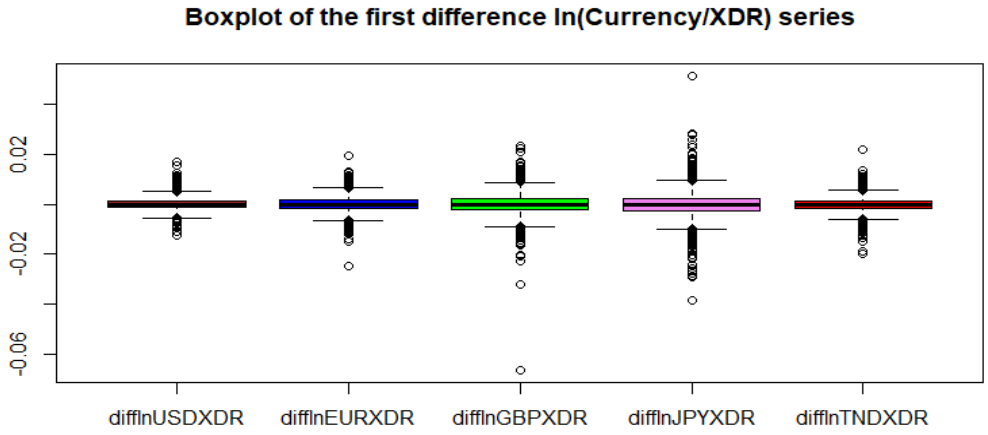


Fig. (2). The Boxplot of the First Difference of ln(Currency/XDR) Series.

value against the four foreign currencies studied, namely the USD, EUR, GBP, and JPY. We can also note that the marked appreciation has accelerated the pace since 2017, which could be the result of the popular speech of the Tunisian Minister of Finance for the period under review. Furthermore, all the four exchange rate series present moments of decline and others of appreciation. These movements can be explained by financial and economic events, both national and international. An increase (decrease) in the curve shows depreciation (appreciation) of the TND against the foreign currency, and then it can be explained by an unfavorable (favorable) event.

The graphical analysis for the three other sets of exchange rates indicate approximately the same outcomes explained by the same reasons (not reported).

For a general visualization for the data on which we will apply our empirical model, we present in the Fig. (**2**) the box plot, which presents a standardized way of displaying the distribution of our exchange rates data.

From this graph, we see that the first quartile and the third one are very close to the mean for all the return series of the five Currency/XDR exchange rates confirming then their stationarity. The presence of outliers in the series is more pronounced in the JPY/XDR exchange rate returns and less noticeable in the USD/XDR exchange rate returns compared to the others. These outliers can be justified by the local or international events affecting the exchange rate of the concerned country.

Moving on the data related to the macroeconomic variables presented by a set of 126 monthly observations for the period from January 2011 to June 2021. The Fig. (**3**) allows us to visualize the series of the selected macroeconomic variables. Beginning with the most volatile series, which is the RBP. The excessive volatility of this series can be explained by its higher sensibility to international events compared to the other macroeconomic variables series. Considering that this indicator includes the current operations, and the capital and financial transactions with the external world, thus, summa-

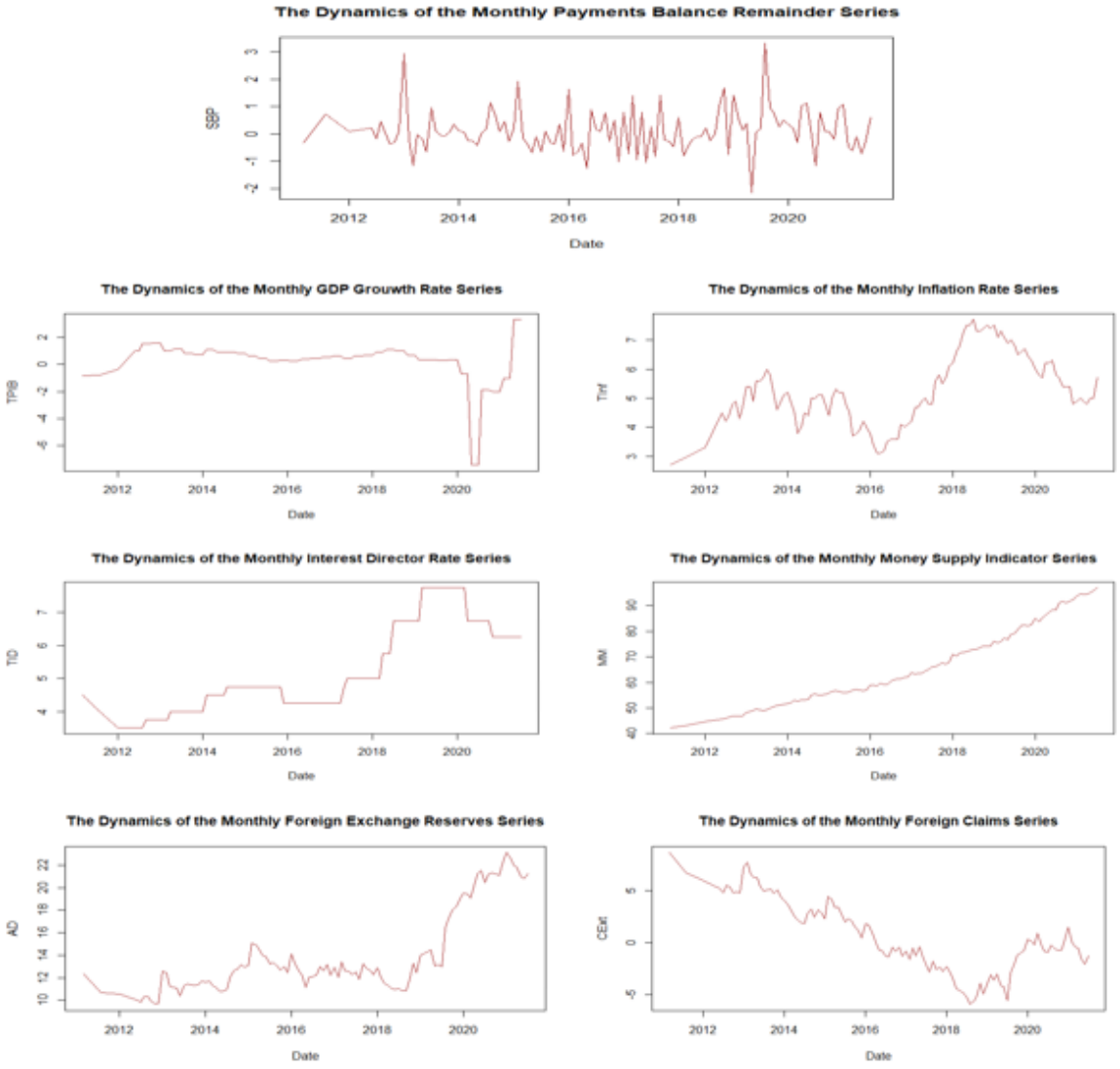


Fig. (3). The Dynamics of the Macroeconomic Variables Series.

rizes Tunisia's relation with the international. We see an upward peak towards the beginning of 2013, a downward fall in early 2019, designating the worst monthly value of this indicator, followed by an upward peak towards the end of the same year. In financial terms, an increase (decrease) of the balance payments remainder can be explained by a higher increase (decrease) of the exports compared to the imports, or by more (less) sales compared to the acquisition of non-financial assets, or by the higher (lower) level of the international monetary inflows compared to the outflows ones related to investment. In the Tunisia case, the variation in the balance of payments is mainly justified by a change in the same direction as the commercial balance.

Moving on to the monthly GDP growth rate series, we recall that the values presented are calculated using the actuarial rate method as previously shown. We can notice remarkable curve stagnation until the start of 2020 when a serious drop followed by a recovering of the curve is observed. This decrease is "unprecedented" for Tunisia. These patterns can be justified mainly by the critical health situation in Tunisia caused by the excessive spread of the Covid-19 pandemic. The presented inflation rate series, on its side, indicates relatively fluctuating values. The period from the beginning of 2011 to the end of 2016 presents more remarkable fluctuates compared to the followed period that can be mainly justified by the January 2011 Tunisian revolution. The latter is specified by an appreciation that continued for about two years, to start depreciating around the beginning of 2020. This appreciation and depreciation can be essentially explained by the financing strategies conducted by the BCT based on the financial and economic situation of Tunisia. Going to the monthly KIR, it presents a specific allure compared to the other presented curves, a stepped curve from 2012. This series specificity can be related directly to the BCT strategy that is fixed, each time, for relatively long periods, making this indicator's values fixed for every considered period. The BCT financial strategy establishing is presented by the KIR level and based on the economic and financial Tunisia situation. A higher KIR level means that banks will limit their borrowing, then, less money will be in circulation on the market, and however, a lower level stands for the more money the banks will borrow, so more liquidity will be on the

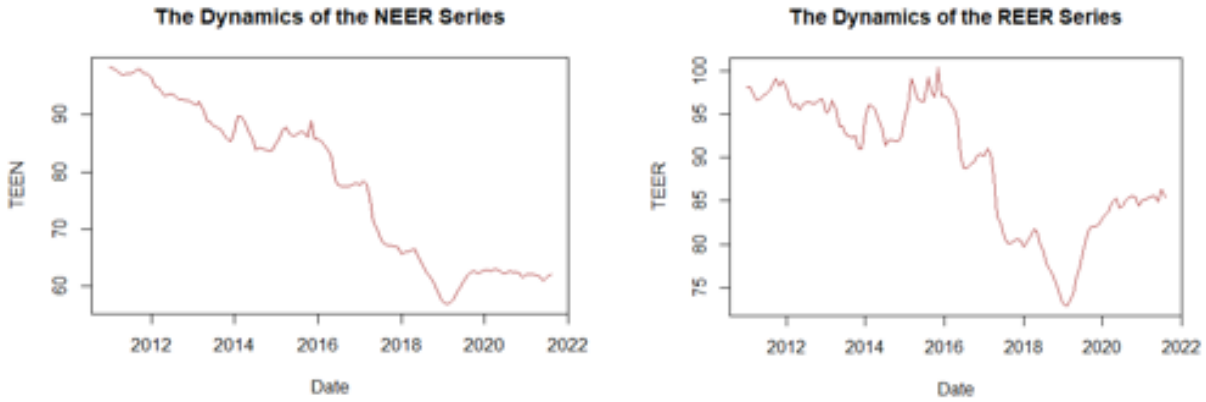


Fig. (4). The Dynamics of the NEER and REER Series.

market. For this reason, we can state a homogeneity between the variations of these two curves, an increase in the inflation rate curve is followed by an increase in the KIR one, and vice-versa. The monthly MSI curve has an upward trend. The fact that the MSI presents the amount of money in circulation in the Tunisian economy to meet its current monetary needs, and that this latter is always growing explains this trend. The increase of Tunisia's economy needs is justified by several reasons, as the population growth then its consumption, the high inflation rate level, and others. The monthly FER and NFC series present fluctuating curves with different allures. The first curve starts with relative fluctuation to have towards the start of 2019 a remarkable increase while the second curve presents a continuous decline from the beginning of 2011 until the beginning of 2019 to begin after to fluctuate relatively. The FER have exceeded the "security level" established at 90 days of imports since 2019. These changes in the variation direction can be attributed to the tourism, energy and mining sectors, which have been moribund since the revolution, have picked up again. As explained by the journalist Mathieu Galtier in his article published on the official site of "Jeune Afrique" magazine, in the first half of the year, tourism revenues reached nearly 2 billion dinars (623 million euros, +42.5% compared to the same period in 2018), according to the Ministry of Tourism. Energy and phosphate exports climbed 23.5% and 22.7%, respectively, in the first seven months of 2019, according to the INS.

For presenting graphically the nominal effective exchange rate NEER and the real effective exchange rate REER, the Fig. (**4**) is reserved.

From this graph, we can clearly notice that these two exchange rates nominal and real advance in the same direction as the series of TND against the selected foreign currency. It is to be noted that the figure presented for the exchange rates series, which indicates the inverse is because the presented series are exchange rates for TND with a quotation to the unknown.

3.1.2. Statistical Analysis

We initially tested our all database of exchange rates series consisting of the four sets of series. Table **1** summarizes the statistics that we have achieved.

Confirming the results of the graphical analysis, and interpreting only the set of series on which we will explore our empirical model, this table allows us to conclude that the returns of Currency/XDR exchange rate series form that we are studying vary around a zero average, by admitting positive and negative values that compensate each other. The median value is zero too. It is for this reason that our interpretations will focus on the rest of the calculated statistics. Moreover, the Jarque-Bera test, confirmed by the symmetry indicator Skewness and the tailedness measure Kurtosis, indicates that the distributions of the different series do not follow the normal one; therefore the concerned series are not symmetrical. Furthermore, the ADF test results state that all returns series of Currency/XDR exchange rates form are stationary and have not unit roots for the significance level of 1%, which allows as estimating our linear regression for our first step of the empirical part based on these returns series. Finally, the test of heteroskedasticity ARCH LM test point out that all series present an ARCH effect. For the test of autocorrelation LB-Q statistical test, it is not the case for autocorrelation since the values of this test are not all significant for all levels of significance as for $\Delta\ln(EUR/XDR)$, $\Delta\ln(USD/XDR)$, and $\Delta\ln(JPY/XDR)$ series.

Moving on the macroeconomic variables statistical analysis, Table **2** enables us to recapitulate the calculated statistics.

In confirmation of the results of our graphical analysis, this table leads us to conclude for our 126 monthly observations that the MSI series has the highest average value and median for the values 65.79 and 61.97, respectively. This variable takes values that vary between 97.048 and 42.142, two positive values that are considered relatively high. Since we have different measurement scales for our series (% and mDT), we calculated the coefficient of variation of each (not reported) to be able to compare their volatility. Indeed, it allows us to confirm our results in the graphical analysis and to find that the monthly series of the RPB is the most volatile with an indicator equal to 6.89. On its part, the GDP growth rate has a coefficient of Skewness and Kurtosis the most different from the 0 and 3 norms respectively, i.e. (-3.222) and 14.343, respectively, confirming the non-normality of this series. Only the inflation rate series and the FC one are normally distributed following the results of Jarque-Bera test. The unit root test ADF, the test of autocorrelation LB-Q

Table 1. Descriptive Statistics of Exchange Rate Historical Series.

Series	Ob	Mea	Med	Max	Min	Std	Ske	Kur	J-B	ADF	LB1	LB5	LB10	ARCH1	ARCH5	ARCH10
USD/TND	2510	2.149	2.039	3.198	1.34	0.539	0.14	-1.44	196.7***	-1.46	1987.9***	9690.9***	19236***	2134.2***	1563.37***	972.03***
EURTND	2510	2.562	2.301	3.471	1.9	0.512	0.39	-1.48	271.05***	-1.53	1984.3***	9673.8***	19187***	2137.2***	1561.4***	970.7***
GBP/TND	2510	3.034	2.936	4.103	2.19	0.514	0.15	-1.15	115.89***	-2.59	1991.3***	9713.1***	19211***	2123.8***	1558.4***	969.8***
JPY/TND	2510	20.58	19.95	28.13	15.2	4.018	0.36	-1.35	228.2***	-1.5	1984.9***	9606.5***	19056***	2137.3***	1559.7***	968.8***
TND/XDR	2510	0.339	0.353	0.459	0.23	0.071	0.05	-1.44	177.3***	-1.29	1995.9***	9748.6***	19340***	2143.9***	1564.6***	972.2***
EUR/XDR	2510	0.834	0.833	0.917	0.77	0.034	0.29	-0.92	144.56***	-1.83	2002.3***	9695.4***	19092***	2087.6***	1524.7***	948.1***
USD/XDR	2510	0.691	0.705	0.748	0.62	0.034	-0.4	-1.26	237.25***	-1.31	2001.8***	9760.7***	19315***	2111.9***	1542.3***	959.2***
GBP/XDR	2510	0.994	1.004	1.122	0.86	0.065	0.16	-1.24	159.71***	-1.91	1985.3***	9595.1***	18951***	2101.2***	1535.01***	952.5***
JPY/XDR	2510	0.007	0.007	0.009	0.01	0.001	1.06	0.142	361.28***	-1.49	1995.4***	9775.9***	19298***	2134.3***	1556.9***	967.4***
Ln(TND/XDR)	2510	-1.10	-1.04	-0.78	-1.5	0.214	-0.12	-1.48	198.34***	-1.50	1992.2***	9719.2***	19287***	2144.3***	1564.9***	972.3***
Ln(EUR/XDR)	2510	-0.18	-0.18	-0.09	-0.3	0.040	0.23	-0.95	139.41***	-1.84	2001.7***	9688.9***	19075***	2086.1***	1523.9***	947.9***
Ln(USD/XDR)	2510	-0.37	-0.35	-0.29	-0.5	0.050	-0.47	-1.22	238.08***	-1.31	2003.3***	9770.2***	19334***	2112.38***	1542.5***	959.4***
Ln(GBP/XDR)	2510	-0.01	0.004	0.115	-0.2	0.065	0.09	-1.27	163.40***	-1.97	1983.9***	9586.5***	18928***	2095.69***	1531.2***	949.9***
Ln(JPY/XDR)	2510	-5.00	-5.03	-4.76	-5.2	0.100	0.9	-0.05	264.26***	-1.52	1995.6***	9765.8***	19272***	2134.75***	1557.4***	967.5***
Δ Ln(TND/XDR)	2509	0.00	0.00	0.022	-0.02	0.003	-0.1	5.224	2467.03***0	-10.6 ****	69.60***	77.41***	100.93***	133.18***	108.4***	78.67***
Δ Ln(EUR/XDR)	2509	0.00	0.00	0.019	-0.02	0.003	-0.3	3.870	1382.3***	-14.7 ***	1.596	3.817	6.708	2.019	22.87***	41.05***
Δ Ln(USD/XDR)	2509	0.00	0.00	0.017	-0.01	0.002	0.39	3.236	1062.1***	-15.4 ***	0.013	2.038	5.706	5.221**	30.86***	39.73***
Δ Ln(GBP/XDR)	2509	0.00	0.00	0.024	-0.07	0.004	-1.6	24.41	69817***	-14.6 ***	15.547***	21.731***	36.841***	111.596***	100.06***	132.7***
Δ Ln(JPY/XDR)	2509	0.00	0.00	0.054	-0.04	0.005	0.24	9.003	7003.3***	-13.7 ***	3.665*	4.285	7.345	58.367***	51.14***	55.7***

The *, **, and *** imply the rejection of null hypothesis for normality using J-B, for unit root using ADF test, for no ARCH effects using ARCH LM test and for no autocorrelation using Ljung–Box Q-statistic test at 10%, 5%, and 1%, respectively.

Table 2. Descriptive Statistics of Monthly Macroeconomic Variables Series.

Statistics	RPB	GDPGR	InfR	KIR	MSI	FER	FC
Observations	126	126	126	126	126	126	126
Mean	0.115	0.304	5.244	5.259	65.79	13.931	0.608
Median	0.073	0.629	5	4.75	61.97	12.651	-0.2
Maximum	3.312	3.311	7.7	7.75	97.048	23.099	8.592
Minimum	-2.16	-7.44	2.7	3.5	42.142	9.639	-5.914
Std. dev.	0.792	1.57	1.201	1.322	15.098	3.641	3.449
Skewness	0.965	-3.222	0.221	0.665	0.511	1.242	0.17
Kurtosis	2.996	14.343	-0.592	-0.902	-0.883	0.221	-0.791
J-B	60***	1164.1***	2.573	12.2***	8.58**	29.3***	3.491
ADF	-5.4***	-2.911	-1.853	-1.469	0.269	-1.236	-1.343
LB-Q (1)	0.843	74***	102.5***	112***	108.8***	106.5***	104.5***
LB-Q (5)	7.029	156.7***	415.6***	516.9***	490.1***	453.1***	460.5***
LB-Q (10)	8.983	171.9***	646.2***	913.5***	854.2***	710.7***	816.3***
ARCHLM 1	0.334	52.81***	94.09***	98.98***	110.6***	105.3***	87.6***
ARCHLM 5	3.974	62.7***	94.19***	96.25***	106.9***	102.5***	85.66***
ARCHLM 10	5.173	64.99***	91.59***	92.97***	102.4***	98.77***	82.63***

*, **, and *** imply the rejection of null hypothesis for normality using J-B, for unit root using ADF test, for no ARCH effects using ARCH LM test and for no autocorrelation using Ljung–Box Q-statistic test at 10%, 5%, and 1%, respectively.

Table 3. Descriptive Statistics of NEER and REER Variables Series.

Series	Obs	Mean	Med.	Max	Min	Std. dev.	Skew	Kurt
NEER	126	77.99	83.11	98.26	56.94	13.49	-0.09	-1.55
REER	126	89.33	91.01	100.35	72.87	7.48	-0.46	-1.03
Series	J-B	ADF	LBQ1	LBQ5	LBQ10	ARCH1	ARCH5	ARCH 10
NEER	16.3***	-1.50	124.9***	585.3***	1075***	117.3***	112.9***	107.2***
REER	12.4***	-1.83	124.3***	575.6***	1041***	115.4***	111.2***	105.8***

*, **, and *** imply the rejection of null hypothesis for normality using J-B, for unit root using ADF test, for no ARCH effects using ARCH LM test and for no autocorrelation using Ljung–Box Q-statistic test at 10%, 5%, and 1%, respectively.

statistical test, and ARCH LM test point out, respectively, that only the monthly series of the RPB is stationary at the level of significance of 1%, only this same series has no autocorrelation between its observations for the different levels, and uniquely this series is homoscedastic. In other words, the latter series differs from all other macroeconomic variables in these three characteristics.

Turning to the results of the descriptive analysis for the macroeconomic variables NEER and REER presented in Table **3**. We note that these two exchange rates have not both a normal distribution, and have unit root, ARCH effect and autocorrelation. We can also note that the nominal effective exchange rate series is more scattered than the real effective one as confirmed by the standard deviation indicator.

Building on this descriptive analysis of our database and our different series of exchange rates and selected macroeconomic variables, we will report and interpret the results of our empirical study in the following sub-section.

3.2. Empirical Results

3.2.1. For the Weightings Calculation

We tested firstly, the structural stability of our series by the test of the Cumulative Sum CUSUM test (not reported). Then, as a second step in the calculation of the weightings and as mentioned in the methodology description, we calculated the relative volatility of the different exchange rates parities in the aim of the OMA of TND determination. Table **4** recapitulates this calculation.

Table 4. Relative Volatility Calculation of the Different Exchange Rate Parities.

	USD/TND	EUR/TND	JPY/TND	GBP/TND
Standard Deviation	0.0055	0.0078	0.0078	0.0067
Relative Volatility	0.1977	0.2811	0.2809	0.2402

We can assert that all the selected currencies belong to the TND anchor basket for the period from 03/01/2011 to 30/06/2021. After examining our database and correcting the non-stationarity that we have detected by calculating the first difference of the ln of the four exchange rate series that we have selected, we estimated the OLS method a multiple linear regression relating the TND and the 4 currencies belonging to its OMA through the reference currency XDR. The latter presents the exchange rate TND/XDR as the endogenous variable that will be explained by the four exogenous variables USD/XDR, EUR/XDR, GBP/XDR and JPY/XDR. This estimation was under the assumption that the sum of the coefficients of these variables is equal to 1. The mathematical presentation of the estimated equation is:

$$\Delta \ln(TND/XDR) = \alpha_0 + \alpha_1 \Delta \ln(USD/XDR) + \alpha_2 \Delta \ln(EUR/XDR) + \alpha_3 \Delta \ln(GBP/XDR) + \alpha_4 \Delta \ln(JPY/XDR) + \varepsilon_t \quad (17)$$

Under assumption:

$$\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1 \leftrightarrow \alpha_1 = 1 - \alpha_2 - \alpha_3 - \alpha_4 \quad (18)$$

By introducing this assumption into the equation above, the equation to be estimated becomes:

$$\Delta \ln[(TND/XDR)/(USD/XDR)] = \alpha_0 + \alpha_1 \Delta \ln[(EUR/XDR)/(USD/XDR)] + \alpha_2 \Delta \ln[(GBP/XDR)/(USD/XDR)] + \alpha_3 \Delta \ln[(JPY/XDR)/(USD/XDR)] + \varepsilon_t \quad (19)$$

From the estimation of the described equation above, we reach the results described in Table **5**.

From the results presented in Table **5**, we can conclude that the selected multiple linear regression model describes well the local currency TND in terms of the four foreign currencies USD, EUR, GBP, and JPY for all our sampling period. This statement is justified by the fact that the fitting quality and representativity level indicator is distinctly large with a value of 75.5%. In addition, we notice that the EUR has the most important weight in the TND anchor basket, i.e. 0.722. Thus, the EUR is considered the most involving currency in the TND basket for our whole research period with a weight of more than 72% compared to an average weight of less than 30% for the three other foreign currencies including the USD for about a weight of 25%. From this, we can affirm that the EUR is the currency the most weightily and impacting on the TND determination and evolution. This statement can be reinforced by the fact that the relationship of the Tunisian economy, finance, and politics are more linked to the European world than to other countries like the United States, Great Britain, and Japan. It is to be noted that the currencies related to the latter are not all significant, showing thus their low importance in the determination of the TND anchor basket compared to the EUR firstly and the USD in the second place.

3.2.2. For the Macroeconomics Determinants of the TND Currency

Like any empirical procedure, a statistical analysis of the database is a crucial step. For this reason, we have addressed a descriptive analysis of our monthly database composed of the 9 selected macroeconomic variables including the two effective exchange rates nominal and real and the monthly USD/TND, EUR/TND, GBP/TND, and JPY/TND rates. This analysis is reported for the monthly macroeconomic variables in a section above and not reported for the 4 monthly exchange rates. During this stage, we will explore our original variables series without the need to calculate its variation series as we did in the step just above. In other terms, we will apply our multiple linear regression model on our collected monthly database in the aim to specify the macroeconomic determinants of the 4 studied monthly exchange rates. The

Table 5. Weightings Determination.

Value	Interpretation
$\alpha_0 = -2\,e^{-4}$	The constant of the equation represents the intercept of the correspondent curve. It is negative, low and statistically significant. It means that the average return of (TND/XDR) compared to (USD/XDR) is equal to $-2\,e^{-4}$ when the returns of the foreign currency/XDR parities compared to USD/XDR are null.
$\alpha_1 = 0.247$ *	The weight of the USD in the determination of the TND.
$\alpha_2 = 0.722$	The weight of the EUR in the determination of the TND.
$\alpha_3 = 0.036$	The weight of the GBP in the determination of the TND.
$\alpha_4 = -0.005$	The weight of the JPY in the determination of the TND. (It is statically not significant)
$R^2 = 75.5\%$	A high quality of fitting and a good level of representativity. 75.5% of the fluctuations of the TND variations is explained by the USD, EUR, and GBP for our entire sampling period.

* : $\alpha 1 = 1 - (0.722 + 0.036 - 0.005) = 0.247$

Table 6. TND Macroeconomic Determinants Specification.

	USD/TND	EUR/TND	GBP/TND	JPY/TND
α_0 (Constant)	0.9 (1.402 e^{-12})	0.45 (6.26 e^{-7})	1.6 (1.1 e^{-28})	1.05 (0.503)
α_1 (RPB Coeff.)	0.006 (0.66)	0.018 (0.103)	-0.023 (0.103)	0.598 (0.005)
α_2 (GDPGR Coeff.)	-0.013 (0.112)	-0.0099 (0.129)	0.027 (0.001)	-0.434 (5 e^{-4})
α_3 (InfR Coeff.)	0.035 (0.028)	0.047 (0.0003)	0.041 (0.011)	-0.225 (0.338)
α_4 (KIR Coeff.)	0.087 (7.9 e^{-6})	0.07 (5.4 e^{-6})	0.13 (5.3 e^{-10})	0.873 (0.002)
α_5 (MSI Coeff.)	0.004 (0.458)	0.04 (3.2 e^{-15})	-0.0025 (0.61)	0.518 (2.7 e^{-8})
α_6 (FER Coeff.)	0.035 (0.034)	-0.06 (8.6 e^{-6})	0.059 (0.0005)	-1.29 (6.5 e^{-7})
α_7 (NFC Coeff.)	-0.074 (1.3 e^{-10})	0.006 (0.484)	-0.06 (2.6 e^{-8})	0.589 (2 e^{-4})
R^2	95.66%	97.19%	95.06%	85.79%

The values between parentheses indicate the p-value for each correspondent t statistic of every calculated coefficient. The p-value indicates the level of significance of each coefficient.

results of the regression estimation for the 4 different exchange rate series are summarized in Table **6** and interpreted nextly.

From this table we can conclude that the constant of the regression equations meaning the intercepts of the corresponding curves is positive, relatively low and significant for the three first currency parities and it wasn't the case for JPY/TND. The latter statement means that this equation hasn't an intercept so that its curve starts from the origin (0, 0) of the reference frame. Additionally, the RPB coefficient is only significant for the JPY/TND exchange rate having a positive value of 0.598 then meaning that a variation of 1 million Tunisian dinars of this variable will affect positively in average the JPY/TND exchange rate of 5980 points. Moreover, the GDP growth rate coefficient is significant for only GBP/TND and JPY/TND exchange rates, meaning then the affecting role of this variable on these two exchange rates. This coefficient is equal to 0.027 and (-0.434) for the GBP/TND and JPY/TND exchange rates, respectively. This means then that the growth rate of the GDP indicator affects positively the GBP/TND exchange rate and negatively the JPY/TND exchange rate with a higher altitude than the first. In other words, an increase in the GDP growth rate of 1% implies in average an increase of 270 points in the GBP/TND exchange rate, and a decrease of 4340 points in the JPY/TND exchange rate. In addition, the coefficient of the inflation rate is not significant only on the JPY/TND exchange rate and it has the higher impact on the EUR/TND one in the level of significance of 1%. For this case, a variation of 1% of the Tunisian inflation rate causes a variation in the same sense of the EUR/TND exchange rate by 470 points. Furthermore, the KIR coefficient is significant in the level of 1% of significance for the different studied exchange rates, meaning so the importance of this macroeconomic variable in the determination of the exchange rate of the foreign currencies components of the TND basket anchor. In addition, the coefficient of the MSI is statically significant only for EUR/TND and JPY/TND exchange rates. The present notice indicates that only for these two exchange rates a variation of 1 Tunisian dinar million in this macroeconomic variable involves a deviation in the same sense of 370 points and 5180 points for the EUR/TND and JPY/TND exchange rates, respectively. It is to be noted that the effect of this variable on the JPY/TND exchange rate is more pronounced than on the EUR/TND one. The FER coefficient is significant for all the exchange rates studied in the level of 5% of significance for USD/TND exchange rate and in the level of 1% of significance for the rest of exchange rates. This coefficient is positive for USD/TND and GBP/TND exchange rates and negative for EUR/TND and JPY/TND exchange rates. On its side, the coefficient of the net foreign claims is significant for USD/TND, GBP/TND, and JPY/TND with values of (-0.074), (-0.062), and (0.589), respectively. This stands that an increase (decrease) of 1 Tunisian dinar million in this variable implies a decrease (increase) of 740 points, a decrease (increase) of 620 points, and an increase (decrease) of 5890 points for the USD/TND, GBP/TND, and JPY/TND, respectively. Furthermore, the R^2 indicator showing the overall significance level of the model is quite high for the four estimated multiple linear regression models, having values between 85.79% and 97.19%. This statement implies a high linear fitting level and a good representativity degree of the endogenous variables (i.e. USD/TND, EUR/TND, GBP/TND, and JPY/TND) by the exogenous variables (i.e. macroeconomic variables). Moving on to the study of the Tunisian foreign exchange market in its entirety; presented by the NEER and the REER; and the identification of its most determining macroeconomic variables, Table **7** presents the results of the equations' estimates.

Table 7. NEER and REER Macroeconomic Determinants Specification.

	NEER	REER
α_0 (Constant)	118.7 (4.455 e^{-89})	112.05 (9.48 e^{-78})
α_1 (RPB Coeff.)	-0.346 (0.22)	-0.568 (0.091)
α_2 (GDPGR Coeff.)	0.116 (0.48)	0.26 (0.184)
α_3 (InfR Coeff.)	-1.77 (2.56 e^{-9})	-1.57 (4.45 e^{-6})
α_4 (KIR Coeff.)	-0.776 (7.73 e^{-8})	-1.29 (2.27 e^{-4})

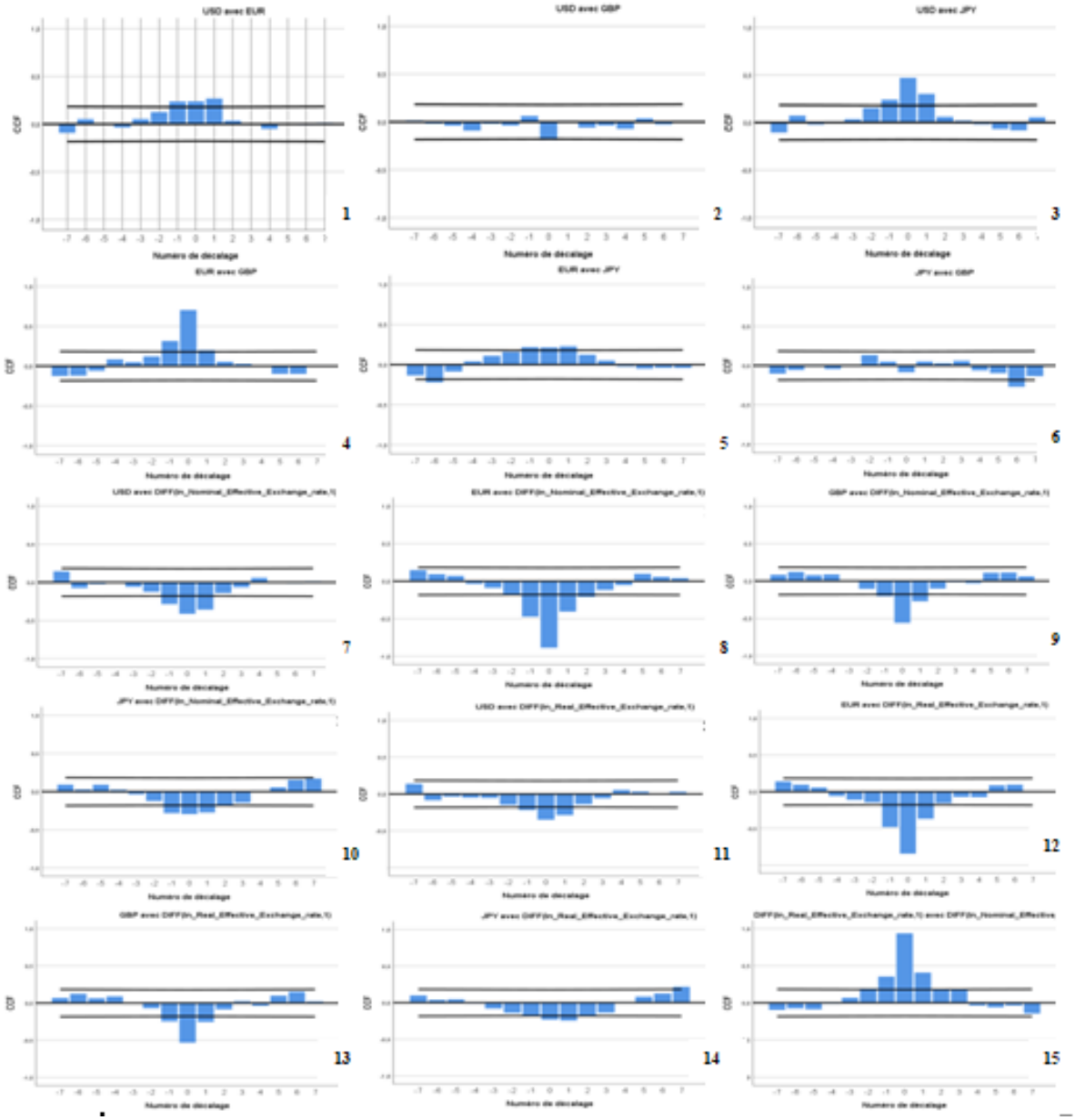


Fig. (5). Correlation Presentation.

α_5 (MSI Coeff.)	-0.473 (4.82 e^{-6})	-0.40 (8.67 e^{-4})
α_6 (FER Coeff.)	0.087 (0.782)	1.26 (9.51 e^{-4})
α_7 (NFC Coeff.)	1.123 (5.46 e^{-8})	0.17 (0.46)
R^2	97.45%	88.54%

The values between parentheses indicate the p-value for each correspondent t statistic of every calculated coefficient. The p-value indicates the level of significance of each coefficient.

By observing table **7**, we can confirm that the NEER is more presenting the global state of the foreign exchange Tunisian market than the REER, based on the level adjustment indicator R^2. In other words, the NEER is better explained by the significant estimated macroeconomic variables than the REER one, and then the first reflects better the global evolution of the Tunisian market then the second.

To conclude, we can say that the KIR, presenting the financing strategy followed by the BCT, is the most determinant variable compared to the other variables studied of the different exchange rates examined. In addition, the FER, which is significant in the different significance levels for the different studied exchange rates, is also one of the most determinant macroeconomic variable on these exchange rates. This variable is considered as a tool used by the BCT to defend the parity of the TND against the other currencies to avoid erratic variations in the value of the TND and smooth its volatility, as confirmed by Charfi (2018) in an article published in the web manager center official site by WMC with TAP. In fact, the BCT is the main responsible for deriving the evolution (upward or downward) of the studied exchange rates. Moreover, we can notice an inverse effect of the FER and the NFC variables on the studied exchange rate justified

Table 8. Instantaneous Correlation Matrix.

USD/TND	EUR/TND	GBP/TND	JPY/TND	NEER	REER
1					
0.239	1				
-0.190	0.705	1			
0.471	0.215	-0.086	1		
-0.413	-0.887	-0.560	-0.294	1	
-0.351	-0.844	-0.534	-0.232	0.938	1

The series treated in this correlation matrix are the return ones of the historical exchange rates.

Table 9. Results of the Different Tests of Model Effects.

Features	USD	EUR	GBP	JPY	NEER	REER
USD	3.39***	1.40	0.51		1.55	2.18*
EUR	3.48***	1.43		0.82	6.92***	1.92*
GBP	2.21*	1.97*	0.27	0.61	12.14***	
JPY	0.61		0.79	2.98**	4.62***	4.17***
NEER	1.40	2.01*		1.70	2.73**	3.12**
REER	0.85	1.53		1.11	2.39**	2.55**

*, **, and *** imply the significance of the indicator at the 10%, 5%, and 1% level of significance, respectively.

by the opposite relationship of these two macroeconomic variables. In simpler terms, a positive effect (negative effect) of the foreign exchange reserves on the studied exchange rates is accompanied by a negative effect (positive effect) of the net foreign claims in the case where the latter is statically significant on the respective exchange rates.

3.2.3. For Hedging Strategy Deployment

For this part, the different other steps for our hedging exchange risk strategy implementation will be explained and interpreted. So, our strategy will be deployed in 5 steps. For the latter reason we have the idea to name our hedging strategy as 5SSERH referring to the nomination 5 Steps Strategy for Exchange Risk Hedging. Thus, proceeding the exploratory analysis and the existing study already reported, an analysis of the cross correlation of our historical exchange rate variables for our whole sampling period is stated. To do so, this test will be established on the return series of the exchange rate series. The results for the correlation test for the different possible pairs of these series are presented in Fig. (**5**).

The following matrix synthesizing the instantaneous correlation and reinforcing the Fig. (**5**) results is presented in table **8**.

Interpreting the graphical and statistical cross correlation results, we can state that remarkably, the correlation coefficient between the NEER and the REER and the different exchange rates is negative, due to the fact that the studied exchange rates are written with an unknown quotation, as explained previously. Also, the correlation's amplitude between the EUR/TND and the NEER and the REER, presented respectively graphically by the bar curves 8 and 12 and statically with coefficients of (-0.887) and (-0.844), respectively, is higher compared to the other exchange rates. This statement asserts that the EUR is the most important foreign currency on affecting the general evolution of the foreign exchange Tunisian market. In addition, for all the presented and calculated correlation except for the pairs USD/TND-GBP/TND and JPY/TND-GBP/TND, the level of the instantaneous correlation is always the highest. The two most correlated series, in absolute value, are NEER and REER followed by the couple EUR/TND and NEER. Since the EUR is the most weighted foreign currency in the TND anchor basket, it is normal to be the most impacting on the NEER reflecting the global evolution of the Tunisian exchange market. It should be noticed that the correlation test for our case was more suitable than an application of a Vector auto-Regressive VaR model, since the latter highlights only the lagged relationships whereas the correlation test supplies different levels of lagged relationships, different levels of advanced correlations and eventually the instantaneous correlation which was the most important for our different selected exchange rate pairs. To further our study, we have choose to proceed with the Temporal Causal Modeling TCM approach to better explain the different exchange rate movements even the extreme ones and their sources. It is able to point out the sources of each outstanding value from the input variables. This causality modeling approach is advanced compared to the test of correlation since it provides more detailed and specified results. The latter is due to the fact that a time series X is said to "Cause" another time series Y if regressing Y by taking into account historical values of X and Y produces a better model for Y than regressing only the historical values of Y (VaR model). As a first set of TCM model results, tests of model effects were established for each inputted series. Table **9** summarizes these results.

The different series reported in this table are the return ones for the various exchange rate variables, and the reported values are Fischer statistic for the different coupling series. This table allows us to affirm that the exchange rate returns series have different levels of mutual effects as for the couple return exchange rate EUR/TND EUR series and NEER series, and the couple NEER-REER, and diverse degrees of one direction effects as for GBP/TND return exchange rate series GBP that affects the USD/TND and the EUR/TND ones without being affected by them in counterpart. Summarizing the just reported effects relationships, the diagram below presents them with arrows showing the direction of these effects whose thickness reflects the amplitude of the impact:

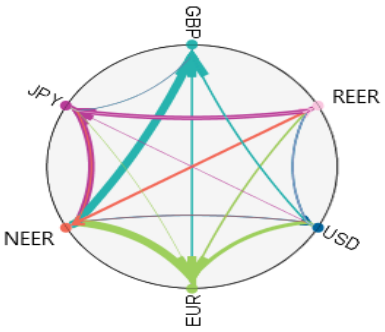


Fig. (6). The Global Model System.

From this diagram, it is remarkable that the return EUR/TND series is the better explained by the different rest variables since it receives effect from them with different levels while the NEER is the variable that makes the most impact. Table 10 presenting the model fitting statistics for the different models can enhance our thoughts, just noticed, from the Fig. (**6**).

Table 10. Models Fitting Statistics.

Model for the Target	RMSE	RMSPE	AIC	BIC	R^2
EURTND	0.01	20.13	-1235.47	-1162.78	0.87
GBPTND	0.02	10.44	-914.33	-841.67	0.47
USDTND	0.01	4.96	-1033.84	-961.15	0.44
NEER	0.01	5.52	-1066.17	-993.48	0.41
JPYTND	0.02	19.78	-921.91	-849.22	0.40
REER	0.01	14.46	-1038.30	-965.61	0.34

RMSE: Root Mean Square Error, RMSPE: Root Mean Square Percentage Error, AIC: Akaike Information Criterion, BIC: Bayesian Information Criterion.

Thus, confirming our graphical explanation, we can find that the EUR/TND return series as a target variable is the best explained by the other variables, followed by the GBP/TND return series, then the USD/TND return one, then the rest, according to the R^2 indicator, having values of 87%, 47%, and 44%, respectively (Table **10**). It should be noticed that this models order differs according to the fitting statistics criterion chosen. As an example, according to the BIC indicator, by which the better fitted model is the one having the less value of this indicator, the EUR/TND exchange rate return variable is still the better fitted, followed by the NEER return series, then the REER one, then the other exchange rate return series. It is to be pointed out that the EUR/TND return series is the best fit according to all the reported fitting statistics.

The figures 7, 8, 9 and 10, presenting a set of impact diagrams of exchange rate variables return series and on them, allow us to confirm our statistical results. These graphs indicate, in general, that the exchange rate returns have an impact directly and indirectly, with different levels on each other and on the macroeconomic variables, and vice versa.

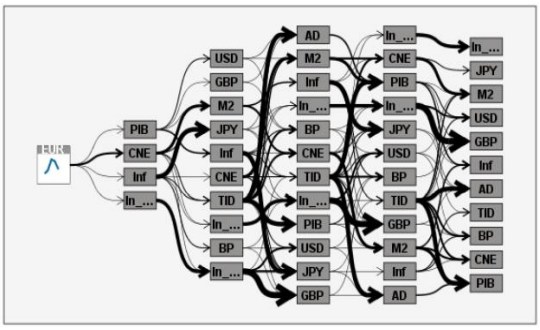


Fig. (7). Impact Diagram of EUR/TND return series.

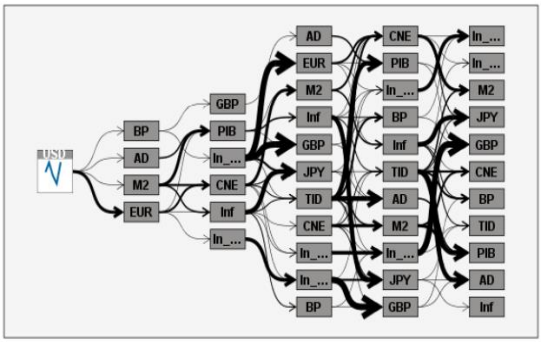


Fig. (8). Impact Diagram of USD/TND return series .

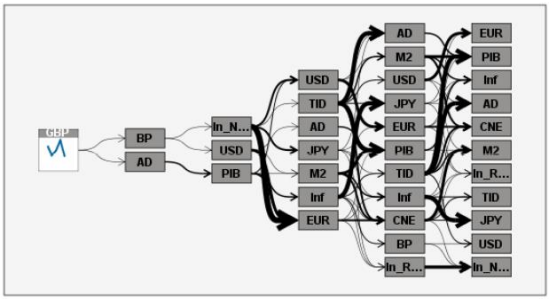


Fig. (9). Impact Diagram of GBP/TND return series.

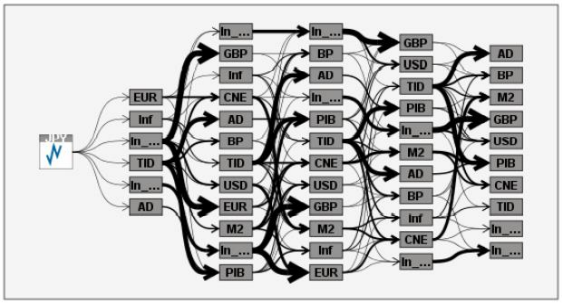
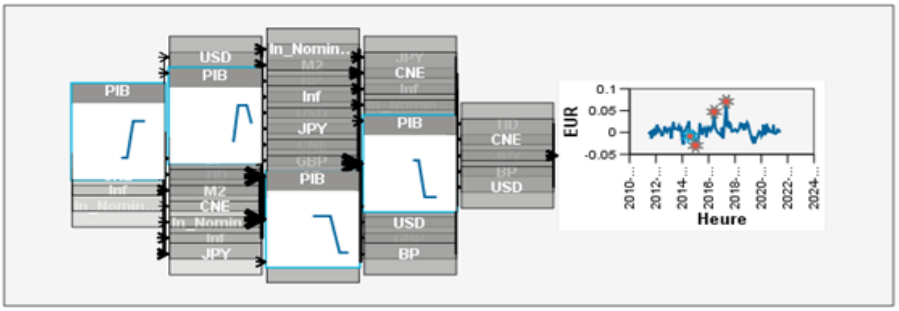


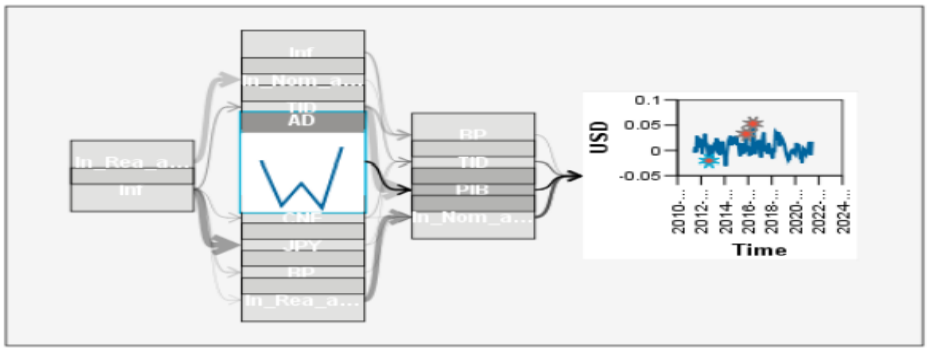
Fig. (10). Impact Diagram of JPY/TND return series.



Valeurs extrêmes

Heure	Valeur observée	Valeur prédite	Probabilité de valeur extrême	Causes premières
2015-01-01	-0,03	1,63E-004	0,99	ln_Nominal_Effective_Exchange_rate
2017-05-01	0,07	0,04	0,99	CNE
2016-06-01	0,05	0,02	0,98	Inf
2014-08-01	-0,01	0,02	0,98	PIB

Fig. (11). Extreme Values of EUR/TND return series Causes.



Outliers

Time	Observed Value	Predicted Value	Outlier Probability	Root Causes
2015-11-01	0.03	-6.71E-004	0.99	Inf
2012-09-01	-0.02	0.01	0.97	AD
2016-06-01	0.05	0.03	0.97	ln_Rea_avancé

Fig. (12). Extreme Values of USD/TND return series causes.

Moving on to the extremes values analysis, Table **11** allows us to see the negative and positive extreme values for the different studied return series by indicating the date of each:

Table 11. Extreme Values Visualization.

	-Extreme Value	Date	+Extreme Value	Date
USD/TND	-0.03	01/08/2020	0.05	01/06/2016
EUR/TND	-0.03	01/01/2015	0.07	01/05/2017
GBP/TND	-0.07	01/07/2016	0.05	01/09/2017
JPY/TND	-0.06	01/11/2014	0.09	01/06/2016
NEER	-0.06	01/04/2017	0.03	01/10/2015
REER	-0.05	01/05/2016	0.04	01/12/2013

In order to understand these extreme values and specify their sources, we have tried to introduce the macroeconomic variables that we have selected. The set of figures below accompanied each with its interpretation are presenting this stage results. From the Fig. (**11**), we can deduct the outliers of the EUR/TND return series causes, which are mainly the nominal effective exchange rate return for its extreme negative value remarked on 01-01-2015, and the foreign claims for its extreme positive value noticed in 01-05-2017. The Fig. (**12**) presents the first causes of the detected outliers for the USD/TND returns series and showing that the first cause for the negative extreme value of USD/TND returns is the real effective exchange rate. We have limited our presentation to the extreme values of these two series of exchange rate returns only since they present the principal exchange rates.

Based on the exploration of the TCM model and its achieved results, we will create the different scenarios for the various possible market situations that were detected by our analyses. Learning from the scenarios based period, we obtain the closest to reality previsions for the desired exchange rate. For our scenarios creation, the Value at Risk indicator as the representative of the global system or the entire market is required. For this need, we had the choice of either subtracting it directly from the already calculated percentile table, or

Table 12. Forecasted Values of EUR/TND for Scenarios of Global Market Depreciation.

Date	**01/07/2021**	**01/08/2021**	**01/09/2021**	**01/10/2021**	**01/11/2021**
EUR/TND	3.36	3.38	3.41	3.43	3.46
Date	**01/12/2021**	**01/01/2022**	**01/02/2022**	**01/03/2022**	**01/04/2022**
EUR/TND	3.48	3.49	3.50	3.52	3.53

Table 13. Forecasted Values of USD/TND for Scenarios of Global Market Depreciation.

Date	**01/07/2021**	**01/08/2021**	**01/09/2021**	**01/10/2021**	**01/11/2021**
USD/TND	2.85	2.91	2.95	3.01	3.06
Date	**01/12/2021**	**01/01/2022**	**01/02/2022**	**01/03/2022**	**01/04/2022**
USD/TND	3.13	3.20	3.26	3.32	3.38

calculating it analytically using the expected return and the standard deviation of the market variable, which is the NEER. Computing the VaR assumes that the returns series of NEER exhibits a Normal Distribution. For this second option, the VaR is calculated based on the following equation:

$$VaR = [R_{NEER} - (z)(\sigma)]V_{NEER} \quad (20)$$

Where R_{NEER} is the return of the NEER series, z is a value for 5% level of confidence in one-tailed test, σ is the standard deviation of NEER series and V_{NEER} is the value of NEER variable. We have opted to subtract this VaR values from the percentile table. By manipulating our computer tool, we obtained the following results for the different scenarios we have created, namely a market appreciation scenario, a market depreciation scenario and a market stability scenario. In the following, we will present two cases of scenarios created for a depreciation situation of the global foreign exchange market, respectively, for an importation in EUR and exportation in USD by the studied company for a term of three months.

For the first case, Table **12** presents the different previsions for the EUR/TND exchange rate for a period of 10 months starting from the first of July 2021:

According to this table and in view of the fact that the market as a whole is in a situation of extreme depreciation, we can notice that the EUR/TND exchange rate forecasted will be continuously increasing for the forecasting period. Comparing the latter with the forward exchange rate subtracted from the BCT official site for a term of 3 months, either 3.3133, is a crucial step to have the decision of hedging or not by the treated holding. Based on this comparison, we can conclude that in 01/02/2022, and for a term of 3 months our holding can decide in this date to hedge its exchange rate risk by a forward contract for this term since its rate (3.3133) will be less than the spot exchange rate at that date (3.53).

For the second case, Table **13** presents the different previsions for the USD/TND exchange rate for a period of 10 months starting from the first of July 2021:

Based on table **13** and in view of the fact that the market as a whole is in a situation of extreme depreciation, as for the first case, we can notice that the USD/TND exchange rate forecasted will be continuously increasing for all the forecasting period. Comparing the latter with the forward exchange rate subtracted from the BCT official site for a term of 3 months, either 2.9500, is a crucial step to have the decision of hedging or not by the holding in question. Based on this comparison, we can conclude that in 01/02/2022, and for a term of 3 months our studied company can decide in this date to not hedge its exchange rate risk by any forward contract for this term since its rate (2.9500) will be less than the spot exchange rate at that date (3.38), and the latter is more profitable for it.

CONCLUSION

Throughout this research, we have investigated the manifold exchange rate determinants for the TND that influence directly as well as indirectly its direction and value. This phase was followed by scanning the various prevailing approaches and models employed in the literature to appraise the most suitable in our case. After diving into the models' details and their main distinctiveness, we proceeded to analyze the behavior of the national currency TND regards to the pinpointed macroeconomic variables as well as the prevalent influential currencies on the Tunisian trade market. It must be highlighted that in the first place of targeting the most implicated currencies, an expert perspective was considered to narrow our scope to the impactful ones. Undoubtedly, a validation procedure was implemented to endorse the experts' assertions about the actual currencies involved. After this phase, the weights for the basket of currencies to which the Tunisian Dinar is pegged are estimated mathematically. On top of that, an additional process concerning the macro-economic factors' substantial ramifications on the Tunisian currency and its behavior was carried out. It should be pointed out that we, likewise, studied the macroeconomic determinants of the Tunisian exchange market as an entirety by investigating the macroeconomic determinants of the real effective and nominal effective exchange rates to decide upon the one that best presents the market. The successful candidate among those is adopted for the subsequent phases of our methodology as the one reflecting better the economic and financial Tunisian health. Afterward, a review of the diverse mechanisms, lawfully, available for the companies inwardly and outwardly to adopt a hedging strategy against the risk of exchange rate

instability and direction uncertainty was performed. Then, a correlation study is established in order to test the different effects that can exist between the studied exchange rates, lagged effect, advanced effect and instantaneous effect. In order to dive further in our study, an exploration of the TCM model (Temporal Causality Model) was performed. The major motivations of employing TCM concern its capacity of explaining the causes of the movements of the exchange rate series (Compared to the correlation test). Another motive regards writing a series Y according to its history as well as the history of its explanatory variables (Compared to the VaR model). A final motivating ground is extracting extreme values and inferring their sources. As a final step, we create and deploy scenarios based on the market situation that help us to forecast exchange rates referring to the scenario period, the studied company position, the contract term, and its currency. Then, a comparison between the obtained previsions and the Forward rate calculated is established to enables us to make the decision to hedge or not.

In simpler words, deploying our exchange rate risk hedging strategy is a feasible procedure consisting of five steps: beginning with an exploratory analysis of the data that are subtracted directly from the BCT official site via a developed Artificial Intelligence based program, then an analysis of the existing is established to study the TND anchor basket and its macroeconomic determinants. Thirdly, a correlation analysis is conducted to examine the different cause and effect relationships that may exist between the different possible combinations of our data. Fourthly and in the aim to proceed and enhance our study, the TCM model was explored. Finally, our different hedging scenarios are created and the desired exchange rate is forecasted for a period (from 1 month to 12 months). Based on the forecasted exchange rate values, the studied Holding was able to conclude the most advantageous forward hedging contract by choosing the term of the contract at which the exchange rate level is the most profitable rate according to its position in the market. So, our research dealing with the Tunisian dinar anchor basket and its macroeconomic determinants and exploring an exchange risk hedging strategy is important (1) for companies with international transactions that seek to minimize their exchange risk and (2) for the Tunisian exchange market decision makers to better specify the TND determinants among foreign currencies and macroeconomic factors.

Despite the several benefits' results of our study that contribute to a better exchange rate risk hedging strategy deployment, and Tunisian currency determinants identification, some shortcomings related to the nature of the selected macroeconomic variables and the econometric process are worth mentioning. First, to explore our empirical study, we limited ourselves to monthly data, which can affect the reliability of our results given the high volatility of the variables under study, particularly those of exchange rates. In other words, exploring a daily data for the case of our study can be the target of further research. Second, we have considered only one of the exchange rate risk aspects, which is the tendency based on the graphical exchange rates evolution analysis. Therefore, it is important to include the other two aspects, which are the high volatility and the foreign market liquidity to have a more detailed and specific analyses for future researches.

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CONFLICT OF INTEREST AND AUTHORSHIP CONFORMATION FORM

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version. This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue. The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

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