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Abstract

Multinational enterprises (MNEs) operating across different currencies are exposed to exchange rate risk. They may utilize a variety of tools to mitigate that risk. While there are different types of exchange rate risk, this study focuses specifically on the ongoing exposure of cash flow transactions denominated in the currencies of seven different developed countries. Since other types of risk (i.e., economic and translation) are evaluated based on yearly results, they are not considered in this study. The *modified* value-at-risk (MVaR) model is employed to estimate the maximum one-period losses during the eighteen months before the onset of the COVID-19 pandemic and, in addition, the maximum one-period losses during the eighteen months following the onset of the COVID-19 pandemic. The predicted losses using MVaR are then compared with the actual ex-post results. Our objective is to analyze the extent of the cash flow transaction exposure and provide practical insights to MNEs as they decide whether or not they should hedge this risk. This study is noteworthy because it compares the pre- and post-COVID-19 periods.

Keywords

foreign exchange rate, currency risk, transaction exposure, maximum loss

Revisions

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COVID-19 and Its Impact on Multinational Enterprises: A Modified Value at Risk Approach

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Abstract

Multinational enterprises (MNEs) operating across different currencies are exposed to exchange rate risk. They may utilize a variety of tools to mitigate that risk. While there are different types of exchange rate risk, this study focuses specifically on the ongoing exposure of cash flow transactions denominated in the currencies of seven different developed countries. Since other types of risk (i.e., economic and translation) are evaluated based on yearly results, they are not considered in this study. The *modified* value-at-risk (MVaR) model is employed to estimate the maximum one-period losses during the eighteen months before the onset of the COVID-19 pandemic and, in addition, the maximum one-period losses during the eighteen months following the onset of the COVID-19 pandemic. The predicted losses using MVaR are then compared with the actual ex-post results. Our objective is to analyze the extent of the cash flow transaction exposure and provide practical insights to MNEs as they decide whether or not they should hedge this risk. This study is noteworthy because it compares the pre- and post-COVID-19 periods.

Keywords: foreign exchange rate, currency risk, transaction exposure, maximum loss

Introduction

Multinational enterprises are entities that engage in international business ventures in a variety of ways. While their engagement in the international arena exposes them to exchange rate risk, including transaction exposure, whether or not they should hedge this risk depends on the specific circumstances. Depending on the expected costs and benefits of hedging, multinational enterprises (MNEs) may be better off hedging their foreign currency positions. There exist several tools that can be used to mitigate and/or eliminate the ongoing exposure of cash flow transaction risk. However, there may also be circumstances where maintaining an open position in a particular currency or portfolio of currencies (i.e., not hedging) is justified. Since most of the MNEs operate across multiple currencies, transaction exposure is generally associated with their total foreign currency portfolio. This portfolio risk is, in part, a function of the net positions in each currency (including both cash inflows and cash outflows) and the volatility of the individual exchange rates. It also depends critically on the co-movements of the currencies. As is well known, the volatility of exchange rates themselves and their co-movements are not stable over time. Accordingly, transaction exposure can change over time.

Given MNE's intrinsic exposure to transaction risk, and due to the volatility in the foreign exchange markets, this study aims to provide a clear comparison of the transaction risk for the eighteen months before the onset of COVID-19 and the transaction risk for the eighteen months following the start of COVID-19. A limited number of conceptually related studies are found in the recent literature. For example, Garcia and Castro (2018) analyzed the impact of the Great Recession on the Mexican peso/U.S. dollar exchange rate. Sharma and Mathur (2016) evaluated changes in the risk associated with several currency rates resulting from Brexit. Our study's findings, and the associated insights, will provide an important context as MNEs consider whether or not to hedge their exchange rate risks. Because the volume of foreign exchange transactions has increased so dramatically in recent years, the stakes involved in these decisions have become very high. As indicated in Table 1 below, the daily volume of trading around the world has increased from .14 trillion U.S. dollars in 1985 to over 7.5 trillion U.S. dollars in 2022, and this trend is likely to continue.

We believe there are no studies –as of now, to have explored possible changes in MNE's ongoing transaction risk in the pre- and post-COVID-19 periods. It is possible that the economic instability introduced by COVID-19, including greater exchange rate volatility and changed co-variances, has had a measurable impact on transaction risk. Focusing on seven developed countries' currencies during the eighteen months before and the eighteen months after COVID-19, we use the MVaR approach to quantify predicted losses and then compare these losses with the actual/ex-post results. Pandemics like COVID-19 are *black swan* events that will likely impact an MNE's operations and ultimately its bottom line. By analyzing ongoing transaction risk pre- and post-COVID-19 to observe the immediate impact, we provide insight into how MNEs can prepare and plan for such unforeseen, but inevitable, future events. The rationale for selecting only eighteen months (prior and post) is to capture the volatility of currency movements due to the pandemic. We tested our results with twenty-four-month and longer periods and found less volatility compared to the eighteen-month benchmark. This study also reveals how MNEs can minimize potential losses by determining which particular currency portfolios (i.e., combinations of currencies) have the least/most transaction risk and whether this has changed in the post-COVID-19 period. Further, the results of this study will offer valuable insights into effectively managing an MNE's short-term assets and liabilities and provide important information about potential entry and exit strategies for particular currency markets in the post-COVID-19 era.

Research Question and Empirical Contributions

An increasingly important question for MNEs operating across multiple emerged economies is the following: given the costs of hedging their ongoing currency exposure, should MNEs attempt to mitigate (hedge) their currency exposure during black swan events like the COVID-19 pandemic, and subsequently, should their hedging strategy change during such events (assuming a decision has been made to hedge)?

Both the *traditional* value-at-risk (VaR) and the *modified* VaR (MVaR) methods may be utilized to estimate a firm's maximum one-period loss resulting from foreign currency exposure. In recent years, however, the shortcomings of the traditional VaR approach have become better understood. The traditional VaR approach to quantifying the transaction risk associated with flexible exchange rates has been popular, in part, because of its relative simplicity and straightforward interpretation. More specifically, it places a specific dollar value on the downside risk (i.e., the maximum likely

loss) an MNE will experience over a specific time period at a particular confidence level. However, the principal limitation and vulnerability of traditional VaR is its implicit assumption that the distributions of exchange rate movements are normal. Therefore, in this study we utilize the MVaR approach, in which the skewness of the population as well as the excess kurtosis and/or absolute kurtosis are considered. More specifically, we: a) compare the MVaR measures against the actual currency gains/losses (i.e., the ex-post results) during the pre-and post-COVID-19 time periods, and b) analyze the optimal currency portfolios for the seven currencies considered.

In many cases, MVaR will give MNEs a more accurate estimate of their exchange rate risk. We believe this study represents a significant methodological contribution to the literature and will provide MNEs with superior information when considering their global business strategy and whether hedging their ongoing currency risks makes sense in each case.

Background and Global Context

Half a century ago the era of fixed exchange rates ended, and the reliability and relative predictability of fixed exchange rates gave way to today's era of floating exchange rates, with all its uncertainty and complexities. Unlike a fixed exchange rate system, a floating exchange rate system opens the door for speculators to take advantage of the notion that exchange rate values are determined by market forces without intervention from the government. That is, speculators are the ones who assume a certain direction that currencies will take in the foreign exchange markets. They then take positions based on these expectations, which in turn impact demand and supply conditions for the currency and hence its international value. More than twenty years ago, it was estimated that the composition of daily foreign exchange transactions was only 5% international trade (approximately), 15% international investment, and 80% speculation. More recently, to help mitigate their own foreign currency exposure, MNEs have utilized statistical techniques to quantify the exchange rate risks they face and, in addition, developed approaches to mitigate these risks.

The extraordinary growth in the daily volume and value of currency trading (see Table 1, below) has given rise to significant volatility in developed markets. In order to protect their bottom lines, MNEs must hedge (or not hedge) their currency risks optimally. While there have been many studies utilizing traditional VaR measures, there have been no comprehensive studies of the MVaR measure comparing the maximum expected losses with the actual currency losses over this particular post-COVID-19 crisis period for developed markets' currencies. A comparison of these findings with the pre-COVID-19 findings will have significant practical implications for MNEs and even mid-sized U.S. firms that have significant revenues and/or expenditures across seven developed markets' currencies. The seven currencies included constitute the majority of the forex trading volume globally.

Table 1. Milestones of Daily Foreign Exchange Transaction Volume Globally

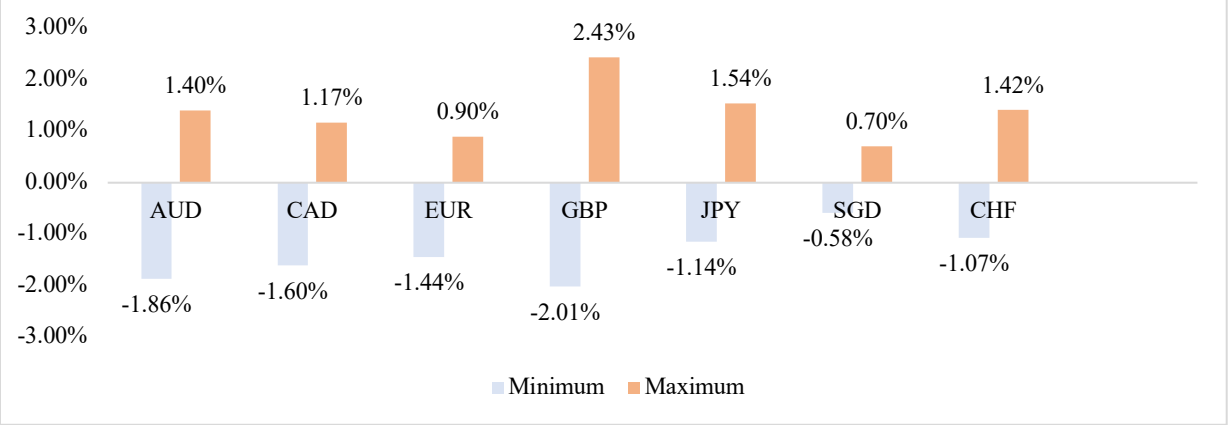
Year	Amount in Trillion-Dollar
1985	0.14
1995	1.00
2006	2.00
2010	4.00
2014	5.00
2019	6.60
2022	7.50

Source. Drehmann and Sushko, 2022

The results of this research will help MNEs determine the best possible hedging strategy, given the expected benefits and costs of hedging and management's preference regarding the familiar risk/return trade-off. Pandemics like COVID-19, and other widespread dislocations, have a global impact and may change the trajectory of exchange rates and impact their co-movements. Profit maximizing firms operating internationally need to be aware of how extensive these impacts might be and remain nimble in adjusting their hedging strategies as warranted. Our findings relating to the COVID-19 pandemic represent a case study of how a real-world black swan event can impact exchange rates, ongoing transaction risk, and profitability. Furthermore, they provide a template to MNEs for evaluating changes to the costs and benefits of hedging ongoing transaction risk in the face of such a significant international event.

The pre-COVID-19 period in this study starts July 1, 2018, and ends December 31, 2019. It was in December 2019 the WHO confirmed the existence of a transmissible respiratory virus emanating from Wuhan, China. The post-COVID-19 period is from January 1, 2020, through June 30, 2021. Both the pre- and post-COVID-19 periods are eighteen months in duration. Our study is based on daily exchange rates for seven developed currencies using data obtained from the Federal Reserve System (2021). Specifically, the following developed market currencies were considered in this study: the Australian dollar (AUS), the Canadian dollar (CAD), the euro (EUR), the British pound (GBP), the Japanese yen (JPY), the Singapore dollar (SGD), and the Swiss franc (CHF). Figures 1 and 2, below, indicate the minimum and maximum daily percentage changes for the seven developed market currencies during pre- and post-COVID-19 periods.

Figure 1. Minimum and Maximum Daily Percentage Change for Developed Market Currencies

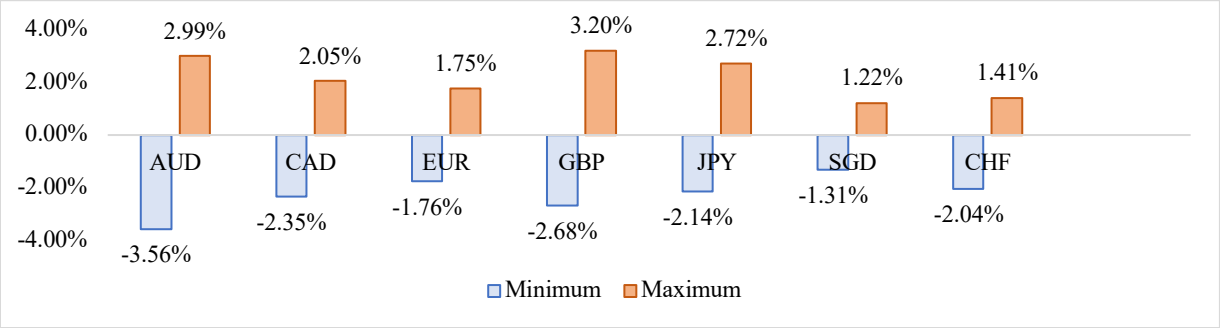


Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
Source. Federal Reserve System, 2021

As indicated, the British pound experienced the largest percentage changes during both eighteen-month periods with +2.43% and -2.01% pre-COVID-19, and +3.2% and -2.68% post-COVID-19 –the only exception is the -3.56% reduction in the Australian dollar in the post-COVID-19 period. By contrast, the Singapore dollar experienced the smallest percentage changes of the seven currencies with +0.70% and -0.58% pre-COVID-19 and +1.22% and -1.31% post-COVID-19. One can speculate that the relatively large upward and downward percentage changes in the British pound during the pre-COVID-19 period (see Figure 1) are attributable to the uncertainty surrounding Brexit and Britain's future trade relationship with the eurozone. The British pound's large percentage one-day increase in the post-COVID-19 period (see Figure 2) may reflect positive momentum in achieving a successful trade agreement with the eurozone. One can also speculate

that the comparatively large one-day percentage decrease in the value of the Australian dollar during the post-COVID-19 period (Figure 2) was the result of trade tensions with China, including the imposition of tariffs on Australian exports.

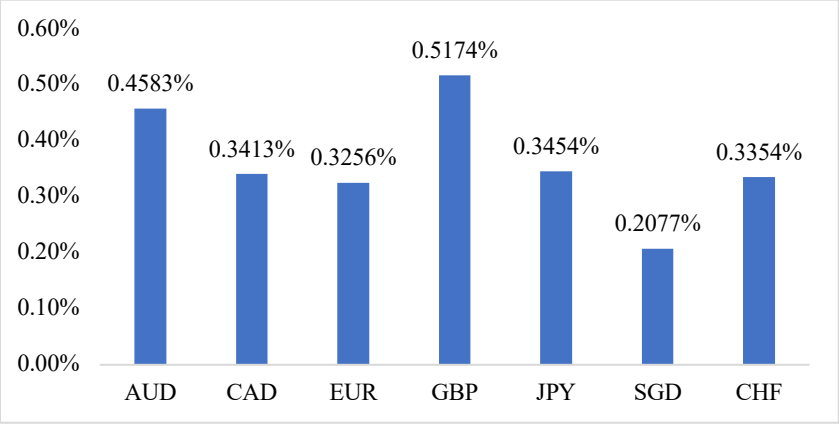
Figure 2. Minimum and Maximum Daily Percentage Change for Developed Market Currencies



Note. Dates are between January 2020 – June 2021(post-COVID-19).
Source. Federal Reserve System, 2021

Figures 3 and 4, below, indicate the standard deviations of the seven currencies based on their daily percent changes during the pre- and post-COVID-19 periods. As indicated in Figure 3, the British pound and the Singapore dollar experienced the highest and the lowest volatility in the pre-COVID-19 period, respectively, with standard deviations of .5174% and .2077%. During the post-COVID-19 months (Figure 4), the Australian dollar and the Singapore dollar had the highest and the lowest variability with standard deviations of .7500% and .2974%, respectively.

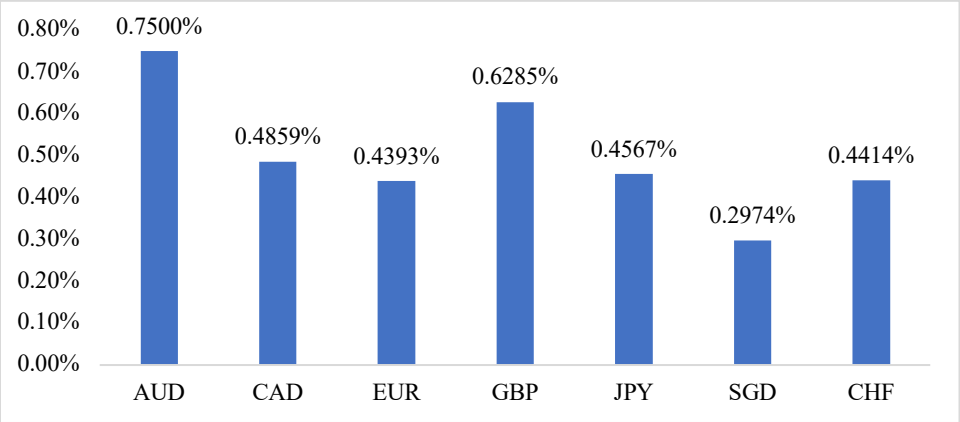
Figure 3. Standard Deviation of Developed Market Currencies



Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
Source. Federal Reserve System, 2021

The large volatility of the British pound during the pre-COVID-19 period (Figure 3, above) may reflect, as previously described, uncertainty over Brexit and repeated failed negotiations with the eurozone on free trade and tariffs. In addition, the forced resignation of former Prime Minister Theresa May in July 2019 (Kunessberg, 2019) may have destabilized the pound. Figure 4, above, indicates the Australian dollar had the highest standard deviation among the seven currencies during the post-COVID-19 period. A likely explanation for this instability is, once again, Australia's trade dispute with China. China restricted imports of beef, barley, wine, coal, and cotton from Australia between May through December 2020, likely destabilizing the Aussie dollar.

Figure 4. Standard Deviation of Developed Market Currencies



Note. Dates are between January 2020 – June 2021 (post-COVID-19).
Source. Federal Reserve System, 2021

Literature Review

A review of the literature reveals a variety of approaches to estimating the different types of exchange rate risk, including transaction exposure. Chambers et al. (2014) provide an excellent overview of the most common methods of estimating VaR, and by implication, provide the broad context for the current study. More specifically, the study describes the analytical parametric, historical, and Monte Carlo simulation approaches to estimating VaR, and, in addition, discusses the advantages and the potential dangers of each approach in various applications (Chambers et al., 2014).

We believe the current study is the first to test for changes in MVaR between the pre- and post-COVID-19 periods. Indeed, this is the current study's principal contribution to the literature. The current study extends the recent literature which recognizes that important worldwide or regional events (either economic or non-economic) can impact the volatility and correlations of currencies and hence the risks to corporations of doing business around the world. For example, Garcia and Castro (2018) apply the VaR methodology to assess the risk associated with the Mexican peso/U.S. dollar exchange rate and how the risk differed/changed in the pre-and post-Great Recession (2008/2009) periods. Sharma and Mathur (2016) estimate how the VaR associated with the exchange rates between the Indian rupee and the U.S. dollar, the euro, and the British pound have changed as a result of Brexit. In applying VaR to the Tunisian foreign exchange market, Saidane (2019, p. 241) seeks to improve decision-making in the face of financial crises noting that "when financial markets are subjected to a major regime shift, many volatilities and correlations can be expected to shift". Badaye and Narsoo (2020) note that a variety of worldwide financial or other crises have elevated the need for robust models that can accurately forecast exchange rate risk. Similar to the current study, Badaye and Narsoo (2020) consider equally weighted portfolios of currencies for developed economies.

It is also possible that institutional changes to currency markets will impact the volatility and correlations of currencies. For example, Uppal and Mudakkar (2021) find evidence that VaR increases when exchange rates are *managed* (sometimes referred to as a *dirty float*) rather than freely floating. They evaluate the risk associated with Pakistan's currency to some major world currencies and determine that the risk of a managed float (e.g., vis-a-vis the U.S. dollar and the

Japanese yen) exceeds the risk of a free float. Interestingly, they find that the exchange rate volatility associated with managed floats can exceed that of freely floating exchange rates, in part, as a result of fat tails and skewness in the distribution of returns. The authors of the current study note that by using the MVaR approach, the skewness and kurtosis problems that concern Uppal and Mudakkar (2021) are eliminated (this is explained in the Methodology section of the current study, immediately below).

Of course, many VaR studies do not necessarily involve a *pre*- and *post*-analysis of identifiable and potentially destabilizing occurrences or events. These studies can involve the currencies of either emerged or emerging nations, or both. Poornima et al. (2014) use VaR to forecast the risk of the Indian rupee to the U.S. dollar, the euro, and the U.K. pound sterling. Kemda et al. (2015) use VaR to estimate the risk associated with the U.S. dollar/ZAR (South African) exchange rate. Fink et al. (2018) examine the relationship between the yield curve and VaR for the U.S. dollar/euro exchange rate. Some studies estimate VaR using high-frequency data. For example, Abbara and Zevallos (2018) test the accuracy of employing 15-minute VaR data for five major, equally-weighted currency portfolios to forecast exchange rate risk. Bedowska-Sojka (2018) uses VaR to test if the use of intraday data can improve forecasting the risk associated with the euro/Polish zloty foreign exchange rate.

In addition to estimating exchange rate risk, the basic VaR approach can be employed to predict the maximum likely loss for other important financial variables. These closely related studies can extend our basic understanding of VaR modeling and how best to employ it. For example, Su and Hung (2018) use a variety of VaR models to forecast the risk of 21 stock and seven currency portfolios with different weighting combinations. Interestingly, they note that if a firm's VaR model overestimates the true risk, they may lose *the opportunity cost.*

Kristjanpoller Rodríguez and Barahona Ossa (2014) employ VaR to forecast the risk associated with a variety of Latin American stock and currency markets. Jammazi and Nguyen (2017) use VaR and extreme value theory to forecast the portfolio risk associated with crude oil prices and the U.S. dollar. Like the study by Uppal and Mudakkar (2021) mentioned above, Jammazi and Nguyen (2017) note the important role of both *heavy tailness* and skewness. The paper by Cera et al. (2019) uses the VaR model to forecast risk associated with the relatively new stock markets in Eastern European countries. Gaio et al. (2018) compare VaR for a variety of emerging and developed countries' stock markets both pre- and post-two different international financial crises. Noting that VaR studies have been criticized for their inaccuracy resulting from the 2008-2009 financial crisis, Buberkoku (2019) examines and evaluates a variety of approaches to estimating VaR for eight different types of financial variables, including foreign exchange rates. Sinha and Agnihotri (2015) examine the effects of *nonnormality* in Indian financial markets due to financial instability and political uncertainty.

Using the standard deviations of the seven developed currencies studied (shown in Figures 3 and 4 above) and, equally important, their correlation coefficients (subsequently described), the present study will be the first to compare the MVaR of various combinations (portfolios) of developed currencies with their ex-post results (i.e., the actual maximum losses) for both the pre-and post-COVID-19 time periods. As noted above, this is the present study's principal contribution.

Methods

The exchange rate data was obtained from the Federal Reserve System (2021) website In this study, the results for the maximum 1-period holding period loss for an individual currency *i* or for a portfolio of currencies *p* is

$$E(e_t) - Z\ x\ (\sigma_{i\ or\ p}) \quad (1)$$

where $E(e_t)$ is the expected percentage change in the currency's value for the relevant period.

The results for the *modified* maximum 1-period holding loss for an individual currency *i* or for a portfolio of currencies *p* can be estimated using

$$E(e_t) - ModZ\ x\ (\sigma_{i\ or\ p}) \quad (2)$$

$$where\ ModZ = \left(z + \frac{Skew(z^2-1)}{3!} + \frac{Kurt(z^3-3z)}{4!} + \frac{Skew^2(2z^3-5z)}{36}\right) \quad (2A)$$

Where:

- z is the normal *z-score* corresponding to the desired confidence level
- Skew is the skewness of the population
- Kurt is the excess kurtosis or absolute kurtosis - 3

Portfolio's variance is computed using the equation below:

$$\sigma_p^2 = \sum_i w_i^2 \sigma_i^2 + \sum_i \sum_{j \neq i} w_i\, w_j \sigma_i \sigma_j \rho_{ij} \quad (3)$$

Where:

- σ_p = standard deviation of daily % changes in currency portfolio
- σ^2_p = variance of daily % changes in currency portfolio
- w_i = proportion of total portfolio value denominated in currency *i*
- w_j = proportion of total portfolio value denominated in currency *j*
- σ_i = standard deviation of weekly percentage changes in currency *i*
- σ_j = standard deviation of weekly percentage changes in currency *j*
- ρ_{ij} = correlation coefficient of weekly percentage changes between currencies *i* and *j*

Currency Correlation

The correlation coefficients –included in the above equation, between any given pair of currencies can vary and, hence, are not stable and/or constant over time. Based on their daily percentage changes, the correlation coefficients for the seven developed market currencies for the pre-and post-COVID-19 periods are presented in Tables 2 and 3, below. As can be observed, for any given pair of currencies the correlation coefficients generally change from one time period to the next. For example, the correlation coefficient for the JPY/CAD exchange rate changed from -.0393 (pre-COVID-19) to .1338 (post-COVID-19); for the JPY/AUD exchange rate the correlation coefficient changed from .0223 (pre-COVID-19) to .3102 (post-COVID-19).

Table 2. Correlation Coefficients Between Developed Market Currency Pairs

Currency	AUD	CAD	EUR	GBP	JPY	SGD	CHF
AUD	1.0000	0.5413	0.4860	0.3094	0.0223	0.7499	0.2389
CAD		1.0000	0.3608	0.2862	-0.0393	0.5263	0.2231
EUR			1.0000	0.4807	0.2673	0.6316	0.6741
GBP				1.0000	0.0918	0.4429	0.2533
JPY					1.0000	0.1157	0.5067
SGD						1.0000	0.3548
CHF							1.0000

Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
Source. Federal Reserve System, 2021

Table 3. Correlation Coefficients Between Developed Market Currency Pairs

Currency	AUD	CAD	EUR	GBP	JPY	SGD	CHF
AUD	1.0000	0.7640	0.6151	0.7181	0.3102	0.8159	0.4822
CAD		1.0000	0.5047	0.6284	0.1338	0.6848	0.3706
EUR			1.0000	0.5812	0.4828	0.6911	0.8577
GBP				1.0000	0.3710	0.7260	0.5092
JPY					1.0000	0.3590	0.5681
SGD						1.0000	0.5765
CHF							1.0000

Note. Dates are between January 2020 – June 2021 (post-COVID-19).

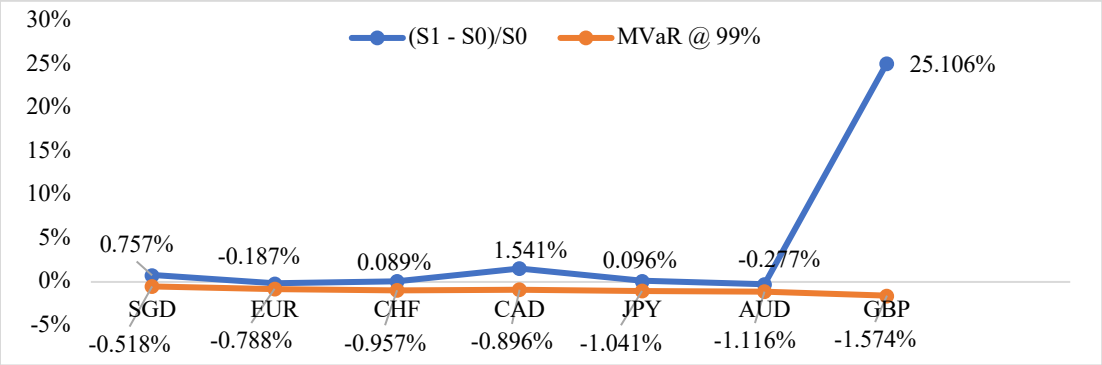
Tables 4 and 5, below, compare the predicted MVaR against the actual ex-post results for each currency for the pre-and post-COVID-19 periods, respectively. The MVaR predicts what will be the maximum one-day loss for the particular currency. Figure 5 depicts the realized return and maximum one-day loss based on Table 4 data. The ex-post result is the actual average daily gain/loss for the particular currency for the entire 18-month time period. It is worth noting that the MVaR for the pre-COVID-19 period indicates the British pound (GBP) had the largest likely average maximum one-day loss (-1.57392%). For the post-COVID-19 period, the Australian dollar (AUD) had the largest likely maximum likely one-day loss (-2.036%). Despite these predicted maximum losses, the actual ex-post results for the GBP and the AUD for both periods were *gains* of 25.10625% and 0.046% respectively. There were, in fact, no losses in either case.

Table 4. Developed Markets Currencies Realized Return and MVaR

Currency	$(S_1 - S_0)/S_0$[a]	MVaR[b]
SGD	0.7569%	-0.5175%
EUR	-0.1869%	-0.7884%
CHF	0.0890%	-0.9568%
CAD	1.5406%	-0.8963%
JPY	0.0959%	-1.0410%
AUD	-0.2770%	-1.1158%
GBP	25.1062%	-1.5739%
Average	3.8750%	-0.9842%

Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
[a]Actual realized return.
[b]Maximum one-day loss at 99% confidence level.
Source. Federal Reserve System, 2021

Figure 5. Realized vs MVaR for Developed Currencies One-Period Loss/Gain



Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
Source. Federal Reserve System, 2021

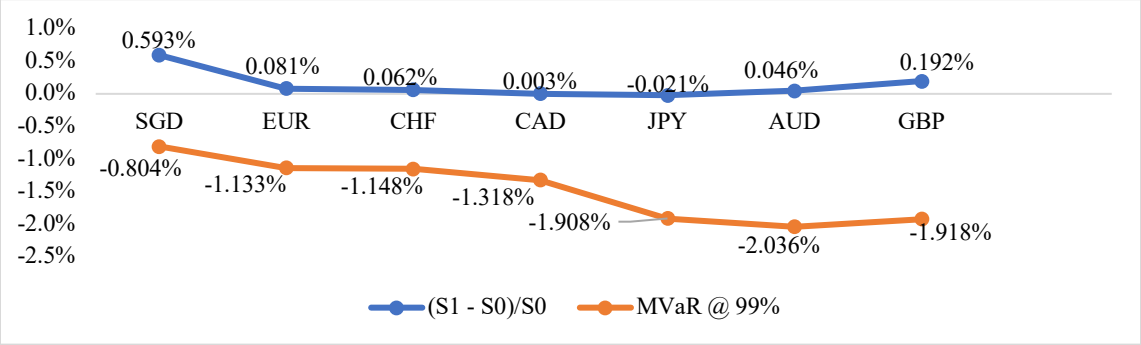
Importantly, comparing MVaR with the ex-post results during the pre-COVID-19 period (Table 4) reveals that, except for EUR and AUD which experienced moderate losses, unhedged positions on all other currencies would have resulted in gains. Comparing the averages across all seven currencies, the actual ex-post gain of 3.8750% was far superior to the average MVaR of -0.9842%. For the post-COVID-19 period in Table 5, the findings were quite similar: except JPY, which experienced a modest actual loss, unhedged positions in all other currencies would have resulted in gains. Comparing the averages across all seven currencies, the ex-post gain of .1367% was far superior to the average MVaR of -1.4664%. Figure 6 shows the realized return and maximum one-day loss based on Table 5 data.

Table 5. Developed Markets Currencies Realized Return and MVaR

Currency	$(S_1 - S_0)/S_0$	MVaR @ 99%
SGD	0.5930%	-0.8044%
EUR	0.0808%	-1.1326%
CHF	0.0623%	-1.1476%
CAD	0.0030%	-1.3184%
JPY	-0.0209%	-1.9079%
AUD	0.0463%	-2.0360%
GBP	0.1925%	-1.9179%
Average	0.1367%	-1.4664%

Note. Dates are between January 2020 – June 2021 (post-COVID-19).
Source. Federal Reserve System, 2021

Figure 6. Realized vs MVaR for Developed Markets Currencies One-Period Loss/Gain



Note. Dates are between January 2020 – June 2021 (post-COVID-19).
Source. Federal Reserve System, 2021

Findings

Equally weighted MVaR estimates and the realized/ex-post outcomes ($(S_1-S_0)/S_0$) for the currency portfolios of the seven developed markets are presented in Tables 6 and 7, below. Table 6 represents the pre-COVID-19 period. Table 7 represents the post-COVID-19 period. For both periods, MVaR is based simply on the arithmetic averages of the MVaR for each currency included, but not including the impact of any possible interactions (correlations) between the currencies. These equally weighted portfolios are constructed starting with the currency with the lowest standard deviation. Then each additional currency is added from lowest to highest volatility. Accordingly, the last currency added to the portfolio has the highest standard deviation. Since these are equally weighted portfolios, every additional currency added to the portfolio increases the average predicted maximum one-day loss, as evidenced by the rising Avg MVaR values in both Tables 6 and 7.

Table 6. Developed Markets Equally Weighted Currency Portfolio

Currency	Avg $(S_1 - S_0)/S_0$	Avg MVaR	Portfolio Composition
SGD	0.7569%	-0.5175%	SGD
EUR	0.2850%	-0.6530%	SGD, EUR
CHF	0.2197%	-0.7542%	SGD, EUR, CHF
CAD	0.5499%	-0.7898%	SGD, EUR, CHF, CAD
JPY	0.4591%	-0.8400%	SGD, EUR, CHF, CAD, JPY
AUD	0.3364%	-0.8860%	SGD, EUR, CHF, CAD, JPY, AUD
GBP	3.8750%	-0.9842%	SGD, EUR, CHF, CAD, JPY, AUD, GBP

Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
Source. Federal Reserve System, 2021

Table 7. Developed Markets Equally Weighted Currency Portfolio

Currency	Avg $(S_1 - S_0)/S_0$	Avg MVaR	Portfolio Composition
SGD	0.5930%	-0.8044%	SGD
EUR	0.3369%	-0.9685%	SGD, EUR
CHF	0.2454%	-1.0282%	SGD, EUR, CHF
CAD	0.1848%	-1.1007%	SGD, EUR, CHF, CAD
JPY	0.1437%	-1.2622%	SGD, EUR, CHF, CAD, JPY
AUD	0.1274%	-1.3912%	SGD, EUR, CHF, CAD, JPY, AUD
GBP	0.1367%	-1.4664%	SGD, EUR, CHF, CAD, JPY, AUD, GBP

Note. Dates are between January 2020 – June 2021 (post-COVID-19).
Source. Federal Reserve System, 2021

In contrast to Table 6 and 7 which were based solely on arithmetic averages, Table 8 and 9 (below) show both the MVaR and the standard deviations of the currency portfolios including the effect of the covariances between the various currencies. As we construct the currency portfolio using rolling standard deviations, correlation coefficient on an annual basis, the computed MVaR value for portfolios are different from Table 6. For example, in Tables 4 and 6 the SGD MVaR value is -0.5175% (which is computed using eighteen months of return), whereas in Table 8; SGD MVaR value is -0.5589% (rolling returns for annually with six months of return). They reflect, in a sense, *optimal* currency portfolios based on modern portfolio theory and, hence, should provide superior information to MNEs about the risks of operating across multiple currencies. A point of clarification; we use nonlinear optimization methods to construct the optimal portfolios. The order of each currency's entry in the portfolio numerically makes the MVaR as small as possible at every instance. The MVaR of the portfolio is a complex function of the standard deviation as well as the

kurtosis, etc., from the MVaR equation on the Methods section. So, the entry order is influenced by the standard deviation, but also the covariances and kurtosis (i.e., we might have two currencies with equal standard deviations but unequal kurtosis, leading one of the two to be favored).

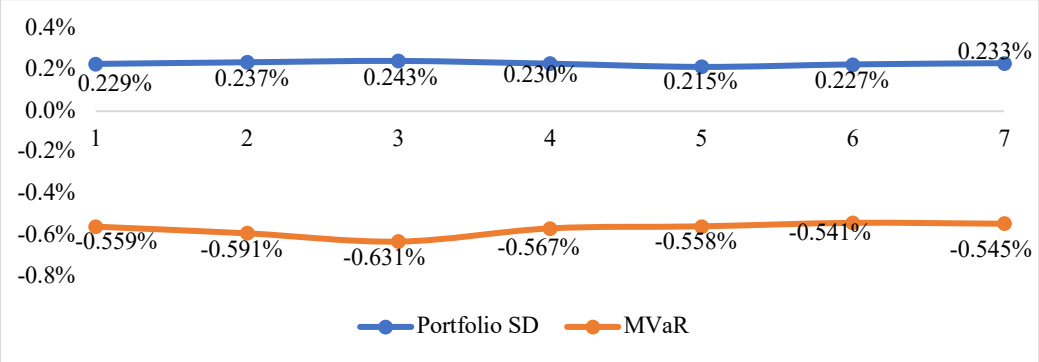
Table 8. Developed Markets Equally Weighted Currency Portfolio

Portfolio SD	MVaR	Portfolio Composition
0.22905%	-0.55897%	SGD
0.23691%	-0.59135%	SGD, EUR
0.24346%	-0.63138%	SGD, EUR, CHF
0.23027%	-0.56748%	SGD, EUR, CHF, CAD
0.21458%	-0.55753%	SGD, EUR, CHF, CAD, JPY
0.22666%	-0.54058%	SGD, EUR, CHF, CAD, JPY, AUD
0.23261%	-0.54482%	SGD, EUR, CHF, CAD, JPY, AUD, GBP

Note. Dates are between July 2018 – December 2019 (pre-COVID-19). The currencies are added to the portfolio based on the least to most standard deviation.
Source. Federal Reserve System, 2021

In the pre-COVID-19 period (see Table 8 and Figure 7), other than the Singapore dollar, we find that the equally weighted five-currency portfolio of the Singapore dollar, euro, Swiss franc, Canadian dollar, and Japanese yen has the lowest standard deviation (.21458%), while the six-currency portfolio of the Singapore dollar, euro, Swiss franc, Canadian dollar, Japanese yen and Australian dollar has the lowest MVaR value (-.54058%).

Figure 7. Equally Weighted Developed Markets Currency Portfolio



Note. Dates are between July 2018 – December 2019 (pre-COVID-19).
Source. Federal Reserve System, 2021

For the post-COVID-19 period (see Table 9 and Figure 8), other than the Singapore dollar, we find that the equally weighted five-currency portfolio of the Singapore dollar, euro, Swiss franc, Canadian dollar, and Japanese yen also has the lowest standard deviation (0.31115%). Interestingly in the post-COVID-19 period, the two-currency portfolio of the Singapore dollar and the euro has the lowest MVaR value (-0.35053%).

Interestingly, there are two distinguishing features of adding currencies in the pre-and post-COVID-19 periods based on the individual standard deviations. While the first three currencies are the same, in the post-COVID-19 period the Japanese yen with lower volatility replaced the Canadian dollar as the fourth currency in the portfolio. Additionally, the Australian dollar has higher volatility in the post-COVID-19 period and hence is the last currency to be added. We can conclude that during the pre-COVID-19 period the Brexit-related volatility resulted in the British

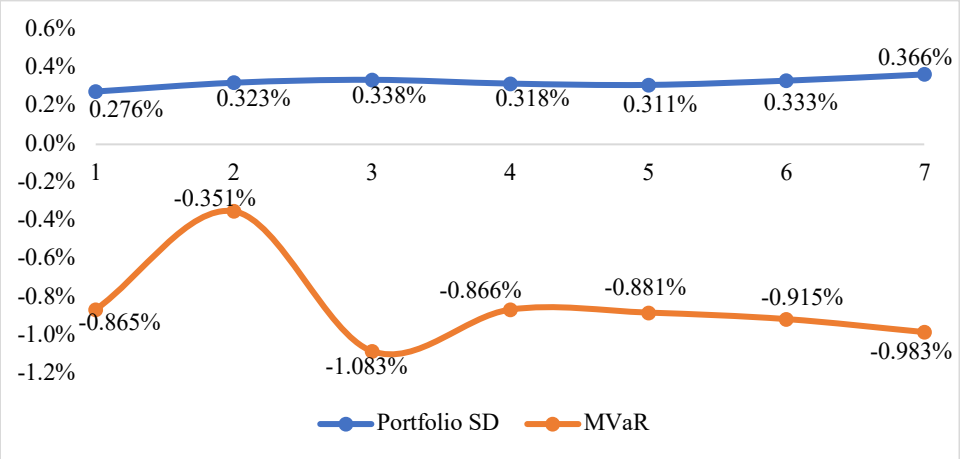
pound having the highest volatility amongst all developed market currencies. In the post-COVID-19 period, the trade dispute between Australia and its largest trading partner China, and the retaliatory tariffs imposed by China, resulted in the Australian dollar having the highest volatility amongst these seven developed country currencies.

Table 9. Developed Markets Equally Weighted Currency Portfolio

Portfolio SD	MVaR	Portfolio Composition
0.27649%	-0.8651%	SGD
0.32258%	-0.3505%	SGD, EUR
0.33795%	-1.0828%	SGD, EUR, CHF
0.31809%	-0.8655%	SGD, EUR, CHF, JPY
0.31115%	-0.8809%	SGD, EUR, CHF, JPY, CAD
0.33328%	-0.9149%	SGD, EUR, CHF, JPY, CAD, GBP
0.36611%	-0.9830%	SGD, EUR, CHF, CAD, JPY, GBP, AUD

Note. Dates are between January 2020 – June 2021 (post-COVID-19).
Source. Federal Reserve System, 2021

Figure 8. Equally Weighted Developed Markets Currency Portfolio



Note. Dates are between January 2020 – June 2021 (post-COVID-19).
Source. Federal Reserve System, 2021

Conclusions

Utilizing the MVaR approach, the maximum likely 1-period portfolio losses ranged from -0.9842% in the pre-COVID-19 period to -1.4664% in the post-COVID-19 period (Tables 6 and 7). Surprisingly, the realized/ex-post results for those same portfolios for the two time periods were +3.8750% and +0.1367%, respectively. Because the MVaR methodology employed in this study includes the effects of skewness and kurtosis, it is clearly superior to the less sophisticated VaR approach employed in a wide variety of previous studies. In this study, we have utilized a nonlinear estimation method to construct the optimal portfolios. The order of each currency's entry into the portfolio makes the MVaR as numerically small as possible in every instance. The MVaR of a portfolio is a complex function involving skewness and kurtosis as well as standard deviations and covariances.

In addition to the above findings, a comparison of the volatility in the developed countries' currency markets in the pre-and post-COVID-19 periods is revealing as transaction risk

dramatically increased in the post-COVID-19 era. Specifically, the maximum one-period loss surged by nearly 49% post-COVID-19 while at the same time the realized gain plummeted by nearly 96%. Although the impacts of Brexit and Australia's trade tensions with China may have impacted these findings, it is highly improbable that they would have changed our fundamental results. We note the impact of Brexit would have been felt primarily locally rather than globally (i.e., within eurozone currencies as opposed to the non-eurozone currencies). A similar argument can be made about the possible effects of the China-Australia tension. Both the magnitude and the breadth of our findings across all seven currencies strongly suggest a more powerful, and more universal, black swan event.

Theoretical Implications

The theoretical rationale for studying the pre- and post-COVID-19 time periods is to better understand the degree to which major international events, economic or otherwise, can impact currency movements and the associated risks. To the extent that these international dislocations alter exchange rates and their co-movements, MNEs' ongoing exposure to cash flow transaction risks will change, and hedging decisions based on earlier or historic relationships will lead to suboptimal results. In addition, this study also contributes insights to our understanding of best practices. The MVaR model provides a better estimate than VaR of the risks of operating across multiple currencies, and better insights into the optimal currency portfolios based on modern portfolio theory. Our enhanced findings based on the MVaR model provide MNEs with superior insights and objective data on the potential costs and benefits of hedging their exchange rate risks, and how these benefits and costs may have changed in the post-COVID-19 era.

Practical Implications

Our results strongly suggest that MNEs operating in the seven identified developed currency markets who hedge their positions on a routine basis should pause to reevaluate their hedging strategy. Hedging is expensive, and maintaining a hedge is costly. Despite the severe dislocations to world trade and finance resulting from the COVID-19 pandemic, our findings indicate that MNEs with net overall cash inflows would have benefited by *not hedging* their currency positions during both time periods, regardless of how many of the seven developed market currencies they were dealing with. Of course, any MNEs experiencing net cash outflows would indeed have benefited from hedging their positions. Our results also help calibrate the potential impact of black swan disruptions on the volatility of exchange rates and their correlations, both of which are central concerns as MNEs attempt to manage the risks of doing business on a complicated and sometimes volatile world stage. MNEs possessing the most accurate estimates of transaction exposure will have a potentially decisive advantage over the competition.

Future Research and Limitations

In the future, an analysis of an expanded time frame may provide MNEs with an even clearer and more confident understanding of the decision-making process. Additionally, a study of developing market currencies during the same time frame would be warranted. Further, studies using trade-weighted portfolios of currencies rather than the equal-weighted portfolios of the present study might provide additional, actionable insights.

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