Contagion across Financial Markets during COVID-19: A Look at Volatility Spillovers between the Stock and Foreign Exchange Markets in South Africa

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ERSA working paper 872

February 2022

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February 8, 2022

Abstract

The onset of the novel coronavirus pandemic (COVID-19) and previous crises have heightened interest in the interaction of stock market and exchange rate volatility. This paper aims to investigate the interdependence and volatility transmissions between the stock and foreign exchange markets for South Africa over the period 1979:01–2021:08, including the effect the COVID-19 pandemic has had on the interdependence and transmissions. Using bivariate Exponential Generalised Autoregressive Conditional Heteroscedasticity (EGARCH) modelling, this paper provides strong evidence in support of the "stock-orientated' approach, where significant price and volatility spillovers propagate from the stock market into the foreign exchange market; whilst evidence of the "flow-orientated" approach is seen in the second moment and significant shock and asymmetric spillovers from the exchange to stock market are found. The results support the asymmetric and long-range persistence volatility spillover effect and show strong evidence of contagion between stock and foreign exchange market. These spillovers became more pronounced during the COVID-19 pandemic, confirming heightened contagion during periods of crisis. The results heed important implications for not only policymakers who are concerned by the contagion and better regulation of these markets, but also for investors and fund managers who seek to hedge investment risks in South Africa.

JEL Classification: C22, C58, F31, G10, O11

Keywords: COVID-19 Pandemic; Stock market returns; Exchange rate changes; Bivariate EGARCH model; Asymmetric volatility spillover.

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[§]The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

1 Introduction

Economic globalisation has led to vast expansion in international trade which has ushered in the integration of world financial markets. In the last quarter century the world has witnessed expeditious changes in the international financial system, such as the emergence of new capital markets, the adoption of more flexible exchange rate arrangements in emerging and transition economies, and the gradual eradication of capital flow barriers and foreign exchange restrictions (Aloui, 2007). Driven by advancements in information technology and improved world-wide processing of news, the international conveyance of returns and volatilities among financial markets has amplified. As the stock market and the foreign exchange market are generally regarded as important indicators of the state of a country's financial markets, there is considerable interests in the exchange rate–stock price linkage.

Yang and Doong (2004) state that the adoption of freely floating exchange rate regimes by numerous industrialised countries in 1973 declared an age of heightened volatility in the foreign exchange market as well as the associated risk. Consequently, firms were left more exposed to exchange rate risks which meant that stock markets would react to excessive movements and heightened volatility of exchange rates. Exchange rates are similarly more sensitive to stock market innovations and global portfolio investments due to the rapid integration and deregulation of international financial markets since the 1980s that led to easier and faster capital flows across borders than ever before. Kanas (2000) observed that as of the mid-1980s, international equity flows had taken place at an increasing rate of 34% per annum − creating a higher demand for and supply of currencies in which international equity prices are denominated, leading to some degree of interdependence between stock returns and exchange rate changes.

In contemporary finance literature, the dynamic interaction among stock prices and exchange rates has enticed financial economists and specialists alike, as both variables play fundamental roles in portfolio decisions and economic development (Chkili & Nguyen, 2014). The occurrence of financial and currency crises in economies has ascribed even more interest − as the onset of heightened volatility in the stock prices and exchange rates have the potential to propagate volatility shocks between the markets. The recent coronavirus pandemic (COVID-19) which developed in Wuhan, China in late-2019 presented quite a unique economic, geopolitical, and social challenge which triggered a new type of recession different from the past triggers of recessions. For instance, the 1997 Asian financial crisis was caused by the collapse of the Thai baht in July 1997 which caused a region-wide financial crisis and economic recession in Asia. The global financial crisis (GFC), a period of extreme stress in global financial markets and banking systems between mid-2007 and early 2009, was caused by loose monetary policy which created a bubble, followed by subprime mortgages, weak regulatory structures, and high leverage in the banking sector. The COVID-19 pandemic has been termed a "black swan" event in the history of the financial markets and brought a stark warning with regards to the exceptional vulnerabilities and fragility that can quickly transpire and disseminate. Uncertainty due to the pandemic has led to an associated rise in the volatility of stock prices and exchange rates in economies (OECD 2020). Further, the literature on the impact of unanticipated events, like terrorist attacks and government shutdowns, suggests that unanticipated events contain valuable information and may improve financial variables' predictive power (Narayan *et al.*, 2018; Sharma, Phan, and Narayan, 2019). The COVID-19 pandemic is an ideal context to test the hypothesis whether the occurrence of an unanticipated event improves our understanding of the dynamic relationship between stock prices and exchange rates. Understanding volatility co-movement and associated spillover effects is crucial to the management and prevention of financial crises.

Early empirical literature offers conflicting verdicts regarding the transmission of volatility, known as the 'meteor shower' effect according to Engle *et al.* (1990), between stock and foreign exchange markets. This literature can be divided into three distinct realms: first, the studies that claim significant bidirectional spillover between the two markets; second, the studies which found unidirectional flow either from stock to foreign exchange market or from foreign exchange market to stock market; third, those studies which reported no significant spillover between the two markets. A significant relationship between these markets assures that a negative shock that disrupts one market may be instantaneously transmitted to the other through contagious effects.

The empirical inquiry into the interdependence among the stock and exchange markets is made more interesting by the fact that economic theory states that there are various ways in which these markets can interact. The prevailing theoretical approaches take on two fundamental forms: (i) the "flow-oriented" approach proposed by Dornbush and Fisher (1980) which claims causality flows from exchange rates to stock prices, and (ii) the "stock-oriented" approach proposed by Branson (1983) and Frankel (1983) which claims causality flows from stock prices to exchange rates. To date, a cardinal disagreement exists as theoretical approaches have come short of reaching a consensus on the existence of a link between stock prices and exchange rates as well as the direction of causality between the two markets (Chkili *et al.*, 2011). The theoretical ambiguity in the literature surrounding this relationship compels an empirical analysis.

The interactions between these markets have been deliberated extensively in the international finance literature by means of different frameworks and sophisticated econometric models. These studies are generally based on first moments in the specification and only a narrow body of research has attempted to detect volatility spillovers between the two variables. Volatility is an important gauge of financial performance, indicating uncertainty or risk, and volatility spillovers can provide a measure of the transmission of financial stress across the markets. Understanding the dynamics of volatility spillovers (namely crashes, distress and contagion) is paramount for: (i) determining if the extent of the spillovers across markets could point to some degree of market inefficiency; (ii) understanding the nature of shock propagation across markets in order to ascertain the magnitude and persistence of these innovations over time; (iii) specifying how markets are interconnected to advance an effective hedging strategy; (iv) and, ultimately from a policy stand point, awareness of the inherent nature of volatility transmission across the two markets is imperative from a financial stability perspective as financial markets may be threatened by increasing financial volatility spillover effects while linkages across markets may have an influence on policy efficacy (Aloui, 2007).

The majority of these types of studies have also only focused on developed countries and only recently studies started to emerge that look at the interdependence between these financial markets in emerging economies (see Pan *et al.,* 2007; Diamandis & Drakos, 2011; Chkili & Nguyen, 2014; and Jebran & Iqbal, 2016). The role of developing economies cannot be ignored by the global investors who need to diversify the risk of their international investment portfolio. South Africa has been identified as one of the top 20 emerging economies in the Emerging Markets Economic Outlook of 2021 by Focus Economics (2021). South Africa's economy is considered "very open" which lends itself to greater volatility as the local economy is in large influenced by global events and economies. South Africa is also home to the Johannesburg Stock Exchange (JSE), established in 1886, which is the oldest and largest stock exchange market in Africa, and has developed into one of the biggest stock exchanges in the world comparable to those in developed countries, making it the most attractive and lucrative African investment destination for equity investors. By the end of 2020, market capitalisation of the JSE stood at around US$1,052 trillion (World Federation of Exchanges, 2021). These attributes make South Africa, a country that has not received much attention in the literature, an interesting case study for contagion across the stock and exchange markets.

This paper employs a bivariate extension of the Nelson (1991) Exponential Generalised Autoregressive Conditionally Heteroscedastic (EGARCH) model in order to explore the dynamic volatility spillovers between stock returns and exchange rates for South Africa covering the period 1979:01 to 2021:08, as well as focusing on the dynamic volatility spillovers during the COVID-19 pandemic. The framework is implemented to facilitate the understanding of short-run movements and to investigate the volatility transmission mechanism between the two markets − allowing the quantity (size) and the quality (sign) of an innovation to significantly affect the degree of volatility spillovers across markets. That is, this study searches for evidence of asymmetry where negative shocks originating in the stock market (foreign exchange market) exert more or less impact on the foreign exchange market (stock market) than a positive shock of equal magnitude. This study contributes to the literature by: (i) extending the existing studies on the spillover between stock price and exchange rate in South Africa providing a contribution to the debate between whether the "flow-orientated" or "stock-orientated' approach holds; (ii) being one of very few studies that applies the multivariate EGARCH technique in the recent period to South Africa; (iii) and, is one of the fist studies that investigates how these spillovers were impacted by the recent COVID-19 pandemic. The results of this paper provide evidence in support of the "stock-orientated" approach in which movements in stock prices will affect future exchange rate movements, whilst evidence of the "flow-orientated" approach is seen in the second moment and significant shock and asymmetric spillovers from the exchange to stock market are found. There is also evidence of bidirectional asymmetric volatility spillover effects between the stock to exchange market. The results of this paper also find that spillovers, both price and volatility, became more pronounced during the COVID-19 pandemic, confirming that there is heightened contagion during periods of crisis.

The rest of this paper is structured as follows. Section 2 commences with a brief review of the theory related to the transmission mechanisms between currency markets and stock markets. Section 3 provides a literature review on previous empirical studies. Section 4 introduces the econometric framework through an analysis of the data and details the methodology implemented. Empirical results are reported and discussed in Section 5, while Section 6 concludes the paper.

2 Linkages between Exchange Rates and Stock Markets: Theoretical Motivation

Orthodox economic theories suggest a relation between stock prices and exchange rates, where empirical inquiry into the interdependence of the stock and exchange markets is made interesting by the fact that economic theory states that there are various ways in which these markets can interact. Theoretical approaches have come short of reaching a consensus on the direction of causality between the two markets. It is also possible that movements in the stock and currency markets may well be interrelated due to "... some underlying economic variables that systematically affect both markets leading to convergence of some expectations among market participants." (Ajayi *et al.*, 1998, p. 242). The prevailing theoretical approaches take on two fundamental forms: (i) the "flow-oriented" approach proposed by Dornbush and Fisher (1980), and (ii) the "stock-oriented" approach proposed by Branson (1983) and Frankel (1983).

According to the "flow-orientated" approach, the exchange rate hinges upon a country's current account balance or trade balance. These models posit that exchange rate changes affect international competitiveness and the trade balance of a country, which subsequently effects real income and inputs. When local currency depreciates, this leads to greater competitiveness of domestic firms given that exports will now be relatively cheaper in international trade. Higher exports will lead to greater domestic income and hence the firm's stock prices will appreciate as they are evaluated as the present value of firms' future cash flows. Based on this economic perceptive, the "flow-orientated" approach claims a positive link between exchange rates and the stock market where causality runs from the exchange rate to stock price. With this theory in mind, Heckman (1995) derived a present-value based financial valuation model for multinational firms, where the exchange rate is an explanatory variable for the stock price. Sercu and Vanhulle (1992) observed the effect of exchange rate volatility on a firm's market value by focusing on the price and volume effects of exchange rate changes and found that an increase in exchange rate volatility has a positive effect on the market value of firms.

In contrast, the "stock-orientated" approach asserts that the exchange rate adjusts to equate demand and supply of alternative financial assets – including domestic money, domestic bonds and equities, and foreign securities. In this approach the capital account plays a significant role in dictating exchange rate dynamics (Yang & Doong, 2004). Two forms of "stock-orientated" models are stipulated in the literature, namely portfolio balance and monetary models.

The portfolio balance model proposed by Branson and Henderson (1985) and Frankel (1983) claims that causality runs from the stock price to the exchange rate. According to this model, as shareholders assign their wealth between alternative assets, the model reflects on an internationally diversified portfolio and the role of exchange rates in balancing domestic and foreign financial assets demand and supply. An increase in domestic stock price returns will yield an appreciation of the currency by means of two central channels postulated in the literature – the direct and indirect. The direct channel specifies that an increase in domestic stock price will entice international shareholders to revise their portfolio and substitute foreign assets for domestic assets. As a result, they have more domestic currency at hand to acquire more domestic assets and accordingly domestic currency will appreciate. The notion of the indirect channel centres on the 'wealth effect' in that the increase in domestic stock assets will increase wealth and the demand for each of the assets in the model where the surplus demand for money will lead to higher interest rates which cause a substitution from foreign securities to domestic assets (Phylaktis & Ravazzolo, 2005). All these transition mechanisms lead to domestic currency appreciation and a rise in the real exchange rate.

This line of causality was found by early empirical studies. Smith (1992) found that both the United States (US) and German stock prices have a significant effect on the German mark–US dollar exchange rate, and similarly that Japanese and US stock prices affect the Japanese yen–US dollar exchange rate. Gavin (1989) shows that, using an open economy model in which domestic aggregate demand is determined by stock prices, stock prices may exercise a significant influence on exchange rate dynamics, especially if stock market effects are large, they can change the impact of an expansionary monetary policy on the exchange rate, leading to appreciation rather than depreciation of the currency. Zapatero (1995) shows that, in fully integrated financial markets, there is an explicit linkage between the volatility of stock prices and the volatility of the exchange rate.

The monetary approach to exchange rate determination emerged as an important exchange rate paradigm (see Frenkel, 1976; Mussa, 1976; Bilson, 1978) and asserts that the exchange rate is incorporated into financial asset prices (Gavin, 1989). Centred on the view that the exchange rate is perceived as a value of a financial asset which is determined by the present value of anticipated cash flows, the dynamics inherent in the exchange rate are determined by all the applicable macroeconomic factors affecting the anticipated value (Macdonald and Taylor, 1993). Consequently, the presence of common factors affecting the two variables will result in stock price innovations potentially having an impact on, or being influenced by, the behaviour of the exchange rate. Since both exchange rates and stock prices may be influenced by a variety of common factors, the "stock-oriented" exchange rate model suggests that there is no linkage between exchange rates and stock prices (Gavin, 1989).

3 Literature Review

In conjunction with the orthodox theories stipulated in Section 2, the empirically acknowledged correlations between exchange rates and economic activity (e.g., Branson and Masson, 1977; Cornell, 1983; and Wolff, 1988) and between stock prices and economic activity (e.g., Fama, 1981; Mandelker & Tandon, 1985; and Chen *et al.*, 1986) advocates an implicit link between exchange rates and stock markets. As noted by Nieh and Lee (2001), macroeconomic fundamentals are seen by economists as providing the robust avenue to link stock prices and foreign exchange rates. The interactions between these markets have been deliberated in the international finance literature extensively by means of different frameworks and econometric models. Nevertheless, based on the existing empirical evidence it is still challenging to infer if the relationship is unilaterally, bilaterally, or interactively significant (Sui & Sun, 2016).

Early empirical studies on the contemporaneous relation between stock returns and exchange rates originate with Franck and Young (1972) and Ang and Ghallab (1976). Franck and Young considered the reactions to exchange rate realignments of equity securities of low- and high intensity multinational firms as well as the stock market in general and found no significant interaction between the two variables. On the contrary, Ang and Ghallab studied how 15 US multinational firms react to US Dollar devaluations for a period of August 1971 to March 1973 and conclude that, due to the efficiency of stock markets, the stock prices adjust quickly to changes in the exchange rate. The scarcity of the early research may be attributed to the fixed exchange rate regime of the Bretton Woods[1] era when exchange rates hardly moved. A study by Aggarwal (1981) a few years later found that US stock prices and the trade-weighted dollar exchange rate are positively correlated for the post-Bretton Woods Agreement period. In contrast, authors Soenen and Hennigan (1988), using monthly data for the US dollar effective exchange rate and US stock index during 1980–1986, established a strong negative correlation between the two variables – contesting that exchange rate volatility distresses business operations and international competitiveness of multinational firms. Other studies focusing on the US also found conflicting results: Roll (1992) found a positive relationship between the two markets over the period 1988−1991; whilst Chow *et al.* (1997) found no

[1] An international system of stable but adjustable exchange rates was introduced under the International Monetary Fund Agreement at Bretton Woods in 1944. This system introduced formal devaluations and revaluations to adjust the exchange rate values of currencies *vis-à-vis* one another, using the US dollar as the dominant international reserve currency.

relationship over the period 1977−1989. However, upon repeating the analysis with longer than six-month horizons, Chow *et al.* (1997) reported a positive relationship between the markets. Ma and Kao (1990) offer insight into a possible reason for these conflicting correlations based on the export or import orientation among countries. They consider the impact of changes in currency values on stock prices in six industrial economies and their results propose that for an export-dominant economy, currency appreciation has a negative effect on the stock market, while currency appreciation boosts the stock market for an import-dominant economy.

Thereafter, studies arose on the directions of causality between exchange rates and stock prices for major industrial economies. Bahmani-Oskooee and Sohrabian (1992) were among the first to implement cointegration techniques and Granger-causality tests to postulate the causality direction between the two variables for major industrial countries. Their results indicate that there is bidirectional causality between stock prices measured by the S&P 500 index and effective exchange rates of the US dollar in the short run; however, no long-run co-movements exist between the two variables. Ajayi and Mougoué (1996) implement an error correction model (ECM) for eight industrial economies and find significant short-run and long-run feedback relations between the two variables. The outcome of their study indicates that an increase in stock prices has a negative short-run and a positive long-run effect on domestic currency value, whereas currency depreciation has a negative short-run and long-run impact on the stock market. Authors Ajayi *et al.* (1998) utilise pairwise Granger-causality tests and find evidence to indicate unidirectional causality from the stock to the currency markets for advanced economies; whilst no consistent causal relations in emerging markets is found. They speculate that the contrasting result between the advanced and emerging economies is attributed to the differences in the structure and features of financial markets within the economies.

In addition to the studies on the linkages and interactions between exchange rates and stock prices, a rich body of research emerged that endeavoured to analyse the transmission of volatility or a volatility spillover effect between the stock and currency markets. Volatility is typically defined as a measure of dispersion of returns of an asset or market index, where higher volatility generally translates to riskier assets. These studies primarily employed the autoregressive conditional heteroskedastic (ARCH) framework of Engle (1982)[2] along with Generalised ARCH (GARCH) models – which have been used to study volatility spillovers between markets in different countries and between different assets (see Hamao *et al.*, 1990; Koutmos & Booth (1995); Chiang & Yang, 2003; Laopodis, 1998; and So, 2001). Authors Chiang *et al.* (2000) employ a bivariate GARCH model to evaluate individual national stock returns in nine Asian economies – namely Taiwan, Hong Kong, South Korea, Singapore, Malaysia, Philippines, Indonesia, Thailand, and Japan – and their interaction to the foreign exchange rate changes over the period 1990–1998. Their results show that stock returns and currency values are positively related; suggesting that higher stock returns

[2] See Bollerslev *et al.* (1992) for a detailed summary of the literature.

are encouraged by an appreciation of the national currency. Caporale *et al.* (2002) employ a similar technique to four Asian countries (Indonesia, Japan, South Korea and Thailand) using daily data covering the period 1987–2000. Significant volatility spillovers in all four countries are found, where results for Japan and Korea are in line with the portfolio approach and positive spillovers from the stock market to exchange rate are experienced in Indonesia and Thailand.

In order to detect asymmetric spillover effects among the financial markets, Kanas (2000) employed the bivariate exponential GARCH (EGARCH) framework for six advanced economies (US, UK, Japan, Germany, France and Canada) using daily data from 1986 to 1998 and established evidence of symmetric volatility spillovers from stock returns to exchange rate changes for five of the six countries, with Germany being the exception; whilst volatility spillovers from exchange rate changes to stock returns are found to be insignificant for all countries. Similarly, covering the same time frame, Kanas (2002) finds that stock return volatility is a significant determinant of exchange rate volatility in the US, UK and Japan. Yang and Doong (2004) employ a similar model for the G7 countries over the period 1979–1999 and their empirical evidence supports the asymmetric volatility spillover effect and shows that movements of stock prices will affect future exchange rate movements, but changes in exchange rates have a less direct impact on future changes of stock prices. Aloui (2007) explores the nature of mean, volatility and causality transmission mechanisms between stock and currency markets for the US and some major European markets for the period pre- and post-Euro by means of a multivariate EGARCH model. The results support the asymmetric and long-range persistence volatility spillover effect and indicate strong evidence of causality in the mean and variance between the markets for both sub-periods. In particular, results point to significant volatility spillovers and/or asymmetric effects from stock market to exchange rates for Germany, France, Spain and Belgium for the post-Euro period, where stock markets are less affected by exchange rate movements for the two periods pre- and post-Euro.

By means of a copula-based approach, Ning (2010) investigates the dependence structure between the equity and foreign exchange markets for the period pre- and post-Euro using the financial markets of the G5 countries (US, UK, Germany, Japan and France). Significant upper and lower tail dependence is found between the foreign exchange market movements and the stock market in each country for the two sub-periods. Lin (2012) adopts a similar approach to investigate the co-movements between exchange rates and stock prices for six Asian emerging markets – namely India, Indonesia, Korea, the Philippines, Taiwan and Thailand – over the period 1986–2010 and finds evidence of stronger co-movement during crisis periods, after some economic and policy events such as market openings and crises are accounted for. It emerged that most spillovers can be attributed to the channel running from stock price shocks to exchange rates, affirming the argument that the slowdown of an economy affects stock prices. Yau and Nieh (2009), implementing a threshold ECM (TECM) for Taiwan and Japan for the period 1991–2008, find evidence of a long-run equilibrium relationship between the exchange rate and stock prices of Japan and Taiwan, whilst an asymmetric threshold cointegration relationship only exist in Taiwan's financial market. The results of TECM Granger-causality tests show that in the long run a positive causal relationship running from either the Japan or US exchange rate to the stock prices of Taiwan strongly argues for the traditional approach. Caporale *et al.* (2013) employ a bivariate UEDCC-GARCH model which produced evidence of unidirectional Granger causality from stock returns to exchange rate changes in the US and the UK, in the opposite direction in Canada, and bidirectional causality in the euro area and Switzerland. Furthermore, causality-in-variance from stock returns to exchange rate changes is found in the US and in the opposite direction in the euro area and Japan, whilst there is evidence of bidirectional feedback in Switzerland and Canada. Morales-Zumaquero and Sosvilla-Rivero (2018) empirically analyse the evidence of intra-spillovers and inter-spillovers between foreign exchange and stock markets in the seven economies, which constitute the majority of foreign exchange transactions (the UK, the USA, the euro area, Australia, Switzerland, Canada and Japan) for the period from 1990 to 2015, including the pre- and post-GFC periods. Using C-GARCH methodology and the SVAR framework their results suggest that: (i) the long-run volatility relationships are stronger than the short-run volatility linkages and are reinforced during the post-GFC period; (ii) the presence of intra-spillovers and inter-spillovers increases substantially during the post-global financial crisis period, and (iii) the stock markets play a dominant role in the transmission of long-run and short-run volatility in all samples, except for the period after the GFC, where the foreign exchange markets are the main long-run volatility triggers.

In view of the increasing significance of the emerging economies in the global financial system, more recent studies have directed emphasis on these economies. Pan *et al.* (2007) use a vector autoregression (VAR) approach to analyse the links between exchange rates and stock markets for seven East Asian countries over the period 1988–1998 and provide evidence of a significant bidirectional relationship between these markets before the Asian financial crisis. Specifically, their results show a causal relation from exchange to stock market for Hong Kong, Japan, Malaysia, and Thailand, along with a causal relation from the stock market to the foreign exchange market for Hong Kong, Korea, and Singapore. Further, while no country shows a significant causality from stock prices to exchange rates during the Asian crisis, a causal relation from exchange rates to stock prices is found for all countries except Malaysia. Using a similar approach, Aydemir and Demirhan (2009) find a bidirectional causal relationship between exchange rate and stock market indices in Turkey for the 2001–2008 period, where negative causal relation exists between the stock market and foreign exchange market and *vice versa*. Kutty (2010) considers Mexico, covering the period 1989–2006 and concludes that stock prices Granger-cause exchange rates in the short run but that there is no significant relationship between these two markets in the long run. Adjasi *et al.* (2011), also using a VAR framework, investigate the relationship in seven African countries and find that shocks induced by either stock prices or the exchange rate are more protracted in Ghana, Kenya, Mauritius and Nigeria than in South Africa and Egypt. Stock market returns in Ghana, Kenya, Mauritius and Nigeria reduce within the first month of the shock to a shock induced by the exchange rate; whilst in Egypt and South Africa the stock market returns increase in response to a shock induced by the exchange rate within the first month of the shock.

Zhao (2010) examines the dynamic relationship between the real effective exchange rate and the Chinese stock price using a VAR with a multivariate GARCH model covering the period 1991–2009. The results show that there is no stable long-run equilibrium relationship between the two financial markets and no significant mean spillovers. Furthermore, the paper reveals that significant bidirectional volatility spillover effects exist between the two financial markets. Diamandis and Drakos (2011) study the long- and short-run dynamic linkages between exchange rates and stock prices by means of cointegration analysis and multivariate Granger-causality tests for Latin American countries, namely Argentina, Brazil, Chile and Mexico. Their empirical analysis covers 1980–2009 and the results conclude the existence of a significant positive long-run relationship between the stock market and the exchange market; however, the stability of the relationship is influenced by financial and currency crisis such as the Mexican currency crisis of 1994 and the 2007–2009 global financial crisis. Chkili *et al.* (2011) employ a Markov-Switching EGARCH model to investigate the dynamic relationships between stock returns and exchange rates in four emerging countries (Hong Kong, Singapore, Malaysia and Mexico) in a regime-switching environment of both "calm" and turbulent periods. Covering the period 1994–2009, they provide evidence of regime-dependent links and asymmetric responses of stock market volatility to shocks affecting foreign exchange market. Employing a multivariate EGARCH model, Mozumder *et al.* (2015) examine three developed (Ireland, Netherlands and Spain) and three emerging (Brazil, South Africa and Turkey) countries across the recent pre-financial-crisis, crisis and post-crisis periods. The evidence indicates asymmetric volatility spillover effects between stock prices and exchange rates in both developed and emerging economies during the financial crisis. Using the same technique, Jebran and Iqbal (2016) consider Pakistan, India, Sri Lanka, China, Hong Kong and Japan from 1999–2014. Their analysis reveals bidirectional asymmetric volatility spillover between stock and foreign exchange markets of Pakistan, China, Hong Kong and Sri Lanka and a unidirectional transmission of volatility from stock market to foreign exchange market of India, with no evidence of volatility transmission between the two markets in reference to Japan. Živkov *et al.* (2021) investigate four African countries (Nigeria, South Africa, Egypt, and Morocco) employing daily data – with sample ranges from January 2005 to December 2019 – using a wavelet approach, an MS-GARCH model and measurement of the volatility spillover effect in the quantile regression framework. They find evidence of the bidirectional volatility spillover effect – which intensify during periods of crisis – but the volatility impact from exchange rate market to stock market is stronger in all the African countries, except Nigeria. Regarding the direction from stocks to exchange rate, this study finds that volatility spillover effect is the strongest in South Africa, attributed to the Johannesburg Stock Exchange being the most developed and liquid market. As for the reverse direction, the spillover effect is recorded in longer time-horizons in the Egyptian and Moroccan cases, which indicates to flow-oriented model, while for South Africa, the effect is found in shorter time-horizons, which is in line with the portfolio-balance theory

Looking more closely at BRICS economies, Chkili and Nguyen (2014) use Markov-switching VAR models over the 1997–2013 period and show the unilateral impact from stock market to foreign exchange market is significant during the period of the high volatility, except for South Africa. In contrast, Sui and Sun (2016) employ variance decomposition and impulse response functions and discover unilateral spillover effects to exist from exchange to stock markets in BRICS economies (where stock-market shocks only slightly impact the foreign exchange market in Brazil and Russia) and insignificant long-run effects between the two markets, except for China. Kumar (2013) uses a multivariate GARCH model to analyse the nature of returns and volatility spillovers between exchange rates and stock price in the IBSA nations (India, Brazil, South Africa), with results suggesting the integration between stock and foreign exchange markets and indicates the existence of bi-directional volatility spillover between stock and foreign exchange markets in the IBSA countries and, in particular, the stock markets play a relatively more important role than foreign exchange markets in the first and second moment interactions and spillovers. Also looking at the IBSA countries, Mikhaylov (2018) employ a Fractionally Integrated GARCH (FIGARCH) model and found bidirectional spillover effect existed in the period 2009–2017, which was significantly stronger than it was been before global financial crisis. Mroua and Trabelsi (2020) combine the panel generalised method of moments (GMM) model and the panel auto-regressive distributed lag (ARDL) method to investigate the existence of a causal short-/long-run relationships and dynamic dependence among all stock market returns and exchanges rates changes of BRICS countries for 2008–2018 and find that exchange rate changes have a significant effect on the past and the current volatility of the BRICS stock indices. Rai and Garg (2021) examine the impact of the COVID-19 pandemic on dynamic correlations and volatility spillovers between the markets in BRICS economies. Using volatility modelling, implementing the Dynamic Conditional Correlation GARCH (DCC-GARCH) to calculate the dynamic correlations and the BEKK-GARCH (where the acronym comes from Baba, Engle, Kraft and Kroner) model to capture the volatility spillovers, the study finds significant negative dynamic correlations and volatility spillovers between stock and exchange returns in most of the economies. Further, the relationship strengthened during the initial days of lockdowns.

Focusing on South Africa, Bonga-Bonga and Hoveni (2013) used a multistep GARCH model to assess the contemporaneous volatility spillover between exchange rate and equity markets for 1995–2010 and found a unidirectional relationship in terms of volatility spillovers from the equity market to the foreign exchange market. The paper supports the view that the extent of foreign participation in the South African equity market possibly contributes to this phenomenon. Oberholzer and Von Boetticher (2015) employ a multivariate

Constant Conditional Correlation GARCH (CCC-GARCH) model on daily data from 2002 to 2014 to examine the relationship between the South African Rand and the 5 main indices of the Johannesburg Stock Exchange. These authors find that there is a volatility spillover from the Rand to the FTSE/JSE All Share Index, Top 40 Index, Fledgling Index, and the Mid Cap Index. Using yearly data over the post-Bretton Woods period 1979–2014 in South Africa and a cointegration estimator, Mitra (2017) finds that the relationship between exchange rates and stock returns is positive in the long term. Sikhosana and Aye (2018) implemented a multistep EGARCH model, alongside other asymmetric GARCH models – the Glosten, Jagannathan and Runkle GARCH (GJR-GARCH) and Asymmetric Power ARCH (APARCH) models, from 1996–2016 and find bi-directional volatility spillover effect between the two markets in the short-run − with these effects being asymmetric.

This study, through the use of an extensive data set, spanning a period of more than 40 years at a monthly frequency, endeavours to establish whether evidence exists of contagion across the stock and foreign exchange market in South Africa in an attempt to reconcile the literature on whether the "flow-orientated" or "stock-orientated" approach holds in an emerging market context. It also aims to determine whether the contagion across these financial markets amplified during the COVID-19 pandemic.

4 Data and Methodology

4.1 Data series used and stylised facts

This paper is based on South African monthly FTSE/JSE All Share Index data and monthly averages of the nominal effective exchange rate for the period January 1979 to August 2021, containing 512 observations. The FTSE/JSE All Share Index data was procured from Bloomberg and the nominal effective exchange rate from South African Reserve Bank (SARB) database, where the data has been seasonally adjusted specifying 2015 as the base year. The nominal effective exchange rate is expressed as a trade weighted basket of currencies of South Africa's main trading partners, relative to the domestic currency − the South African rand. The starting date is chosen to coincide with South Africa adopting a managed floating exchange rate regime. Monthly return series are considered as quarterly data does not capture the information content of changes in stock prices and exchange rates and make analysis during crisis periods worthless as crises tend to be relatively short-lived, whilst daily data contains too much noise to analyse which leads to defective estimation results (Ramchand & Susmel, 1998). The extensive reach of the data in an era of increasing integration of financial markets envelopes the various exchange rate regimes that the South African Rand underwent, along with including major historic events that distressed both markets such as the Apartheid era and its collapse in 1994 as well as major global events − such as the global financial crisis of 2008 and the COVID-19 pandemic. Thereafter, the stock returns and the percentage change in the exchange rate (hereafter referred to as exchange rate changes) denoted by r_t and e_t , respectively, are calculated by taking the natural log differential of the monthly average values of two consecutive months i.e. $r_t = 100 * \ln\left(\frac{P_t^S}{P_{t-1}^S}\right)$ and $e_t = 100 * \ln\left(\frac{P_t^E}{P_{t-1}^E}\right)$ where P_t^S and P_t^E are the stock price and the effective exchange rate at period t respectively.

The South African rand is a volatile currency (Hassan, 2014). As seen in figure 1, the rand has seen a persistent downward trend through the years since its inception. As will be explained, despite enjoying a strong value amid an ever-changing international economic climate, the Apartheid regime − which governed from 1948 to 1994 − ultimately caused the rand to lose its footing in the global market.

On 14 February 1961, the system of Rands and cents was introduced with USD1.00 equal to R0.714. The domestic exchange rate retained this value until December 1971 when the Bretton Woods Agreement ended, and South Africa's reaction was to devalue the rand. Thereafter, the rand was pegged against the US dollar until 1974 and at the time 67.12 cents bought USD1.00. In June 1974, the South African authorities decided to delink the rand from the dollar and introduced a policy of independent managed floating. During the five-year period from 1974 to 1978, the level at which the rand was pegged to the dollar had been changed six times.

On 7 February 1983, the South African government announced the abolishment of the financial rand[3]. After the then President PW Botha's infamous 'Rubicon speech' on 15 August 1985, during which he failed to announce immediate and major reforms in the country's Apartheid system and international confidence in South Africa plummeted. As a result, on 28 August 1985 the rand reached an all-time low as economic and political pressure against South Africa heightened following the announcement of a state of emergency earlier that year. The earlier easing of exchange control over non-residents could not be sustained as key international banks denied renewing credit lines for South Africa which compelled authorities to declare the momentary closure of the foreign exchange market six months later, and on 1 September 1985 a standstill on South Africa's international debt repayments was declared and exchange controls were reinstated.

Since the release of former President Nelson Mandela in February of 1990, economic sanctions were gradually lifted and after the democratic elections in 1994 a degree of normalcy resumed in South Africa's international relations. The depreciating trend however continued, albeit at a slower rate and for a period between during the mid to late 1990s, the domestic currency was somewhat stronger than the equilibrium value dictated by economic fundamentals. The exchange rate of the domestic currency against foreign currencies in the post-apartheid South Africa continued to be impacted by national and international

[3]From June 1961 up until the first half of 1995 (except for a short period during the early eighties), SA utilised a dual exchange rate system of Commercial Rand and Financial Rand. The financial rand was intended to curb the outflow of foreign investments from SA. It was only applicable to investments by non-residents, and it was cheaper for foreigners than the Commercial Rand.

social, political, and economic events.

During the Asian currency crisis, the South African rand was heavily affected and had depreciated as much as 41.5% from 4.53 rand per US dollar in June 1997 to 6.41 in August 1998. Between 1996 and 1998, the SARB intervened heavily in the forward exchange market to support the value of the rand, and thus dampen market volatility. The policy of continuously defending the rand from market forces had the negative consequence that the SARB was forced to accumulate a very large net open forward position (NOFP). The NOFP amounted to USD23.2 billion by the end of September 1998 (Myburgh Commission, 2002). The costliness of defending the rand during the 1990s may be regarded as a primary motivation for the change in policy stance that occurred in 2000. With the advent of inflation targeting, the SARB effectively abandoned the policy of consistently intervening in the foreign exchange market. Consequently, when pressure mounted against the rand in the latter parts of 2001, domestic market volatility increased substantially. The 2001 September 11 attacks on the World Trade Center in the USA caused the rand to skyrocket to R13.84 to the dollar at the end of December 2001 – its worst level ever experienced at the time – with a recovery happening the following year. From this point on, the currency kept on improving and on the back of the commodity boom of 2003 to 2006, a low value of R5.71 against the US dollar was registered in December 2004.

During the recent global financial crisis, the South African rand had depreciated as much as 39.2% against the US dollar from R7.33 in July 2008 to R10.20 in January of 2009, but it had recovered most of the losses in the following years. However, as of 4 December 2015, the South African rand had lost 24.3% of its value against the US dollar and ended the year at a value of R14.37 against the US dollar. The weakening in the currency may in part be attributed to weakened investor confidence after former President Jacob Zuma unexpectedly fired finance minister Nhlanhla Nene. The economy has seen some confidence returning to the market after the election of President Cyril Ramaphosa as president of the African National Congress (ANC) and the country at the end of 2017, which affected the value of the domestic currency favourably. Between December 2017 and March 2018, the rand strengthened from R13.25 to a value of R11.84 against the US dollar. Unfortunately, the positive trend was short-lived, and the currency lost some footing in the international currency market amidst uncertainty surrounding the issue of land expropriation without compensation. By the end of December 2018, the currency registered a value if R14.09 against the US dollar.

The first official identification of COVID-19 by the World Health Organisation (WHO) was on the 31 December 2019, with the organisation officially declaring that the Coronavirus outbreak became a global pandemic on 11 March 2020[4]. Since then, there has been a worldwide economic slowdown that has thrust a number of countries into severe recessions, with the probability of a broad economic depression ever increasing. On 05 March 2020, The National Institute for Communicable Diseases (NICD) detected the first COVID-19 case

[4] https://www.who.int/news/item/27-04-2020-who-timeline-covid-19

in South Africa[5]. With the virus spreading at an exponential rate and the onset of community transmission in South Africa, the government declared a national state of disaster on 15 March 2020 and implemented a hard lockdown and stay-at-home order on 26 March 2020 to curb the spread of the virus. While the contagion effects of the pandemic began to take its toll on economic conditions, South Africa saw a major depreciation of the Rand as it hit a new all-time low in early April breaching R19 to the US dollar − making it the worst-performing emerging-market currency over the past year. This was also following a long-expected downgrade to junk status by credit ratings agency Moody's Investors Service and a further downgrade by Fitch Ratings. The Rand remained in the R17 - R18 range until October of 2020 and strengthened to R14.69 against the US dollar by the end of 2020. The rand initially depreciated at the turn of 2021 as sentiment towards the rand deteriorated amid further lockdown restrictions brought about by the second wave of COVID-19 infections. However, the external value of the rand then appreciated up to mid-June 2021, reflecting improved investor sentiment towards emerging market currencies amid continued accommodative monetary policy in the US as well as better-than-expected domestic economic outcomes. Due to domestic civil unrest in July, which resulted in significant property damage, looting and affected movements of goods along an important trade corridor, as well as rising concerns about the impact of new COVID-19 outbreaks and the Delta variant on the global and domestic economic recovery, the Rand weakened and breached R15 to the US dollar during August 2021.

Figure 1 also depicts the FTSE/JSE All Shares Index, which was introduced in June 2002 to replace the old All Share index after the adoption of the FTSE global classification system, with data on the index spliced back to 1979. The FTSE/JSE Africa All Shares Index is a market capitalisation-weighted index. Companies included in this index make up the top 99% of the total pre-free-float market capitalisation of all listed companies on the Johannesburg Stock Exchange[6]. JSE Limited (previously the JSE Securities Exchange and the Johannesburg Stock Exchange) is the oldest and largest stock exchange in Africa, in operation for almost 120 years.

From figure 1 it is evident that the share price index displays an increasing trend following 1994, compared to the years leading up to the transition to democracy and majority rule of 1994. Du Plessis and Smit (2007) describe the varying time trend pattern in terms of South African macroeconomic developments. The authors refer to the slow growth in both the share price index and real output in the South African economy as the "decade of decline" which ended in 1994.

The share price index trend picked up substantially during the period 1995 to 2004, although there was noticeable volatility in the stock market. During this period, described by Du Plessis and Smit (2007) as a "recovery period", real economic growth averaged 3.1% per annum, with varying growth rates in

[5] https://www.nicd.ac.za/first-case-of-covid-19-announced-an-update/
[6] https://www.bloomberg.com/quote/JALSH:IND

the All Shares Index (ALSI), registering an average growth of 7.5% per annum. Political stability arising from the end of Apartheid and the adoption of sound economic policies have been contributing factors to create an atmosphere conducive to investment and growth in the economy, and in the stock market in particular. Further, until the onset of the global financial crisis in 2008, South Africa was experiencing a period of high real economic growth: annual real GDP growth between 2005 and 2007 averaged 5.1% per annum. The associated growth in the ALSI amounted to an average as high as 36% per annum during this period. The improved growth may largely be attributed to increased domestic demand arising from high credit-financed consumer spending, public sector infrastructure investment and private sector fixed investment. This macroeconomic recovery could explain the persistent bullish market attributes depicted in the share price trend until 2007. However, the subsequent global recession distinctly disturbed this trend, such that real GDP only increased by an annualised quarterly average of 3.7% in 2008 and declined by an annualised quarterly average of 1.8% in the first three quarters of 2009. At the same time the ALSI declined by 34% between June 2008 and May 2009. Figure 1 clearly shows this adverse effect on the stock market due to the financial crisis. After a recovery following May 2009, the stock market displayed another bull run up until mid-2015.

Trade tension between the US and China brought uncertainty to the stock market from 2018 onwards. In July 2018, US President Donald Trump followed through on months of threats to impose sweeping tariffs on China for its alleged unfair trade practices. Over the months that followed, the two countries have been embroiled in countless back-and-forth negotiations, a tit-for-tat tariff war, introduced foreign technology restrictions, fought several WTO cases, consequently leading US-China trade tensions to the brink of a full-blown trade war. On January 15, 2020 the two sides signed the Phase One Deal, which officially agreed to the rollback of tariffs, expansion of trade purchases, and renewed commitments on intellectual property, technology transfer, and currency practices; a breakthrough in the nearly two-year trade war between the world's two largest economies.

On the back of this breakthrough, the COVID-19 pandemic began metastasising worldwide and the All Share index began losing value sharply when global risk-off sentiment heightened amidst the pandemic and the traditional flight-to-safety in safe haven assets. Signals of profound economic repercussions increased alongside fears of surges in cases. In the first half of March, the JSE experienced extreme market volatility and unprecedented volumes causing it to widen its circuit breaker[7] trigger points, which enforce temporary trading halts

[7] Circuit Breakers are defined as a percentage in relation to the Static Reference Price (Previous Day's closing price or latest auction trade) and Dynamic Reference Price (Last Traded Price). Circuit breakers trigger temporary halts in trading of an equity on the JSE during market volatility and are imposed by regulators across the globe. This brief pause in trading is to assist investors to understand market conditions better and to try and curb the panic-selling of an equity. Circuit breakers are triggered automatically on an instrument level if the circuit breaker tolerance is breached, which will enforce a trading halt for periods of 5

for periods of 5 minutes at a time. By 27 March 2020 the ALSI had lost 25.5% of its value since the beginning of 2020. Oil price movements play a key role in the performance of the foreign exchange and stock markets of oil importing economies, such as South Africa. On April 20, 2020, due to the collapse in the demand for oil as lockdown measures took place, combined with international geopolitical issues, the price of West Texas Intermediate (WTI) futures turned negative as increased supply and reduced storage capacity hindered standard market operations. The front-month May 2020 WTI crude contract dropped 306%, or $55.90, for the session, to settle at negative $37.63 a barrel, the largest one-day plunge on records going back to 1983, and the settlement was the lowest on record marking the first and only time a contract closed with a negative value[8].

Once the possibility of vaccines was in sight, coupled with very strong synchronised global support to financial recovery by the means of monetary support as well as fiscal support from governments across the world, markets received the support that they needed which boosted a very strong recovery. In particular, the South African Government implemented several relief measures which focused on providing tax relief, unemployment support, support for Small, Micro and Medium-Sized Enterprises (SMME's), and various loan funding .– in partnership with the major banks, National Treasury, and the South African Reserve Bank – to help assist the country overcome the detrimental effects of COVID-19. In the US, the FED announced a series of big measures to help support the economy and markets in March 2020, including unlimited quantitative easing, cutting interest rates down to zero and buying both investment-grade and high-yield corporate bonds[9]. This was the catalyst for stock market recovery in the US and, therefore, also in South Africa as the ALSI closely follows the US stock market. The US equity markets also saw a surge in demand as the public was stuck at home which resulted in additional traders, as well as sporting events being cancelled worldwide which led to sports bettors rather taking part in stock trading market[10]. By August 2020 the ASI had recovered to pre-COVID levels. In the first week of November, with the announcement of vaccines being rolled out and being approved across the world, SA started seeing a broad-based recovery where sectors that were linked to the broader economy really started participating in this rally[11].

The inauguration of President Joe Biden saw Trump supporters storm the Capitol on January 6, 2021, which disrupted a joint session of Congress, which was convened to certify the results of the presidential election of 2020. Stock markets barely reacted to this news as it was known that this insurrection will not change the election outcome and will do nothing to change expectations

minutes at a time (JSE, 2021).

[8] https://globalriskinsights.com/2020/05/making-history-coronavirus-and-negative-oil-prices/

[9] https://www.brookings.edu/research/fed-response-to-covid19/

[10] https://www.axios.com/sports-betting-stock-market-surge-0e945773-d676-4f0a-a6a0-a0f92611b10b.html

[11] https://www.moneyweb.co.za/in-depth/ninety-one/jses-performance-for-the-past-12-months/

around the near-term political and economic outlook, as President-elect Joe Biden will be able to push through more aggressive stimulus packages and fund spending with higher taxes[12]. From the low base of the market crash in March, the ALSI saw strong runs and was up about 50% for the 12 months to the end of March 2021. It has since been trending upwards and by August 2021 it was about 17% stronger than it was at the turn of 2020.

In order to gain insight into the univariate time series properties of the data series, descriptive statistics of the stock returns and exchange rate changes are presented in Table 1. Panel A provides the descriptive statistics of the full sample from 1979:01-2021:08 and shows that sample means of all the time series are significantly different from zero. The mean stock return is 0.95% and the volatility associated with stock returns is quite high indicated by the standard deviation of 5.42. The mean and associated volatility of the exchange rate changes are lower than stock returns at -0.53% and 3.27, respectively. The standard deviations for both stock and exchange rate returns are higher than their mean, indicating a higher level of risk in both markets. The skewness and excess kurtosis statistics show that the distributions of stock returns and exchange rate changes are negatively skewed (i.e., asymmetric distribution) and highly leptokurtic with respect to the normal distribution hypothesis. Thus, both time series exhibit a non-normal distribution, supported by the strong rejection of Jarque-Bera statistic at the 1% level of significance. The Ljung–Box (1979) statistic, which tests for serial correlation, calculated for up to 10 lags[13] relative to the absolute returns and squared returns for stock and exchange rates indicates some linear and nonlinear dependencies. This result is consistent with the Breusch-Pagan-Godfrey (1978) test. The linear dependency contrasts with the 'informational efficiency' hypothesis and may be evidence of some form of market inefficiency[14]. The nonlinear dependencies may be captured by a certain autoregressive conditionally heteroskedastic (ARCH) model (Nelson, 1991). Panel B provides the descriptive statistics of the COVID-19 period and shows that the mean stock market returns were higher during the COVID-19 period, explained by the possibility of vaccines coupled with very strong synchronised global support to financial recovery and higher demand in the equity market; whilst the exchange rate changes saw a smaller mean as the full sample saw episodes of major depreciation around 1985, 1998, 2001 and 2008/9 which was not matched during the COVID-19 period. Both markets saw higher volatility with larger standard deviations during the COVID-19 period.

[12] https://www.marketwatch.com/why-stocks-and-financial-markets-shrugged-as-a-violent-mob-stormed-the-capitol-11609972407

[13] In-line with Yang and Doong (2004).

[14] The 2013 Nobel Prize winner, Eugene F. Fama, defined a market to be "informationally efficient" if prices always incorporate all available information. In this scenario, all new information about any given firm is certain and immediately priced into that company's stock.

4.2 Methodology

Black (1976) recognised that in stock markets, volatile periods are often initiated by a large negative shock, which suggests that positive and negative shocks may have an asymmetric impact on the conditional volatility of subsequent observations. Black attributed this to the way ?rms are ?nanced. When the value of (stock of) a ?rm falls, the debt-to-equity ratio increases, which in turn leads to an increase in the volatility of the returns on equity in a phenomenon commonly referred to as the 'leverage effect'. This is a well-documented empirical finding in the finance literature (see Bae & Karolyi, 1994; Koutmos & Booth, 1995; and Booth *et al.*, 1997). A different economic explanation than that given by Black (1976) would be required to explain a 'leverage effect' or asymmetries in foreign exchange markets. Bollerslev *et al.* (1992) review a significant body of empirical evidence and conclude that "whereas stock returns have been found to exhibit some degree of asymmetry in their conditional variances, the two-sided nature of foreign exchange markets makes such asymmetries less likely" (Bollerslev *et al.*, 1992, p. 38).

The asymmetric phenomenon in combination with the observed volatility clustering in financial market returns validates the use of a bivariate EGARCH framework. A bivariate framework is implemented since one of the drawbacks of a univariate EGARCH process is that the model fails to consider the information of covariance between stock return and exchange rate change (Chiang *et al.,* 2000). The bivariate EGARCH model developed by Nelson (1991) captures the potential asymmetric behaviour of financial market returns and avoids imposing non-negativity constraints by specifying the logarithm of the variance – so that it is no longer necessary to restrict parameters, such as in GARCH modelling, in order to avoid negative variances (Bhar & Nikolova, 2008). The bivariate EGARCH model allows both "good" news and "bad" news to have a different impact on volatility, while also allowing "big" news to have a greater impact on volatility.

This paper follows the bivariate EGARCH specification set out by Aloui (2007) in order to investigate whether the volatility of stock returns affects the volatility of exchange rate changes and *vice versa* within the South African economy. The framework is set out as follows:

$$\begin{aligned} S_t = \alpha_{S,0} + \sum_{i=1}^{r} \alpha_{S,i} S_{t-i} + \sum_{i=1}^{r} \alpha_{E,i} E_{t-i} + \varepsilon_{S,t} \\ \varepsilon_{S,t} / \Omega_{t-1} \sim N(0, \sigma_{S,t}^2) \end{aligned} \tag{1}$$

$$\begin{aligned} E_t = \alpha_{E,0} + \sum_{i=1}^{r} \alpha_{E,i} E_{t-i} + \sum_{i=1}^{r} \alpha_{S,i} S_{t-i} + \varepsilon_{E,t} \\ \varepsilon_{E,t} / \Omega_{t-1} \sim N(0, \sigma_{E,t}^2) \end{aligned} \tag{2}$$

where equations (1) and (2) specify the conditional mean equations for the stock returns, S_t, and exchange rate changes, E_t. These equations will capture the mean spillover effects between stock returns and exchange rates and *vice versa*. In these equations, $\alpha_{S,0}$, $\alpha_{E,0}$, $\alpha_{S,i}$ and $\alpha_{E,i}$ for $i = 1, 2, ..., n$ are parameters to be estimated. The stochastic error terms are given by $\varepsilon_{S,t}$ and $\varepsilon_{E,t}$. Conditional on Ω_{t-1} (the information set at time t-1), the stochastic error terms are assumed to be normally distributed with zero mean and variance $\sigma^2_{S,t}$ and $\sigma^2_{E,t}$, respectively, where $\sigma^2_{S,t}$ and $\sigma^2_{E,t}$ are the conditional time-varying variances of stock returns and exchange rate changes. In the current study, a one-period lag of stock returns and exchange rate changes will be included in equations (1) and (2). This is determined using the general-to-specific approach attributed to Hendry (1995) and evaluating the different information criteria[15], keeping the parsimony principle in mind.

As maintained by the EGARCH specification, the variance is conditional on its own past values as well as on past values of the standardised residuals[16] (Kanas, 2000). The conditional variance equations for the stock returns, $\sigma^2_{S,t}$, and the exchange rate changes, $\sigma^2_{E,t}$, are given by:

$$\begin{aligned} \sigma^2_{S,t} = \exp\{c_{S,0} + \textstyle\sum_{j=1}^{p_k} \mathrm{b}_{S,j} \log(\sigma^2_{S,t-j}) \\ +\delta_{S,S}[(\,|z_{S,t-1}| - E\,|z_{S,t-1}|\,)] + \theta_{S,S} z_{S,t-1}] \\ +\delta_{S,E}[(\,|z_{E,t-1}| - E\,|z_{E,t-1}|\,) + \theta_{S,E} z_{E,t-1}]\,\} \end{aligned} \quad (3)$$

$$\begin{aligned} \sigma^2_{E,t} = \exp\{c_{E,0} + \textstyle\sum_{j=1}^{p_E} \mathrm{b}_{E,j} \log(\sigma^2_{E,t-j}) \\ +\delta_{E,E}[(\,|z_{E,t-1}| - E\,|z_{E,t-1}|\,)] + \theta_{E,E} z_{E,t-1}] \\ +\delta_{E,S}[(\,|z_{S,t-1}| - E\,|z_{S,t-1}|\,) + \theta_{E,S} z_{S,t-1}]\,\} \end{aligned} \quad (4)$$

which represent the diagonal elements of the 2×2 covariance matrix Q_t. Equations (3) and (4) reflect the EGARCH(p,1) representation of the variances of $\varepsilon_{S,t}$ and $\varepsilon_{E,t}$ where the lag truncation length, p, is determined using Likelihood Ratio (LR) tests of alternative specifications. Specifically, in this study we tested for EGARCH(2,1) against EGARCH(1,1) for South Africa[17]. Based on these tests, an EGARCH(1,1) specification is selected for South Africa.

Equations (3) and (4) depict how the conditional variance in one market depends on its own lag values and past values of the standardized residuals. The persistence of the volatility is measured by $\sum_{j=1}^{p_S} \mathrm{b}_{S,j}$ for the stock returns and by $\sum_{j=1}^{p_E} \mathrm{b}_{E,j}$ for the exchange rate changes, where conditional variances are finite if $\sum_{j=1}^{p_S} \mathrm{b}_{S,j} < 1$ and $\sum_{j=1}^{p_E} \mathrm{b}_{E,j} < 1$. The persistence of volatility may be quantified by considering the half-life, given by $HL = \frac{\ln(0.5)}{\ln \sum_{j=1}^{p_S} \mathrm{b}_{k,j})}$ *where* $k = S$ *or* E, which indicates the time period required for the shocks to reduce to one

[15] The information criteria evaluated include Akaike, Schwarz and Hannon-Quinn.

[16] $z_{S,t}$ and $z_{E,t}$ are the standardised residuals of stock returns and exchange rate changes where:
$z_{S,t} = (\varepsilon_{S,t}/\sigma_{S,t})$ and $z_{E,t} = (\varepsilon_{E,t}/\sigma_{E,t})$.

[17] The likelihood ratio (LR) test is calculated as: 2x|$\ln_{EGARCH(2,1)} - \ln_{EGARCH(1,1)}$|.The best-suited model is selected on the basis of Davies (1987) critical values.

half of their original size. The terms $\delta_{S,S}[(\,|z_{S,t-1}| - E\,|z_{S,t-1}|) + \theta_{S,\,S} z_{S,t-1}]$ and $\delta_{E,\,E}[(\,|z_{E,t-1}| - E\,|z_{E,t-1}|) + \theta_{E,\,E} z_{E,t-1}]$ capture the ARCH effect. The expressions $(|z_{S,t-1}| - E\,|z_{S,t-1}|)$ and $(\,|z_{E,t-1}| - E\,|z_{E,t-1}|)$ capture the "size" effects of stock returns and exchange rates, respectively, where if the past absolute value of $z_{S,t-1}$ or $z_{E,t-1}$ is greater than its expected value, the current volatility will rise. The parameters $\theta_{S,S}$ and $\theta_{E,\,E}$ allow the effect to be asymmetric: if $\theta_{S,S}$ and $\theta_{E,\,E}$ are not statistically different from zero, then a positive and negative shock possess the same magnitude of effect; however, if $0 > \theta_{S,S}$ then negative shocks increase volatility more than positive shocks which allows the asymmetry effect to be captured. This is called the 'leverage effect' documented by Black (1976) and Nelson (1991).

The volatility spillover effect from exchange rate changes to the stock returns is captured by the term $\delta_{S,E}[(\,|z_{E,t-1}| - E\,|z_{E,t-1}|\,) + \theta_{S,\,E} z_{E,t-1}]$ in equation (3), while the volatility spillover effect from stock returns to exchange rate change is captured by the term $\delta_{E,\,S}[(\,|z_{S,t-1}| - E\,|z_{S,t-1}|\,) + \theta_{E,\,S} z_{S,t-1}]$ in equation (4). In these equations, the parameter $\delta_{S,E}$ measures the spillovers from the exchange rate changes to stock returns and the parameter $\delta_{E,\,S}$ measures the spillovers from the stock returns to the exchange rate changes. To determine whether asymmetric effects are present, the parameters $\theta_{S,\,E}$ and $\theta_{E,\,S}$ are considered: if $\theta_{S,\,E} < 0$ in equation (3) then a negative exchange rate shock increases the volatility of stock returns more than a positive shock; while if $\theta_{E,\,S} < 0$ in equation (4) then a negative stock returns shock increases volatility of exchange rate changes more than a positive shock.

According to Bhar and Nikolova (2008), the asymmetric effect of standardised innovations on volatility may be measured as derivatives:

$$\frac{\partial\,(|z_{k,t-1}| - E\,|z_{kt-1}|) + \theta_{k,\,k} z_{k,t-1})}{\partial\, z_{k,t-1}} = \left(\frac{1 + \delta_k \quad if\ z_k > 1}{-1 + \delta_k \quad if\ z_k < 1}\right) \tag{5}$$

where $k = S$ or E. The relative asymmetry, or leverage effect, is defined as $\frac{|-1+\delta_k|}{(1+\delta_k)}$ and considers the differing impact of a market's own innovation on the current conditional variance. This quantity is greater than, equal to, or less than 1 for negative asymmetry, symmetry and positive asymmetry, respectively.

The conditional covariance, $\sigma_{S,\,E,\,t}$, represents the off-diagonal elements of the covariance matrix Q_t and is specified as:

$$\sigma_{S,\,E,\,t} = \rho_{S,\,E}\,\sigma_{S,\,t}\sigma_{E,\,t} \tag{E6}$$

where $\rho_{S,\,E}$ is the cross-market correlation coefficient between the standardised residuals from the stock returns and exchange rate change equations. In line with Bollerslev (1990), the conditional correlations are assumed to be constant over time. With the assumption of normality and given a sample of T observations, the abovementioned parameters are estimated by numerical maximisation of the log likelihood function of a bivariate EGARCH model given by:

$$L\,(\Theta) = -0.5\,(NT)\ln(2\pi) - 0.5\sum_{i=1}^{T}(\ln|\,Q_t| + \varepsilon_t^{'}\,Q_t^{-1}\varepsilon_t) \tag{E7}$$

where N is the number of equations (two in this instance), Θ is the parameter vector to be estimated, ε_t is the 1×2 vector of residuals at time t, and Q_t is the 2×2 conditional variance-covariance matrix with diagonal elements given by equations (3) and (4) and cross-diagonal elements given by equation (5). The log-likelihood function is estimated using the Broyden, Fletcher, Goldfarb and Shanno (BFGS) optimisation method (see Broyden, 1965, 1967; and Fletcher & Powell, 1963).

5 Empirical Results

Following the prevailing empirical literature, estimating the conditional mean equations (1) and (2) of stock returns and exchange rate changes first requires unit root tests of the variables as well as cointegration tests to determine a possible relation between the variables for the period January 1979 to August 2021. These results are presented in Section 5.1. Thereafter, in Section 5.2 the bivariate EGARCH results are presented, followed by an analysis and discussion of the first and second moment outcomes.

5.1 Cointegration Analysis

The cointegration analysis is critical – if the above variables under consideration are found to be cointegrated, the error correction terms need to be inserted into the conditional mean equations. To test for stationarity of the series, the Phillips-Perron (1988) test (PP) is implemented. This test is justified as autocorrelation and ARCH effects were detected in both financial time series and the PP test is robust to strong autocorrelation and heteroscedasticity in the series (Yang & Doong, 2004). The bandwidth is based on Newey-West using the Barlett kernel spectral estimation method. The results of the PP stationarity tests are reported in Table 2, panel A, and conclude that both the time series are not stationary in level form. Whether or not a time trend is included in the unit root test estimation, the PP test shows that the first differences of both the time series are stationary. The stock index and the nominal effective exchange rate time series are therefore integrated of the same order – I(1). This result is consistent when implementing the Augmented Dickey-Fuller (ADF) and the Ng-Perron unit root tests. The data series for stock returns and exchange rate changes are stationary in levels.

Based on this finding, Johansen's (1988) cointegration test is implemented to establish whether any combinations of the time series have a long-run relationship or are cointegrated. Phylaktis and Ravazzolo (2005) suggest that the use of the cointegration technique overcomes the problem of non-stationarity and allows investigation into both the levels and differences of the stock index and exchange rates series. The Johansen test is used here as it is also shown to be robust in the presence of heteroscedasticity (Lee & Tse, 1996). The bivariate cointegration test results are presented in Table 2, panel B.

The test results show that stock market indices and exchange rates are not cointegrated for the period under consideration. As a result, there is no significant long-run relationship between stock index prices and the effective exchange rate. Given this outcome, the conditional mean equations (1) and (2) will be estimated without the error correction terms. This result is consistent with those of Granger *et al.* (2000), Aloui (2007), Kutty (2010), Zhao (2010), Diamandis and Drakos (2011) and Sikhosana and Aye (2018); whilst being contrary to the reported results of Bahmani-Oskooee and Sohrabian (1992), Ajayi and Mougoué (1996) and Aydemir and Demirhan (2009), where the latter studies do find a cointegrated relationship to exist between the stock market indices and exchange rates for the respective economies under consideration, and therefore do include the error correction term in the conditional mean equations.

5.2 The bivariate EGARCH results

Table 3 reports the results of estimations of the bivariate EGARCH model specified by equations (1) to (6) for South Africa for the period from January 1979 to August 2021 and Table 5 reports the estimation results for the COVID-19 period from March 2020 to August 2021. A RATS routine has been developed based on the methodology cited for the bivariate EGARCH model[18]. The model presented considers both price (mean) and volatility (variance) spillovers between stock returns and exchange rate changes.

Considering the first moment interdependence, Table 3 shows that the previous month's stock returns have a significant impact on the current month's stock returns. There are also positive price spillovers from the foreign exchange to the stock market. In South Africa, currency depreciation (appreciation) habitually drags up (down) stock prices. In the long run, for an economy with a significant import (export) sector, the unfavourable effects of currency depreciation (appreciation) on imports (exports) may induce a 'bearish' stock market. In 2020 South Africa was the 39th largest exporter in the world[19]leading exports in: (i) pearls, precious stones, metals, coins, (ii) ores slag and ash, (iii) vehicles other than railway, tramway, and (iv) mineral fuels, oils and distillation products.. In 2020, the top five export destinations include China, US, Germany, UK and Japan. In the short run, currency depreciation may have a negative effect on the stock market as the domestic counterpart of currency depreciation is inflation, which may exert a dampening effect on the stock market (Yang & Doong, 2004). In addition, the inflationary effects of a declining domestic currency may encourage international investors to decrease their portfolio of domestic assets, thereby depressing the stock market in the long run. This price spillover is however found to be statistically insignificant.

Looking at exchange rate changes, the previous month's exchange rate change has a significant impact on the current month's exchange rate change. There are also significant positive price spillovers from the stock to the exchange mar-

[18] Empirical estimation was implemented using the econometric modelling package Estima WinRats Version 10.0.

[19] https://tradingeconomics.com/south-africa/exports-by-category

[19] https://tradingeconomics.com/south-africa/exports-by-country

ket. In the South African economy, an increase (decrease) in stock price causes currency appreciation (depreciation). The short-run effect of increases in stock prices on the domestic currency value can be explained by the stock market's providing a barometer for the health of an economy (Solnik, 1987). This is attributed to the fact that stock returns forecast changes in economic activity as measured by industrial production, real growth in gross national product, employment rate, or corporate profits (Giovannini & Jorion, 1987). A 'bullish' market reflects economic expansion where an increase in domestic stock assets will: (i) entice international share-holders to revise their investment portfolio and substitute foreign assets for domestic assets, and (ii) increase wealth and the demand for each of the assets in the model where the surplus demand for money will lead to higher interest rates which cause a substitution from foreign securities to domestic assets (Phylaktis & Ravazzolo, 2005). This result is generally in line with the portfolio balance model proposed by Branson and Henderson (1985) and Frankel (1983). Overall, this empirical finding is consistent with those available in the literature being similar to those of Nieh and Lee (2001), Yang and Doong (2004), and Sikhosana and Aye (2018). Changes in stock prices provide significant informational signals to foreign exchange brokers whilst the exchange rate does not appear to be a significant factor for the stock markets in terms of price spillovers.

Looking at the variance equation, the persistence of volatility or GARCH effects is measured by $\Sigma_{j=1}^{p_S} b_{S,j}$ for stock returns and by $\Sigma_{j=1}^{p_E} b_{E,j}$ for exchange rate changes. As seen in Table 3, volatility persistence is common in both markets and is less than unity suggesting that the unconditional variance is finite which is a necessary condition for the volatility process to be stable (Aloui, 2007). It is therefore possible to estimate the degree of volatility persistence based on the half-life of a shock in the stock and foreign exchange markets. The volatility in the stock market took an average of approximately 1 month to reduce the impact from its shocks by half, whilst volatility in the foreign exchange market took on average approximately 6 months to reduce the impact from its shocks by half. There are also significant ARCH effects in both markets which indicates volatility clustering – referring to the observation first noted by Mandelbrot (1963) where in financial series large changes tend to be followed by large changes, of either sign, or small changes tend to be followed by small changes. The asymmetric effect is captured in parameters $\theta_{S,S}$ and $\theta_{E,E}$. Since $0 > \theta_{S,S}$ and is statistically significant, a negative shock in the stock market increase volatility more than positive shocks – known as the 'leverage effect' documented by Black (1976) and Nelson (1991). Looking at the exchange rate market, $\theta_{E,E} > 0$ and is statistically significant implying that positive shocks in the exchange market have greater impact on volatility than negative shocks of the same magnitude. This finding could be attributed to the fact that South Africa is an export dominated country making it more sensitive to currency appreciations than depreciations, where a currency appreciation is viewed as 'bad news' as it harms the export industry.

The asymmetric effect of negative and positive shocks in each market is evaluated by the relative asymmetry statistic or leverage effect. The stock market presents with a relative asymmetry greater than 1, indicating that the stock market exhibits negative asymmetric effects, and a negative innovation will have a greater impact on conditional volatility than a positive innovation. This is telling of the 'leverage effect', where unexpected "bad" news will have greater impacts on current conditional volatility than "good" news. The exchange rate presents with a relative asymmetry less than 1, indicating a positive asymmetric effect and the impact of "good" news will outweigh "bad" news of the same size. In other words, a local currency appreciation has a greater impact on current conditional volatility compared to a currency depreciation. The management of the exchange rate by South African authorities over the years may be a possible explanation for asymmetries since "...interventions may affect important variables such as interest rates and inflation, which the market considers truly "bad" news." (Maya & Gomez, 2008).

Turning attention to the second moment interdependence, the off-diagonal elements of the ARCH effect capture the cross-market shock effects and the results show there is evidence of significant bidirectional shock spillovers between stock returns and exchange rate returns. On the other hand, the results show that there exists no significant volatility spillover between the stock and exchange markets. Jorion (1990) asserts that a possible justification for the lack of exchange rate spillovers is that the positive exchange rate volatility effects on stock returns for some firms are negated by negative effects for others leading to a weak or zero net exchange rate effect. An alternative explanation, given by Bodnar and Gentry (1993), is that volatility spillovers are counteracted by the sound use of exchange rate risk hedges, such as forwards, futures, and currency options – which creates a flow that reduces the exchange rate effects on profits after exchange rate transactions have been completed, thereby reducing the sensitivity of profit to exchange rate fluctuations.

In terms of asymmetric spillover effects, the results show significant asymmetric volatility spillovers from the exchange rate to the stock market and from the stock market to the exchange rate. This result has implications for the level of exchange rate risk faced by multinationals with costs and revenues denominated in more than one currency (Kanas, 2000). The volatility of stock returns in South Africa has a direct effect on the exchange rate risk. This result is supportive of the model of Zapatero (1995), in which, with integrated financial markets and free capital movements, the volatility of stock returns is a determinant of the volatility of the exchange rate. The results suggest that positive innovations in the stock market have greater impacts on the conditional volatility of exchange rates than negative innovations. This finding is not in line with those of Kanas (2000), Yang and Doong (2004) and Aloui (2007) based on the premise that investors are more skittish to "bad" news but does agree with the results of Sikhosana and Aye (2018). The results also suggest that positive innovations in the exchange rate market have greater impacts on the conditional volatility of exchange rates than negative innovations. Moreover, based on the estimations of the multivariate EGARCH model, a simulation on the different impacts of good and bad news on the cross-market volatility is performed. The results are presented in Table 4, which supports prior findings and shows that positive shocks in the stock market have greater impacts on the future volatilities for the exchange rate than negative shocks, as well as positive shocks in the exchange rate have greater impacts on the future volatilities for the stock market than negative shocks.

Finally, we consider the correlation coefficient between the standardised residuals of the stock return and the exchange rate changes equations. The standardised residuals are interpreted as exchange rate changes and stock returns from which linear and nonlinear dependencies have been filtered through the bivariate EGARCH modelling (Kanas, 2000). As Table 3 displays, the correlation coefficients are positive and significant for South Africa suggesting that there is a statistically significant contemporaneous relationship between stock returns and exchange rate changes.

In general, these results imply that changes in stock prices signal important information about the economic fundamentals to the foreign exchange market in the first and second moment interactions, and exchange rate movements convey information about future stock price movements in the second moment interdependence. Therefore, findings suggest there is information transmission between the two markets and that the two markets are integrated. Generally, these findings are in line with findings of Kumar (2013) and Sikhosana and Aye (2018).

Turning attention to Table 5, results are reported for the volatility spillovers between stock returns and exchange rate changes during the COVID-19 pandemic. Considering the first moment interdependence, there are significant price spillovers from the exchange rate to the stock market and vice versa. This contrasts with the full sample results where only significant spillovers were seen from stock market to exchange rate. During the COVID-19 pandemic, changes in stock prices provide significant informational signals to foreign exchange brokers and, similarly, the exchange rate is a significant factor for the stock markets. Similar price spillovers are seen during the global financial crisis and the East-Asian financial crisis .

Looking at the variance equation, volatility persistence remains common in both markets. Given that the volatility persistence is less than unity, it is possible to estimate the degree of volatility persistence during the COVID-19 pandemic based on the half-life of a shock in the stock and foreign exchange markets. The volatility in the stock market took an average of approximately 0.3 months, or about 9 days, to reduce the impact from its shocks by half; whilst volatility in the foreign exchange market took on average approximately 0.5 months, or 15 days, to reduce the impact from its shocks by half. Similarly, there are also significant ARCH effects in both markets which indicates volatility clustering. The asymmetric effect is captured in parameters $\theta_{S,S}$ and $\theta_{E,E}$. Since both $0 > \theta_{S,S}$ and $0 > \theta_{E,E}$ and are statistically significant at 1%, a negative shock in the stock market and exchange rate market increase volatility more than positive shocks – known as the 'leverage effect' documented by Black (1976) and Nelson (1991).

Turning attention to the second moment interdependence, results show there is evidence of significant unidirectional shock spillovers from the stock returns to the exchange rate returns. Results also show that there exists significant volatility spillover from the stock to exchange markets and vice versa, suggesting that during COVID-19 an increase in volatility in one market leads to an increase in the volatility of the other market. This finding is in contrast with the full sample, where no significant volatility spillovers were found, suggesting that spillovers are more pronounced during COVID-19. This finding can be attributed to the number of foreign investors in the South African stock markets. High volatility in equity markets, which signals an increasing degree of market risk, may lead to the rapid sale of assets by foreign market participants for them to relocate funds to more stable equity markets, which results in massive capital outflow and, thus, volatility in the foreign exchange market. Thus, the activities of foreign investors in the South African equity market provide a channel through which shocks in the equity market are transmitted to the foreign exchange market. To explain the reverse spillover, Živkov et al. (2021) assert that the exchange rate volatility carries various set of news related to different macroeconomic regularities, such as trade news, real interest rate news and expected inflation news. These fundamentals affect stock markets in different ways, and thus when foreign exchange market become more volatile, stock markets also become more uncertain, in terms of higher conditional volatility. In terms of asymmetric spillover effects, the results show significant bidirectional asymmetric spillovers between the two markets. The results suggest that negative innovations in the stock market have greater impacts on the conditional volatility of exchange rates than positive innovations; while positive innovations in the exchange rate market have greater impacts on the conditional volatility of stock market returns than negative innovations. Table 6 supports these findings. Similar shock, volatility and asymmetric spillovers are seen during the global financial crisis and the East-Asian financial crisis.

Overall, we find significant price and volatility spillovers between the stock returns and exchange rate returns during the period of COVID-19. These findings suggest that the integration between stock and exchange rate returns intensified with the unfolding of the COVID-19 pandemic. In conclusion, we find support for volatility spillovers increasing the likelihood of financial crises, which is in line with previous studies that have documented the effect of extreme market turmoil on stock markets and foreign exchange (see, for example, Diamandis and Drakos, 2011; Lin, 2012; Mozumder et al., 2015; Morales-Zumaquero and Sosvilla-Rivero, 2018; Živkov et al., 2021). In comparison to previous studies, the multivariate EGARCH results for the COVID-19 crisis are in line with the studies focusing on the East-Asian financial crisis and the global financial crisis which found that spillovers became more pronounced during economic turmoil. Similarly, with reference to volatility spillover during the COVID-19 pandemic, Rai and Garg (2021) found strong bidirectional volatility spillovers.

To assess the robustness of these results, diagnostic and sensitivity checks were implemented. Looking at the diagnostic tests in panel B of Tables 3 and 5, both the standardised innovations have zero mean and unit variance based on the Ljung–Box Q statistic and there are no mutually linear and nonlinear dependence in the series. Hence, modelling the multivariate EGARCH model can successfully capture the price volatility interactions between foreign exchange and stock markets. To gauge the sensitivity of results, the cointegration and EGARCH estimations are re-run using real effective exchange rate instead of nominal effective exchange rate. The results are broadly in line with those reported in Tables 3 and 5, thus corroborating the earlier findings.

6 Conclusion

This study tested for volatility spillovers between stock returns and exchange rate changes for South Africa using a multivariate EGARCH modelling approach for the period 1979:01– 2021:08, including an analysis of the COVID-19 pandemic in South Africa over 2021:03–2021:08. Empirical outcomes of this study provide evidence in support of the "stock-orientated" approach where both price and volatility information from the stock market has significant impacts on the behaviour of the exchange market, whilst evidence of the "flow-orientated" approach is seen in the second moment and significant shock and asymmetric spillovers from the exchange to stock market are found. There is also evidence of bidirectional asymmetric volatility spillover effects between the stock to exchange market. During COVID-19, price and volatility spillovers between stock returns and exchange rate returns became more pronounced, confirming that there is heightened contagion during periods of crisis. Overall, findings indicate that there was a significant contagion between the two markets during COVID-19 which led to decline in domestic stock returns and subsequent capital outflows thereby weakening the exchange rates. Due to the elevated probability of recurrence of pandemics in the future, it is important to understand the behaviour of investors in the aftermath of such events. The correlation coefficient between the EGARCH filtered stock returns and exchange rate changes is positive and significant, signifying that there is a significant contemporaneous relationship between stock returns and exchange rate changes.

Important implications flow from these findings as improved knowledge of the price and volatility spillover effect between the stock and currency markets, and consequently the degree of their integration, will expand the information set available to international portfolio managers, multinational corporations, and policy makers alike. Evidence that stock and foreign exchange markets are interrelated implies that lagged information from one market can be used to forecast changes in the other − signifying those markets are 'informationally' inefficient, with one market having significant predictive power on the other. Investors who seek to hedge their investment risks in South Africa may use the information to manage their international portfolio risk and currency risk strategies, as the finding of the volatility spillover effect between these markets suggests that they should not include both assets in the same basket if aiming to diversify risk in their asset portfolio. This knowledge is also important for multinational firms which intend to manage their international currency exposures.

Policy makers may benefit from this study by having a better understanding of how the stock market and foreign exchange market volatility affect each other and the economic consequences that may arise by integration of these two markets. Having this knowledge allows policy makers to implement policies from a financial stability perspective. Although governments are known to frequently intervene in the foreign exchange markets, the question of the desirability of direct intervention in the stock market remains part of the broader economic debate. Proponents of intervention claim that intervention can avoid swift price declines in the stock market and restore investor confidence. Conversely, opponents claim that any form of intervention can seriously endanger the integrity of the market since the stock market stands as a leading financial indicator of the economy, and any tampering with it can transmit incorrect signals about the state of a nation's economy (Khan & Batteau, 2011). These results therefore heed important implications for policymakers.

Avenues for future research are boundless. A time-varying spillover model, as suggested by Diebold and Yilmaz (2012), could be used for future research to assess the magnitude of volatility transmission between the foreign exchange and equity markets during the tranquil and tumultuous periods in South Africa (Bonga-Bonga & Hoveni, 2013). Previous studies have provided strong evidence of regime switching behaviour in stock market returns (see Turner *et al.*, 1989; Chu *et al.*, 1996; and Schaller & Van Norden, 1997). A future study can use a two regime bivariate MS-EGARCH model motivated by at least three points: (i) this model allows the variance of stock returns to switch across different regimes; (ii) the model is able to detect regime dependence in the impact, persistence and asymmetric response to shocks since the conditional variance depends on past shocks and the present and past states of the economy; and (ii) this model is founded on the assumption that stock returns may shift across different volatility regimes, which is linked to the diverse perceptions and reactions of foreign exchange traders and stock market participants to volatility spillovers between exchange and stock markets (Chkili *et al.,* 2011). A study can consider the 'meteor shower' effect from global financial markets to stock and exchange rate markets in South Africa as South Africa's financial markets are vulnerable to global events (Živkov *et al.,* 2021).

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Table 1: Descriptive statistics of stock returns and exchange rate changes in South Africa

Panel A: 1979:01-2021:08		
	Stock Returns	Exchange Rate Changes
Mean	0.9508	-0.5305
Std. Dev.	5.4228	3.2702
Skewness	-1.0963	-1.0488
Kurtosis	8.390	9.663
Jarque-Bera	722.4	1041.0
Probability	0.0000	0.0000
Q(10)	18.527**	68.451***
$Q^2(10)$	18.076*	83.3240***
Panel B: COVID-19 period 2020:03 – 2021:08		
	Stock Returns	Exchange Rate Changes
Mean	1.5471	-0.1412
Std. Dev.	5.8972	4.2435
Skewness	-0.5375	-1.1569
Kurtosis	3.974	3.4292
Jarque-Bera	1.5781	4.1536
Probability	0.4543	0.1253
Q(10)	8.1559	9.5573
$Q^2(10)$	4.7896	5.0764

Note: *, **, *** indicate a rejection at 10%, 5% and 1% critical level.

Jarque-Bera is the test statistic for testing whether a time series is normally distributed. The test statistic is computed as $JB = \frac{N-k}{\sigma}\left(skew^2 + \frac{1}{4}(kur-3)^2\right)$ where skew is skewness, kur is kurtosis, N is the number of observations and k is the number of the estimated coefficients. Q(10) and $Q^2(10)$ are the Ljung–Box (1979) statistics for returns and squared returns, respectively, both with chi-square distribution with 10 degrees of freedom.

Table 2: Results of the Phillips-Perron unit root tests and Johansen cointegration test

Panel A: Phillips-Peron unit root test				
	Level		First difference	
	No trend	With trend	No trend	With trend
Stock market index	1.8882	-0.9399	-23.670***	-24.0684***
Effective exchange rate	-2.3380	-1.0924	-16.820***	-17.0847***

Panel B: Johansen cointegration test		
H_0	$\boldsymbol{\lambda}_{max}$	Trace
$r \leq 0$	9.9409 (14.2646)	10.5974(15.4947)
$r \leq 1$	0.6566 (3.8415)	0.6566 (3.8415)

Note: *, **, *** indicate a rejection at 10%, 5% and 1% significance level.

H_0 is the null hypothesis that the number of cointegrating vectors is less than or equal to the number specified and $\boldsymbol{\lambda}_{max}$ and Trace are the Johansen (1988) test statistics for testing for the existence of cointegration. The 5% critical values of $\boldsymbol{\lambda}_{max}$ and Trace are given in parentheses.

Table 3: Bivariate EGARCH model for volatility spillovers between stock returns and exchange rate changes in South Africa 1979:01–2021:08

		Stock returns		Exchange rate changes
Panel A: Parameter estimation				
Mean equation				
	$\alpha_{S,0}$	0.8773*** (4.24)	$\alpha_{E,0}$	-0.4334*** (-4.52)
	$\alpha_{S,1}$	0.1746*** (4.1)	$\alpha_{S,1}$	0.0464** (2.37)
	$\alpha_{E,1}$	0.0047 (0.09)	$\alpha_{E,1}$	0.2443** (6.37)
Variance equation				
	$c_{S,0}$	3.1287*** (9.67)	$c_{E,0}$	0.2543** (2.22)
GARCH effect	$\sum_{j=1}^{p_S} b_{S,j}$	0.5177*** (5.69)	$\sum_{j=1}^{p_E} b_{E,j}$	0.8930*** (56.52)
ARCH effect	$\delta_{S,S}$	0.4561*** (5.36)	$\delta_{E,E}$	0.2788*** (4.68)
Asymmetric effect	$\theta_{S,S}$	-0.6637*** (-5.29)	$\theta_{E,E}$	0.4998*** (8.08)
Shock spillover		-0.2805*** (-3.38)		0.04* (1.75)
Volatility spillover	$\delta_{S,E}$	0.0725 (1.48)	$\delta_{E,S}$	0.0019 (0.08)
Asymmetric spillover	$\theta_{S,E}$	0.2657* (1.87)	$\theta_{E,S}$	0.0504* (1.87)
Half life		1.05		6.13
Relative asymmetry		4.94		0.33
$\rho_{S,E}$		0.1398***		
Panel B: Model diagnostic test				
Ljung-Box Q(5) statistics				
$z_S \cdot z_E$		11.84		

Note: *, **, *** indicate a rejection at 10%, 5% and 1% significance level.

The numbers in parentheses indicate t-statistics. Half-life represents the time it takes for the shocks to reduce its impact by one-half: $HL = \frac{\ln(0.5)}{\ln(\sum_{j=1}^{p_S} b_{k,j})}$ where $k = S$ or E. Relative asymmetry = $\frac{|-1+\delta_k|}{(1+\delta_k)}$ and may be greater than, equal to or less than 1 indicating negative asymmetry, symmetry, and positive asymmetry, respectively.

LB(5) and $LB^2(5)$ are the Ljung-Box statistics (of order 5) applied to the cross-correlation. Lag length of 5 is sufficient as it is unlikely that a relationship will only be apparent when longer lags are used (Estima, 2021).

Table 4: Total impact of innovations on volatility in the markets

Total impact of Innovations in the Stock Market on Volatility in the Exchange Rate Market	
Innovations	Percentage change in Volatility of Exchange Market
+1% in Stock Market	0.001996
-1% in Stock Market	0.001804
Total impact of Innovations in the Exchange Rate Market on Volatility in the Stock Market	
Innovations	Percentage change in Volatility of Stock Market
+1% in Exchange Market	0.091763
-1% in Exchange Market	0.055072

Note: Entries represent the total impact of innovations in one market on the volatility in the other market, which is defined as $\delta_{i,j}(1 + \theta_{i,j})$ for a positive 1% innovation and $\delta_{i,j}|-1 + \theta_{i,j}|$ for a negative 1% innovation.

Table 5: Bivariate EGARCH model for volatility spillovers between stock returns and exchange rate changes in South Africa during COVID-19 from 2020:03–2021:08

		Stock returns		**Exchange rate changes**
Panel A: Parameter estimation				
Mean equation				
	$\alpha_{S,0}$	-0.6476***	$\alpha_{E,0}$	-1.4018***
		(-18.5)		(-1955)
	$\alpha_{S,1}$	0.3115***	$\alpha_{S,1}$	0.3884***
		(56.21)		(8289)
	$\alpha_{E,1}$	0.1559***	$\alpha_{E,1}$	0.2202***
		(42)		(3049)
Variance equation				
	$c_{S,0}$	-0.2263***	$c_{E,0}$	0.1911***
		(-13.87)		(13.81)
GARCH effect	$\sum_{j=1}^{p_S} b_{S,j}$	0.1***	$\sum_{j=1}^{p_E} b_{E,j}$	0.2709***
		(25.94)		(57.42)
ARCH effect	$\delta_{S,S}$	0.0325***	$\delta_{E,E}$	-0.8423***
		(30.81)		(-12.56)
Asymmetric effect	$\theta_{S,S}$	-2.9253***	$\theta_{E,E}$	-2.7295***
		(5.58)		(-6.13)
Shock spillover		-0.0154		-0.0267***
		(-0.22)		(-30.56)
Volatility spillover	$\delta_{S,E}$	-0.0844***	$\delta_{E,S}$	-0.3209***
		(-26.04)		(-59.5)
Asymmetric spillover	$\theta_{S,E}$	1.4243***	$\theta_{E,S}$	-2.7319***
		(8.22)		(-5.58)
Half life		0.3		0.53
Relative asymmetry		-2.0388		-2.1564
$\rho_{S,E}$		0.4352***		
Panel B: Model diagnostic test				
Ljung-Box Q(5) statistics				
$z_S \cdot z_E$		44.978		

Note: *, **, *** indicate a rejection at 10%, 5% and 1% significance level. The numbers in parentheses indicate t-statistics. Half-life represents the time it takes for the shocks to reduce its impact by one-half: $HL = \frac{\ln(0.5)}{\ln(\sum_{j=1}^{p_S} b_{k,j})}$ where $k = S$ or E.

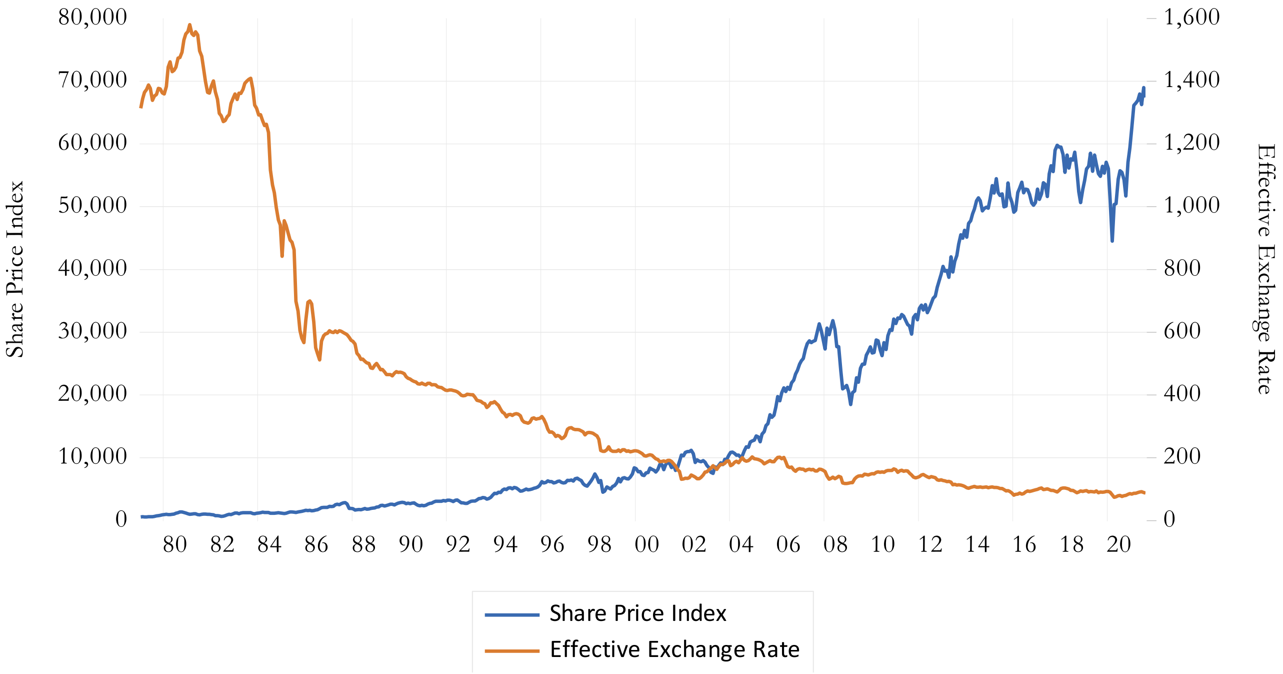
Relative asymmetry considers the impact of a market's own innovation on the current conditional variance and may be greater than, equal to or less than 1 indicating negative asymmetry, symmetry and positive asymmetry, respectively. LB(5) and $LB^2(5)$ are the Ljung-Box statistics (of order 5) applied to the cross-correlation. Lag length of 5 is sufficient as it is unlikely that a relationship will only be apparent when longer lags are used (Estima, 2021).

Table 6: Total impact of innovations on volatility in the markets

Total impact of innovations in the stock market on volatility in the exchange market	
Innovations	Percentage change in volatility of exchange market
+1% in stock market	0.555767
-1% in stock market	-1.197567
Total impact of innovations in the exchange market on volatility in the stock market	
Innovations	Percentage change in volatility of stock market
+1% in exchange market	-0.204611
-1% in exchange market	-0.035811

Note: Entries represent the total impact of innovations in one market on the volatility in the other market, which is defined as $\delta_{i,j}(1 + \theta_{i,j})$ for a positive 1% innovation and $\delta_{i,j}|-1 + \theta_{i,j}|$ for a negative 1% innovation.

Figure 1: Share Price Index and Effective Exchange Rate for South Africa 1979:01 – 2021:08



Source: Bloomberg, SARB and author's own calculations

APPENDIX

Table A1: Bivariate EGARCH model for volatility spillovers between stock returns and exchange rate changes in South Africa during the East-Asian Financial crisis (1997:07-1998:12)[1] and Global Financial Crisis (2007:08-2009:03)[2]

		East-Asian Financial Crisis				**Global Financial Crisis**		
		Stock returns		Exchange rate changes		Stock returns		Exchange rate changes
Panel A: Parameter estimation								
Mean equation								
	$\alpha_{S,0}$	2.067***	$\alpha_{E,0}$	-0.196***	$\alpha_{S,0}$	-2.284***	$\alpha_{E,0}$	-0.439***
	$\alpha_{S,1}$	0.041***	$\alpha_{S,1}$	-0.056***	$\alpha_{S,1}$	0.595***	$\alpha_{S,1}$	0.672***
	$\alpha_{E,1}$	2.183***	$\alpha_{E,1}$	0.148***	$\alpha_{E,1}$	-0.735***	$\alpha_{E,1}$	-0.549***
Variance equation								
	$c_{S,0}$	0.000	$c_{E,0}$	0.000	$c_{S,0}$	4.027***	$c_{E,0}$	-2.576***
GARCH effect	$\sum_{j=1}^{ps} b_{S,j}$	0.009***	$\sum_{j=1}^{pE} b_{E,j}$	0.001***	$\sum_{j=1}^{ps} b_{S,j}$	0.239***	$\sum_{j=1}^{pE} b_{E,j}$	0.196***
ARCH effect	$\delta_{S,S}$	1.101***	$\delta_{E,E}$	-1.408***	$\delta_{S,S}$	0.954***	$\delta_{E,E}$	-0.521***
Asymmetric effect	$\theta_{S,S}$	1.188***	$\theta_{E,E}$	-0.008***	$\theta_{S,S}$	0.363***	$\theta_{E,E}$	-0.153***
Volatility spillover	$\delta_{S,E}$	0.511***	$\delta_{E,S}$	-0.001***	$\delta_{S,E}$	-0.307***	$\delta_{E,S}$	-0.153***
Asymmetric spillover	$\theta_{S,E}$	-0.322***	$\theta_{E,S}$	0.441***	$\theta_{S,E}$	-0.124***	$\theta_{E,S}$	0.184***
Half life		0.148		0.102		0.484		0.425
Relative asymmetry		0.0859		1.0161		0.4674		1.3597
$\rho_{S,E}$		0.3208***				0.4067***		
Panel B: Model diagnostic test								
Ljung-Box Q(20) statistics								
$z_S \cdot z_E$		778.74				419.08		

Note: *, **, *** indicate a rejection at 10%, 5% and 1% critical level.

Half-life represents the time it takes for the shocks to reduce its impact by one-half: $HL = \frac{\ln(0.5)}{\ln(\sum_{j=1}^{ps} b_{k,j})}$ where $k = S$ or E.

Relative asymmetry $= \frac{|-1+\delta_k|}{(1+\delta_k)}$ and may be greater than, equal to or less than 1 indicating negative asymmetry, symmetry, and positive asymmetry, respectively.

LB(5) and $LB^2(5)$ are the Ljung-Box statistics (of order 5) applied to cross-correlation. Lag length of 5 is sufficient as it is unlikely that a relationship will only be apparent when longer lags are used (Estima, 2021).

[1] Dates in-line with Bonga-Bonga and Hoveni (2013).

[2] Dates in-line with Mozumder *et al.* (2015).

Figure A1: Standardised Residuals from Bivariate EGARCH Estimation 1979:01 – 2021:08

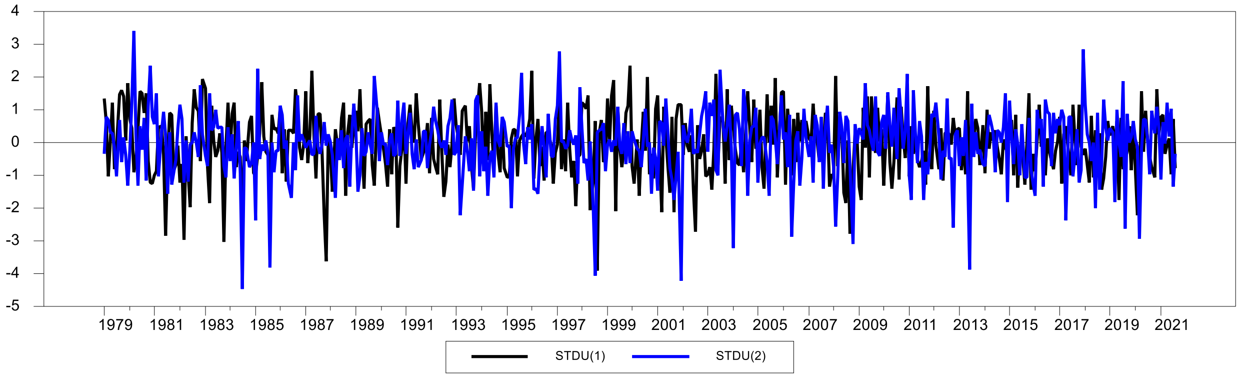


Figure A2: Standardised Residuals from Bivariate EGARCH Estimation during COVID-19 pandemic 2020:03 – 2021:08