Flavin, Thomas; Sheenan, Lisa

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Thomas Flavin
Maynooth University

Lisa Sheenan
Queen's University Belfast

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Can Green Bonds be a Safe Haven for Equity Investors?

Thomas Flavin

Maynooth University

thomas.flavin@mu.ie

Lisa Sheenan

Queen's University
Belfast

l.sheenan@qub.ac.uk

Abstract

We investigate if green bonds can act as a safe-haven asset for equity investors by analysing their relationship with stocks and other alternative safe havens, namely sovereign bonds and gold. Safe havens are defined as assets that exhibit zero or negative comovement with equity during a stock market downturn. We analyse the interrelationships between the asset classes using the Marginal Expected Shortfall of Acharya et al. (2017) and by comparing the regime-dependent GIRFs from a Markov-switching VAR model. Our results suggest that green bonds are not safe haven assets for equity investors but rather show positive comovement during periods of market stress. The sovereign bond is the most consistent in delivering diversification benefits across market conditions, while gold acts as a safe-haven asset during all regimes except during rare periods of extreme turbulence.

Keywords: *Green bonds; Contagion; Financial crisis; Markov-switching VAR.*
JEL Classification Codes: *C15, C34, Q56s*

I. Introduction

Green bonds, described by the International Capital Markets Association (ICMA) as bonds that 'enable capital-raising and investment for new and existing projects with environmental benefits', are a relatively new debt instrument. They share many characteristics with conventional bonds, both sovereign and corporate, but differ in one important aspect. The issuer of a green bond commits to use its proceeds to fund projects that are deemed to be environmentally friendly, to promote sustainable business practices or to be socially responsible. Throughout the 1990s and 2000s, these issues have grown in importance, with the Kyoto Protocol of 2005 (a treaty signed by the governments of 192 countries) on climate change demonstrating an international consensus among policymakers on the need to address this problem. Furthermore, an increasing number of extreme weather events and growing evidence of global warming has resulted in amplified media coverage of climate issues (see the Media Climate Change Concerns index of Ardia et al., 2022), which in turn has intensified public and investor awareness of the need to cut carbon emissions and other associated climate policies (Pastor et al., 2022). As attention to climate change increased the spotlight turned to the role that financial markets could play in helping to tackle the issue. In November 2008 the World Bank issued the first green bond. Since 2015, 26 stock exchanges around the world have launched segments dedicated to green bonds and this market has enjoyed rapid growth in recent years as investor demand for green assets increased (Pastor et al., 2021). For example, Descombes et al. (2022) report that green bond issuance has increased from about €2 billion in 2013 to over €460 billion (or $522 billion) in 2021, with the latter figure representing about 5% of all global bond issuance in that year. By 2021, the green bond market value stood at $1.6tn, with over 800 issuers distributed across 58 countries and 33 currencies, (Climate Bonds Initiative, 2022).

The emergence of green bonds has spawned a voluminous academic literature focusing on various aspects of this asset class, such as its pricing and its relationships with other assets. In this paper, we focus on green bonds and their potential safe haven properties. While green bonds may have been initially aimed at investors with a focus on Environmental, Social and Governance (ESG) matters, it may be that they can also be an attractive investment for more conventional

investors, whose sole focus is on economic benefits, and this is the focus of our study. In particular, we analyse if green bonds can act as a safe haven for equity investors during episodes of high volatility in financial markets. Following Baur and Lucey (2010) and Flavin et al. (2014) among others, we define a safe haven asset as one which exhibits zero or negative correlation with another asset class during market downturns. Safe haven assets should deliver diversification benefits during periods of market turbulence. The extant literature has already identified sovereign bonds (Connolly et al., 2005; Chan et al., 2011; Flavin et al., 2014; among others) and gold (Baur and Lucey, 2010; Baur and McDermott, 2010; Flavin et al., 2014; among others) as assets that deliver such protection for equity investors.

We hypothesize that green bonds may also display safe haven properties for a number of reasons. Firstly, as uncertainty over climate change and its consequences for the economy grows, a number of papers have shown that climate and carbon risks are significantly priced in financial markets and should be included as a systematic pricing factor, see Bolton and Kacperczyk (2021), Engle et al. (2020), Krueger et al. (2020) and Hsu et al. (2023) among others. Green bonds are designed to offset these types of risk, thereby making them a potentially natural safe haven asset for equities. Secondly, there is evidence that green bond prices are not only driven by economic factors but also by ESG factors. This implies that investors derive utility from these additional factors and the environmental improvements that green bonds strive to deliver. MacAskill et al. (2018) present a review of the literature on the existence of a 'greenium' (i.e. a premium paid to hold green bonds) and conclude that such a premium exists and is driven by social and environmental factors.[1] They find that this 'greenium' is more pronounced in the secondary bond market as investors compete to hold green assets. The pricing of these factors confirms the importance of non-economic benefits to investors in this asset class.

Hence, green bonds may prove to be more resilient during a crisis as investors may be more likely to resist the pressure to divest, thus (partially) insulating this asset class from market turbulence. Reboredo (2018) finds that there are few diversification benefits from holding green

[1] There are some notable exceptions to this finding. Both Larcker and Watts (2020) and Flammer (2021) in their respective studies of green municipal bonds and green corporate bonds, find no evidence of such a greenium

bonds as part of a bond portfolio but finds substantial diversification benefits for stock market investors. This is based on a relatively short sample, covering mainly bullish markets and we are interested to see if green bonds can deliver these benefits across different market regimes, particularly when most needed during a stock market downturn. Similarly, Ferrar et al. (2021) find that green bonds are strongly connected to sovereign and high credit quality corporate bonds but do not exhibit the same strong comovement with the stock market. Since sovereign bonds have already been shown to provide safe haven asset characteristics it is possible that green bonds will also deliver these benefits. Thirdly, Pastor et al. (2021), provide a theoretical framework to show that higher prices (and hence lower returns) for green bonds, compared to conventional bonds, can be sustained in equilibrium as long as investors have a preference for such assets. Again, this may potentially lead to longer-term holdings of green bonds and less price volatility in a crisis period.

We analyse the efficacy of green bonds as safe haven assets for equity investors using two distinct but complementary methods. Firstly, we compute the Marginal Expected Shortfall (MES), as a measure of tail dependence, which reveals that on average over the entire sample, when the equity market is experiencing a left-tail event, green bonds also suffer negative returns. Secondly, we jointly model the returns on equities, green bonds and two other potential safe haven assets, long-term sovereign bonds and gold, using a Markov-switching VAR (MS-VAR). An analysis of the regime-dependent Generalized Impulse Response Functions (GIRFs) allows us to study the dynamic relationships between these four asset classes across different market conditions. Following Dungey et al. (2020), we differentiate between interdependence, contagion and decoupling as markets transition from the normal (tranquil) regime to high-volatility crises regimes. Interdependence refers to the situation where pairs of assets have stable linkages across regimes; contagion occurs when assets exhibit stronger co-movement during crisis periods and thus reduce or eliminate diversification benefits; while decoupling implies that assets have lower levels of co-movement in crisis periods and thus deliver greater than anticipated diversification benefits. Our analysis shows that the relationship between equities and green bonds suffers from contagion during periods of high market volatility, thereby failing to deliver diversification benefits when most needed and not meeting our definition of a safe-haven asset.

The remainder of the paper is organised as follows. Section 2 describes the data, outlines our econometric methodology and discusses our model specification, Section 3 reports and discusses our results. Finally, Section 4 contains our concluding remarks.

II. Literature

There is a burgeoning literature examining green bonds. Here we limit ourselves to a review of the research concerning the relationships between green bonds and other asset classes, most notably equity, sovereign bonds and commodities which are also the focus of our analyses. In particular, we examine the stability of relationships and look for evidence of contagion and spillovers from, and to, the green bond market. We discuss this in the context of potential diversifying features of these bonds.

Turning first to the equity - green bond relationship the evidence concerning the diversification benefits for an equity investor of holding green bonds is mixed. On one hand, Reboredo (2018) reports substantial diversification benefits in terms of risk reduction from including green bonds in an equity portfolio. Similarly, Arif et al. (2021) focus on the hedging effectiveness of green bonds during the COVID-19 pandemic period, finding that green bonds could act as a diversifier asset for medium- and long-term equity investors. Han and Li (2022) report that portfolios with green bonds outperform portfolios with traditional bonds in both the USA and Europe. Park et al. (2020) analyse equity and green bond markets between 2010 and 2020, finding that although the two markets display some volatility spillover effects, neither responds significantly to negative shocks in the other, while Ferrer et al. (2021) report limited connectedness between equity and green bond markets. Kuang (2021) finds that both green bonds and clean energy stocks act as a diversifier for investors holding dirty energy but green bonds reduce risk while clean energy stocks generally increase the risk of equities between 2011 and 2020. Nguyen et al (2021) investigates the relationship between green bonds and stock, commodity, clean energy, and conventional bond markets between 2008 and 2019, finding strong diversification benefits from green bonds due to the low correlation displayed between these and both stocks and commodities. In contrast, Huynh et al. (2020) analyses the diversification benefits of various new asset classes including green bonds

between 2017 and 2020, finding that in periods of turbulence there is a high probability of simultaneous significant losses and so traditional safe assets such as gold should still be included in portfolios. Green bonds are found to be strong transmitters of shocks, particularly to equity markets. Dutta et al (2021) focus on the COVID-19 pandemic outbreak in early 2020, finding that climate bonds provide the largest reduction in risk in a portfolio comprising of US equities or gold as a part of a hedging strategy but this hedging effectiveness is considerably reduced during the pandemic period. Hung (2021) finds bidirectional connections between green bonds and stock markets, while Saeed et al (2020) find that clean energy stocks provide a more effective hedge than green bonds for energy exchange traded funds (ETF) and crude oil prices. Lin and Su (2022) show that green bonds are driven by financial uncertainty in the US (and economic uncertainty in China), making them more sensitive to financial market downturns and thus less likely to be effective safe-haven assets.

There is a greater consensus regarding the relationship between green bonds and sovereign bonds. In general, the literature finds strong connections between these asset classes with evidence of contagion and volatility spillovers during periods of market turbulence. Huynh (2020) analyses co-movements between green bonds and AAA-rated government bonds between December 2008 and November 2019 using a Copula approach and reports evidence of contagion between them. Ferrer et al (2021) investigate whether green bonds are in fact a different asset class compared to more traditional bonds. They find strong evidence of connectedness at shorter time frames, with the effects of shocks lasting around one week, and the strongest connectedness is observed between the global green bond market and the global Treasury and investment-grade corporate bond markets. Reboredo and Ugolini (2020) analyse price connectedness between the green bond and financial markets using a structural VAR model and identify close links between the green bond market and fixed income and currency markets. In particular, they show that the green bond market receives sizable spillover impacts from price changes in treasuries, while spillovers in the opposite direction are negligible. Thus, green bonds are a net spillover receiver. Similarly, Roboredo at al. (2020) find strong connectedness between green bonds and treasury and corporate bonds in the short- and long-run for both the EU and the USA between 2014 and 2018, with green bonds receiving sizeable spillovers from treasury and corporate bond prices and transmitting

negligible effects. Pham (2016) finds evidence for time-varying volatility spillover among the green bond market and the conventional bond market between 2010 and 2015. Hammoudeh et al (2020) analyse the time-varying causal relationship between green bonds and other assets between mid-2014 to February 2020, finding significant causality from the US 10-year Treasury bond index to green bonds from end-2016 until the end of the sample period. Focusing on the Chinese market, Gao et al (2021) find significant two-way risk spillovers between the green bond market and traditional bond markets in China from 2015 to 2020.

Naeem et al. (2021) study the relationship between green bonds and commodities, including precious metals such as gold and silver. They find evidence of asymmetric connectedness between green bonds and commodities but crucially conclude that green bonds do not hedge risk in gold, a traditional safe haven asset. In contrast, Dutta et al. (2021) finds that green bonds provided an effective hedge against gold price risk during the Covid-19 pandemic.

III. Data and Econometric Methodology

III.1 Data

We use daily data on four asset classes over the time period January 1, 2012 to December 30, 2022. This is the longest sample possible for the green bond, which is a relatively new asset class compared to the others. We use the S&P 500 index to represent the U.S. stock market; a 10-year sovereign bond to capture the government debt market; the US dollar price of gold; and the S&P Dow Jones Green Bond Index. This index has been used in previous studies such as Reboredo (2018), Arif et al. (2021) and Naeem et al. (2021) among others as a proxy for the green bond market.[2] The index is a market-value weighted index of all globally issued green bonds.[3] Since it contains both government and corporate bonds this allows us to assess if there is something inherently different about being green. Table 1 presents summary statistics for the daily log returns on these assets over the sample.

[2] Reboredo (2018) shows that this index has similar dynamics and has almost a correlation of unity with other green bond indices.

[3] To be included in the index, a bond must meet the 'green' criteria set out by the Climate Bonds Initiative. Full details of the methodology used to construct the index can be found at https://www.spglobal.com/spdji/en/documents/methodologies/methodology-sp-green-bond-indices.pdf

[Insert Table 1 about here]

All assets except the green bond exhibit positive daily returns over the 11-year period. Equity returns are an order of magnitude greater than the other assets but also are the most risky, as evidenced by their standard deviation. Green bonds have a small negative daily return and also are the least risky. Gold has a mean return that is approximately double that of the sovereign bond but it is also twice as risky, resulting in both assets delivering roughly equal risk-adjusted returns. All assets are negatively skewed, particularly so for equity and gold, implying a longer left tail for all return distributions. All assets exhibit fat tails, implying that extreme events occur more frequently than implied by a normal distribution. Such events are more likely for equity markets. Overall, the high levels of skewness and kurtosis show that these returns are not normally distributed and modelling them in a single regime setting is unlikely to be an adequate representation of their behaviour. It provides a motivation for adopting a regime-switching approach as described below.

III.2 The econometric methodology

To identify safe haven assets, we employ two complementary methodologies, namely MES and a Markov-switching VAR model. The former requires that the crisis period is exogenously defined, while the latter endogenously identifies the crisis or crises from the data. Firstly, we compute MES to answer the question, what happens to the returns in market *j* when the return of market *i* is in its left-hand tail, i.e. having a historically bad day? This methodology, proposed by Acharya et al. (2017), is usually applied as a measure of systemic risk but is also suitable for identifying safe haven assets as it captures the cross market vulnerability to shocks emanating from market *i*. We define two tail event, to identify an equity market crisis, as realised equity returns that are in the lower 5% and 1% tail of their distribution. The MES of asset *j* is computed as:

$$MES_{j,x\%} = \frac{1}{No.of\ Bad\ Days} \sum r_j. \quad (1)$$

where x is either 5% and 1%, No. of Bad Days represents the number of days in which the market experienced a tail event and r_j is the return on asset j on those days.

We also utilise the methodology of Dungey et al. (2020), who use a Markov-switching VAR model to analyze regime-dependent generalized impulse response functions (GIRFs) to detect if cross-asset responses to a given shock are consistent with market interdependence, contagion or decoupling. This complements the MES measure and also allows us to assess the dynamics of the shock transmission between the specified markets.

The econometric model is specified as:

$$y_{i,t} = \alpha(s_t) + \sum_{k=1}^{K} \beta_k\,(s_t) y_{i,t-k} + \varepsilon_{i.t}^{st},$$

$$s_t \epsilon \{1,2,3\}, \tag{2}$$

$$\varepsilon_{i.t}^{st} \sim i.i.d.N(0, \sigma_s^2),$$

where $y_{i,t}$ is an n dimensional time series vector of dependent variables, α is a matrix of state dependent intercepts, . . . β_k are matrices of the state dependent autoregressive coefficients and capture the relationships between our variables, and $\varepsilon_{i.t}^{st}$ is a state dependent noise vector, which has a zero mean and constant variance within each regime. s_t is an unobserved random variable that signals the switch from regime to another. Since the true regime cannot be observed, we must specify the paths by which the regimes transit from one to another. We assume s_t follows a first-order Markov process in which the current regime, s_t relies only on the regime one period in the past, $s_t - 1$.

The model is estimated using a Bayesian Markov-chain Monte Carlo (MCMC) approach. We first specify the prior distributions for the parameters. For the variances, we employ a Wishart distribution, the VAR coefficients have a flat prior and we use a weak Dirichlet prior for the transitions, with a preference towards remaining in the same state. Using Gibbs sampling, we estimate the parameters and regimes in the following sequence:

Step 1: We draw the sigmas, given the mean coefficients and regimes.

Step 2: We draw the mean coefficients (α and β) given sigmas and regimes.

Step 3: We draw the regimes, given the sigmas and mean coefficients.

Step 4: We draw the transition parameters.

This sequence of steps is repeated 10, 000 times after discarding an initial burn-in set of 2, 000

replications. Once we have obtained our estimated parameters, we generate the regime-dependent GIRFs (see Ehrmann et al., 2003) and their associated confidence bands to analyse the safe haven characteristics of the various assets. Ideally, a safe haven asset should respond negatively (i.e. in the opposite direction) or be unresponsive to a shock in another market, during the high-volatility regime(s). This type of decoupling provides diversification benefits when most needed. On the other hand, assets that increase their comovement with the source of the shock are said to suffer from contagion and do not act as hedging instruments during crisis episodes.

IV. Discussion of Results

We begin our analysis by computing the MES for the 10-year sovereign bond, the green bond and gold with respect to the equity market. Though not a statistical test, it provides insight regarding the hedging ability of these assets against equity market shocks. The MES of the asset class is its average return on the days in which the equity market experiences an adverse shock that occurs in the q% tail of its return distribution. MES is calculated for two values of q, namely 5% and 1%, when the equity market return is $\leq$ -1.60% (realised on 144 days) and $\leq$ -3.10% (realised on 29 days) respectively. The results are presented in Table 2.

[Insert Table 2 about here]

We find that on the days in which the equity market experiences a 5% tail event, the average returns for the 10-year sovereign bond and gold are positive, with the former delivering a much more positive return than the latter (0.29% versus 0.05%). In contrast, the green bond return is small but negative, suggesting that it moves in the same direction as the equity market on these 'bad' days for the equity market. Focusing on the 1% tail and thus the subset of more extreme adverse shocks, our results reveal an interesting insight. The sovereign bond return remains positive and is, in fact, it more positive than before. Gold's MES, on the other hand, becomes negative and its average return on these days is -0.13%. The return on the green bond is still negative and larger in magnitude than for the 5% tail event. Figure 1 provides more insight into the differences in the MES of these potential safe haven assets. It presents the daily returns on each

asset on the days in which the equity market experiences a 5% tail event. With a small number of exceptions, the sovereign bond consistently generates positive returns, as an equity investor would require from a safe haven asset. Gold is more volatile than the other asset classes, with larger returns of both positive and negative sign, while the green bond return on these days is generally small in magnitude but predominately negative. This preliminary analysis points to the sovereign bond as the asset that most consistently delivers safe haven attributes in the face of an equity market downturn.

[Insert Figure 1 about here]

Next we turn to the Markov-switching VAR model to provide a statistical analysis of the relationships between these assets across different market conditions. Our sample period coincides with great turbulence in financial markets and we find that a 3-regime specification best describes the data, with the two distinct regimes required to capture the crises that occurred across this period.[4] The model is estimated and three regimes are identified from the time-varying asset volatilities, labelled as Normal (low-volatility), Crisis (high-volatility) and Intense (intense-volatility). Figure 2 plots the smoothed probabilities of each regime. Our sample starts in a crisis regime, with global financial markets feeling the effects of the Euro zone sovereign debt crisis and global banks still recovering from the credit and liquidity crises of 2007-08. For much of the sample, the system moves between crisis and normal periods as financial markets recovered but remained sensitive to events such as the US/China trade war, Brexit, and the commodity price crash of 2014, among others. The intense regime is only experienced on rare occasions, predominantly during the COVID-19 pandemic (see also Ghabri et al. (2022) who find that the pandemic served as a catalyst for contagious effects across financial markets), and in early 2022 when Russian forces invaded Ukraine, precipitating a period of global economic and financial uncertainty.

[Insert Figure 2 about here]

[4] Similarly, Cronin et al. (2016), Bird et al. (2017) and Dungey et al. (2021) model the Eurozone sovereign bond crisis in a three regime setting, with two regimes needed to characterise the crisis period.

We assess the stability of cross-asset relationships and the safe haven attributes of the assets by analysing the regime-specific GIRFs associated with a shock to each asset in the system. Since we are predominantly concerned with the safe haven properties of these assets from the perspective of an equity investor, we begin with the impulse response functions associated with a shock to equity returns, depicted in Figure 3. The figure is divided into panels with the rows referring to an asset class and the columns indicating the regime. Each panel shows the IRF for the given asset and regime with its 95% confidence bands and the scale is the same across regimes (columns) but differs across assets (rows).

[Insert Figure 3 about here]

The low-volatility, normal regime (column 1) serves as our benchmark case. These are the responses of each asset to an equity market shock during relatively tranquil periods when stock markets are enjoying bullish sentiment and shocks are generally positive. The contemporaneous response of all the potential safe haven assets is either negative (in the case of the sovereign bond) or not statistically different from zero (in the case of the green bond and gold). The dynamics of the response are short lived and in all cases die out within two days. In this regime, all of these assets display attributes consistent with being good risk diversifiers. However, it is during the crisis or high volatility periods when these diversification benefits are most required so we assess the stability of our results during these regimes to gauge the suitability of each asset as a safe haven. When we transition to a crisis period, with high volatility, this relationship remains stable for both the sovereign bond and gold. Both behave as in the low-volatility (Normal) regime and, by our definition, these relationships display interdependence between the low- and high-volatility regimes. In contrast, there is evidence of contagion from the equity market to green bonds. The response of the green bond to the equity shock becomes positive, i.e. it moves in the same direction as the equity market and is statistically significant. Given that these high-volatility shocks are most often adverse shocks, this is an undesirable feature of the green bond and inconsistent with a safe haven asset. This aligns with Lin and Su (2022) which identifies a left tail dependence between U.S. green bond returns and financial market uncertainty indicators, finding that green bond volatilities

may respond abnormally to extreme increasing changes in financial and economic uncertainties. During the intense-volatility regime, the responses are again different with all showing an increase in the life of the shock. More importantly, all assets show increased comovement with the equity market and therefore, exhibit contagious effects from it. However the strength and consequences of this contagion differs by asset. The sovereign bond continues to display a negative contemporaneous reaction to the equity market shock. Thus, its reaction to equity shocks remains steadfastly negative across all market conditions. The contagion has more serious implications for both the green bond and gold, with both having positive and statistically significant responses to the intense-volatility equity market shock. The green bond exhibits a particularly strong positive response which takes about five days to work through the system. In contrast, while the contemporaneous reaction of gold is positive, the effect becomes statistically indistinguishable from zero within one day, so it is short-lived.

Taking a holistic view of the analysis it highlights the importance of taking market conditions into account as there is significant time variation in the cross-asset relationships, which is particularly strong in the case of equity and the green bond. Treating any sample as a homogeneous time period could give rise to misleading conclusions regarding the strength of their linkages. Overall, it appears that the sovereign bond is the only reliable safe haven asset across all regimes. Gold is a reasonably good diversifier of equity market risk but tends to be positively associated during extreme market downturns. The green bond, on the other hand, fails to exhibit safe haven attributes in both crises regimes and is thus not a good asset to include in an equity portfolio to hedge against bad shocks. There is no evidence to suggest that their prices may be more robust during downturns due to their holders having a more long-term perspective. Overall, the picture painted by these GIRFs is consistent with the conclusions derived from the MES analysis of Table 2 and Figure 1.

We next turn our attention to the cross-market transmission of shocks that emanate from the potential safe haven assets. Even though an equity investor might include these assets in their portfolio to diversify their risk, their inclusion exposes the investor to shocks hitting these markets, so it is insightful to ascertain if these shocks generate contagion or spillovers to the equity market. We begin with the green bond with the associated IRFs displayed in Figure 4.

[Insert Figure 4 about here]

In the benchmark, low-volatility regime, the green bond shock elicits no response (not statistically different from zero) in the equity market but the reaction of equity turns positive in both the high- and intense-volatility regimes. Thus we find evidence of contagion from green bonds to equity during these crisis periods. Coupled with the earlier evidence of contagion from equity to green bonds (see Figure 3), we conclude that there are bi-directional contagious effects between the two asset classes during turbulent periods, which further undermines the suitability of the green bond as a safe haven asset for equity investors. For both the sovereign bond and gold, the relationship with the green bond is consistently positive across all market conditions. In the intense regime, the shock persists for a few days longer but there is no evidence that these assets can hedge risk in the green bond market. This is consistent with the finding that the sovereign bonds, green bonds and corporate bonds do not hedge each other's risk and, in fact, share similar attributes (see Reboredo and Ugolini, 2020; Arif et al., 2021, among others).

Next we focus on the sovereign bond which, in our analysis of the propagation of equity market shocks, was identified as the asset which delivered safe haven properties most consistently across all market conditions. Figure 5 plots the IRFs in response to a shock that comes from the sovereign bond market.

[Insert Figure 5 about here]

Figure 5 reinforces the case for the sovereign bond as a safe haven for equity investors. The response of equities to a shock emanating from the government bond market is always negative across regimes. Irrespective of the source of the shock or the market condition, these assets deliver diversification benefits for the other and therefore the inclusion of both equities and sovereign bonds in a portfolio will help to reduce asset price risk. Likewise, a consistent story emerges for the transmission of the sovereign bond shock to the other potential safe haven assets. Both green bonds and gold react positively (same direction) to shocks in the sovereign bond market in all regimes. While these cross-market linkages are stable there are limited benefits from including all in a portfolio.

Finally, we complete the picture, we analyse the cross-asset responses to a shock in the gold

market. Figure 6 presents the IRFs. We find that the linkages identified between gold and the other assets are largely bi-directional. For example, equity price movements are independent of gold shocks in both the low-volatility and high-volatility regimes. Thus, equity and gold form a well-diversified portfolio during these episodes but, once more, the intense regime evokes a different response, with the equity market recording a positive reaction to gold shocks and, thereby, reducing diversification benefits during these infrequent but severe market episodes. This is consistent with Mujtaba et al. (2023) who show that commodities, including precious metals, are weak safe haven assets for all sectors of the U.S. and Chinese stock markets. The bonds, both sovereign and green, react positively to gold price shocks, showing positive correlation, across all regimes.

[Insert Figure 6 about here]

V. Conclusion

Safe haven assets are much sought after. The extant literature has identified sovereign bonds and gold as assets that deliver safe haven characteristics for equity market investors, i.e. they that exhibit zero or negative comovement with equity during a stock market downturn. With high-quality sovereign bonds being in limited supply, we investigate if green bonds can also fulfill such a role. A priori, there are reasons to believe that green bonds may be more robust than other more traditional asset classes in the face of market turbulence since investors value the non-economic benefits that they deliver and thus may be less likely to divest these assets during a crisis.

We study the cross-market linkages of equity, green bonds, a 10-year sovereign bond and gold across different market conditions to analyse the safe haven properties of the green bond from the perspective of an equity investor. Capturing the time variation in these linkages is crucial, since asset co-movements are found to vary substantially across different states of the world. We assess the stability of all pairwise cross-market relationships to investigate if shocks in a source market generate contagion, interdependence or decoupling in another asset class. We use two distinct, but complementary, methodologies to address the issue and we obtain a consistent answer. Green bonds do not act as a safe haven for equity investors during episodes of heightened financial

market volatility. Our MES computation shows that on average green bond returns are negative on the days when the stock market is suffering an extreme bad day, measured as either a 5% or 1% tail event. The MS-VAR framework confirms the unsuitability of the green bond as a safe haven asset for equity investors. It provides evidence of bi-directional contagion between the two assets, implying that negative shocks in either market generate a similarly signed response in the other market. Focusing on relationships between green bonds and the other assets, we find that responses to a shock in any of these markets elicits a positive response (movement in the same direction) in the other assets across all market conditions. This confirms findings in previous literature that green bonds have poor ability to diversify sovereign bond or gold risk.

The sovereign bond, in contrast, consistently delivers diversification benefits for an equity portfolio across all market conditions. It typically moves against the stock market during crisis periods. In fact, the MES analysis suggests that the returns on sovereign bonds are larger on days when equity market shocks are more negative. Likewise, there is no contagion from sovereign bond shocks to the equity market, meaning that these two assets diversify each other's risk. Gold displays safe haven properties during periods of high volatility but this diversification benefits let investors down during the rare periods of extreme volatility that marked the COVID-19 pandemic and the global economic tensions that followed Russia's decision to invade Ukraine.

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Table 1: Summary statistics

Variable	Observations	Mean	Std Deviation	Skewness	Kurtosis
S&P 500	2870	0.000410	0.0106	-0.5343	16.112
10-Year Sovereign Bond	2870	0.000045	0.0042	-0.0742	3.0254
Gold	2870	0.000096	0.0092	-0.4982	6.3836
Green Bond	2870	-0.000015	0.0036	-0.2163	4.9876

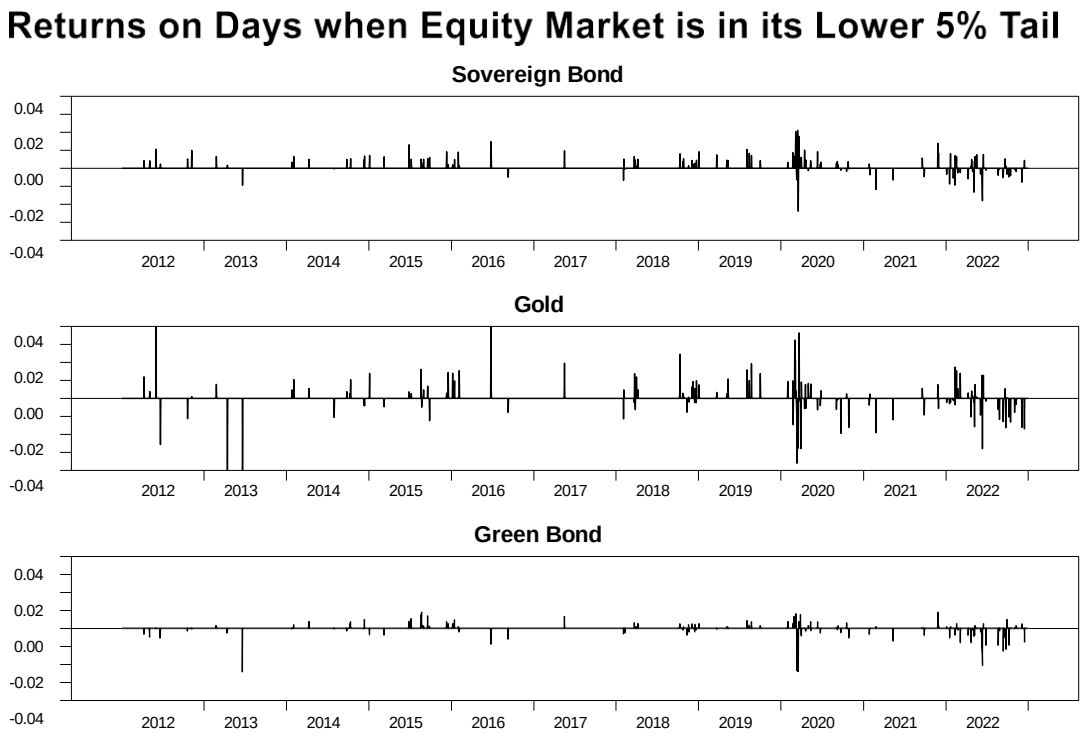
Notes: This table reports summary statistics for the daily log returns for the indicated variable. The sample runs from January 3, 2012, to December 30, 2022.

Table 2: MES for Potential Safe Havens

Asset	MES 5%	MES 1%
10-Year Sovereign Bond	0.00293	0.00313
Gold	0.00051	-0.00132
Green Bond	-0.00066	-0.00239

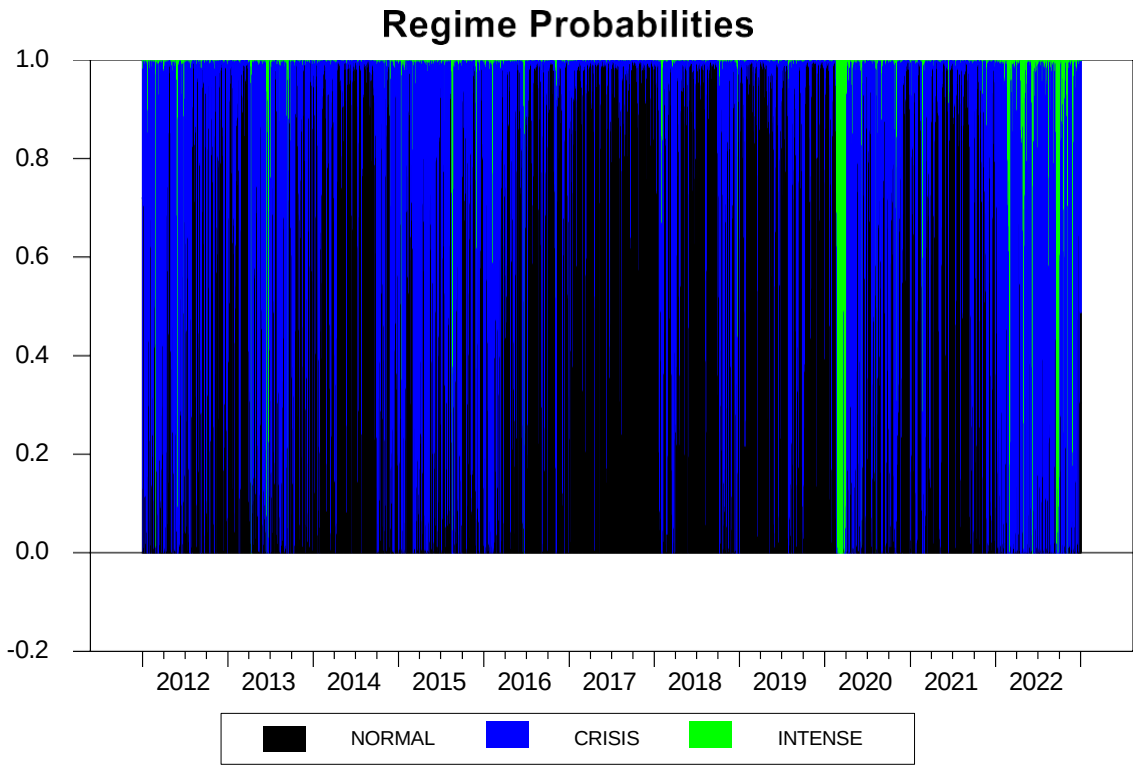
Notes: This table reports the Mean Expected Shortfalls (MES) for the denoted potential safe haven assets, i.e. their average return when the equity market is experiencing a tail event. For equity returns, a 5% tail event is a return of $\leq$ -1.60% and this occurred on 144 days during our sample. A 1% tail event is a return of $\leq$ 3.1% and occurred on 29 days of the sample.

Figure 1: Marginal Expected Shortfall (MES) Results



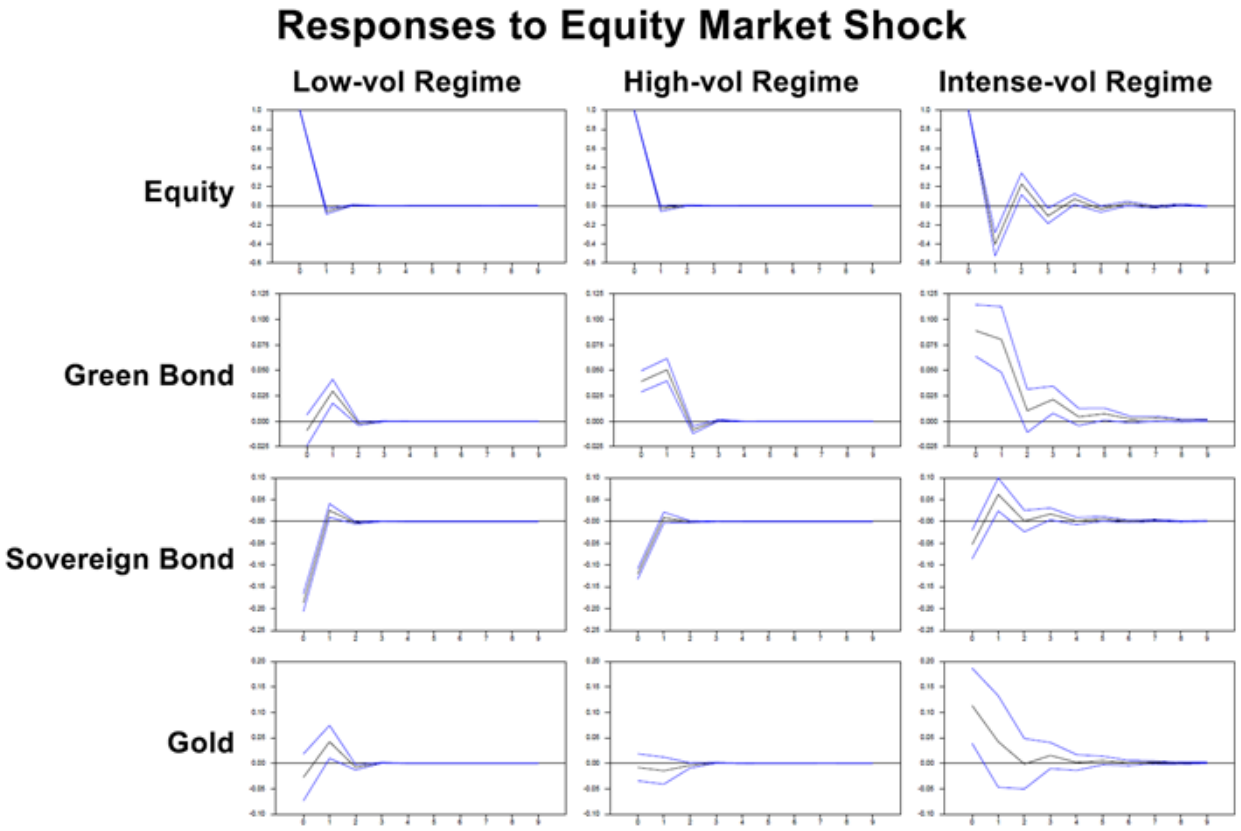
Notes: Figure 1 presents the returns on days when the equity market is in its lower 5% tail from 2012 to 2022.

Figure 2: MS-VAR Smoothed Probabilities



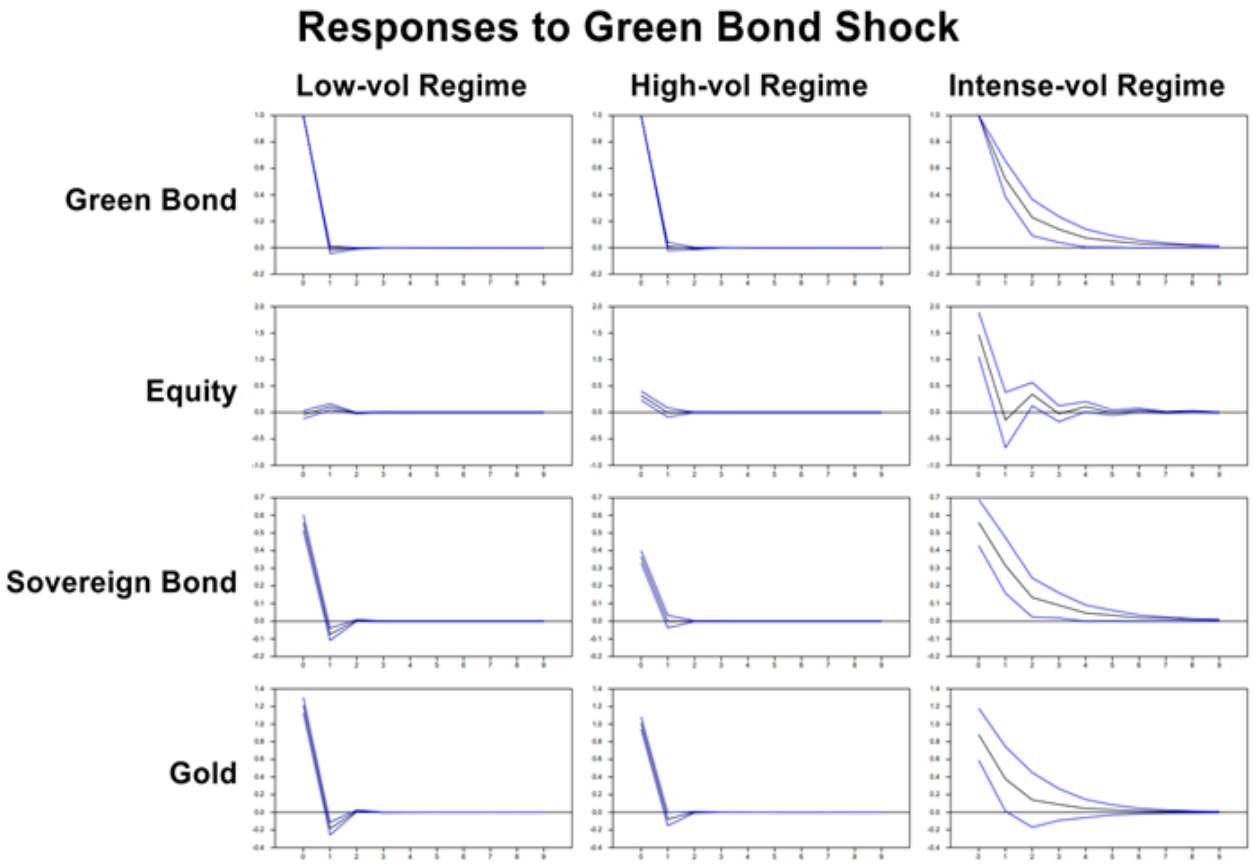
Notes: Figure 2 presents the smoothed probabilities of each regime extracted from the estimated MS-VAR model.

Figure 3: Regime Dependent Generalized Impulse Response Functions (GIRFs) I



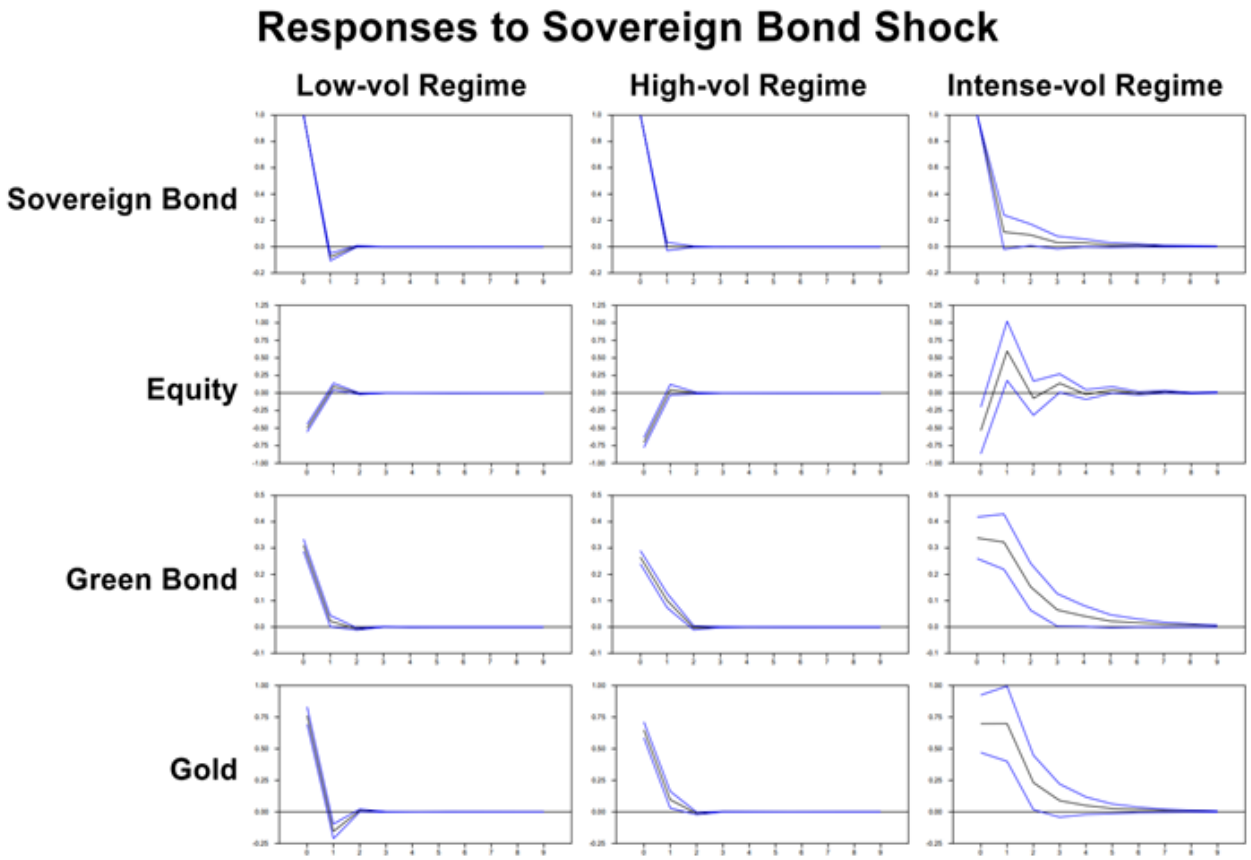
Notes: Figure 3 shows the response of each variable to an equity market shock in each regime. The black lines depict the IRF with the blue lines showing the 95% confidence intervals.

Figure 4: Regime Dependent Generalized Impulse Response Functions (GIRFs) II



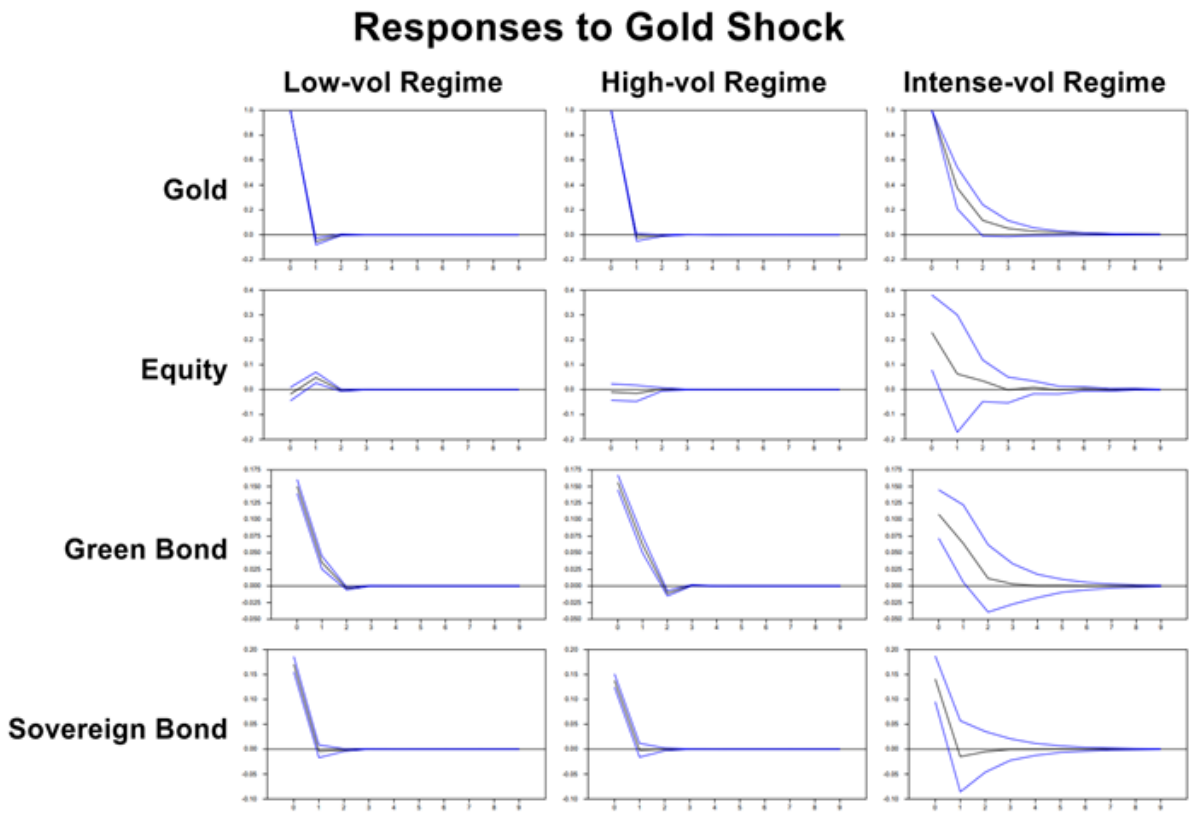
Notes: Figure 4 shows the response of each variable to a green bond market shock in each regime. The black lines depict the IRF with the blue lines showing the 95% confidence intervals.

Figure 5: Regime Dependent Generalized Impulse Response Functions (GIRFs) III



Notes: Figure 5 shows the response of each variable to a sovereign bond shock in each regime. The black lines depict the IRF with the blue lines showing the 95% confidence intervals.

Figure 6: Regime Dependent Generalized Impulse Response Functions (GIRFs) IV



Notes: Figure 6 shows the response of each variable to a gold market shock in each regime. The black lines depict the IRF with the blue lines showing the 95% confidence intervals.