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Drivers of China Green Bonds: An ARDL Analysis of Economic Policy Uncertainty, Financial Market Volatility, Exchange Rates, and Commodity Prices

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ABSTRACT

Understanding the impact of macroeconomic variables on China's green bond market is crucial for developing effective policies and strategies that promote sustainable finance. This study examines the influence of economic policy uncertainty, financial market volatility, exchange rates, and commodity prices on green bond prices in China in the long- and short term. Using the Autoregressive Distributed Lag (ARDL) model for monthly data spanning January 2019-December 2023, the study indicates that China's economic policy uncertainty significantly negatively impacts green bond prices in both the short and long term. In contrast, global financial market volatility and exchange rate have positive and significant long-term effects on green bonds, reinforcing their role as a stabilising asset during economic uncertainty. Meanwhile, nickel and copper prices negatively affect green bonds in the short term but show positive or neutral long-term effects. By contrast, oil prices positively impact green bonds in the short term, driven by heightened awareness of energy transition needs, but their influence diminishes in the long term. These findings provide necessary insights for policymakers and investors in strengthening the green bond market through stable economic policies and strategic investment decisions.

Keywords: Green Bond, Economic Policy Uncertainty, Global Financial Volatility, Exchange Rate, Commodity Prices, ARDL, China

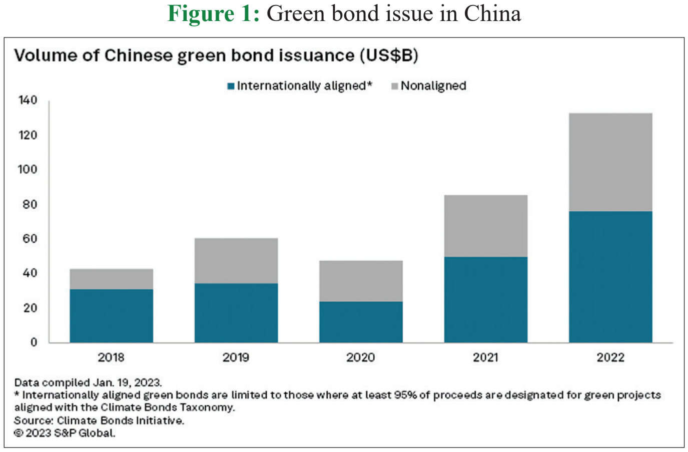
JEL Classifications: D8, F30, G24

1. INTRODUCTION

The economic development process, while driving progress, has also led to significant negative consequences, prompting the adoption of sustainable development strategies that seek a balance between economics, governance, social, and environmental priorities (Ma et al., 2025). In recent years, sustainable finance has gained widespread traction with governments and financial markets due to its ability to solve these challenges (Shah et al., 2023; Ziolo et al., 2020). Green bonds have emerged as a pivotal tool in addressing these challenges, as they provide a mechanism to channel financial resources directly into projects that promote environmental sustainability (Alamgir and Cheng, 2023; Abhilash et al., 2023). These bonds not only facilitate investment in critical areas such as clean energy, eco-friendly transportation, and climate-resilient infrastructure but also signal a shift in global financial systems toward long-term ecological and social benefits (Yadav et al., 2024; Hu and Jin, 2023; Qian, 2022). By 2020, the global issuance of green investment bonds had reached approximately one trillion USD, with projections estimating an annual issuance of five trillion USD by 2025. These funds have been allocated to initiatives such as sustainable agriculture, clean energy, eco-friendly transportation, food security, and infrastructure development across 62 developed and developing nations (Rehman et al., 2023). The growing acceptance of green bonds underscores their potential to mitigate the adverse effects of climate change, align economic growth with sustainability goals, and encourage broader adoption of environmentally responsible investment practices (Wang et al., 2023; Saha and Maji, 2023). Green bonds, introduced by the European Investment Bank in 2007, are fixed-income securities designed to finance environmentally sustainable projects. These instruments, similar to traditional bonds, raise capital for eco-friendly assets while addressing environmental crises and supporting long-term investments (Saravade and Weber, 2020). The emergence of green bonds has shifted perceptions of structured financial products from contributors to short-term volatility and waste to tools for financing environmental sustainability. However, there remains debate about whether this "go green" approach is a fundamental necessity or a passing trend. The increasing urgency to mitigate climate change impacts has heightened attention on green bonds, particularly as they offer pathways for ecological transitions. Despite the absence of universal legal mandates for green bond principles, some researchers argue for their potential to drive sustainable finance (Vulturius et al., 2024; Giráldez and Fontana, 2022).

China plays a pivotal role in global green financing, driven by regulatory reforms that align with the International Capital Market Association's (ICMA) and Green Bond Principles (GBP) (Tang et al., 2023; Lin and Hong, 2022). According to Zhang et al. (2024), China's green bond market demonstrated significant maturity, with cumulative issuances reaching approximately 495.25 billion USD, despite a 4.4% decrease in annual issuance volume to 118.29 billion USD in 2023. Green bonds accounted for 1.17% of the overall bond market, reflecting a slight decline from 1.5% in 2022. The market saw increased participation from non-state-owned enterprises (20% of issuance volume), while the financial sector reclaimed dominance with 58.97% of total issuances. Although regulatory reforms in 2023, mandating that 95% of green bond proceeds be allocated to green projects, addressed prior greenwashing concerns but contributed to slower market growth amidst broader economic challenges (Figure 1). Moving

Figure 1: Green bond issue in China



Source: Climate bonds initiative 2023

forward, China's continued refinement of green finance standards and incentives aims to enhance transparency, international alignment, and investor confidence, supporting the market's long-term development.

While industrialisation and modernisation have driven economic growth in China, they have simultaneously intensified energy consumption and environmental degradation (Aquilas et al., 2024; Nguyen et al., 2024). To address these challenges, China has introduced environmentally sustainable financial instruments such as green bonds, carbon trading, and green credits (Zhou et al., 2020). However, macroeconomic factors, such as economic policy uncertainty (EPU), significantly influence investor sentiment and, by extension, the green bond market (Bagh et al., 2023; Darsono et al., 2022). Despite this, there remain notable research gaps in understanding how macroeconomic factors, particularly EPU, impact the green bond market. Previous studies suggest that heightened EPU dampens investor sentiment, discourages risk-taking, and reduces investments in innovative financial instruments, including green bonds (Liu et al., 2024; Dai et al., 2022). While some evidence points to green bonds potentially acting as counter-cyclical tools, offering stability and hedging against economic uncertainties (Chopra and Mehta, 2023; Haq et al., 2021), the mechanisms by which green bonds respond to EPU remain underexplored.

Moreover, market volatility introduces additional complexity to the dynamics of green bond investments. Spillover effects from conventional bond markets highlight the interconnectedness of financial systems and expose green bonds to external shocks, which can undermine their stability and performance (Wang and Li, 2024; Peng et al., 2023). Despite these vulnerabilities, green bonds have shown potential for relative stability, primarily due to their alignment with long-term sustainability objectives (Liu et al., 2024; Alamgir and Cheng, 2023). This alignment attracts investors seeking diversification and risk mitigation, offering a degree of resilience in turbulent markets. However, sector-specific dynamics further complicate green bond performance. For instance, fluctuations in commodity prices (CMP) - particularly those of metals, oil, and rare earth elements essential for renewable energy technologies - can significantly influence investor sentiment and the attractiveness of green finance instruments (Zhong et al., 2021). Volatility in commodity prices may impact costs for renewable energy projects, potentially enhancing or reducing their attractiveness to green bond issuance (Yadav et al., 2024; Acikgoz et al., 2024; Tsagkanos et al., 2022). These sectoral sensitivities reveal a critical gap in understanding how specific economic and industrial trends shape green bond markets. Green bonds hold dual significance in this context: as financial instruments addressing environmental challenges and as mechanisms for weathering market uncertainties while contributing to economic resilience. Nonetheless, their effectiveness depends on deeper insights into their interactions with macroeconomic factors, market volatility, and sector-specific drivers. Hence, addressing these gaps is critical to enhancing the effectiveness of green bonds as tools for sustainable development and understanding their dual role in reflecting investor confidence and reinforcing the importance of stable policy frameworks.

Previous studies highlight the complex relationship between EPU, market volatility, exchange rates, commodity prices, and green bonds in China (Huang and Luk, 2020; Zhou et al., 2020; Bagh et al., 2023; Guo et al., 2023; Peng et al., 2023; Yang and Peng, 2024). However, questions remain regarding the benefits of financial- and economic- conditions for green bonds, as well as their effectiveness in mitigating risks, and their resilience in volatile economic conditions. To address these gaps, this study employs the Autoregressive Distributed Lag (ARDL) model, a robust econometric method well-suited for examining relationships among variables such as EPU, VIX, CMP, and exchange rates (EXR). The ARDL model is particularly advantageous in contexts where data series exhibit mixed orders of integration (e.g., I(0), I(1), or a combination), allowing for the simultaneous estimation of both short-run and long-run dynamics for economic factors (Bui et al., 2023; Nguyen et al., 2022). This dual capability provides a understanding of the interactions between financial and macroeconomic variables, which often exhibit time-varying behaviour and complex interdependencies. The ARDL approach is especially relevant for exploring the temporal transmission of shocks, such as those stemming from uncertainty and market volatility, to green bond performance (Shang et al., 2023; Darsono et al., 2022). The model captures delayed effects by incorporating lagged variables, offering critical insights into how economic shocks propagate over time. Moreover, its ability to handle small sample sizes addresses a common limitation in studies of macroeconomic uncertainty and market dynamics (Yang and Peng, 2024; Haque et al., 2022). ARDL's flexibility in accommodating exogenous shocks, including shifts in economic policies or market conditions, further enhances its suitability for analysing the dynamic relationships among EPU, VIX, CMP, and EXR. The primary objectives of this study are to:

- Examine the short- and long-term impacts of economic policy uncertainty, commodity price, and market volatility on green bond performance
- Investigate the cointegration among green bonds and economic policy uncertainty, commodity price, and market volatility fluctuations through tests
- The theoretical and practical implications of the ARDL findings are given.

By leveraging the ARDL framework, this research aims to fill critical gaps in understanding the dynamic interactions between macroeconomic variables and green bond markets, contributing to the broader discourse on sustainable finance in uncertain economic environments. The rest of this study is constructed as follows: Section 2 reviews the literature foundation on macroeconomic variables and green bonds. Section 3 outlines the research methodology, including the ARDL model and data sources. Section 4 presents empirical results and discussion. Section 5 remarks the key findings and their policy and research implications.

2. LITERATURE REVIEW

The theory of market efficiency assumes that all information related to environmental performance has been reflected in stock prices, and the modern portfolio theory states that restricting investment options can reduce risk-adjusted returns (Badía et al., 2024). Green bonds are often issued at a premium, resulting in lower yields than conventional bonds, which can increase the attractiveness of these instruments for investors looking to align their portfolios with environmental objectives (Caramichael and Rapp, 2024; Tang and Zhang, 2020). Furthermore, the issuance of green bonds is essential to attract more investors, particularly those focused on socially responsible investing (Marín-Rodríguez et al., 2023).

Thus, green bonds and their relationships with other financial-economic factors have received much attention from scholars and investors, with the role of economic policy uncertainty (EPU) stands out. On the one hand, several studies indicate that green bonds can act as a hedge during periods of uncertainty, offering diversification benefits for investors. For instance, Haq et al. (2021) found that green bonds provided protective advantages against EPU and complemented clean energy stocks and rare earth components during the COVID-19 pandemic in the US and China. Similarly, Guo et al. (2023) revealed that the composite EPU index strengthened the long-term relationship between green bonds and stock markets while reducing the connection with traditional bonds in China. This suggests that green bonds can offer a more stable investment avenue during turbulent economic conditions compared to conventional bonds. However, Pham and Nguyen (2022) observed that while green bonds served as a hedge in periods of low uncertainty, their performance diminished during heightened uncertainty, highlighting the conditional nature of their protective role. Furthermore, Boutabba and Rannou (2022) found that the correlation between EPU and green bonds intensified during periods of elevated uncertainty, such as the Russia-Ukraine conflict, further undermining the returns on green bonds. The findings of Wei et al. (2022) with wavelet-based quantile analysis and Lin and Su (2023) with cross-quantilogram method corroborate the view that the impact of EPU on green bonds is nonlinear, varying across time scales and market conditions, with extreme uncertainty leading to significant fluctuations in bond returns in the USA and China. Using the quantile-on-quantile methodology for the top 10 green bond-issuing countries, Liu et al. (2024) examined the asymmetric impact of economic policy uncertainty on green bonds, showing that EPU significantly reduces green bond prices across various quantile levels in most economies.

Moreover, the debate surrounding the short-term and long-term effects of EPU on green bonds adds further complexity to this relationship. Several studies suggest that the long-term relationship between EPU and green bonds is complex, exhibiting both stabilising and destabilising dynamics depending on market conditions (Wang et al., 2022). In the short term, green bonds often demonstrate resilience and hedging capabilities, as evidenced by the findings of Su et al. (2022), who employed the quantile-on-quantile (QQ) method and found that the positive relationship between oil prices and green bonds in the short term becomes negative in the long term. This suggests that while green bonds can provide immediate protection against economic shocks, their effectiveness diminishes as uncertainty persists. Pham and Cepni (2022) also reported that green bonds serve as a reliable hedge during low uncertainty periods, but this benefit weakens under high uncertainty conditions. In contrast, long-term effects reveal a more intricate pattern. Adekoya et al. (2023) demonstrated that long-term exposure to EPU negatively influences green bond performance, as increased uncertainty undermines corporate confidence in green investments, leading to higher risk premiums and lower returns. This finding aligns with Tian et al. (2022), who noted that the asymmetric effects of EPU on green bonds are more pronounced in China's market, reflecting how prolonged uncertainty can erode investor confidence. This is further evidenced by a later study by Li et al. (2023), whose results confirmed a dynamic relationship between green bond shocks and economic policy uncertainty and carbon prices in China from 2014 to 2022. Furthermore, Lundgren et al. (2018) employed nonlinear causality and connectedness network analysis, confirming that economic uncertainty significantly impacts green bonds over extended periods, particularly in the Eurozone. Therefore, while green bonds may offer short-term stability, their long-term viability is challenged by sustained economic policy uncertainty, highlighting the need for adaptive investment strategies in evolving market conditions.

In more detail, the relationship between green bonds and volatility shocks reflects the influence of market uncertainty on green financial instruments. On the one hand, green bonds often act as net recipients of volatility shocks rather than transmitters, providing insulation during heightened uncertainty. Hence, Liu (2022) finds that the COVID-19 pandemic caused significant fluctuations and negative abnormal returns, with green bond volatility primarily driven by uncertainties in traditional fixed-income, currency, and stock markets. Indeed, Le et al. (2021) employed the Diebold and Yilmaz technique and the Baruník and Křehlík connectedness model, finding that while volatility is predominantly transmitted across markets in the short run, green bonds remained relatively insulated, thus serving as a stabilising investment during turbulent periods. Similarly, Nguyen et al. (2021) observed that green bonds exhibit a weak correlation with common stocks and commodities, further cementing their role as a safe haven during market volatility. On the other hand, the negative impact of volatility on green bonds becomes apparent when volatility reaches extreme levels or persists over the long term. Huynh (2020) demonstrated that green bond markets experience increased tail dependency during periods of financial chaos, indicating a higher likelihood of joint losses alongside other assets. The study further revealed that short-term volatility transmission was more significant than long-term transmission, suggesting that while green bonds can initially weather market shocks, prolonged volatility undermines their resilience. Furthermore, Pham (2021) found that shocks from conventional bond markets tend to spill over into the green bond market, amplifying volatility under high-risk conditions. Therefore, while green bonds can provide short-term stability during volatility spikes, their long-term performance remains susceptible to persistent market fluctuations.

Another aspect that may affect green bonds is the exchange rate. On the positive side, Burger et al. (2012) emphasised that strengthened macroeconomic stability, including stable exchange rates, improved creditors' rights, and facilitated the growth of local currency corporate bond markets, further encouraging green bond development. Moreover, Broadstock and Cheng (2019) demonstrated that stable exchange rates contributed to stabilising and developing green bond markets through their interaction with conventional bond markets. Conversely, exchange rate volatility poses significant risks to green bond markets, particularly in emerging economies. For example, Eichengreen et al. (2023) highlighted that international investors historically excluded local currency bonds from their portfolios due to currency mismatches and exchange rate instability, which hindered green bond market growth in developing regions. This volatility increases the risk premium for green bonds, making them less attractive to foreign investors. Meanwhile, Mizen et al. (2021) noted that exchange rate fluctuations contributed to the illiquidity of corporate bond markets in seven Asian emerging markets, further deterring long-term borrowing in local currencies. Therefore, while stable exchange rates can enhance green bond market growth by attracting investment and reducing risks, volatility undermines investor confidence and limits the market's expansion potential.

Last but not least, the relationship between commodity prices - specifically copper, nickel, and oil - and green bonds is characterised by both positive and negative dynamics. On the positive side, green bonds exhibit resilience against certain commodity price fluctuations, providing hedging benefits in times of volatility. Naeem et al. (2021) found that green bonds offered significant hedging advantages against industrial metals, including copper and nickel, with non-correlation or negative associations during heightened volatility periods. This suggests that green bonds can act as a diversification tool for investors exposed to commodity markets. Additionally, oil price shocks can stimulate green bond issuance. Azhgaliyeva et al. (2022) revealed that oil supply shocks positively influenced private green bond issuance, while sovereign green bond issuance in public markets encouraged further activity in the private sector. Conversely, the negative relationship between commodity prices and green bonds becomes evident during periods of market stress. Dutta et al. (2021) highlighted that risks from the crude oil market were significantly transmitted to green stock indices, particularly during bearish stock market conditions, indicating that green bonds are vulnerable to energy market instability. Furthermore, the strong long-term correlation between crude oil and green bonds identified by Naeem et al. (2021) implies that persistent increases in oil prices can undermine the stability of green bond markets. While green bonds remain relatively insulated from short-term fluctuations in copper and nickel prices, long-term commodity price instability can reduce investor confidence and increase risk premiums. This is supported by Su et al. (2022) with the quantile-on-quantile method, and their findings stated that the positive relationship between oil prices and green bonds in the short term becomes negative in the long term. Therefore, while green bonds can provide protection against short-term commodity price volatility, their long-term resilience is contingent upon stable commodity markets.

Although China holds a significant position in global green finance, previous studies highlight the complex relationship between EPU, market volatility, exchange rates, commodity prices, and green bonds in China (Huang and Luk, 2020; Zhou et al., 2020; Bagh et al., 2023; Guo et al., 2023; Peng et al., 2023; Yang and Peng, 2024). Despite these insights, research gaps remain. First, existing studies often examine individual factors like EPU, exchange rates, or commodity prices in isolation rather than exploring their combined effect on green bonds. Second, while the time-varying nature of EPU and market volatility has been identified, their long-term impact on green bond performance remains underexplored. Finally, while Peng et al. (2023) highlighted bond market spillovers, they did not consider how commodity price fluctuations further influence green bond volatility. To address this gap, this study employs the Autoregressive Distributed Lag (ARDL) model, which allows for examining both short-term and long-term dynamics between economic policy uncertainty, volatility, exchange rates, commodity prices, and green bonds. By capturing the heterogeneity of these relationships, the ARDL approach provides a more comprehensive understanding of how macroeconomic uncertainties impact green bond markets, informing more adaptive investment strategies and policymaking. Based on the above theoretical arguments, this study puts forward the following hypotheses:

- Hypothesis 1: Economic policy uncertainty and green bonds have a long-term and short-term relationship
- Hypothesis 2: The volatility index and green bonds have a long-term and short-term relationship
- Hypothesis 3: Exchange rates and green bonds have a long-term and short-term relationship
- Hypothesis 4: A long-term and short-term relationship exists between commodity prices (nickel, copper, and oil) and green bonds.

3. DATA AND METHODOLOGY

3.1. Data

The dataset for this research was sourced from the Investing platform (investing.com), the Chinese Bond website (yield.chinabond.com.cn), and Federal Reserve Economic Data (https://fred.stlouisfed.org) and includes monthly data spanning January 2019-December 2023. The study's dependent variable, China's Green Bond Net Price (GBNP), is represented by its market price in Reminbi (RMB). The independent variables examined include China's Economic Policy Uncertainty (EPUC), Global Volatility Index (VIXG), Yuan Renminbi Exchange Rate (XRTC), World Nickel Commodity Price (NKL), World Copper Commodity Price (CPR), World Oil Commodity Price (OIL). These variables are described in Table 1.

Table 1: Variable descriptions

Name	Code	Measurement	Source
China's Economic Policy Uncertainty	EPUC	Economic Policy Uncertainty Index	FRED
Financial Market Volatility	VIXG	Global Volatility Index	FRED
Yuan Renminbi Exchange Rate	XRTC	Renminbi (RMB)	FRED
World Nickel Commodity Price	NKL	USD/TON	INVESTING
World Copper Commodity Price	CPR	USD/TON	INVESTING
World Oil Commodity Price	OIL	USD/BBL	INVESTING

Authors' summary

3.2. Methodology

Before selecting an appropriate econometric estimation method, verifying the data to avoid spurious regression issues is essential. The first step in cointegration analysis involves conducting a unit root test to determine the integration order of each variable. Before applying the ARDL model, it is crucial to satisfy the normality assumption of the ARDL bounds testing approach (Bui et al., 2023; Nguyen et al., 2022). This requires all variables to be either integrated at order zero (I(0)) or order one (I(1)). This is achieved by applying the Augmented Dickey-Fuller (ADF) test to assess the stationarity of the time series variables. Additionally, we implement an autoregressive distributed lag (ARDL) model estimation along with a causality procedure. In this step, the autoregressive distributed lag (ARDL) approach is used to examine both short- and long-term relationships among the variables. The general equation of this study is constructed by:

$$GBNP_t = \alpha + \beta_1 EPUC_t + \beta_2 VIXG_t + \beta_3 XRTC_t + \beta_4 NKL_t + \beta_5 CPR_t + \beta_6 OIL_t + \varepsilon_t \quad (1)$$

Where α is the constant, β is the estimated parameter and t is the lag order for each independent variable, ε_t is the residual term, often assumed to be a white noise process. To achieve both the long-run and short-run dynamics among the variables, the Equation (1) is reformulated using an Error Correction Model (ECM) representation:

$$\Delta GBNP_t = \varphi_0 + \sum_{i=1}^{\rho-1}\varphi_i \Delta GBNP_{t-i} + \sum_{m=0}^{q-1}\gamma_{1m} EPUC_{t-m} + \sum_{m=0}^{q-1}\gamma_{2m} VIXG_{t-m} + \sum_{m=0}^{q-1}\gamma_{3m} XRTC_{t-m} + \sum_{m=1}^{q-1}\gamma_{4m} NKL_{t-m} + \sum_{m=1}^{q-1}\gamma_{5m} CPR_{t-m} + \sum_{m=1}^{q-1}\gamma_{6m} OIL_{t-m} + \delta_0 GBNP_{t-1} + \delta_1 EPUC_{t-1} + \delta_2 VIXG_{t-1} + \delta_3 XRTC_{t-1} + \delta_4 NKL_{t-1} + \delta_5 CPR_{t-1} + \delta_6 OIL_{t-1} + \omega_t \quad (2)$$

The parameters φ and γ capture the short-term dynamics of the model. For each explanatory variable, the long-term coefficient β_i is derived from Equation (2) as $\beta_i = \delta_j/\delta_0$, with j ranges from 1 to 6. Equation (2) is structured to facilitate the bounds test for cointegration, as Pesaran et al. (2001) introduced. The null hypothesis assumes no long-term association between the variables, while the alternative hypothesis is at least one long-run relationship between the variables. In Equation (2), the Ordinary Least Squares (OLS) and partial F-test significance are applied for the lagged levels of the variables. Following Narayan (2004), critical boundaries for the F-statistic are used to determine cointegration in small samples. If the computed F-statistic exceeds the upper critical threshold, cointegration is confirmed; if the statistic falls below the lower boundary, no cointegration is detected among the variables.

To select the optimal lag length, the Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC), or Hannan-Quinn

Criterion are applied (Shabbir et al., 2019; Bui et al., 2023). Once a long-run relationship is established, we assess model stability using the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ) tests, as developed by Brown et al. (1975). As suggested by Pesaran et al. (2001), these diagnostic tests evaluate the reliability of the ARDL model by analysing the residuals of the ECM. The graphical representation of the CUSUM and CUSUMSQ statistics provides insights into stability - where results remaining within the 5% critical band indicate model stability.

4. FINDINGS AND DISCUSSIONS

4.1. Findings

The descriptive statistics for the research variables are presented in Table 2, including the mean, median, minimum, maximum, and standard deviation. The dataset consists of 60 observations for each variable from 2019 to 2023, totalling of 420 observations.

In Table 2, the GBNP variable averages 101,964 with a standard deviation of 1.223, ranging from 99.884 to 104.322, and a median of 102.119. EPUC and VIXG show greater fluctuations, averaging 327.907 and 21.323, respectively, with wider standard deviations and ranges of 160.979-661.828 and 12.52-57.74. While GBNP remains relatively stable with a narrow standard deviation, EPUC and VIXG exhibit higher fluctuations, suggesting greater uncertainty in economic policy and market volatility. XRTC remains relatively stable, with a mean of 6.813, a standard deviation of 0.287, and values between 6.343 and 7.307. Commodity prices vary significantly, with NKL averaging 18,692.9 RMB per ton (ranging from 11.484 to 32.107), CPR at 7,772.5 dollars per ton (ranging from 4.951 to 10.375), and OIL at 67.078 US dollars per barrel, fluctuating between 18.84 and 114.67. The wide range in NKL and CPR prices highlights the dynamic nature of commodity markets, whereas OIL prices show significant variability, likely influenced by global economic conditions.

Table 3 presents the results of unit-root tests obtained using the Augmented Dickey-Fuller (ADF) method. The test indicates that EPUC and VIXG are stationary at I(0), while the GBNP, XRTC, NKL, CPR, OIL become stationary at I(1) after taking the first difference. These results confirm that the ARDL estimation is appropriate for this sample.

The next step is to determine the optimal lag using the Akaike Information Criterion (AIC). The model with the smallest AIC value in the leftmost position is selected as the optimal lag model, as shown in Figure 2. Model 12029 is identified as the leftmost model, with an optimal lag structure of ARDL (1, 1, 0, 3, 3, 4, 1), making it the most suitable choice for the ARDL method.

The Bounds Test in Table 4 is used to check for a long-term relationship. The test results show an F-statistic of 4.225, which is higher than the lower bound (2.88) and upper bound (3.99) at the 1% significance level. Since the F-statistic exceeds both bounds, it confirms the presence of cointegration, indicating a long-term relationship among the research variables.

Table 4 explains that the CointEq (ECT) value = −0.473 with a probability value of 0.0000 indicates that short-term cointegration occurs in the model. The ECT or CointEq value is considered valid if the coefficient is negative with a significance level of 5% or 0.05. The greater the value of the ECT(−1) coefficient, the faster the adjustment process for green bonds in China, meaning it takes <1 month to return to balance and vice versa. The ECT(−1) coefficient is −0.473, which reflects the speed of adjustment of China's green bonds.

In Table 5, the EPUC has a negative and significant short-term impact on GBNP. This is indicated by a coefficient of −0.0013 and a probability value of 0.0043 at the 1% significance level, meaning that a rise in EPUC leads to a 0.0013% monthly decline in green bonds. The D(XRTC) at lag one also has a positive and significant short-term effect on GBNP, with a coefficient of 9.306 and a probability value of 0.0611 at the 10% significance level. However, at lag 2, its relationship turns negative, with a coefficient of −12.344 and a probability value of 0.0071. The NKL has a negative and significant short-term effect on GBNP. A coefficient of −2.811 and a probability value of 0.0000 at the 1% significance level indicate that a 1% increase in nickel prices leads to a decline of 2.811 in green bonds per month. Similarly, CPR negatively affects Chinese green bonds, and its coefficient is −1.761, with a probability value of 0.0921 at the 10% significance level, suggesting that a 1% increase in copper prices decreases 1.761 in green bonds per month. Meanwhile, OIL has a positive and significant short-term impact on GBNP, with a coefficient of 1.312 and a probability value of 0.0003. This suggests that an increase in oil prices leads to a rise in green bonds by 1.312. These findings highlight the varying effects of economic and commodity factors on China's green bond market, which will be discussed in the next section.

In the long term, Table 6 indicates that EPUC also has a negative and significant long-term impact on GBNP, as shown by a coefficient of −0.0045 and a probability value of 0.0055, meaning that an increase in EPUC reduces green bonds by 0.0045. In

Table 2: Statistics description

Variable	Mean	Median	Max.	Min.	Standard deviation	Observations
GBNP	101.964	102.119	104.322	99.884	1.223	60
EPUC	327.907	319.243	661.828	160.979	102.892	60
VIXG	21.323	19.79	57.74	12.52	7.543	60
XRTC	6.813	6.844	7.307	6.343	0.287	60
NKL	18692.9	18024.5	32107	11484	5286.827	60
CPR	7772.5	8099.75	10375	4951	1536.783	60
OIL	67.078	67.205	114.67	18.84	20.467	60

Source: Authors' calculation

Table 3: Unit-root tests

Variable	Unit root test			
	Levels		First Difference	
	ADF	Prob.	ADF	Prob.
GBNP	−1.413	0.5700	−6.144***	0.0000
EPUC	−4.896***	0.0002	−10.494***	0.0000
VIXG	−3.615**	0.0160	−8.594***	0.0000
XRTC	−1.871	0.3430	−4.631***	0.0004
NKL	−1.759	0.3967	−6.048***	0.0000
CPR	−13.578	0.5968	−7.646***	0.0000
OIL	−1.773	0.3899	−6.407***	0.0000

***P<0.01, **P<0.05, *P<0.1, respectively. Source: Authors' calculation

Table 4: Bounds test results

Statistical tests	Result	K
F-Statistics	4,225	6
Signification	I (0) Lower bounds	I (1) Upper bounds
10%	1.99	2.94
5%	2.27	3.28
2.5%	2.55	3.61
1%	2.88	3.99

Source: Authors' calculation

Table 5: Short-term estimation results

ARDL (1, 1, 0, 3, 3, 4, 1) based on AIC values (Dependent variable: GBNP)		
Variable	Coefficient	Probability
D (EPUC)	−0.0013*** (0.0004)	0.0043
D (XRTC(−1))	9.306* (4.814)	0.0611
D (XRTC(−2))	−12.344*** (4.325)	0.0071
D (NKL(−3))	−2.811*** (0.563)	0.0000
D (CPR)	−1.761* (1.017)	0.0921
D (CPR(−1))	−2.638*** (0.948)	0.0086
D (CPR(−2))	−3.236*** (0.979)	0.0022
D (OIL)	1.312*** (0.327)	0.0003
CointEq(−1)*	−0.473*** (0.074)	0.0000
R-squared: 0.668		
Adjusted R-squared: 0.576		
S.D. dependent var: 0.490		
S.E. of regression: 0.319		
Log-likelihood: −8.133		
Akaike info criterion: 0.754		
Schwarz criterion: 1.224		
Hannan-Quinn criterion: 0.937		

( ) is standard error, ***P < 0.01, **P < 0.05, *P < 0.1, respectively. Source: Authors' calculation

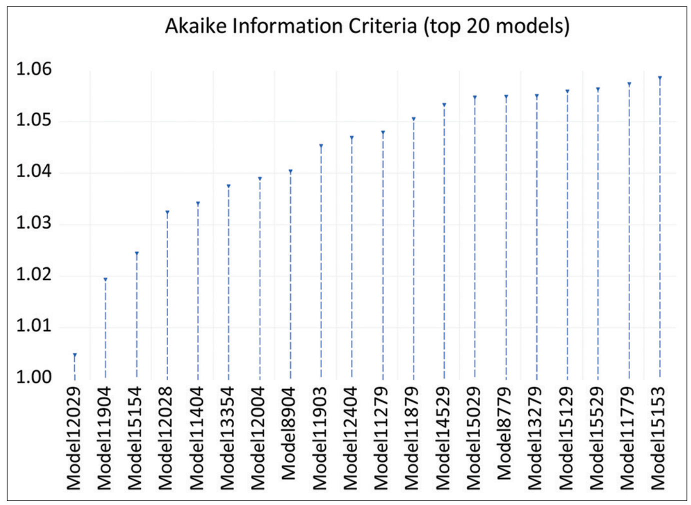
contrast, the VIXG positively and significantly affects GBNP, with a coefficient of 0.048 and a probability value of 0.0430. Similarly, the XRTC has a positive and significant impact, with a coefficient of 14.872 and a probability value of 0.0054, suggesting that a 1% increase in the exchange rate raises green bonds by 14.872. Moreover, the NKL has a positive and significant effect, as

Table 6: Long-term estimation results

ARDL (1, 1, 0, 3, 3, 4, 1) based on AIC values (Dependent variable: GBNP)		
Variable	Coefficient	Probability
C	37.467	0.0253
EPUC	−0.005*** (0.0015)	0.0055
VIXG	0.048** (0.023)	0.0430
XRTC	14.872*** (0.433)	0.0054
NKL	2.118* (1.214)	0.0896
CPR	1.947 (1.559)	0.2198
OIL	−0.367 (0.912)	0.6895

( ) is standard error, ***P<0.01, **P<0.05, *P<0.1, respectively. Source: Authors' calculation

Figure 2: AIC for optimal lags

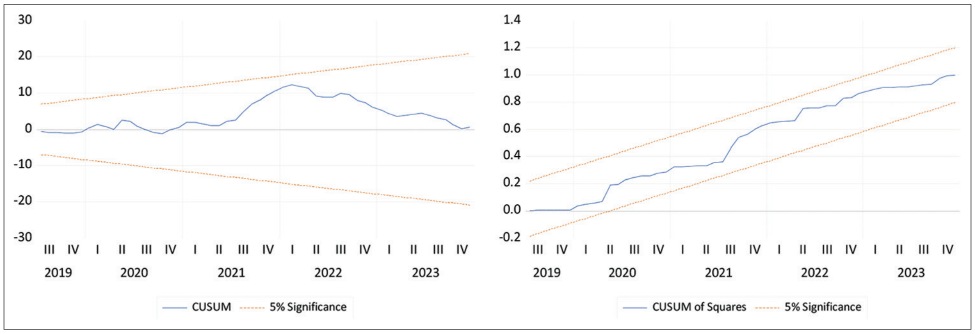


Source: Authors' calculation

shown by a coefficient of 2.118 and a probability value of 0.0896. However, the CPR has a positive but insignificant effect, with a coefficient of 1.947 and a probability value of 0.2198, while the OIL has a negative and insignificant impact, with a coefficient of −0.367 and a probability value of 0.6895.

Next, Figure 3 presents the results of stability tests for the ARDL (1,1,0,3,3,4,1) model using the CUSUM and CUSUM of Squares methods, respectively. Figure 3 shows the estimated parameters' stability over time, illustrating whether the model remains consistent throughout the sample period (CUMSUM). The graphical representation demonstrates that the test statistic remains within the critical bounds, confirming that the estimated model is stable. Similarly, the CUSUM of Squares test assesses the presence of structural breaks or volatility shifts in the model's residuals. Since the test statistic remains within the confidence intervals, the results indicate no significant structural instabilities, supporting the reliability of the ARDL model for analysing the relationship between macroeconomic variables and China's green bond market.

Figure 3: CUSUM and CUSUM of squares tests for ARDL (1,1,0,3,3,4,1) model



4.2. Discussions

4.2.1. Economic policy uncertainty and green bond

The findings indicate that China's economic policy uncertainty significantly negatively impacts the market price of China's green bonds in both the short and long term. These results align with Adekoya et al. (2023) and Lundgren et al. (2018), who also determined that economic policy uncertainty negatively affects green bond performance. This negative relationship aligns with the market efficiency theory, which states that financial asset prices fully reflect all available information, including economic uncertainty (Badía et al., 2024). The increased risk associated with policy uncertainty leads to lower investor confidence, reducing demand for green bonds and subsequently lowering their prices. Furthermore, modern portfolio theory suggests that restricting investment options can reduce risk-adjusted returns, which may explain why green bonds, despite being issued at a premium (Tang and Zhang, 2020), become less attractive during uncertainty. In addition, Lin and Su (2023) found similar results in China, reinforcing the notion that sustained economic uncertainty weakens investor confidence in green bonds. These findings underscore the importance of stable economic policies in supporting green bond markets and attracting socially responsible investors (Marín-Rodríguez et al., 2023). While green bonds offer potential long-term benefits, their vulnerability to uncertainty highlights the need for adaptive investment strategies that account for evolving market conditions.

4.2.2. Global volatility index and green bond

The findings show that the VIXG has a positive and significant long-term effect on China's green bond market. This suggests that increased financial market volatility leads to greater demand for Chinese green bonds. The results align with Adekoya et al. (2023) and Lundgren et al. (2018), who found that volatility indices significantly influence green bond markets. Green bonds are often seen as net recipients rather than transmitters of volatility shocks, providing relative stability during financial turbulence. Thus, while short-term volatility is transmitted across financial markets, green bonds remain relatively insulated, reinforcing their role as a stabilising asset during periods of heightened market uncertainty (Le et al., 2021). It is demonstrated that green bonds exhibit a weak correlation with conventional stocks and commodities, thereby reinforcing their safe-haven characteristics (Le et al., 2021; Nguyen et al., 2021). Therefore, the findings of this study reinforce that rising global volatility positively influences China's green bond market in the long run. This suggests that investors perceive China's green bonds as a relatively stable asset class during periods of financial uncertainty, likely due to their association with sustainable projects and lower exposure to speculative market behaviour.

4.2.3. Exchange rate and green bonds

The findings reveal that the XRTC has a positive and significant impact on China's green bonds in both the short and long term. These findings are consistent with Adekoya et al. (2023) and Lundgren et al. (2018), who also concluded that exchange rate fluctuations significantly influence green bond markets. However, the long-term estimation results show that an increase in XRTC is associated with a significant rise in GBNP, while exchange rate fluctuations in the short-term exhibit mixed effects, as shown by the significant positive coefficient at one lag and a negative coefficient at two lags. These results suggest that while currency depreciation initially stimulates green bond demand, delayed effects may introduce volatility into the market. A depreciation of the Chinese yuan relative to the US dollar can enhance the attractiveness of Chinese green bonds to foreign investors by lowering the relative cost of investment. This capital inflow increases demand, raising bond prices and improving market liquidity. However, exchange rate volatility can pose risks to green bond markets by increasing uncertainty and raising the required risk premium. In this context, while the study's findings suggest that currency depreciation initially supports green bond demand, persistent fluctuations may weaken investor confidence over time. This aligns with the observed short-term negative effects of exchange rate volatility in the empirical results. The findings support Eichengreen et al. (2023), who noted that international investors have historically been reluctant to hold local currency bonds due to currency mismatches and exchange rate instability, which can hinder green bond market growth in emerging economies. Similarly, Burger et al. (2012) and Broadstock and Cheng (2019) demonstrated that exchange rate stability contributes to the expansion of green bond markets by mitigating uncertainties associated with currency fluctuations and enhancing market liquidity.

4.2.4. Commodity prices and green bonds

The findings demonstrate that world commodity prices -nickel, copper, and oil -exert both short-term and long-term influences on China's green bond market. The results show that nickel and copper prices negatively impact green bond prices in the short term, while their long-term effects become positive or insignificant. Conversely, oil prices exhibit a positive and significant short-term influence but an insignificant negative long-term impact, consistent with Adekoya et al. (2023), Chen et al. (2023), and Lundgren et al. (2018). Moreover, Naeem et al. (2021) found that green bonds offer significant hedging benefits against industrial metals, including copper and nickel, particularly during periods of heightened volatility. This aligns with the study's findings that, while higher nickel and copper prices increase production costs in the short term -leading to financial strain on companies issuing green bonds -their long-term impact is either positive. The long-term positive influence of nickel prices suggests that countries with significant nickel production, such as China, may benefit from increased export revenues, which can then be channeled into sustainable initiatives, further driving green bond demand. Similarly, world copper prices may influence green bonds in the short term, their impact diminishes over time as investments shift toward long-term renewable energy and environmental projects.

In addition, the short-term positive effect of oil prices can be explained by increased awareness of fossil fuel price volatility, prompting investors to seek more sustainable energy alternatives, thereby boosting demand for green bonds. Azhgaliyeva et al. (2022) observed that oil supply shocks positively influenced private green bond issuance, as higher oil prices increased awareness of energy security and incentivised investment in sustainable alternatives. However, as China transitions to renewable energy and improves energy efficiency in the long term, dependence on fossil fuels declines, reducing the direct impact of oil price fluctuations on green bond markets. Government policies and investor preferences for environmentally friendly projects further mitigate the influence of oil prices on green bond performance over time. It aligns with Su et al. (2022), who found that the positive relationship between oil prices and green bonds in the short term reverses as time progresses.

5. CONCLUSION

This study examines the influence of macroeconomic variables on China's green bonds, considering their relevance to global economic trends and sustainable investment policies. The findings indicate that China's economic policy uncertainty negatively and significantly affects green bonds in both the short and long term, suggesting that regulatory uncertainty reduces investor confidence in green financial instruments. In contrast, global financial market volatility, represented by the global volatility index, exhibits a positive and significant long-term impact, implying that green bonds may serve as a stable investment alternative during periods of economic uncertainty. The exchange rate also plays a crucial role in the green bond market, showing a positive and significant short- and long-term impact. This suggests that exchange rate stability enhances investor confidence and facilitates foreign capital inflows into green financial markets. Additionally, commodity prices, particularly nickel and copper, have a mixed influence on green bonds. Rising prices negatively impact green bonds in the short term, likely due to increased production costs. However, in the long term, their effect turns positive, reflecting the role of stable raw material supplies in supporting the transition to a green economy. Similarly, oil prices exhibit a positive and significant short-term impact but become negative and insignificant in the long run, highlighting the influence of global energy transition dynamics and shifting investment preferences from fossil fuels to renewable energy.

The findings provide insights for policymakers and investors in strengthening the green bond market. Investors should consider economic policy uncertainty and financial market volatility when making investment decisions, as these factors significantly affect green bond stability. In addition, given the impact of exchange rate fluctuations, investment strategies should account for currency movements to optimize returns. Monitoring commodity prices, particularly nickel and copper, is essential, as price volatility can influence inflation and production costs, subsequently affecting green bond performance. Lastly, oil price trends should be observed, as they reflect broader energy transition patterns that may shape the future of green bond markets. A strategic approach incorporating these factors can help investors manage risks and enhance portfolio resilience in the sustainable finance sector.

Despite its contributions, this study has certain limitations. The limited availability of prior research on the relationship between macroeconomic variables and green bonds constrains the depth of analysis and the validity of comparative findings. Additionally, data availability and coverage limitations may affect the accuracy and generalizability of the results. Future research should expand data sources and incorporate a broader range of empirical studies to enhance analytical robustness and theoretical implications. Strengthening these aspects will contribute to a more comprehensive understanding of the macroeconomic determinants of green bond markets.

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