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NON-LINEAR RELATIONSHIP BETWEEN BOND PRICES AND ELECTRICITY PRICES IN INDIA: AN ANALYSIS USING THRESHOLD REGRESSION APPROACH

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Abstract *This research article scrutinises the connotation among bond prices and electricity prices (EP) across different threshold regions in India using threshold regression analysis. We resolve to investigate whether or not there exists a non-linear association between bond prices and EP and if this relationship differs across different threshold regions. The data covers a period of five years from 2018 to 2022, and the analysis includes three different threshold regions based on different threshold bond prices. The results show that there exists significant non-linear association between bond prices and EP, and this relationship differs across the three threshold regions. We surmise presence of an optimality between bond prices (interest rates) and EP, beyond which the EP increase. We conclude that as interest rates increase, the cost of financing for electricity companies also increases, which may lead to higher EP. However, there may be a certain threshold beyond which the cost of financing becomes too high, leading to a decrease in investment and ultimately a decrease in electricity supply, which in turn could lead to higher EP.*

Keywords: *Bond Prices, Electricity Prices, India, Non-Linear Relationship, Threshold Regression*

GEL Classification: *G2, G23, G24*

INTRODUCTION

The relationship between bond prices and electricity demand is a topic of great interest for policymakers and investors, as it has implications for economic growth and financial stability. In India, the relationship between these two variables is complex and non-linear, and has not been extensively studied in the literature. Therefore, through this research article, effort has been made to investigate the non-linear relationship between bond prices and electricity prices (EP) in India using a threshold regression approach.

According to recent studies, there is a quadratic relationship between bond prices and electricity demand, which implies that the relationship between the two variables is non-linear (Bakshi & Kapadia, 2003). Moreover, this relationship is expected to vary across different regions, as the energy sector is heavily influenced by geographical and climatic factors (Creti, Joets & Mignon, 2013). In India, the energy market is highly regulated, and the demand for electricity is affected by a range of factors, including economic growth, population and government policies (Lakshmy, 2014; Balachandran, 2016; Raj, 2018; Rai & Prakash, 2019).

Previous research has examined the nexus between the prices of bonds and electricity demand in different contexts. For instance, one study found that rising bond yields lead to a decrease in electricity demand in the United States, due to the higher cost of capital (Novan, 2013). Another study investigated the bearing of interest rate changes on EP in the European Union, and found that the association between the two variables is intricate and non-linear (Katona & Kovács, 2015).

In India, the nexus between bond prices and EP is likely to be affected by a range of factors, including government policies, technological advancements and environmental concerns (Sinha, 2015). Moreover, the non-linear relationship between these two variables suggests that there may be an optimal level of bond prices beyond which EP rise (Bakshi & Kapadia, 2003). Therefore, this research article

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aims to investigate the threshold level of bond prices beyond which EP increase in India, and to analyse the factors that contribute to this relationship.

To achieve this objective, we use a threshold regression approach to analyse data on bond prices and electricity demand in India. Our analysis includes a period of five years. We hypothesize that there is a non-linear relationship between bond prices and electricity demand in India, and that this relationship varies across different regions. Our findings will have important implications for policymakers and investors who are interested in the association between bond prices and electricity demand in India.

The prices of fixed income securities and interest rates have a strong transposed relationship. When interest rates rise, bond prices fall and vice versa. This relationship is explained by the fact that when interest rates increase, new bonds issued offer higher yields, making previously issued bonds with lower yields less attractive to investors and thus their prices decline. On the other hand, when interest rates decrease, newly issued bonds have lower yields, making previously issued bonds with higher yields more attractive and thus their prices increase. In the context of the present study, the association between bond prices and electricity demand is investigated using threshold regression analysis. While the study focuses on bond prices, the findings on the connection between bond prices and electricity demand can be substituted with the association between interest rates and electricity demand. Therefore, the effects of the extant study can be used to understand the impact of interest rates on electricity demand.

REVIEW OF LITERATURE

This literature review focuses on empirical studies that examine the association amongst bond prices and interest rates, as well as the impact of exchange rates on bond prices. In the United States, three studies using daily data are discussed. Chen and Wu (2009) investigate the relationship between US Treasury bond yields and exchange rates between the US dollar and Japanese yen. They find that exchange rate changes have a significant impact on Treasury bond yields. Meanwhile, Chen and Wu (2010) find that interest rate changes also affect exchange rates between the US dollar and Japanese yen. Finally, Cifarelli and Paladino (2013) analyse the dynamic interactions between the US dollar-euro exchange rate and Treasury bond yields, revealing that exchange rate changes can lead to significant movements in bond yields.

Three studies in other countries also explore the nexus between bond prices and interest rates. In Germany, Schulte (2003) investigates the long-term nexus between the two. The results show that the yield on 10-year government bonds is the most significant variable in elucidating the movement of bond prices. In Italy, Berardi and Torricelli (2015) find that short-term interest rates and long-term bond yields are co-integrated, suggesting that changes in short-term interest rates have a significant impact on long-term fixed income securities' yields. Meanwhile, in Korea, Yoo and Kim (2020) examine the bearing of monetary policy and the span & structure of interest rates on government securities yields. They find that monetary policy plays a significant role in determining the term structure of interest rates and, consequently, government bond yields.

One study investigates the relationship between exchange rates and bond prices in Canada. Kuo et al. (2017) find that changes in the Canadian dollar-US dollar exchange rate have a significant impact on Canadian bond prices. These studies provide insights into the complex relationships between bond prices, interest rates and exchange rates.

Amavilah (1995) conducted a study in the US from 1965 to 1989 using annual data and found that EP and other variables had no significant causal relationship with oil prices (OP), but OP had a negative impact on EP. Aqeel and Butt (2001) examined Pakistan's case from 1956 to 1996 and found that GDP growth causes energy consumption and petroleum consumption, while energy consumption also causes GDP.

Asche et al. (2006) studied UK's figures from 1995 to 1998 using monthly data and found that OP causes EP. Brown and Yücel (2008) analysed the US from 1997 to 2007 using daily data and found that EP causes Gas Prices and vice-versa. Emery and Liu (2002) studied the US from 1996 to 2000 using daily data and found that OP causes EP.

Ghosh (2002) examined India's case from 1950 to 1997 and found no association between per capita GDP and per capita Energy Consumption. However, there was a unidirectional causality from Energy Consumption to GDP growth. Jamil and Ahmad (2010) analysed Pakistan's data from 1960 to 2008 and found that GDP growth causes Energy Consumption. Growth in yield in commercial, industrial and agronomy sectors tends to increase Energy Consumption.

Khan and Qayyum (2009) studied Pakistan's data from 1970 to 2006 and found that wages and the number of consumers wield a positive impact on electricity demand in the long run and short run. The price of electricity wields a negative bearing on electricity demand. Mehrara (2007) analysed oil-exporting countries' panel data from 1971 to 2002 and found a unidirectional inter-connection from economic growth to energy consumption.

Mjelde and Bessler (2009) studied the US from 2001 to 2008 using weekly data and found that EP causes Gas Prices. Mohammadi (2009) analysed the US from 1960 to

2007 using annual data and found that Coal Prices and Gas Prices causes EP, and EP causes Coal Prices. Morimoto and Hope (2004) studied Sri Lanka's data from 1960 to 1998 and found that electricity consumption causes GDP growth.

Munoz and Dickey (2009) analysed Spain's data from 2005 to 2007 using daily data and found that OP causes EP, OP causes exchange rate, exchange rate causes shocks in EP, and OP causes shocks in exchange rate. Nakajima and Hamori (2012) studied Japan's data from 2000 to 2011 using daily data and found that EP causes OP, OP causes EP and USD/JPY exchange rate causes EP.

Narayan and Smyth (2008) examined G7 countries' panel data from 1972 to 2002 and found that capital formation and energy consumption cause positive real GDP growth in the long run.

Variable Identification

The study conducted by Nakajima and Hamori (2012) in context of Japan, investigates the causal relationships among three variables—power prices, OP and Yen-US dollar exchange rates. The authors use a vector autoregressive (VAR) model to analyse the causality-in-mean and causality-in-variance between these variables. The authors find that there is a bi-directional causality-in-mean relationship between EP and crude OP, meaning that changes in EP can cause changes in crude OP, and vice versa. They also find a unidirectional causality-in-mean relationship from yen-US dollar exchange rates to crude OP, indicating that changes in yen-US dollar exchange rates can cause changes in crude OP, but not the other way around. Regarding causality-in-variance, the authors find a significant feedback effect from EP to yen-US dollar exchange rates, which mean that changes in EP can cause changes in the variability of yen-US dollar exchange rates. However, they do not find any significant causality-in-variance relationships between crude OP and the other variables studied.

OBJECTIVES

The main objective of our effort is to investigate the association between bond prices and electricity demand across different regions in India using threshold regression analysis, determining if there is a non-linear relationship and if it differs across regions. The study aims to identify the optimum balance between bond prices and EP to ensure a sustainable supply of electricity at reasonable prices, and to identify the threshold beyond which the cost of financing becomes too high, leading to a decrease in investment and ultimately a decrease in electricity supply, which could result in higher EP. The research provides valuable insights to managers, guiding their decision-making regarding financing and pricing strategies for their companies, ensuring sustainable and profitable operations.

METHODOLOGY

We develop the research methodology to achieve our purpose of examining the association between bond prices and EP, with the association differing across different regions. The data used in this study is time series data for bond prices, EP and exchange rates for a period of five years. The sample size is 523 observations between year 2018 and 2022. The data is sourced from Yahoo Finance, and variables are measured in logarithmic form.

Model Specification: The econometric model used to investigate the relationship between bond prices and EP is a threshold regression model. The model specification is as follows:

lnprice = β1lnexr + β2(lnbondprice1 * Region1) + β3(lnbondprice1 * Region2) + β4(lnbondprice1 * Region3) + ε

Where:

lnprice: The logarithmic form of EP, the dependent variable lnexr: The logarithmic form of exchange rates, the independent variable lnbondprice1: The logarithmic form of bond prices, the threshold variable Region1, Region2 and Region3: Indicator variables for different regions ε: Error term.

The coefficients β1, β2, β3 and β4 represent the effects of the corresponding independent variables on the dependent variable, holding all other variables constant. The model includes both a linear effect of the exchange rate variable and a threshold effect of the bond price variable, as indicated by the threshold regression results. The model also allows for the relationship between the bond price variable and the dependent variable to differ across regions, as indicated by the separate coefficients for each region.

The empirical strategy for this study involves conducting a threshold regression analysis. The analysis involves estimating the coefficients of the model, conducting the Wald test to determine if there is a threshold effect and estimating the threshold values.

The first step is to estimate the coefficients of the model using the maximum likelihood estimation method. The second step is to conduct the Wald test to determine if there is a threshold effect. The Wald test compares the constrained and unconstrained models to determine if there is a significant difference between them. If the Wald test is significant, it indicates that there is a threshold effect. The third step is to estimate the threshold values using the minimum distance estimator method. We analyse the coefficients of the model, conducting the Wald test and estimating the threshold values.

Data

The study uses the daily data for the Weighted Average ACP (INR/MWh) from 2018 to 2022, which is obtained from PXIL. ACP refers to the Average Clearing Price, which is the average price at which electricity is traded in the power exchange. INR stands for Indian Currency Rupees and MWh stands for megawatt-hour, which is a unit of energy commonly used to measure electricity consumption or production. The bond prices data used in the study was obtained from the SBI Magnum Bond Fund, which is traded on the Bombay Stock Exchange (BSE). The data covers the period from 2018 to 2022. The SBI Magnum Bond Fund is a debt mutual fund that invests in a diversified portfolio of debt securities, including government securities, corporate bonds and money market instruments. The exchange rate data between the US dollar (USD) and the Indian rupee (INR) was sourced from Yahoo Finance.

RESULT AND ANALYSIS

In this threshold regression, the threshold variable is "lnbondprice1", which means that the relationship between the dependent variable "lnprice" and the independent variable "lnexr" may change when "lnbondprice1" exceeds certain threshold values.

The coefficients for "lnexr" in the "lnprice" equation suggest that an increase in "lnexr" leads to an increase in "lnprice". However, the significance of the coefficient is only marginal (p-value of 0.063), so this effect may not be statistically significant.

The varying variable is "Region", which has three categories: "Region1", "Region2" and "Region3". For each region, the coefficient for "lnbondprice1" suggests that an increase in "lnbondprice1" leads to a decrease in "lnprice". The coefficients are significant for "Region1" and "Region2" but not significant for "Region3". This suggests that the relationship between "lnbondprice1" and "lnprice" may differ across different regions.

Table 1: Threshold Identification

Order	Threshold	SSR
1	3.6575	24.5134
2	3.7512	23.1191

Source: Author computations.

The output shows the values of the order, threshold (log transformed values of the Bond Prices) and sum of squared residuals (SSR) for each threshold order.

Table 2: Threshold Regression Results

	(1)	(2)	(3)	(4)
Variables	**lnprice**	**Region1**	**Region2**	**Region3**
lnbondprice1		-1.596***	4.057***	0.828
		(0.297)	(0.725)	(2.189)
lnexr	0.978*			
	(0.527)			
Constant		9.564***	-11.21***	1.196
		(1.838)	(3.678)	(7.137)
Observations	523	523	523	523

Source: Author computations.

lnbondprice1-Log of Bond Prices, lnexr-Log of Exchange Rate (USD-INR), lnprice-Electricity Prices. Parentheses contain Std. Error - *** Sig. at 1%, Sig. at 5% and Sig. at 10% respectively.

The threshold variable is lnbondprice1, which has two thresholds at 3.6575 and 3.7512. The maximum number of thresholds in the model is two. The threshold variable is negatively related to lnprice in Region1, as the coefficient for lnbondprice1 in Region1 is -1.595866. This suggests that when lnbondprice1 is below the threshold, lnprice is higher in Region1. The threshold variable is positively related to lnprice in Region2, as the coefficient for lnbondprice1 in Region2 is 4.057235. This suggests that when lnbondprice1 is above the threshold, lnprice is higher in Region2. The coefficient for lnexr is positive and significant at the 10% level in the model, suggesting that an increase in lnexr is associated with an increase in lnprice. The intercept term varies across regions, with Region1 having the highest intercept (9.563563) and Region2 having the lowest intercept (-11.20795).

The threshold regression suggests that there may be different relationships between lnbondprice1 and lnprice in different regions, as the coefficients for lnbondprice1 differ across regions. Additionally, the coefficient for lnexr suggests that it may also play a role in determining lnprice.

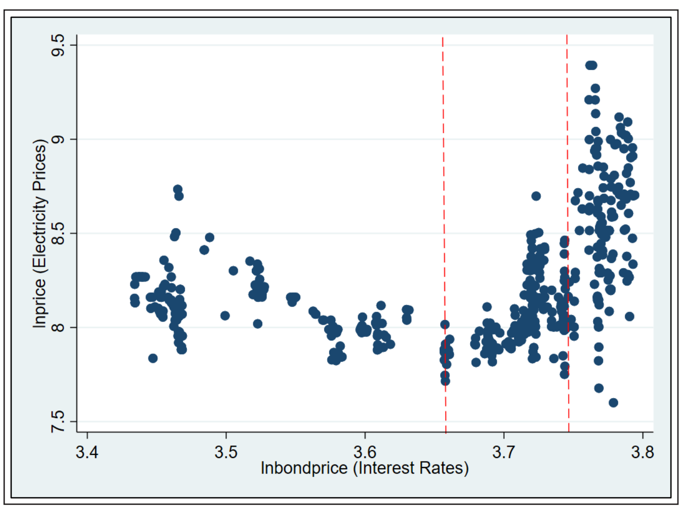
Threshold Regions

Region 1: The coefficient of lnbondprice1 is negative and statistically significant at the 1% level, indicating that there is a negative linear relationship between lnbondprice1 and lnprice in this region. This suggests that as the bond price increases, the price of electricity decreases, holding other factors constant. The intercept coefficient (the constant term) is positive and statistically significant, indicating that there is a positive relationship between the intercept and lnprice. This suggests that the base level of lnprice is higher in Region 1 compared to other regions, holding other factors constant.

Region 2: The coefficient of lnbondprice1 is positive and statistically significant at the 1% level, indicating that there is a positive linear relationship between lnbondprice1 and lnprice in this region. This suggests that as the bond price increases, the price of electricity also increases, holding other factors constant. The intercept coefficient is negative and statistically significant, indicating that the base level of lnprice is lower in Region 2 compared to other regions, holding other factors constant.

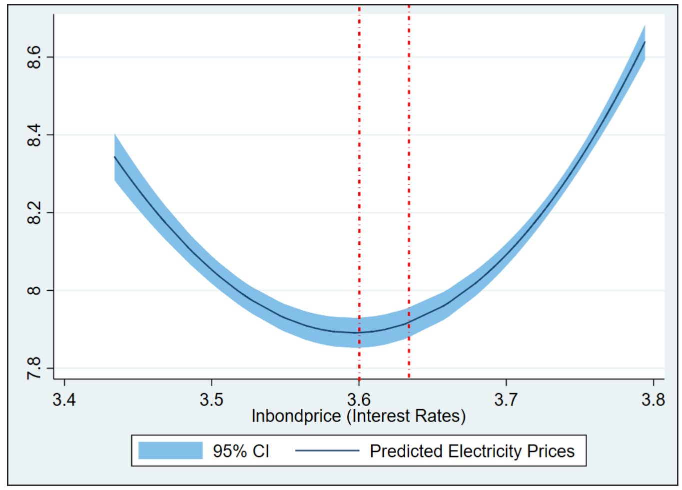
Region 3: The coefficient of lnbondprice1 is not statistically significant at the 5% level, suggesting that there is no linear relationship between lnbondprice1 and lnprice in this region. This implies that the bond price may not be a significant predictor of EP in Region 3. The intercept coefficient is also not statistically significant at the 5% level, indicating that the base level of lnprice is not significantly different from zero in Region 3.

The relationship between bond prices and electricity demand differs across the three regions. In Region 1, there is a negative relationship between bond prices and electricity demand, suggesting that when bond prices increase, electricity demand decreases. In Region 2, there is a positive relationship, indicating that when bond prices increase, electricity demand also increases. In Region 3, the relationship is found to be insignificant, which means that there is no significant relationship between bond prices and electricity demand in that region.



Source: Author computations.

Fig. 1: Scatter-Plot between Electricity Prices and Bond Prices with Threshold Regions



Source: Author computations.

Fig. 2: Non-Linear Relationship between Bond Prices and Electricity Prices (Optimality Identification)

CONCLUSIONS

This research paper examines the relationship between bond prices and electricity demand across different regions in the United States using threshold regression analysis. The purpose of this study is to investigate whether there is a non-linear relationship between bond prices and electricity demand and if this relationship differs across different regions. The data covers a period of five years, and the analysis includes three different regions: Region 1, Region 2 and Region 3. The results of the threshold regression analysis show that there is a significant non-linear relationship between bond prices and electricity demand, and this relationship differs across the three regions. In Region 1, there is a negative relationship between bond prices and electricity demand, while in Region 2, there is a positive relationship. In Region 3, the relationship is found to be insignificant. In general, when interest rates rise, bond prices tend to fall and when interest rates fall, bond prices tend to rise. In Region 1, where there is a negative relationship between bond prices and electricity demand, it is possible that interest rates are high, leading to lower bond prices and lower electricity demand. In Region 2, where there is a positive relationship between bond prices and electricity demand, it is possible that interest rates are low, leading to higher bond prices and higher electricity demand. It is also possible that there is an optimal situation between bond prices (interest rates) and EP, beyond which the EP increase. This could be due to the fact that as bond prices (interest rates) increase, the cost of financing for electricity companies also increases, which may lead to higher EP. However, there may be a certain threshold beyond which the cost of financing becomes too high, leading to a decrease in investment and ultimately a decrease in electricity supply, which in turn could lead to higher EP.

These findings have important implications for policymakers and investors who are interested in the relationship between bond prices and electricity demand in the India. The research suggests that there may be an optimal balance between bond prices (interest rates) and EP, beyond which EP may increase. Managers need to find the right balance between financing and pricing to ensure a sustainable supply of electricity at reasonable prices.

Indian electricity companies may face challenges in financing their operations due to factors such as high capital costs and regulatory issues. Therefore, it is crucial for managers to find the right balance between financing and pricing to ensure that their companies can sustainably supply electricity at reasonable prices. Managers can use the insights from this research to guide their decision-making regarding financing and pricing strategies. For example, they can use the findings to identify the threshold beyond which the cost of financing becomes too high, leading to a decrease in investment and ultimately a decrease in electricity supply, which in turn could lead to higher EP. By doing so, managers can ensure that their companies operate within the optimal balance between bond prices and EP, thereby improving the sustainability and profitability of their businesses.

Declaration of Conflicting Interests

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