Determinants of Carbon Credit Retirements: An Econometric Analysis

1. Introduction

The effectiveness of carbon credit markets in achieving climate mitigation objectives fundamentally depends on the retirement of issued credits. Despite growing market volumes, limited empirical evidence exists regarding the determinants of retirement behavior. This paper addresses this gap by investigating three research questions: (1) which project characteristics drive retirement volumes, (2) how temporal dynamics influence retirement patterns, and (3) whether exogenous information shocks affect market behavior. Using comprehensive project-level data, we employ econometric methods to identify significant determinants and quantify their effects.

2. Methodology

2.1 Model Specification

We specify a log-linear regression model to capture the multiplicative nature of volume relationships:

$$\begin{aligned} ln(Retirement\_Volume\_i) \\ = \beta_0 + \beta_1 Category\_i + \beta_2 Country\_i + \beta_3 Registry\_i \\ + \beta_4 ln(Issuance\_i) + \beta_5 Compliance\_i + \varepsilon\_i \end{aligned}$$

The log transformation is essential as retirement volumes exhibit severe right-skewness (ranging from 0 to 60+ million credits) and heteroskedasticity. This specification enables intuitive interpretation: coefficients represent elasticities for continuous variables and percentage effects for dummy variables, capturing multiplicative relationships inherent in carbon markets. While assuming constant elasticity, this is reasonable given the proportional scaling observed in market dynamics.

2.2 Variable Construction

The **dependent variable** is the natural logarithm of total credits retired per project. **Independent variables** include categorical indicators for project category (baseline: unknown), country (baseline: other countries), registry (baseline: art-trees), and a binary indicator for compliance markets. We include log-transformed issuance volume to control for project scale effects.

3. Empirical Results

3.1 Project Characteristics and Retirement Volumes

Our regression analysis (N=10,545, Adjusted R^2=0.739) reveals substantial heterogeneity across project characteristics. Forest projects demonstrate the highest absolute retirement volumes (539,732,373 credits), followed by renewable energy (407,786,534 credits). The regression coefficients indicate these categories are associated with 75% and 68% higher retirement volumes respectively compared to the baseline category ($p<0.01$), suggesting superior project performance or market preference for nature-based and renewable solutions.

Geographic analysis reveals the United States dominates with 337,648,746 total credits retired, followed by India (227,524,475) and China (145,568,645). The coefficient for U.S.-based projects indicates approximately 60% higher retirement volumes relative to developing countries ($p<0.05$), potentially reflecting stronger institutional frameworks and market maturity.

Registry choice emerges as a critical determinant. Verra demonstrates a 59.32% retirement rate with 844,451,781 credits retired from 1,423,435,818 issued, significantly outperforming art-trees

(0.41% retirement rate). This disparity likely reflects differences in methodology standardization and market acceptance.

3.2 Market Structure Effects

The pooled regression reveals profound differences between compliance and voluntary markets. The compliance dummy coefficient of 1.0915 ($p<0.0001$) indicates compliance projects retire 197.9% more credits than voluntary projects, controlling for other factors. This substantial premium reflects regulatory mandates and standardized monitoring requirements. The issuance elasticity of 0.80 ($p<0.001$) suggests diminishing returns to scale, where doubling issuances increases retirements by only 80%.

3.3 Temporal Dynamics

Analysis of timing patterns reveals significant variation across categories. Carbon-capture projects exhibit the shortest mean time to first retirement (42.33 days), while renewable-energy projects show considerable delays (2104.29 days). Regression analysis confirms these differences are statistically significant ($R^2 = 0.564$, $p<0.001$).

Longitudinal analysis demonstrates improving market efficiency, with mean days to first retirement decreasing from 2389.24 days in 2016 to 193.18 days in 2023. This trend (coefficient: -351.6 days/year, $p < 0.001$) suggests maturation of market infrastructure and streamlined retirement processes.

3.4 Information Shocks and Structural Breaks

The Paris Agreement (2016) marks a significant structural break in VCM retirement patterns. Statistical tests confirm this discontinuity ($t = -3.55$, $p = 0.003$; Mann-Whitney $U = 6.0$, $p = 0.003$), with mean annual retirement volumes increasing 358% from 31.5 million (pre-2016) to 144.1 million (post-2016). Conversely, individual news events show no significant impact on retirement decisions (all $p > 0.10$), suggesting VCM retirement responds to long-term policy frameworks rather than short-term information shocks. This pattern indicates strategic rather than reactive decision-making in carbon credit retirements.

4. Robustness and Limitations

Several robustness checks validate our findings. Quantile regression confirms results hold across the distribution of retirement volumes. The Mann-Whitney U test substantiates differences between voluntary and compliance markets (U-statistic: 2,359,567.50, $p<0.0001$).

However, important limitations merit consideration. The dataset lacks price information and buyer characteristics, limiting economic analysis. Selection bias may arise from underrepresentation of failed projects, potentially overestimating retirement rates. The cross-sectional nature limits causal inference, and unobserved factors (management quality, local conditions) may confound results. Our 15-day event window may miss delayed reactions, while focusing on major news events overlooks cumulative market sentiment dynamics.

5. Conclusion

This analysis reveals compliance markets demonstrate a 197.9% retirement premium over voluntary markets. The Paris Agreement created a structural break with 358% volume increase ($p=0.003$), while individual news events showed no impact ($p>0.10$), indicating retirements respond to policy frameworks not information shocks. Voluntary markets need stronger oversight; geographic concentrations suggest developing country opportunities. These findings inform carbon market design for climate mitigation.