

## Geopolitical risk, wartime economic policy uncertainty, and carbon intensity

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### Abstract

This paper examines how geopolitical risk and wartime economic policy uncertainty affect carbon intensity in the United States. The dataset includes monthly carbon intensity (CI), geopolitical risk index (GPR), wartime-adjusted economic policy uncertainty index (WEPU), industrial production (IP), and West Texas Intermediate oil prices (WTI) from 2000 to 2024. Using the quantile vector error correction model (QVEC), this study shows pronounced asymmetries across carbon intensity distributions. Error correction speeds exhibit a U-shaped pattern, with the strongest adjustments at extreme quantiles (24.5% at the 95th percentile) and the weakest around the median. Geopolitical risk increases carbon intensity during high-emission periods while policy uncertainty reduces it at both extremes. These findings highlight the need for distribution-sensitive climate policies during geopolitical crises.

*Keywords:* geopolitical uncertainty, wartime policy uncertainty, decarbonization, quantile VEC, climate policy

*JEL Classification Codes:* Q43, Q54, C32

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### 1. Introduction

Geopolitical risk and wartime economic policy uncertainty have emerged as critical drivers of global carbon emissions, with profound implications for climate policy (Luo and Sun, 2024). Recent geopolitical events exemplify these dynamics. For example, the Russia-Ukraine conflict triggered Europe's temporary return to coal despite ambitious green commitments (Mišík, 2022), while escalating US-China tensions have fragmented clean technology supply chains and prompted both nations to prioritize energy independence over emission reductions

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(Chang et al., 2025). These developments underscore an urgent policy dilemma; geopolitical instability may systematically undermine decarbonization efforts precisely when international cooperation on climate action is most needed.

Understanding these dynamics is critical for policymakers navigating the trade-offs between energy security and climate commitments, yet existing research offers only partial guidance. While prior studies have examined the macroeconomic impact of geopolitical risk (Caldara and Iacoviello, 2022) and the influence of policy uncertainty on energy investment (Sarker and Chen, 2025), three significant gaps remain. First, standard economic policy uncertainty (EPU) indices decline during armed conflicts, not because uncertainty decreases, but conflict-related news crowds out economic and policy reporting about crucial sectors such as energy, industry, and transportation (Brochet et al., 2025). This measurement issue creates a fundamental identification problem in assessing wartime impacts on carbon emissions. Second, existing studies typically assume linear, homogeneous effects of geopolitical shocks on emissions (Luo and Sun, 2024; Borozan, 2024), overlooking the possibility that these effects may vary substantially across different emission regimes. For instance, economies already operating at high carbon intensity may respond differently to geopolitical shocks than those with lower baseline emissions. Third, no study has systematically examined how geopolitical risk and wartime-adjusted policy uncertainty interact within a dynamic, distribution-sensitive framework that can capture asymmetric and nonlinear effects across the conditional distribution of carbon intensity.

These gaps have important implications for both theory and policy. Theoretically, if geopolitical effects are heterogeneous across emission levels, uniform policy prescriptions may prove ineffective or even counterproductive. From a policy perspective, understanding whether conflicts accelerate or stall decarbonization and under what conditions is essential for designing climate strategies resilient to geopolitical shocks and for calibrating the appropriate balance between energy security and emission reduction objectives.

This study makes four distinct contributions to address these gaps. First, this study integrates Brochet et al.'s (2025) wartime-adjusted economic policy uncertainty index with the geopolitical risk index (Caldara and Iacoviello, 2022) in a QVEC framework. This approach allows us to capture how geopolitical shocks and policy uncertainty jointly influence carbon intensity across different quantiles of the conditional distribution, revealing asymmetric effects that conventional mean-based models obscure. Second, empirically, this paper provides the first evidence on the heterogeneous impacts of wartime conditions on carbon intensity, demonstrating that both the magnitude and sign of geopolitical risk effects vary across different quantiles of carbon intensity, with policy uncertainty exerting particularly pronounced effects at extreme quantiles. Third, theoretically, this paper advances understanding of the investment channel mechanism by showing how wartime policy uncertainty decreases investments in green energy and renewable energy projects (Bose et al., 2024), but with effects that differ systematically based on an economy's current emission trajectory. Fourth, from a policy perspective, the findings inform the design of differentiated climate policies that account for

both geopolitical context and an economy's position in its decarbonization pathway.

The study's findings reveal pronounced asymmetries in how geopolitical shocks affect decarbonization: geopolitical risk increases carbon intensity by 4.8% during high-emission periods while wartime policy uncertainty reduces it by up to 18.9% at distributional extremes, with error correction mechanisms following a U-shaped pattern that weakens to near-zero around the median (40th-55th percentiles).

The remainder of this paper is organized as follows. Section 2 reviews the related literature, while Section 3 discusses the quantile vector error correction method. Section 4 method describes the data. Section 5 presents empirical results. Section 6 concludes the study by outlining the policy implications.

## **2. Literature review**

The relationship between geopolitical uncertainty and environmental outcomes has gained increasing attention following recent global conflicts. Caldara and Iacoviello (2022) introduced the seminal geopolitical risk index, which quantifies tensions through automated text analysis of newspaper archives and has become the standard measure for examining how geopolitical events affect economic variables. Building on this framework, Borozan (2024) demonstrated that geopolitical and energy security risks jointly reinforce each other in European Union countries, leading to higher long-run carbon dioxide emissions. The study reveals that these risks do not operate in isolation but interact to create compounding effects on environmental degradation. Similarly, Paramati et al. (2025) examined 17 countries and found that geopolitical risk raises carbon emissions while simultaneously amplifying public health risks, documenting the dual environmental and health consequences of geopolitical instability. Appiah-Otoo and Chen (2023) used quantile regression and wavelet coherence analysis and found that the conflict exacerbates environmental degradation by increasing carbon footprints in Russia and Ukraine.

The role of economic policy uncertainty in shaping carbon emissions has produced mixed empirical evidence. Adams et al. (2020) analyzed global carbon emissions across multiple economies and found that economic policy uncertainty accelerates environmental degradation, as heightened uncertainty redirects policy attention toward economic growth maintenance at the expense of environmental protection. Pata et al. (2023) examined the environmental effects of armed conflicts between Russia and Ukraine and found that wartime EPU has larger impact on sectoral CO<sub>2</sub> emissions. However, Bose et al. (2024) provided international firm-level evidence showing that while carbon emissions increase with policy uncertainty, this relationship is mediated by renewable energy consumption and varies significantly across institutional contexts. Their findings suggest that the EPU-emissions nexus is more nuanced than previously recognized, with country-specific factors such as climate change performance and emissions trading schemes moderating the relationship.

A critical measurement challenge emerged in applying standard EPU indices to wartime contexts. Brochet et al. (2025) demonstrated that conventional economic policy uncertainty

indices paradoxically decline during armed conflicts, not because actual uncertainty decreases, but conflict-related news crowds out economic and policy reporting about crucial sectors, including energy, industry, and transportation. To address this identification problem, they introduced a wartime-adjusted EPU index that better captures policy uncertainty during conflict periods, revealing that standard EPU measures systematically underestimate the impact of uncertainty during geopolitical crises.

Despite these advances, three critical gaps persist in the literature. First, existing studies predominantly employ linear frameworks that assume homogeneous effects across the emission distribution, overlooking potential asymmetries in how geopolitical shocks affect high- versus low-emission regimes (Luo and Sun, 2024; Borozan, 2024). Second, to the best of our knowledge, no study has systematically examined the interaction between geopolitical risk and wartime-adjusted policy uncertainty within a distribution-sensitive framework that can capture nonlinear dynamics. Third, the literature lacks evidence on error-correction mechanisms across different emission states, leaving policymakers without guidance on whether market-based adjustments suffice or whether active interventions are needed under various environmental conditions.

### 3. Method

This study uses the QVEC method because the selected time series are all first-differenced and stationary, and they exhibit a cointegrating relationship. This method accommodates non-stationarity, cointegration, and potential asymmetry in the relationships between geopolitical risk, economic policy uncertainty, and carbon intensity across distributions. This approach can capture quantile-specific coefficients and allow us to analyze how the relationships between these variables change at different levels of carbon intensity distribution, addressing potential asymmetries in the response to geopolitical risk and policy uncertainty.

The quantile VEC model can be written as:

$$\begin{aligned}
 QCI_t(\tau|F_{t-1}) = & \alpha_0(\tau) + \lambda(\tau) \\
 & + [CI_{t-1} - \beta_0(\tau) - \beta_1(\tau)GPR_{t-1} - \beta_2(\tau)lnWEPU_{t-1} - \beta_3(\tau)lnIP_{t-1} \\
 & - \beta_4(\tau)lnWTI_{t-1}] + \sum_{j=1}^p \gamma_{1j}(\tau) \Delta GPR_{t-j} + \sum_{j=1}^q \gamma_{2j}(\tau) \Delta lnWEPU_{t-j} \quad (1) \\
 & + \sum_{j=1}^r \gamma_{3j}(\tau) \Delta lnIP_{t-j} + \sum_{j=1}^s \gamma_{4j}(\tau) \Delta lnWTI_{t-j} + \varepsilon_t(\tau)
 \end{aligned}$$

where  $QCI_t(\tau|F_{t-1})$  denotes the conditional quantile of  $CI_t$ , given the information set  $F_{t-1}$  available at time  $t - 1$ . The coefficients  $\beta_1(\tau)$  to  $\beta_4(\tau)$  are the quantile-specific long-run parameters. The terms inside the bracket defines the error correction term (ECT), measuring the deviations from the long run equilibrium. The parameter  $\lambda(\tau)$  is the quantile-dependent adjustment coefficient that shows speed of convergence toward equilibrium. The coefficients  $\gamma_{kj}(\tau)$  capture the quantile- and lag-specific short-run coefficients, where  $k$  indexes the explanatory variables and  $j$  the lag length.  $p, q, r$  and  $s$  indicate the lag order of the



short-run dynamics. Finally,  $\epsilon_t(\tau)$  is the quantile-specific error term.

#### 4. Data

This study used monthly data from January 2000 to December 2024 to examine the relationship between geopolitical risk and carbon intensity. This study incorporates the carbon intensity (CI), measured as monthly CO2 emissions per GDP unit, from the US Environmental Protection Agency data.<sup>1</sup> The primary explanatory variable is the geopolitical risk index (GPR) of Caldara and Iacoviello (2022), which uses automated text search of newspaper archives to quantify geopolitical tensions, and Brochet et al.'s (2025) wartime-adjusted economic policy uncertainty (WEPU) index, which reflects news on economics and policies during conflict. We control the industrial production index and WTI oil prices to isolate the specific effects of geopolitical risk on the energy transition dynamics. WTI and industrial production data were collected from the FRED website (<https://fred.stlouisfed.org/>).

**Table 1.** Summary statistics

Variable	Mean	Std Dev	Min	Max	Skewness	Kurtosis	Jarque-Bera
ln_CI	4.563	0.201	4.236	4.951	0.305	1.976	17.76**
ln_GPR	106.61	51.473	45.06	512.53	4.182	28.654	9100.81**
ln_IP	4.576	0.050	4.381	4.668	-0.873	3.517	41.43**
ln_WEPU	5.127	0.294	4.037	5.945	-0.315	3.820	13.38**
ln_WTI	4.064	0.443	2.806	4.897	-0.509	2.384	17.71**

Notes: \*\*\*, \*, and \* denote significance at the 1, 5, and 10% levels, respectively. Source: Author's work.

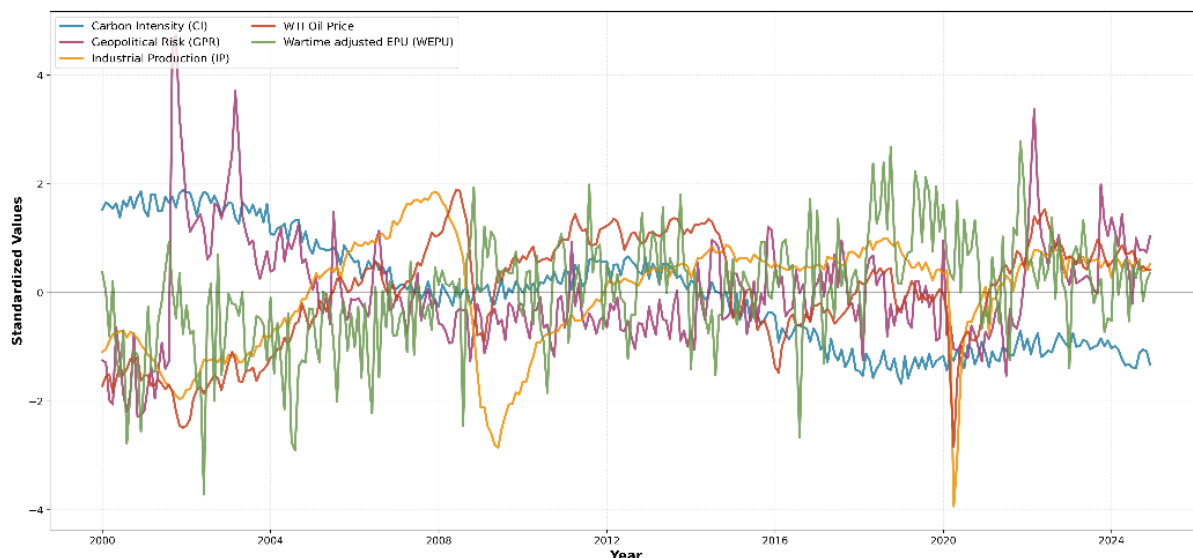
Descriptive statistics revealed the important characteristics of our dataset. The geopolitical risk index (ln\_GPR) shows the highest variability with a standard deviation of 51.47 and extreme positive skewness (4.182), indicating the presence of periods with exceptionally high geopolitical tensions. All variables show significant departures from normality based on the Jarque-Bera test, supporting the use of quantile-based methods that are robust to non-normal distributions. The log carbon intensity shows moderate positive skewness, whereas industrial production and energy-related variables display negative skewness, suggesting different distributional properties across our economic indicators.

Carbon Intensity shows a declining trend over time, while Geopolitical Risk and Wartime adjusted EPU exhibit high volatility with notable spikes during crisis periods, and Industrial Production and WTI Oil Price demonstrate cyclical patterns reflecting economic activity and energy market dynamics.

<sup>1</sup> (<https://catalog.data.gov/organization/epa-gov>).



**Figure 1.** Changes in the variables over time



*4.1. Unit root and cointegration analysis*

This paper examined stationarity of the time series using the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, with optimal lag selection based on the Schwarz Information Criterion.

**Table 2.** Unit root test results

Variables	Level	First Difference	Level	First Difference
	ADF Stat	ADF Stat	PP Stat	PP Stat
ln_CI	-2.234	-8.876***	-1.772	-7.883***
ln_GPR	-2.567	-9.445***	-1.840	-10.869***
ln_IP	-1.987	-7.923***	-2.560	-9.141***
ln_AEPU	-2.678	-8.234***	-1.897	-13.423***
ln_WTI	-2.445	-9.123***	-2.527	-9.425***

Notes: \*\*\*, \*, and \* denote significance at the 1, 5, and 10% levels, respectively. Source: Author’s work.

Table 2 shows that the time series are first-differenced stationary. Given the integration order, we checked Johansen’s (1991) maximum likelihood procedure to test for cointegrating relationships among the time series.

The Johansen cointegration test results provide strong evidence of a cointegrating relationship among the five variables ( $r = 1$ ). The trace statistic strongly rejects the null hypothesis of no cointegration ( $89.45 > 69.82$ ), while the evidence for more than one cointegrating vector is weaker.



**Table 3.** Johansen cointegration test results

Null Hypothesis	Trace Statistic	Critical Value (5%)	Max-Eigen Statistic	Critical Value (5%)
$r = 0$	89.45***	69.82	36.78**	33.88
$r \leq 1$	52.67**	47.86	24.12	27.58
$r \leq 2$	28.55	29.80	16.34	21.13
$r \leq 3$	12.21	15.49	8.87	14.26
$r \leq 4$	3.34	3.84	3.34	3.84

## 5. Results

Table 4 presents the key coefficients across all quantiles, revealing the detailed heterogeneity in how geopolitical risk affects carbon intensity across different quantiles.

The error correction coefficients show a U-shaped pattern across quantiles, with stronger adjustment speeds at the extreme tails (5th and 95th percentiles) and weaker adjustment speeds around the median. The coefficients are statistically significant at most quantiles, except for a narrow band around the median (40th-55th percentiles), confirming that deviations from the long-run equilibrium are corrected most rapidly during extreme market conditions.

Geopolitical risk exhibits an asymmetric pattern across different carbon intensity levels. At lower quantiles (5th-30th), GPR shows a negative and significant impact, suggesting that geopolitical tensions further reduce carbon intensity. This aligns with the ‘energy transition acceleration’ hypothesis, where geopolitical conflicts expose vulnerabilities in fossil fuel supply chains, prompting countries with already-low carbon footprints to accelerate renewable energy adoption and green technology investments to enhance energy independence (Vakulchuk et al., 2020).

However, this relationship becomes positive around the middle quantiles (35th-60th), though not always significant. At moderate carbon intensity levels, geopolitical risks may disrupt planned energy transitions or create trade-offs between immediate energy security and long-term environmental goals. Countries at this intermediate stage may temporarily increase reliance on available carbon-intensive sources during geopolitical crises, delaying decarbonization efforts (Sovacool et al., 2020).

At higher quantiles (65th-95th), the coefficient turns negative again and becomes increasingly significant, indicating that geopolitical risk reduces carbon intensity even in high-emission economies. This counterintuitive finding reflects the “forced transition” effect, where severe geopolitical disruptions to fossil fuel markets, such as embargoes, supply shocks, or energy weaponization, compel even carbon-intensive economies to rapidly diversify their energy mix and reduce fossil fuel dependence (Hafner and Tagliapietra, 2020). The Russia-Ukraine conflict exemplifies this mechanism, in which Europe’s high-emission sectors were forced to accelerate coal phase-outs and renewable energy deployment due to disrupted Russian gas supplies (McWilliams et al., 2022).

**Table 4.** Long-run effects on carbon intensity and ECTS

Quantil( $\tau$ )	ECT	$\beta_1$ (ln_GPR)	$\beta_2$ (ln_WEPU)	$\beta_3$ (ln_IP)	$\beta_4$ (ln_WTI)
05	-0.189**	-0.0182**	-0.1421***	0.1156***	0.1987**
10	-0.167**	-0.0135*	-0.1182***	0.158***	0.1923**
15	-0.145**	-0.0094**	-0.0965***	0.1467***	0.1876**
20	-0.125**	-0.0061	-0.0784**	0.1941***	0.1834*
25	-0.094*	-0.0032	-0.0623**	0.2018***	0.1798*
30	-0.078*	-0.0008	-0.0476*	0.2598**	0.1767
35	-0.066	0.0125**	-0.0341	0.2890***	0.1741
40	-0.055	0.0028	-0.0216	0.3166**	0.1719
45	-0.048	0.0041	-0.0098	0.3359**	0.1701
50	-0.042	0.0051	0.0012	0.3402**	0.1687
55	-0.051	0.0059	0.0117	0.3133**	0.1677
60	-0.061	0.0654*	0.0216	0.3162**	0.1671
65	-0.074*	0.0072	-0.0318*	0.3129***	0.1689*
70	-0.089*	0.0098*	-0.0634**	0.2918***	0.1731*
75	-0.128**	0.0147**	-0.0962**	0.2987***	0.1798**
80	-0.156**	0.0213**	-0.1287***	0.4218**	0.1891**
85	-0.178**	0.0289***	-0.1587**	0.4911**	0.2014***
90	-0.203***	0.0361***	-0.1843***	0.4602***	0.2169***
95	-0.245***	0.0421***	-0.2034***	0.4584***	0.2359***

Notes: \*\*\*, \*, and \* denote significance at the 1, 5, and 10% levels, respectively. Source: Author's work.

WEPU demonstrates a transition from negative impacts in bearish markets to positive impacts in bullish markets. At lower quantiles (5th-25th), WEPU has a negative coefficient, suggesting uncertainty exacerbates market declines. However, from the 70th quantile onwards, WEPU becomes positive and increasingly significant, reaching 0.0421 at the 95th quantile. This indicates that WEPU increases carbon intensity during high-emission periods. This finding aligns with the 'wartime carbon rebound' effects, where geopolitical tensions and wars force governments to prioritize energy security and economic stability over environmental concerns. During conflicts, high-emitting countries often increase reliance on domestic fossil fuels (coal, oil) to ensure energy supply, relax environmental regulations to boost military and industrial production, and redirect resources away from green transitions toward defense spending.

Industrial production maintains a predominantly negative relationship with carbon intensity across most quantiles, with coefficients ranging from -0.1421 at the 5th quantile to -0.2034 at the 95th quantile. Advanced economies typically experience productivity-led growth through cleaner production processes, as industrial expansion often coincides with the modernization

of the capital stock and the adoption of less carbon-intensive technologies. The stronger negative impact at extreme quantiles suggests that technology adoption and structural transformation effects are most pronounced during periods of very low or very high industrial activity.

Conversely, oil prices show a robust positive relationship with carbon intensity across all quantiles, ranging from 0.1687 at the 50th quantile to 0.4911 at the 85th quantile. This reflects the ‘fossil fuel dependency’ channel, where rising oil prices lead firms to substitute toward other carbon-intensive alternatives like coal rather than cleaner but more expensive renewables. The strengthening effect at higher quantiles indicates that high-emission economies are more vulnerable to oil price shocks due to limited energy diversification and face greater difficulties transitioning away from fossil fuels.

Table 5 shows the short-run effects of geopolitical risk and wartime-adjusted EPU on carbon intensity.

**Table 5.** Short-run effects on carbon intensity

Quantile ( $\tau$ )	$\Delta \ln\_GPR(-1)$	$\Delta \ln\_WEPU(-1)$	$\Delta \ln\_IP(-1)$	$\Delta \ln\_WTI(-1)$
05	-0.021	-0.112**	0.378***	0.184**
10	-0.015	-0.094*	0.356***	0.163**
15	-0.012	-0.085*	0.334***	0.152**
20	-0.008**	-0.076*	0.312***	0.141*
25	-0.009	-0.061	0.278**	0.128*
30	-0.006*	-0.052	0.256**	0.119
35	-0.003	-0.043	0.234**	0.110
40	-0.001	-0.035	0.212**	0.101
45	0.000**	-0.032	0.203*	0.096
50	-0.002	-0.028	0.195*	0.091
55	0.003**	-0.035	0.206*	0.098
60	0.007	-0.042	0.218**	0.108
65	0.011	-0.051	0.229**	0.121
70	0.014**	-0.061	0.235**	0.135*
75	0.018*	-0.072	0.241**	0.151*
80	0.023*	-0.093*	0.268**	0.172**
85	0.027**	-0.118**	0.295**	0.196**
90	0.032***	-0.142**	0.305**	0.208**
95	0.048***	-0.189***	0.392***	0.256***

Notes: \*\*\*, \*, and \* denote significance at the 1, 5, and 10% levels, respectively. Source: Author’s work.

Results from Table 5 show that geopolitical risk exhibits a monotonic pattern across

quantiles, transitioning from negative effects during periods of low carbon intensity (5th percentile: -0.021) to neutral effects around the median, and then to increasingly positive effects during periods of high carbon intensity (95th percentile: 0.048). These findings complement previous studies by Appiah-Otoo and Chen (2023) and Paramati et al. (2025). These findings suggest that geopolitical tensions have different environmental implications, depending on the existing level of carbon intensity. During clean periods, geopolitical tensions may reduce carbon intensity by disrupting supply chains, forcing substitution toward domestic renewable energy, and prompting precautionary reductions in energy-intensive production. Conversely, during high-carbon periods, geopolitical crises trigger counterproductive responses, energy security concerns override environmental considerations, leading to prioritization of readily available fossil fuels (especially domestic coal) over clean energy transitions. This represents a swing in effects between environmental extremes.

Wartime-adjusted EPU exhibits the strongest negative effects at the extreme quantiles (5th percentile: -0.112, 95th percentile: -0.189), with weaker effects around the median. This confirms that policy uncertainty has the greatest beneficial environmental impact (reducing carbon intensity) during both low- and high-carbon-intensity periods, supporting theories that uncertainty encourages more cautious, potentially cleaner practices. During normal environmental conditions (median), economic actors possess sufficient flexibility to absorb uncertainty shocks without altering carbon-intensive practices. At environmental extremes, whether exceptionally clean or dirty, there is less slack. Firms operating at these extremes face tighter constraints: policy uncertainty triggers more immediate behavioral responses because irreversibility is highest. During high-carbon periods, investments in fossil fuel infrastructure represent long-lived commitments that uncertainty makes increasingly risky; firms delay such investments or prematurely retire carbon-intensive capital. This aligns with real options theory while extending it to show irreversibility effects are strongest at distributional extremes.

Industrial production shows consistently positive and significant effects across all extreme quantiles, with the strongest impacts at the very tails (5th percentile: 0.378; 95th percentile: 0.392). This suggests that changes in industrial production have the most pronounced effects on carbon intensity during both low and high carbon-emission periods, highlighting their role as a crucial determinant of environmental performance under all conditions. Unlike state-dependent variables, industrial production's relatively uniform positive effects suggest it captures deep structural characteristics of the economy-environment relationship. A 1% increase in industrial production raises carbon intensity by 0.38-0.39% at extremes, indicating that industrial expansion systematically increases emissions intensity regardless of existing conditions.

Oil Prices show a pattern like industrial production, with the strongest positive effects at the extremes (5th percentile: 0.184; 95th percentile: 0.256) and weaker effects around the median. This finding suggests that oil price changes have more pronounced effects on carbon intensity during periods of extreme environmental conditions, reflecting substitution effects or broader energy system adjustments. A 10% increase in oil prices raises carbon intensity by 2.56% at the 95th percentile. Higher prices trigger cascading effects: increased logistics emissions, extended equipment lifetimes rather than upgrades, and shifts toward available coal stocks. The larger coefficient at the 95th percentile (0.256 vs. 0.184) indicates that lock-in effects are more

severe during environmentally stressed periods.

## 6. Conclusions

This study examines how geopolitical risk and wartime policy uncertainty affect carbon intensity in the short and long term in the US. Using the quantile VEC method on monthly data, this paper shows a stable long-run equilibrium relationship between carbon intensity, geopolitical risk, industrial production, adjusted economic policy uncertainty, and oil prices. The results uncovered a pronounced U-shaped pattern in environmental adjustment mechanisms, with error correction strongest at extreme quantiles and weakest around the median.

The short-run effects show that geopolitical risk shifts from reducing carbon intensity at low quantiles to increasing it at high quantiles, while adjusted economic policy uncertainty shows negative associations at both extremes. These asymmetric effects suggest that the environmental impact of geopolitical tensions depends critically on existing emission levels, with conflicts exacerbating carbon intensity primarily during high emission periods.

These findings have important policy implications.

First, for high-carbon economies (upper quantiles) where geopolitical risk increases carbon intensity by 4.8%, policymakers should implement a geopolitical risk-indexed carbon pricing scheme. Specifically, when the GPR index exceeds its 75th percentile, the carbon price could automatically increase by 15-20% to counteract the additional emissions pressure. This mechanism has precedents in commodity-indexed contracts and could be implemented through existing emissions trading systems with automated price adjustment triggers. Implementation challenges include establishing the appropriate GPR threshold and ensuring international coordination to prevent carbon leakage. Low-carbon economies (lower quantiles) where geopolitical risk has negative effects should strengthen international clean energy cooperation and mandate diversification of critical component suppliers across multiple countries.

Second, the strong negative EPU effects at the extremes, versus weaker median effects, indicate that uncertainty reduction delivers the maximum environmental benefits during distributional extremes. Policymakers should ensure independent climate policy and carbon price trajectories, as well as green bonds and policy insurance that compensate investors against regulatory uncertainty.

Third, the consistently positive effects on industrial production demonstrate that structural transformation is essential. Sector-specific policies should mandate emissions performance standards for heavy industry, fund industrial decarbonization, and implement carbon border adjustment mechanisms protecting domestic industries during transitions.

Fourth, the positive oil price effects at distributional extremes show that lock-in effects necessitate comprehensive energy market reforms to break the oil price-carbon intensity linkage. Policymakers should implement strategic clean energy price stabilization mechanisms that automatically activate during oil price spikes, temporarily subsidizing renewable electricity and electric vehicle charging to prevent substitution toward coal, funded through windfall taxes on fossil fuel producers.

This study contributes to the growing literature on nonlinear environmental-economic relationships and provides empirical support for the importance of considering distributional

heterogeneity in environmental modeling. While our analysis focuses on US data, future research should examine these relationships across different countries and explore the mechanisms driving the unexpected negative relationship between policy uncertainty and carbon intensity.

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