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Vulnerability Assessment of the Natural Gas Financial Market Against the Backdrop of the European Energy Crisis

Yong Luo*

School of Economics, Management and Law, University of South China, Hengyang 421001, P.R. China

*Corresponding Author

Abstract

The European energy crisis revealed the fragility between energy markets and the financial system. The Russia–Ukraine conflict and supply cuts drove extreme volatility in natural gas prices, with Germany, the most dependent on Russian gas, facing severe shocks. Uniper, the country's largest gas importer, suffered soaring procurement costs while price controls limited revenues, leading to a liquidity crisis and eventual state takeover. This study reviews the causes of the crisis and applies a modified Z-score model with Monte Carlo simulation to Uniper's financial data from 2019–2023 to assess the impact of price regulation on debt-servicing capacity. Results indicate that price shocks and policy intervention jointly weakened financial health, as cash flow deficits and worsening leverage became key risk drivers. The modified model better reflects the fragility of energy firms under regulation compared to the traditional model, while Monte Carlo simulation shows a persistent probability of high-risk outcomes even after government rescue. The findings confirm financial fragility theory, suggesting that interventions may delay but cannot eliminate risks, and offer insights for balancing energy security with financial stability in China.

Keywords

Energy Crisis; Price Control; Financial Fragility; Z-Score Model; Monte Carlo Simulation; Uniper.

1. Introduction

The Russia–Ukraine conflict in 2022 fundamentally reshaped Europe's energy landscape, exposing the vulnerability of its dependence on Russian natural gas. Before the crisis, Russia supplied over 40 percent of EU imports, with Germany as the largest consumer. The disruption of Nord Stream pipelines and reduced long-term deliveries forced procurement from spot markets at unprecedented costs. In August 2022, the Title Transfer Facility (TTF) benchmark exceeded 300 euros per megawatt-hour, more than seven times the pre-crisis average. The surge in gas prices placed severe strain on utilities and energy-intensive industries. Many firms bound by fixed-price contracts could not transfer higher costs to customers due to price caps, resulting in substantial cash flow deficits. Uniper, Germany's largest importer and a key supplier to households and industry, became the most notable victim. Dependent on Russian contracts, the company was compelled to purchase replacement volumes at record prices, reporting losses of over 12 billion euros in the first half of 2022. Mounting insolvency risk led to state intervention through emergency loans, equity injections, and eventual nationalization, making Uniper a landmark case of direct government rescue.

Crisis management also involved broad regulatory measures. Germany introduced the "gas price brake" to cap costs for households and small businesses, financed by fiscal transfers. At the EU level, a gas price cap mechanism was approved in late 2022, activated when TTF futures

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exceeded 180 euros per megawatt-hour. While these policies stabilized consumer costs and market expectations, they constrained firms' ability to accumulate internal capital, raising concerns about long-term financial sustainability.

This study investigates how price regulation shaped the solvency of energy firms under market stress, focusing on Uniper as a representative case. Anchored in Minsky's financial instability hypothesis, it analyzes the interaction between cash flow shortages, leverage, and external intervention. A modified Z-score model, adjusted for capital-intensive energy firms, is applied to Uniper's financial data from 2019 to 2023, supplemented by Monte Carlo simulation to capture probabilistic risk scenarios. The research contributes to understanding financial fragility in regulated energy markets and offers insights into the trade-off between consumer protection and corporate resilience. By tracing Uniper's trajectory before, during, and after the crisis, it highlights the structural challenges of balancing energy security with financial stability in Europe, with broader implications for other countries facing similar risks.

2. Literature Review

2.1. Research on Financial Vulnerability

The study of financial fragility originates from the "financial instability hypothesis," which argues that during economic upswings, financing structures often shift from stable to speculative and even Ponzi-like forms. Rising leverage and short-term liabilities increase systemic risk, and once cash flows collapse, asset devaluation and crises may follow [1]. Key variables such as capital adequacy, profitability, and liquidity are recognized as channels through which micro-level risks transmit to the macro system, with the effect especially pronounced in highly leveraged sectors like energy. In the European energy crisis, companies dependent on external supply quickly experienced liquidity shortages as gas prices soared, illustrating a chain reaction of "cash flow gaps-asset devaluation-financing breakdown" [2].

2.2. European Energy Crisis

The crisis also offers an empirical case for this theory. Direct triggers included geopolitical conflict and extreme weather, while deeper causes stemmed from structural reliance on fossil fuels and imbalances in the energy transition [3]. Natural gas prices at the peak surpassed 300 euros per MWh, with fuel costs exceeding 90 percent of expenses. Price caps and windfall taxes limited revenue, driving many firms into negative cash flows [4][5]. While these policies reduced the burden on households and small businesses, they constrained firms' capacity for internal accumulation, raised debt dependence, and accelerated fragility [6]. This reflects the dual effect of policy, stabilizing conditions in the short term while amplifying long-term default risks, consistent with the hypothesis that instability is delayed rather than eliminated [7].

2.3. Discussion on Empirical Tools

For empirical assessment, the Z-score model remains widely applied, combining five financial ratios to evaluate bankruptcy risk. Although effective in early warning, its accuracy declines under inflated valuations or short-term debt concentration [8]. Modified versions for capital-intensive and renewable energy firms highlight leverage, income, and cash flow as the most significant indicators, improving predictive accuracy [9]. This demonstrates its utility in capturing both static solvency and dynamic changes under shocks and regulatory measures. Monte Carlo simulation, developed as a stochastic method for numerical approximation, has become a standard tool for assessing financial risk. By generating random price paths, it enables estimation of uncertain impacts on corporate resilience [10]. Applied to natural gas markets, it helps evaluate how volatility and regulation jointly influence firms' debt-servicing capacity.

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2.4. The Existing Literature is Insufficient

Existing studies explain the default mechanisms of leveraged firms and discuss the dual effects of markets and policies during crises, yet they remain largely macro-focused and overlook corporate-level evidence under regulation. This research integrates financial fragility theory with a modified Z-score model and Monte Carlo simulation, constructing an analytical framework of "price shocks-policy intervention-financial fragility ". Within this framework, the European energy crisis and related policy responses are examined to provide the empirical basis for subsequent analysis.

3. European Energy Crisis and Price Regulation Policy Background

Since the second half of 2021, the European energy market has faced unprecedented tension, marked by a sharp surge in natural gas prices. Key drivers include geopolitical conflicts, extreme weather, and structural reliance on imported energy. The Russia–Ukraine war led to a significant reduction in Russian gas exports, while the gradual shutdown of the Nord Stream 1 pipeline in 2022 created a direct supply shortfall. At the same time, unusually cold and dry conditions reduced hydro and nuclear output, forcing higher gas consumption. As Europe accelerated the phase-out of coal and nuclear power during its green transition, natural gas dependence deepened as a transitional energy source. Consequently, the TTF benchmark price exceeded €300/MWh in August 2022, a sevenfold increase from the long-term €20–40/MWh range, placing energy-intensive industries under extreme cost pressures and straining corporate cash flows and financial resilience.

German energy companies were particularly affected. Uniper, Europe’s largest gas importer, supplies over 40% of Germany’s annual consumption and plays a central role in stabilizing downstream utilities and industrial customers. The crisis forced the company to procure gas at high spot-market prices to compensate for Russian supply cuts, resulting in a first-half 2022 loss of €12.3 billion. Reliance on short-term financing and high leverage exacerbated liquidity risk, and declining credit ratings limited access to capital, raising concerns about national energy security. In response, the German government intervened through the state-owned bank KfW, providing emergency liquidity in July 2022 and gradually acquiring a majority stake, surpassing 98% by year-end. Uniper thus became the first large European energy firm to receive complete state rescue, illustrating the complex interplay between market imbalance and policy intervention.

To curb extreme gas price volatility, the EU and member states introduced targeted price interventions. Germany implemented an “energy price brake” in autumn 2022, capping residential and SME gas prices through fiscal subsidies to alleviate social pressure. The EU approved a price cap mechanism in December 2022, automatically triggered when TTF monthly futures exceeded €180/MWh and surpassed global LNG prices, entering effect in February 2023. This mechanism acted as a safety valve to prevent supply shortages or severe financial market disruptions, though negotiations revealed significant divergences among member states, and the final framework represented a compromise.

Price regulation, combined with supply diversification, gradually restored market stability. Germany completed its first floating LNG terminal by late 2022 and commissioned additional terminals in 2023, increasing reliance on U.S. and Qatari imports. EU-wide gas storage targets were largely achieved, with most countries exceeding 90% capacity before winter. Concurrently, industrial and residential energy-saving measures reduced demand. By summer 2023, gas prices fell to approximately €35/MWh, near pre-crisis levels. Nevertheless, corporate financial recovery remained slow, as price caps, while protecting households, limited firms’ profit potential during market rebound, leaving internal reserves insufficient.

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In summary, price regulation temporarily stabilized social and economic operations and mitigated household and SME burdens, but heightened financial vulnerability among energy firms. Uniper's experience demonstrates that policy intervention can postpone systemic risk but cannot fully restore corporate solvency. Moreover, divergences within the EU highlight structural tensions in energy integration. Long-term stability in Europe's energy market will depend not only on price mechanisms but also on diversified supply, enhanced storage capacity, and the steady advancement of the green transition.

4. Research Design and Plan

4.1. Case Selection and Research Framework

This study uses Germany's Uniper as a case, selected for its critical role in European gas supply and its representativeness during the energy crisis. As Germany's largest gas importer, Uniper supplies over 40% of national consumption, relying on a balance between long-term contracts and spot market purchases. Following the 2022 Russia–Ukraine conflict, Russian gas supplies were disrupted, forcing Uniper to procure expensive spot gas to fulfill contractual obligations. Simultaneously, Germany's "gas price brake" policy capped retail prices, creating severe cash flow pressure. This case clearly illustrates how external price shocks combined with policy interventions can rapidly erode the financial stability of energy firms, providing a typical example for studying energy–financial vulnerability.

The research framework follows a "shock–transmission–response" logic, integrating macro-level market analysis with micro-level corporate assessment. At the macro level, it identifies the policy and market origins of price shocks. At the micro level, a modified Z-score model incorporating operating cash flow and equity ratio is applied to evaluate corporate financial vulnerability. Monte Carlo simulations are then used to generate multiple price scenarios, enabling forward-looking assessment of future financial resilience and risk probabilities. This approach combines static historical analysis with dynamic risk forecasting.

4.2. Revise the Application of the Z-score Model

The Z-score model, developed by Altman, is widely used to predict corporate bankruptcy risk based on financial ratios. The original model includes five indicators: working capital (current assets – current liabilities) / total assets (X_1), retained earnings / total assets (X_2), EBIT / total assets (X_3), market value of equity / book value of liabilities (X_4), and sales / total assets (X_5). The formula is as follows:

$$Z = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + 1.0X_5 \tag{1}$$

A Z-score below 1.81 indicates high risk, 1.81–2.65 is a gray area, and above 2.65 is relatively safe. Its simplicity and intuitive results make it widely applied in manufacturing and capital-intensive industries.

However, energy firms are typically highly leveraged and asset-intensive, with financial risk closely tied to cash flow. While the Z-score captures solvency, it has limitations in this context. Government subsidies and long-term supply contracts can distort asset and liability values, and equity market fluctuations influenced by policy and market shocks may reduce model accuracy. Therefore, some indicators require adjustment to enhance sensitivity to cash flow and capital structure.

Previous studies on renewable energy firms have shown that cash flow and leverage are critical for risk identification. Building on these insights, this study extends the traditional Z-score by adding two supplementary indicators: operating cash flow / total assets (X_6) and equity ratio

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(X_7). X_6 reflects the firm's cash-generating capacity and repayment flexibility under external shocks, while X_7 captures equity levels and capital structure stability, revealing the accumulation of financial risk. Comparing the modified and original models allows assessment of whether the adjustments detect risk earlier. The revised formula is as follows:

$$Z = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + 1.0X_5 + \alpha X_6 + \beta X_7 \quad (2)$$

For empirical analysis across industries, the weights of X_6 and X_7 are set to 1, maintaining model simplicity while emphasizing cash flow and capital structure, consistent with Altman's original risk thresholds. Comparing the dynamics of Z and Z* enables evaluation of the model's early warning capacity under crisis conditions.

$$Z^* = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + 1.0X_5 + 1.0X_6 + 1.0X_7 \quad (3)$$

This modified Z-score effectively reveals the temporal evolution of Uniper's financial vulnerability based on historical data. While case analysis primarily explains past events, effective risk management requires forward-looking insights. To enhance predictive value and policy relevance, this study further integrates dynamic Monte Carlo simulations to quantify future gas price volatility and its potential impact on corporate financial health, providing a robust quantitative basis for conclusions.

4.3. Monte Carlo Simulation

To overcome the retrospective perspective of traditional financial analysis and enhance the study's forward-looking and policy relevance, this research extends the static Z-score analysis by incorporating a dynamic quantitative method: Monte Carlo simulation, forming an integrated framework to assess external market risks and the effectiveness of policy interventions.

The study employs a Geometric Brownian Motion (GBM) model to simulate future stochastic paths of TTF natural gas prices. GBM is widely used in finance to model asset price evolution, with its discrete form expressed as:

$$S_{t+\Delta t} = S_t \exp\left(\left(\mu - \frac{\sigma^2}{2}\right)\Delta t + \sigma\sqrt{\Delta t}\varepsilon_t\right) \quad (4)$$

Where S_t denotes the gas price at time t, μ is the drift rate (expected return), σ is the volatility, and Δt is a standard normal random shock. Key parameters (μ,σ) are estimated from historical TTF price data spanning 2022–2025, with volatility reaching 120%, effectively capturing extreme market fluctuations during and after the crisis.

A total of 5,000 future price paths over 24 months are generated to construct the distribution of potential prices, thereby quantifying the financial risk arising from price uncertainty. Based on the previously established quantitative relationship between gas prices and the firm's Z-score, each simulated price path is mapped to a corresponding Z-score trajectory. This enables probabilistic evaluation of Uniper's financial vulnerability under different future scenarios.

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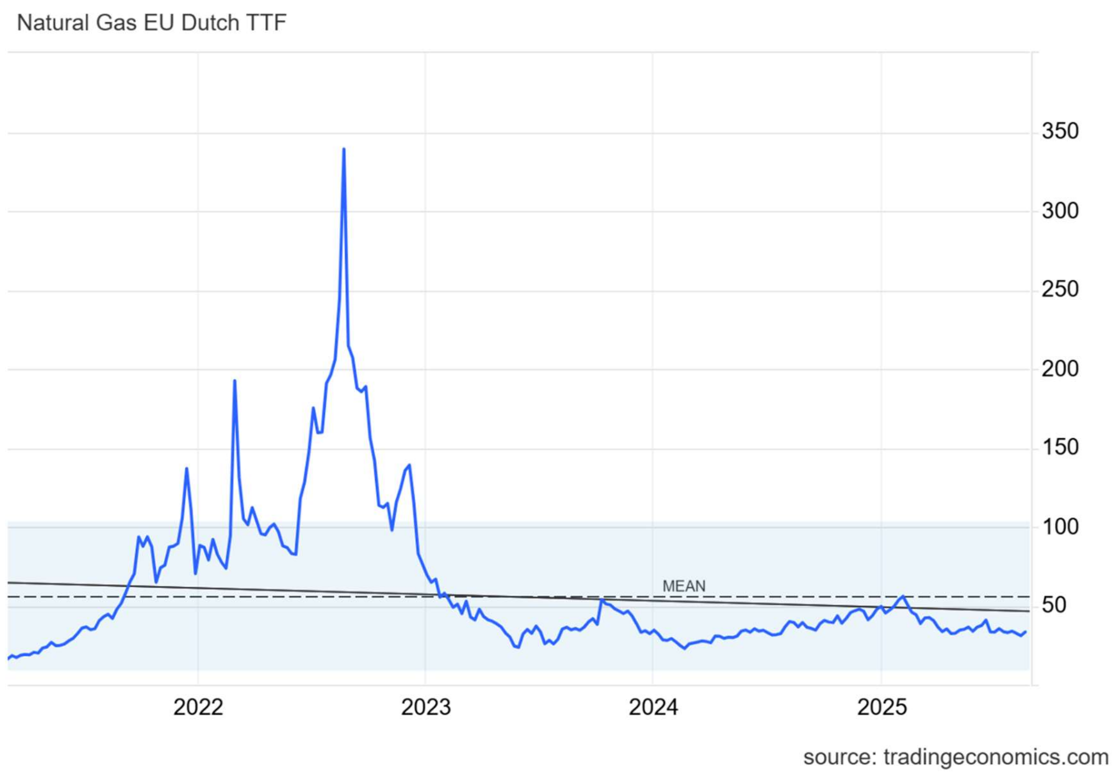

Figure 1. Historical price data of TTF from 2022 to 2025

5. Empirical Analysis and Results

5.1. Data Sources and Results of the Z-score Model

This study uses Uniper's financial statements from 2019 to 2023 to calculate the seven indicators of the modified Z-score model. The required data include total assets, current assets, current liabilities, retained earnings, EBIT, operating revenue, operating cash flow, and total liabilities. If market value of equity is unavailable, book equity is used as a proxy. Annual data were organized to compute each ratio, resulting in yearly Z and Z* values.

Table 1. Uniper Financial Data, 2019–2023

Year	Total Assets	Current Assets	Current Liabilities	Retained Earnings	EBIT	Equity	Total Liabilities	Sales	Operating Cash Flow
2019	43, 756	20, 024	18, 860	3, 145	922	11, 942	31, 814	65, 804	932
2020	40, 222	18, 650	17, 977	3, 082	608	11, 188	29, 033	50, 968	1, 241
2021	128, 397	91, 323	95, 514	-1, 388	-4, 817	6, 788	121, 608	162, 968	3, 296
2022	121, 477	63, 820	57, 443	-19, 840	-11, 530	4, 422	117, 054	274, 121	-15, 637
2023	54, 961	35, 200	26, 316	1, 668	6, 667	10, 436	44, 525	107, 915	6, 549

Table 2. Z and Z* Values of Uniper, 2019–2023

year	Z	Judge	Z*	Judge
2019	1. 93	Grey Interval	2. 23	Grey Interval
2020	1. 68	High Risk	1. 98	Grey Interval
2021	1. 12	High Risk	1. 2	High Risk
2022	1. 8	High Risk	1. 71	High Risk
2023	2. 74	Safe	3. 05	Safe

Results indicate that both the original Z-score and modified Z* model classify the firm as high-risk during extreme crisis years (2021–2022). However, in the borderline year 2020, the original model identifies Uniper as high-risk, whereas the modified model places it in the gray zone. By 2023, both models show the firm entering a relatively safe range, with the modified Z* reflecting a higher value, indicating stronger recovery. This demonstrates that the modified model is more sensitive to changes in cash flow and capital structure, making it better suited for the energy sector.

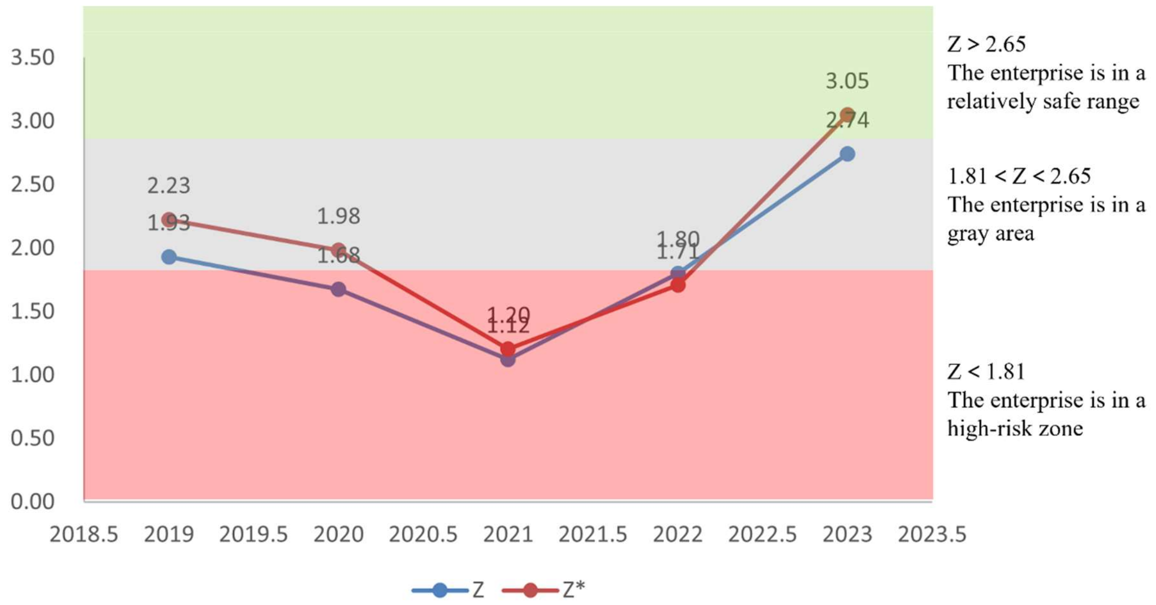

Figure 2. Changes in Z and Z* values from 2019 to 2023

The five-year evolution shows Uniper's financial health following a "stable-tight balance-deterioration-distress-recovery" cycle. The Z* model effectively captures the vulnerability trajectory under the combined influence of market shocks and price regulation.

Changes in financial indicators highlight the profound impact of price control policies on corporate solvency. While stabilizing end-user energy costs, such policies significantly alter the financial structure of energy firms. Between 2021 and 2022, soaring gas import prices coincided with government-imposed retail price caps, preventing cost pass-through. Working capital was rapidly depleted, operating cash flow turned negative, retained earnings declined, and debt growth accelerated. Rising short-term debt ratios increased refinancing difficulty, continuously intensifying repayment pressure.

The modified Z* clearly reflects this mechanism. The model shows that cash flow disruption and declining equity ratio were the key factors driving Z* sharply into the high-risk zone. Even though revenue reached historical highs in 2022, financial health did not improve, as revenue growth decoupled from profitability. Price regulation limited profit recovery, severing the link between revenue scale and debt-servicing capacity. This indicates that while price caps protect end users in the short term, they exacerbate corporate financial vulnerability over the long term.

5.2. Gas Price Risk Analysis based on Monte Carlo Simulation

As discussed earlier, historical data analysis revealed a significant link between price regulation and financial vulnerability. Building on this, this chapter employs Monte Carlo simulation to address forward-looking questions: if gas prices experience extreme volatility again, how would Uniper's vulnerability evolve? How effective are different price regulation policies in mitigating risk? Which policy combinations can best balance consumer protection and corporate risk control?

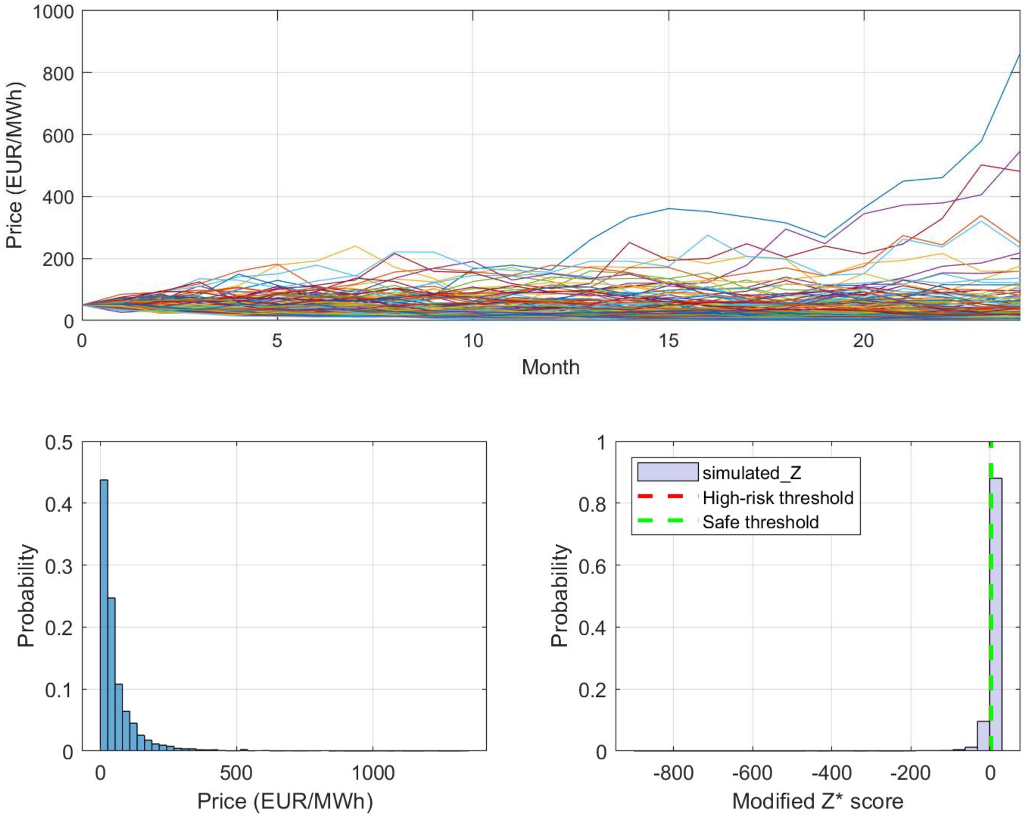

Figure 3. Monte Carlo simulation results

Simulation results map corporate risk under highly uncertain market conditions and illustrate the probability distribution of Z-scores. By the end of the simulation period (2027), the price distribution exhibits a pronounced right skew, indicating that even in the post-crisis era, the European gas market remains highly volatile. Over the next 24 months, TTF prices have a 5% probability of spiking to an extreme high of €200/MWh and a 5% probability of dropping near the €6/MWh operational cost floor. This shows that although unlikely, the market still carries the risk of sharp upward shocks. The 5th percentile extreme low scenario reaches €5.88/MWh, hitting the model's lower bound, reflecting a potential for severe market oversupply.

The probability distribution of Z-scores indicates a 28.58% chance that Uniper could return to the high-risk financial zone ($Z < 1.81$), meaning roughly one-third of scenarios involve severe solvency stress. While the highest probability (48.40%) corresponds to the safe financial zone ($Z > 2.65$), the combination of a 28.58% high-risk probability demonstrates overall financial fragility. The firm's safety buffer is weak, making it highly susceptible to switching between high-risk and safe states in response to external price fluctuations.

5.3. Validation of Gas Market Financial Vulnerability

The Uniper case provides strong empirical support for financial vulnerability theory, illustrating how external shocks, policy interventions, and corporate solvency interact. Using a modified Z-score model, results show that during the 2021–2022 European energy crisis, Uniper remained operational but entered a high-risk financial zone, with solvency heavily reliant on external support. Price regulation stabilized household energy costs and supported

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social stability in the short term, yet it disrupted the firm's market-driven self-repair process and did not resolve structural vulnerabilities caused by cash flow disruptions and declining equity ratios.

Further analysis through Monte Carlo simulation of future scenarios shows that even after nationalization, Uniper has a 28.58% probability of returning to the high-risk zone, confirming that government intervention can prevent immediate collapse but cannot eliminate inherent financial fragility. The firm's solvency remains highly sensitive to volatile international gas prices, highlighting the intrinsic vulnerability of its operating model.

The Uniper case exemplifies the core principle of financial vulnerability theory: risk accumulation driven by cash flow gaps and asset-liability mismatches. Empirical and simulation results show a dual effect at the corporate level: energy price shocks expose financial weaknesses, while price regulation delays but does not resolve risk. These findings suggest that energy security policies should move beyond post-crisis relief, focusing on resilient market structures and corporate financial buffers to maintain stability during the energy transition.

6. Implications and Discussion

6.1. Policy Intervention and Corporate Financial Vulnerability

The Uniper case demonstrates that while price regulation stabilized household and SME energy costs in the short term, it induced cash flow disruptions and debt accumulation at the corporate level. Financial vulnerability arises not only from external price shocks but also from lag effects in policy design. Firms face a disconnect between costs and profits when prices fail to reflect market changes, reducing self-repair capacity. For governments, ongoing subsidies and rescues increase fiscal burden and weaken market self-regulation. This suggests that policy intervention should balance macroeconomic stability with corporate financial resilience.

6.2. Empirical Validation of Financial Vulnerability Theory

Uniper's financial evolution validates Minsky's "financial instability hypothesis." Firms expand operations through external financing during market booms but rapidly face cash flow crises when shocks occur. Policy intervention delays risk realization but does not change the structural vulnerability of finances. Both modified Z-score results and Monte Carlo simulations show that financial vulnerability is structural rather than episodic. Even after state takeover, Uniper has a 28.58% probability of returning to the high-risk zone, indicating that rescue alone cannot fundamentally eliminate fragility.

6.3. Implications for China

China's energy transition and dual carbon goals expose its market to price volatility and policy pressure. The Uniper case offers three lessons: (1) policy should stabilize households while avoiding long-term price distortions that undermine market-driven recovery; (2) energy firms should strengthen capital structure and cash flow resilience to withstand external shocks; (3) multi-layered safeguards combining market signals with fiscal tools can mitigate extreme volatility while maintaining corporate financial independence. These insights are valuable for balancing energy security and financial stability in China.

7. Conclusion

This study analyzes Uniper during the European energy crisis using a modified Z-score model and Monte Carlo simulation to assess the effects of gas price shocks and price regulation on corporate solvency. Results show that while price controls stabilized household energy costs short-term, they undermined Uniper's financial resilience. Between 2021 and 2022, cash flow disruptions and declining equity pushed the firm into a high-risk zone, ultimately requiring

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state intervention. Monte Carlo simulations reveal that even after nationalization, Uniper faces a substantial probability of future financial distress, confirming that policy can delay but not eliminate risk. The findings emphasize the need for energy security policies that balance social stability with corporate resilience, avoid long-term price distortions, strengthen firms' capital structures and cash flow capacity, and implement market-based, multi-layered safeguards. This research provides empirical insights into corporate financial vulnerability during energy crises and offers lessons for China's energy policy and financial risk management.

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