Speculation, Elasticities, and Strategic Storage: Understanding Price Volatility in European Natural Gas Markets

Research Proposal for the
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1. Background and Motivation

Over the past two decades, European energy markets have undergone a profound transformation. In the pursuit of greater liberalization, integration, and efficiency, European countries embraced market-oriented reforms and deepened their dependence on international energy trade—particularly with Russia. Simultaneously, several nations, such as Germany, deliberately phased out domestic nuclear energy production under the assumption that interconnected gas markets would ensure energy security and price stability.

However, recent geopolitical developments—most notably Russia's invasion of Ukraine in 2022—have exposed the fragility of this interdependence. The resulting supply disruptions and price surges have underscored Europe's vulnerability to external shocks. Nowhere has this been more visible than in the natural gas market, where unprecedented volatility in prices and futures contracts has reshaped energy and macroeconomic policy discussions across the continent.

2. Research Objectives

This research program aims to investigate the mechanisms underlying price formation and volatility in European natural gas markets, with a particular focus on the role of speculation, elasticities, and storage. Our overarching goal is to improve the understanding of how financial and physical market dynamics amplify or mitigate macroeconomic vulnerabilities arising from energy dependence.

The study will proceed in three interconnected phases:

2.1. Estimating Elasticities

Building on the framework developed by Knittel and Pindyck in their 2016 *American Economic Journal: Macroeconomics* article, *"The Simple Economics of Commodity Price Speculation,"* we emphasize that the extent to which speculative pressures translate into price movements depends critically on the elasticities of supply and demand. In the context of natural gas markets, it is also essential to account for the role of storage. While not the central mechanism in commodity price dynamics, storage nevertheless affects short-run price responses by providing an additional margin of adjustment. The elasticity of storage—reflecting how inventories respond to price changes, capacity constraints, and regulatory requirements—can influence the degree to which markets absorb or amplify shocks.

For European natural gas markets, these elasticities take on particular importance. Supply responses are shaped by pipeline bottlenecks, LNG regasification limits, and geopolitical disruptions; demand responsiveness remains limited by the restricted short-run substitutability across fuels; and storage operations are affected by physical capacity, injection and withdrawal costs, and seasonal patterns. Together, these factors determine how the system adjusts to shocks and how sensitive prices are to changes in fundamentals or speculative pressures.

Existing empirical estimates for natural gas supply, demand, and storage elasticities are often outdated or based on pre-crisis market structures that no longer reflect current conditions. Using recent data from the Title Transfer Facility (TTF) and other major European hubs, we will estimate updated short-run and long-run elasticities. Our primary approach will employ panel and time-series econometric models that incorporate infrastructure constraints, market integration, and cross-hub arbitrage.

To improve identification and robustness, we will also employ a set of complementary methods and include structural models of gas consumption, production, and storage. Taken

together, these approaches will allow us to develop a more precise and comprehensive set of elasticity estimates for today's European natural gas market.

2.2. Quantifying the Role of Speculation

In our preliminary work, *"Speculators or Fundamentals? European Natural Gas Price Swings Post-2020,"* we find that the impact of speculative activity on short-term price movements remains inconclusive. Estimating the model both over the full sample and across four distinct sub-periods, we find that the influence of speculative pressures on spot prices and the convenience yield is relatively limited. While speculation may play a role, its magnitude and persistence appear modest when compared to shifts in underlying fundamentals.

The next stage will refine this analysis by disentangling speculative trading from fundamental supply-demand shocks using structural time series models and futures–spot prices decompositions. This will allow us to assess the extent to which speculation amplifies volatility and to evaluate whether market-based instruments have destabilized or stabilized price expectations.

2.3. Modeling Strategic Storage and Policy Interventions

Finally, we will develop a dynamic model to analyze the role of government-managed storage facilities as a stabilizing instrument. By simulating alternative policy regimes—such as coordinated European storage, strategic reserves, and capacity expansion—we aim to evaluate how such measures could reduce price volatility, increase resilience, and enhance energy security. This modeling framework will also shed light on the broader macroeconomic implications for the natural gas market instability, including its effects on inflation, fiscal balances, and industrial output.

3. Contribution and Broader Implications

Our research contributes to the intersection of energy economics and macroeconomic policy in three key ways:

1. **Empirical Innovation:** We will provide new elasticity estimates for the European natural gas market—a critical parameter for evaluating both the efficiency and risks of speculative trading.

2. **Financial–Real Linkages:** By quantifying the role of speculation in shaping energy prices, we hope to deepen understanding of how financialization affects real-side outcomes such as investment, production, and energy security.

3. **Policy Relevance:** The analysis of strategic storage policies will offers practical guidance for European and global policymakers seeking to mitigate the macroeconomic effects of energy shocks. Our simulations will inform debates on the optimal design of storage systems and their coordination with fiscal and monetary policy objectives.

4. Relation to Conference Themes

This project directly engages with several core themes outlined in the NBER call for papers:

- The **macroeconomic effects of energy price shocks** and their transmission to inflation, growth, and employment.
- The **transition to more resilient and secure energy systems** in a post-carbon era.
- The **interaction between financial and energy markets**, especially in the context of speculation and volatility.
- The **role of fiscal instruments** (e.g., subsidies, storage investments, severance taxes) in stabilizing local and national economies.

By focusing on Europe's natural gas markets, our research provides a timely case study in how structural dependencies and market design shape macroeconomic exposure to global energy shocks.

5. Expected Outputs and Timeline

- **Phase 1 (Spring–Summer 2025):** Having already collected the relevant datasets, we are currently conducting descriptive analysis, price decompositions, and market structure assessments (see Appendix). The next stage focuses on estimating supply and demand elasticities using panel and time-series econometric techniques. This phase is already underway.

- **Phase 2 (Fall 2025):** Structural decomposition of futures and spot prices to measure speculative activity.
- **Phase 3 (Spring - Summer 2026):** Development of dynamic storage and policy models; simulation of stabilization scenarios.
- **December 2026:** Final paper presentation at the NBER Energy Markets and Macroeconomy Conference.

6. Conflict of Interest Statement

None of the authors have financial or consulting ties to the energy industry. The research is conducted independently and supported solely by academic institutional resources.

Speculators or Fundamentals? European Natural Gas Price Swings Post-2020

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Abstract

We investigate the role of speculation in the European natural gas market over the period 2020–2024. Our analysis proceeds in two steps. First, we replicate the model developed by Knittel and Pindyck (2016) to disentangle the contribution of speculative activity from that of market fundamentals. Estimating the model both over the full sample and across four distinct sub-periods, we find that the influence of speculative pressures on spot prices and the convenience yield is relatively limited.

In the second step, we broaden the analysis by examining the positions of hedgers and speculators on the Title Transfer Facility (TTF), the main benchmark for European gas prices. Leveraging ESMA data on weekly positions in commodity derivatives and the classification by trading type and motive, we explore how the composition and evolution of market participation relate to price dynamics, volatility, and periods of stress.

JEL codes: G13, G23, Q41, Q43.

Keywords: Natural Gas Prices; Speculation; Fundamentals; Futures Markets; Elasticities.

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1. The European Natural Gas Market

In recent years, the European natural gas market has been subject to several policy interventions from the European Commission aimed to promote market integration across regions, to improve the competitive choice and to ensure gas supply security for the EU citizens. The gas trading hubs form the most crucial network for the European natural gas market and serve as the primary platforms for both physical and virtual gas transactions. These hubs can be classified according to their geographical location and level of development (see Heather, 2016, 2020). The variety of traded products is crucial indicators of a hub's maturity.

Heather (2021) points out that in 2020, the Dutch Title Transfer Facility (TTF), virtual marketplace established in 2003 and operated by Gasunie Transport Services (GTS), achieved the highest number of product categories with the greatest level of activity, encompassing more than 500 TWh in each of the exchange-traded product types and 600 TWh in over-the-counter products. Both the British National Balancing Point (NBP) and the Dutch TTF stand out as dominant "mature" hubs, both located in the North-West European region. Nevertheless, the TTF market is more representative of the overall global transactions, since its churn rate (the ratio between the total volume of trades and the physical volume of gas consumed in the area served by the hub) increased from 70.9 in 2018 to 114.5 in 2020, whereas NBP's decreased from 17.0 in 2018 to 12.6 in 2020.

1.1. The Dutch TTF

The Dutch TTF has seen exceptional levels of growth since 2007, when it began its ascension to become the primary European and global gas hub. Several factors and key developments underpinned its growth. First, its location in the Netherlands provided access to a unique intersection of gas infrastructure and industry knowledge. The TTF and market participants on the TTF have access to a developed Dutch gas infrastructure, including domestic production, LNG facilities, storage facilities and, importantly, its geographic location in the "heart" of Europe, where the main consumption area is.

Second, in 2009 the TTF was one of the first gas trading hubs that allowed for quality conversion—i.e. trading gas as energy in MWh rather than a specific quality or type of gas. This has become increasingly important since the transition of the gas market price formation from being mainly oil-linked to increasingly being based on gas-on-gas competition. These developments have significantly simplified the balancing regime by allowing the two separate grids with different quality specifications (related to their calorific values) to operate as if

they were one.

Third, in 2011 the TTF introduced a "market balancing regime", which has allowed participants to balance their positions in real time. This has greatly improved liquidity and transparency, leading to a more robust discovery of 'real' prices, further attracting market participants to trade on the TTF (Oxera, 2022). Figure 1b shows the evolution of the TTF front-month contract (TFM), the most actively traded of all TTF maturities in terms of open interest and average daily volume, from January 2020 to December 2024.

1.2. Market Fundamentals

The fundamentals of the gas market are based on the supply and demand for gas in Europe. On the supply side, the key drivers are the availability of gas production, transportation and storage (pipelines maintenances or outages). On the demand side, the consumption is mainly driven by the weather (heating needs) and by the production of power through natural gas with the use of the combined cycle power plant technology. Figure 1a shows the level of supply, demand, and storage (inventories) over the same period, expressed in millions of cubic meters (Mcm).

According to ACER (2023), there are four main phases characterizing this period, where changes in market fundamentals seem to be responsible for price volatility, which we discuss in more detail below.

Phase 1: May 2021 - February 2022

Phase 1 marked a transition from cyclical recovery to structural vulnerability, as the European gas system became increasingly exposed to geopolitical and infrastructure risks.

Following the easing of pandemic restrictions, European gas demand surged in tandem with the continent's broader economic rebound. On the supply side, Russian pipeline deliveries began to decline well before the invasion of Ukraine, coinciding with delays in the commissioning of Nord Stream 2 and reduced transit through existing routes.

The combination of robust demand and constrained supply drove TTF prices upward from mid-2021. Storage sites entered the 2021–22 winter at below-average levels, and withdrawals during the heating season left inventories critically low by February 2022.

Phase 2: February – May 2022

Phase 2 was characterized by an acute supply contraction, limited demand flexibility, and extreme market volatility reflecting both physical scarcity and geopolitical uncertainty.

The Russian invasion of Ukraine in February 2022 transformed a tight market into a full-scale crisis. Russian gas flows through the Yamal, Nord Stream, and Ukrainian corridors dropped sharply as Moscow curtailed exports and the European Union imposed sanctions. The abrupt loss of pipeline volumes—previously accounting for roughly 40% of EU gas imports—triggered intense competition among European and Asian buyers for limited liquefied natural gas (LNG) cargoes.

LNG imports rose, but global liquefaction capacity was insufficient to offset the deficit, and European regasification and transmission infrastructure offered little spare capacity. Concurrently, low wind and nuclear generation increased gas use in the power sector. Demand elasticity remained weak in the short term, as industrial users and power generators struggled to adjust. Storage injections for the next winter began under record-high prices.

Phase 3: June – September 2022

Phase 3 represents the apex of the crisis and market state of maximum disequilibrium. European gas prices reached unprecedented levels the gas infrastructure is under stress.

In response to the EU's mandated storage-filling targets, Member States and utilities raced to secure volumes for the 2022–23 winter, regardless of cost. The resulting surge in summer demand for storage injections collided with restricted LNG availability and pipeline bottlenecks, especially in North-West Europe. Congestion at LNG terminals and cross-border interconnectors amplified regional price differentials and constrained flexibility.

Although overall EU gas consumption in 2022 fell relative to the previous year, demand during the injection season remained high, driven by compulsory storage refilling and gas-fired generation substituting for low hydro and nuclear output. Supply diversification accelerated—particularly through LNG imports from the United States and Norway—but could not fully offset Russian shortfalls.

Phase 4: October 2022 – October 2023

Phase 4 marks a systemic rebalancing: reduced demand, diversified supply, and high storage coverage underpinned a renewed sense of market stability.

By late 2022 the European gas market began to stabilize. Exceptionally mild winter

temperatures, record LNG inflows, and continued demand-side measures eased pressure on prices and inventories. Storage levels exceeded 90% of capacity entering the 2023 injection season, while recovering nuclear and renewable output reduced gas use for power generation.

Supply diversification deepened as new regasification terminals in Germany, the Netherlands, and Southern Europe entered service, and the United States consolidated its role as the EU's dominant LNG supplier. Temporary disruptions generated short-lived volatility but did not reverse the trend. By May 2023, the TTF front-month price fell below €30/MWh for the first time since mid-2021.

2. The Model

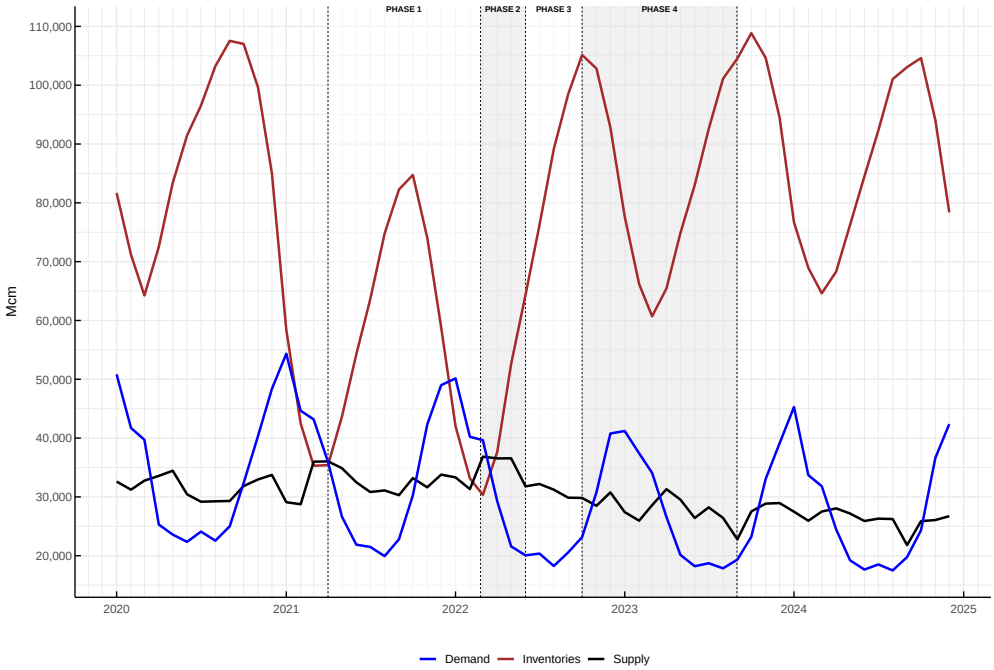
Knittel and Pindyck (2016) develop a simple economic model of commodity price speculation, to disentangle the impact of changes in speculation from fundamentals in the West Texas Intermediate (WTI) crude oil price. In what follows, we apply the same model to the European benchmark for natural gas prices, the TTF, to assess the impact of speculation during the period 2020-2024, when the European natural gas market experienced a prolonged period of disruption due to the Russian invasion of Ukraine and the subsequent Russian cut of large volumes of pipeline gas to Europe.

Starting with the spot market, we maintain two simplifying assumptions: (i) the supply of gas includes imports and domestic production, and the two are indistinguishable; and (ii) the supply and demand functions are isoelastic. Writing supply as $X = k_S P^{\eta_S}$ and demand as $Q = k_D P^{\eta_D}$, the change in inventories (ΔN) is:

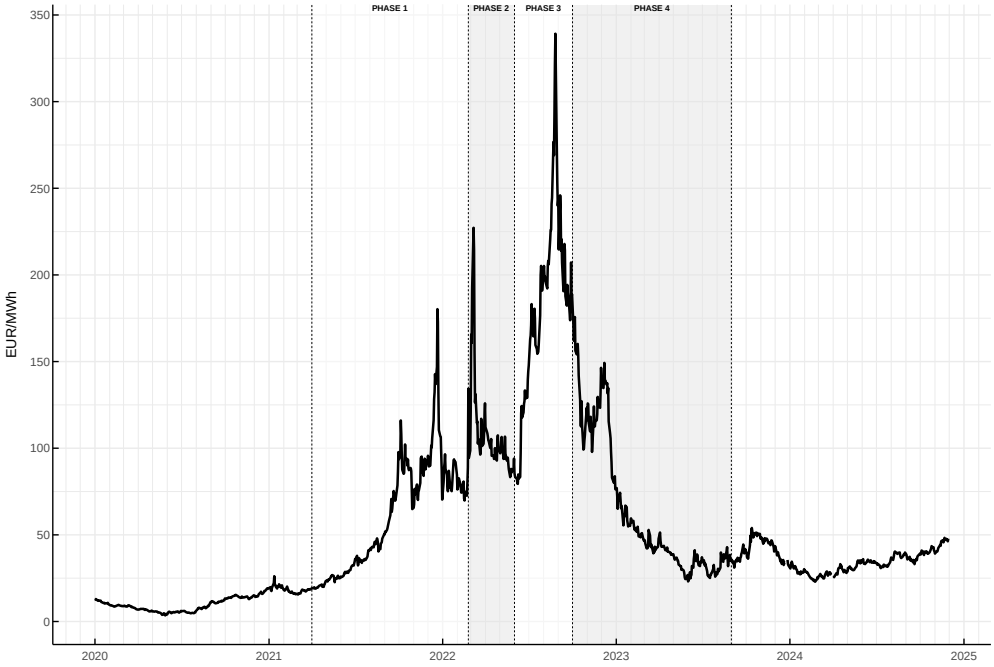
$$\Delta N_t = k_S P_t^{\eta_S} - k_D P_t^{\eta_D} \tag{1}$$

Furthermore, we assume that market fundamentals are incorporated in the supply and demand parameters k_S and k_D, so that a shift in supply or demand would imply a change in one or both of these parameters, rather than in the elasticities η_S and η_D. Due to the simple functional form of supply and demand, the objective of the model is not to precisely estimate the sources of price changes, but rather to determine whether speculation can be ruled out as a significant driver of price. To that end, we do not estimate the supply and demand elasticities η_S and η_D, but instead consider a broad range of plausible values for these parameters.

Figure 1: European Natural Gas Market Fundamentals and TTF Price.



(a) Supply, Demand, and Inventories of European Natural Gas (Monthly).



(b) TTF Front Month (Daily).

Source: Eurostat, Bloomberg.

We start by dividing both sides of equation 1 by Q_t:

$$\frac{\Delta N_t}{Q_t} = \frac{X_t}{Q_t} - 1 = \frac{k_S}{k_D} P_t^{\eta_S - \eta_D} - 1 \tag{2}$$

Now take logs and then first differences of both sides, and rearrange:

$$\Delta \ln P_t = \frac{1}{\eta_S - \eta_D} \left[\Delta \ln k_D - \Delta \ln k_S\right] + \frac{1}{\eta_S - \eta_D} \Delta \ln \left(\frac{X_t}{Q_t}\right) \tag{3}$$

We have assumed that any change in market fundamentals is reflected in a change in k_D and/or k_S. Thus, we can use Equation 3 to isolate the speculative component of price changes:

$$\Delta \ln P_t^S = \frac{1}{\eta_S - \eta_D} \Delta \ln \left(\frac{X_t}{Q_t}\right) \tag{4}$$

Given the spot price P_t, and the futures price F_{t+T}, we can find the convenience yield. Let $\psi_{t,T}$ denote the (capitalized) flow of marginal convenience yield from holding a unit of inventory from t to $t+T$. To avoid arbitrage, $\psi_{t,T}$ must satisfy:

$$\psi_{t,T} = (1 + r_T) P_t - F_{t,T} + k_T, \tag{5}$$

where r_T is the risk-free T-period interest rate and k_T is the T-period per-unit cost of physical storage.

Next, we specify the inverse demand for storage as follows:

$$\psi(N_t) = P_t \, g(N_t) = k_N P_t N_t^{-1/\eta_N}, \tag{6}$$

where $\eta_N > 0$ is the price elasticity of demand for storage.

We assume that any change in market fundamentals is reflected in a change in k_N. For example, an increase in market volatility or an increased threat of war Russian and Ukraine would cause an increase in k_N. If natural gas producers accumulate inventories to speculate on price increases, k_N would remain unchanged and we would observe a movement down the demand for storage curve.

Taking logs and first differences of Equation 6 gives:

$$\Delta \ln \psi_t = \Delta \ln k_N + \Delta \ln P_t - \frac{1}{\eta_N} \Delta \ln N_t \tag{7}$$

Now substitute Equation 3 for $\Delta \ln P_t$ to eliminate the spot price:

$$\Delta \ln \psi_t = \Delta \ln k_N + \frac{1}{\eta_S - \eta_D} \left[\Delta \ln k_D - \Delta \ln k_S\right] + \frac{1}{\eta_S - \eta_D} \Delta \ln \left(\frac{X_t}{Q_t}\right) - \frac{1}{\eta_N} \Delta \ln N_t \quad (8)$$

We use Equation 8 to isolate the speculative component of changes in the convenience yield:

$$\Delta \ln \psi_t^S = \frac{1}{\eta_S - \eta_D} \Delta \ln \left(\frac{X_t}{Q_t}\right) - \frac{1}{\eta_N} \Delta \ln N_t \quad (9)$$

We use Equations 4 and 9, along with alternative plausible values for the sum of the supply and demand elasticities $(\eta_S - \eta_D)$, to measure the speculative components of the spot price and the convenience yield. We proceed as follows.

Consider Equation 4 for log changes in the speculative component of price, $\Delta \ln P_t^S$. We want to know whether such changes are small and tend to cancel out over time, or instead tend to add up to a sustained increase (or decrease) that could help explain the price movements in Figure 2. For example, if price increases during 2022 were partly due to speculation, these log changes would have had to be not just significant in magnitude, but also consistently positive over this period.

The monthly changes in the spot price resulting from speculative activity come directly from Equation 4. We are interested in understanding the cumulative effects of speculative activity over our entire time period. Therefore, at each point in time we add the changes in prices resulting from speculative activity in all previous periods. For January 2020, the first month of our sample, we set $\Delta \ln P_t^S = 0$, and then calculate and accumulate values for $\Delta \ln P_t^S$ over the rest of the sample. This yields:

$$\Delta \ln P_T^S = \ln P_T^S - \ln P_0 = \sum_{t=\text{Jan 2020}}^{T} \Delta \ln P_t^S \quad (10)$$

To calculate speculation-induced changes in the convenience yield using Equation 9, we need the actual convenience yield and an estimate of the price elasticity of the demand for storage, η_N. From Equation 5, we use the 3-month Euribor rate for the risk-free rate of interest, and the price of the three-month TTF futures contract to get a three-month gross convenience yield.

To estimate the gross convenience yield we need an estimate of the storage cost, which depends on injection fees, withdrawal fees, and capacity fees. According to Taboga (2024), storage fees for natural gas in Europe typically range from 2 to 8 EUR/MWh per year. For

this reason, we choose a baseline value of 5 EUR/MWh per year (0.4167 EUR/MWh per month) as a storage cost. However, in several months of our sample, the futures-spot spread was so large that such estimate would imply a negative net convenience yield, violating the arbitrage condition. These large negative values may result from the aggregation of futures and spot prices up to a monthly level or may reflect actual changes in storage costs. To take logs, we truncate the net convenience yield below at 0.4167 EUR/MWh.

The speculative component of convenience yield is given by Equation 9. As with prices, we are interested in the cumulative effect of speculation, so at each point in time we add the changes in convenience yield resulting from speculative activity in all previous periods. The cumulative change in the log of convenience yield due to speculation at any time T is then

$$\Delta \ln \psi_T^S = \ln \psi_T^S - \ln \psi_0 = \sum_{t=\text{Jan 2020}}^{T} \Delta \ln \psi_t^S \tag{11}$$

3. Data and Results

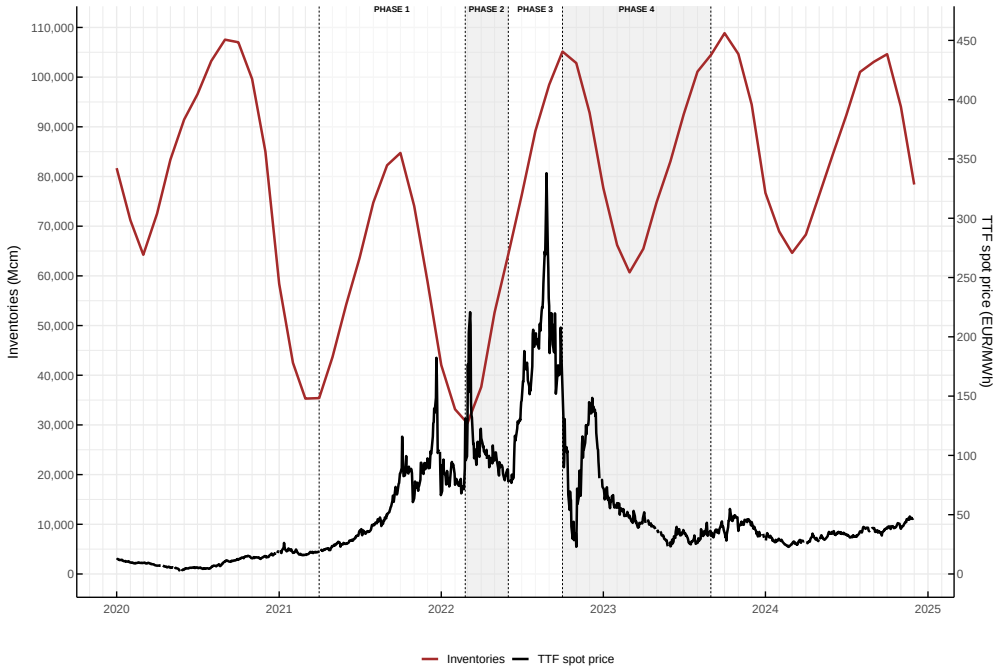
We collected monthly data from Eurostat for the EU 27 countries on natural gas production, commercial stocks, imports, and exports from January 2020 to December 2024. We then aggregate the data and construct consumption as aggregate production plus aggregate imports minus aggregate exports minus changes in commercial stocks.[1] To eliminate the effects of seasonality in demand, we de-seasonalize stocks by first regressing inventories on a set of month dummies and subtracting the coefficients associated with the dummy variables. Thus, consumption is also de-seasonalized given its construction. Finally, we collected daily data on TTF spot price and three-month future price from Bloomberg, and then computed monthly averages.

To establish whether speculative activity that increases spot prices requires a build-up of inventories, we plot this relationship in Figure 2. As we can see, there is no strong evidence of association between sharp increases in the spot price and inventory levels. Indeed, during the Russian invasion of Ukraine (February 2022) there is an inverse relationship between the two variables, whereas during the Nord Stream 1 pipeline shut down (August 2022) the relationship is positive.

To estimate the model, we need numbers for the supply and demand elasticities, which will vary depending on the amount of time over which supply and demand can adjust to price

[1] We aggregate country-level data since European data are not available for some some periods of our sample.

Figure 2: TTF Sport Price (Daily) and Natural Gas Inventories (Monthly).



Source: Eurostat, Bloomberg.

changes. Note, however, that what matters for our analysis is the sum of the elasticities.

Casoli et al. (2024), who develop a Bayesian Structural VAR model to study the relationship between different energy shocks and inflation dynamics in Europe over the period 2010-2022, adopt values for the short-run price elasticity of gas supply and demand as 0.34 and -0.47.[2] Similarly, Colombo and Toni (2025) examine the macroeconomic effects of natural gas supply and demand shocks in the Euro Area from 2004 to 2024, using short-run price elasticities of 0.76 for supply and –0.11 for demand. To reflect variations in elasticities, we estimate our model using both sets of values. Figure 3 shows the impact of speculation on the spot price and the convenience yield for different sets of supply and demand elasticities.

As we can see, the results are robust to reasonable sets of elasticity estimates.[3] More specifically, we can acknowledge that speculative activity did not lead to large or sustained changes in the spot price. The cumulative effect from speculation hovers around zero for

[2]In particular, they specify priors for the prices elasticity of gas supply in the form of a positive truncated Student t distribution with mode at 0.1, standard deviation of 0.2, and 3 degrees of freedom. For the short-run price elasticity of demand, they also adopt a Student t prior distribution, whose support is constrained to be negative, centered at -0.3 with a standard deviation of 0.2 and 3 degrees of freedom.

[3]Following Casoli et al. (2024) specification of priors, we generated a wider range of values for supply and demand elasticity. Even in relatively elastic/inelastic scenarios, the essence of the results does not change.

our entire sample. As with the spot prices, the cumulative change in the convenience yield resulting from speculation tends to fluctuate around zero, suggesting that the main driver of changes are market fundamentals. However, according to the model, the net effect on speculation on the convenience yield is ambiguous. On the one hand, speculative inventory accumulation would result in a reduction of demand for storage curve, so that convenience yield would fall as inventories rose. On the other, there is a second effect operating through the impact of speculation on spot prices, as Equation 8 shows. As spot prices increase, the demand for storage increases, pushing the convenience yield upward.

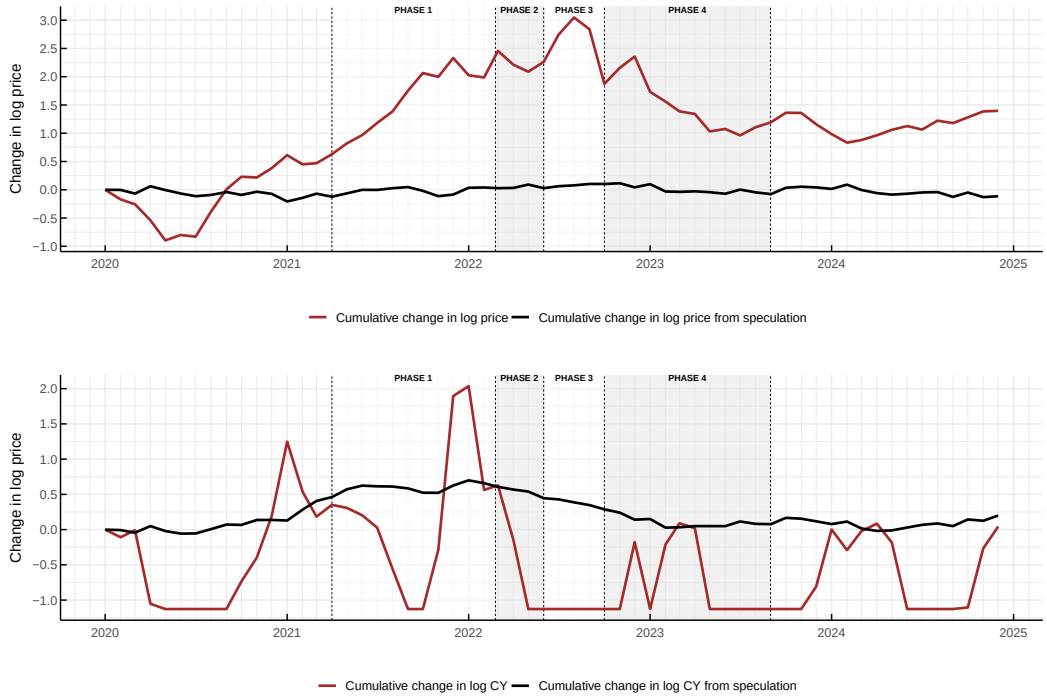
Next, we focus on the specific time periods identified above during which the natural gas market has experienced periods of heightened price fluctuations and structural changes in the underlying fundamentals. Table 1 summarize the results.

Table 1: Phase Analysis.

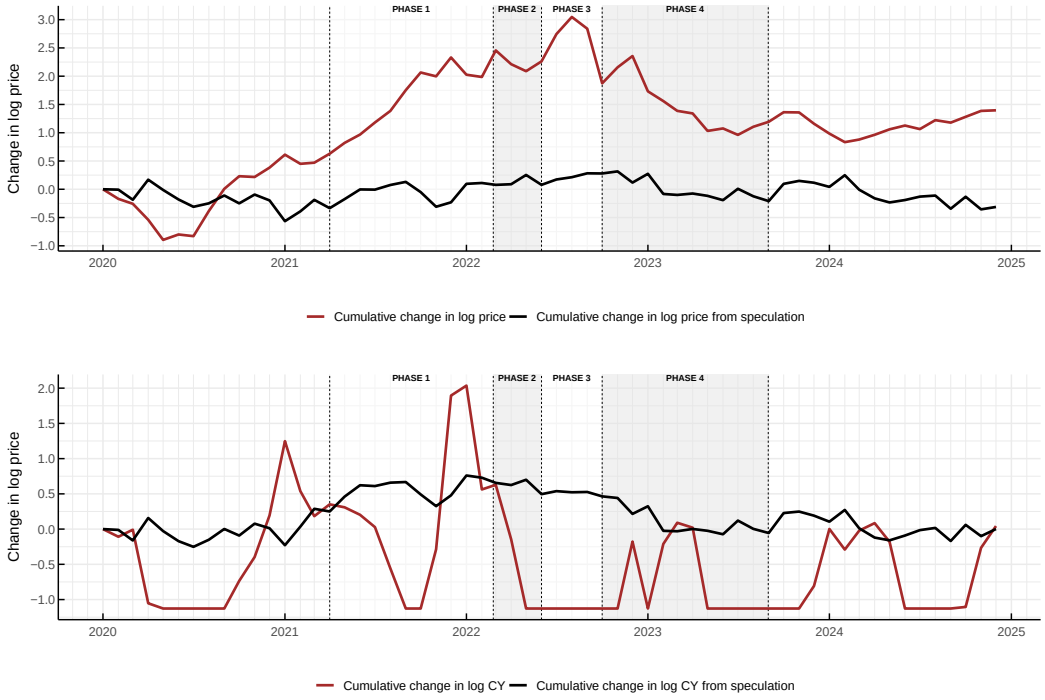
	2021:04–2022:03	2022:03–2022:06	2022:06–2022:10	2022:10–2023:09
Phase	(1)	(2)	(3)	(4)
Supply elasticity (η_S)	0.34	0.34	0.34	0.34
Demand elasticity (η_D)	-0.47	-0.47	-0.47	-0.47
Beginning price (P_0)	20.84	101.51	172.86	96.02
Ending price (P_T)	129.57	106.69	72.38	36.65
Beginning production (Mcm) (X_0)	36135.96	36683.04	32342.26	28637.35
Beginning consumption (Mcm) (Q_0)	41369.05	34712.97	29473.04	24467.57
Ending production (Mcm) (X_T)	36977.03	31925.09	29981.02	22948.00
Ending consumption (Mcm) (Q_T)	35169.39	30358.79	26043.78	24840.46
Change in log price due to speculation ($\Delta \ln P_T^S$)	0.23	-0.01	0.06	-0.29
Ending inventories (N_T)	45827.45	53807.31	67889.19	70029.07
Actual inventory build over entire epoch (ΔN_T)	275.26	6009.80	11212.66	-2029.90
Beginning convenience yield (ψ_0)	1.83	1.11	0.42	0.42
Ending convenience yield (ψ_T)	2.41	0.42	0.42	0.42
Change in log convenience yield due to speculation ($\Delta \ln \psi_T^S$)	0.22	-0.12	-0.12	-0.26

As we can see, for the first and the last phase, the share of the price change resulting from speculation is significant, as opposed to the second and the third phase. Moreover, across all the phases, inventory changes are substantial and, except for the first phase, positive. A similar reasoning applies to the change in the convenience yield due to speculation, which does not seem to be an insignificant factor in the market. The difference between these results and those reported in Figure 3 deserves further analysis.

Figure 3: Impact of Speculation on Spot Price and Convenience Yield.



(a) $\eta_S = 0.76$, $\eta_D = -0.47$.



(b) $\eta_S = 0.34$, $\eta_D = -0.11$.

4. Analysis of Derivative Positions with ESMA Data

In 2018, the European Securities and Markets Authority (ESMA) started publishing the "Commodities Derivatives Weekly Position Reporting System" for European commodity futures, in the style of the Commodity Futures Trading Commission's "Commitments of Traders" (CoT) reports.

CoT reports have been criticized by numerous researchers as the data do not distinguish between different trading motives (Cheng and Xiong, 2014; Duffie, 2014). Once a trader is classified as a speculator, their positions are viewed as speculative. Conversely, once a trader is identified as commercial, their positions are categorized as hedging. Due to the financialization of commercial operators in commodity markers, this procedure leads to an over- or under-statement of the proportion of speculative and hedging positions in the market. In this respect, ESMA reports offer a key advantage as they do not only distinguish between type of traders (hedging and speculative), but also between the "motive" of the position (risk-reducing and others), which allows to more accurately classify traders according to their nature and type of exposure. For the sake of clarity, Figure 4 shows a diagram of the structure of commercial and non-commercial positions.

Article 7 of the Commission Delegated Regulation (EU) 2017/591 states the requirements for a "risk-reducing" position, which needs to meet one of the following criteria:

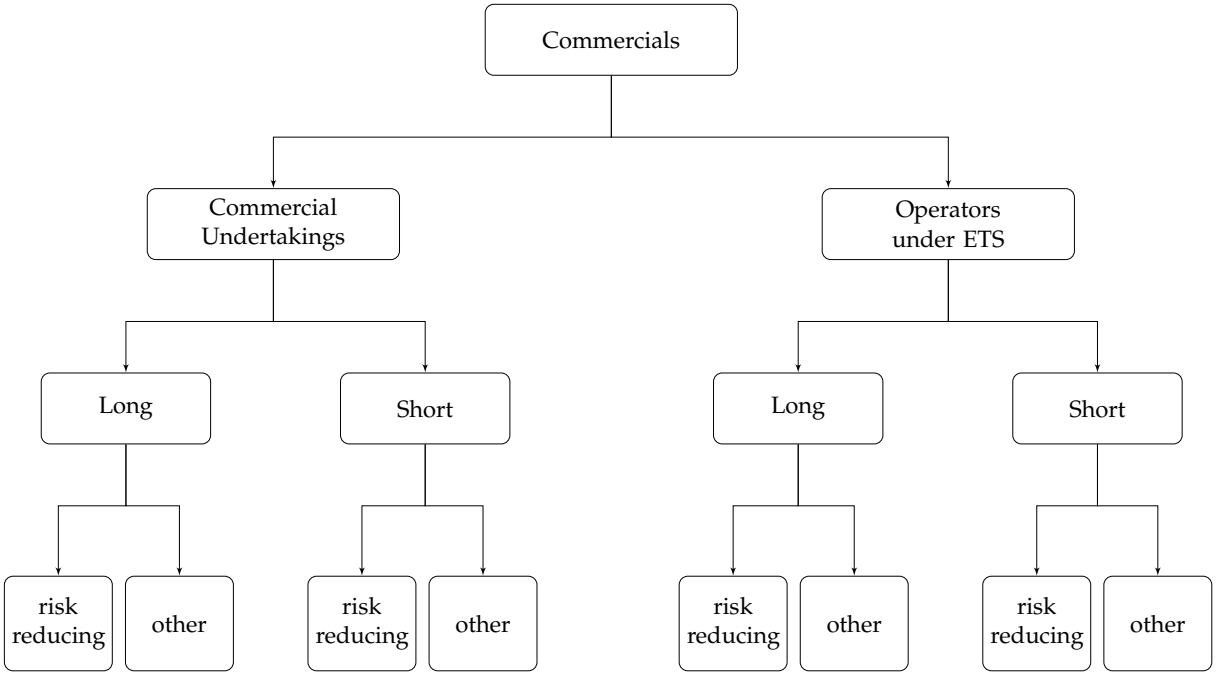
(a) It reduces the risks arising from the potential change in the value of assets, services, inputs, products, commodities or liabilities that the non-financial entity or its group owns, produces, manufactures, processes, provides, purchases, merchandises, leases, sells, or incurs or reasonably anticipates owning, producing, manufacturing, processing, providing, purchasing, merchandising, leasing, selling or incurring in the normal course of its business;

(b) It qualifies as a hedging contract pursuant to International Financial Reporting Standards (IFRS) adopted in accordance with Article 3 of Regulation (EC) No 1606/2002 of the European Parliament and Council.

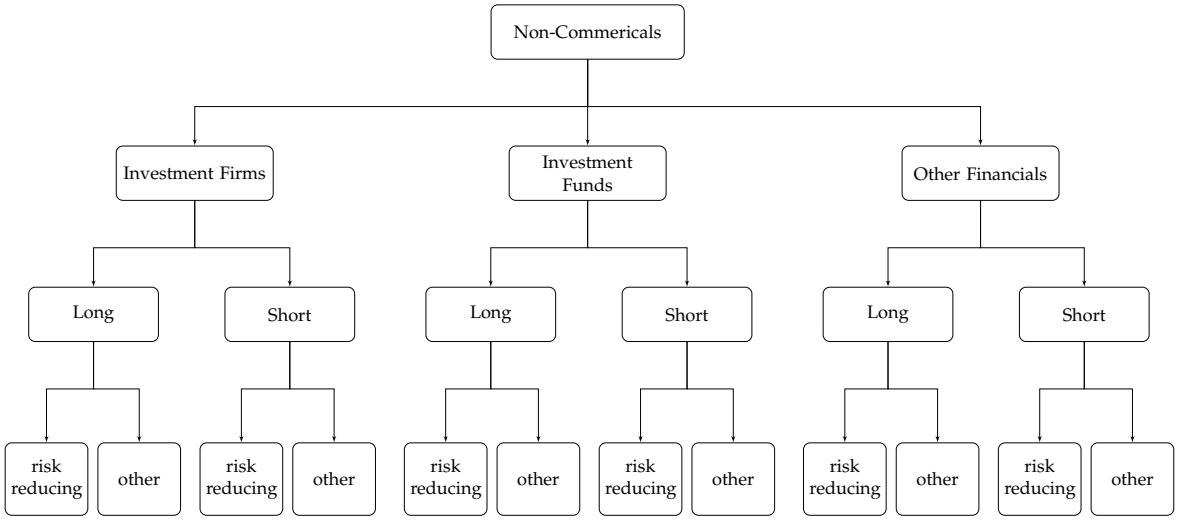
ESMA data report open positions held by different type of traders at the close of a business week, on Friday, according to the following classification (ESMA QA 1544):

- **Investment Firms** or credit institutions – Banks and other firms regulated under MiFID II.
- **Investment Funds** – Entities holding investments directly in the commodity derivatives market as a form of collective investment scheme, such as hedge funds and exchange-traded funds.

Figure 4: Structure of Positions in ESMA Reports.



(a) Commercial Positions



(b) Non-Commercial Positions

Source: Bohl et al. (2019, pp. 17-18).

- **Other Financial Institutions** – Those financial firms not falling within any of the other categories including pension funds, insurance companies, and central clearing counterparties.

- **Commercial Undertakings** – Non-financial entities using commodity derivatives, for example firms using those markets to hedge the risk they directly incur from dealing in physical commodities such as producers, end users, processors, manufacturers, shippers and merchants.

- **Operators with Compliance Obligations** - Operators of carbon dioxide emission intensive installations, such as factories and power plants, which are since 2005 required to participate in the European Union Emission Trading Scheme (ETS). These operators include commercial airlines, entities in power and heat generation, energy-intensive industry sectors including oil refineries, steel works, production of iron, etc.[4]

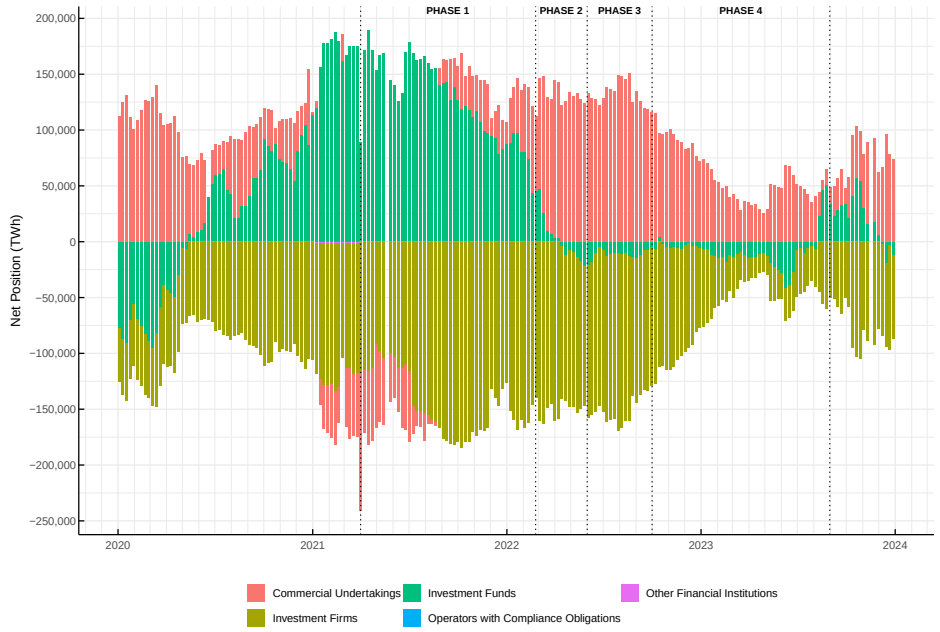
4.1. Data Collection and Analysis

We collect data from ESMA for the period January 1, 2020 to December 31, 2024 on the positions on the Dutch TTF Natural Gas Futures front month contract traded on the ICE Endex, which account for 98% of total positions (long and short) of all natural gas contracts recorded by ESMA. Figure 5 shows the total net positions (the difference between long and short positions), whereas Figure 7 shows the net risk reducing and other positions by type of institution. It is interesting to note how, once we break down the positions into risk-reducing and other, we clearly see the presence of speculative behavior for both commercial and financial traders.

Following the same logic, we can further distinguish between risk reducing and other position of commercial and non-commercial traders, respectively. In this case, we classify commercial undertakings and operators with compliance obligations as commercial entities, whereas investment firms, investment funds, and other financial institutions are classified as non-commercial. Figures 6 and 8 capture this distinction for total net positions and risk-reducing and other, respectively.

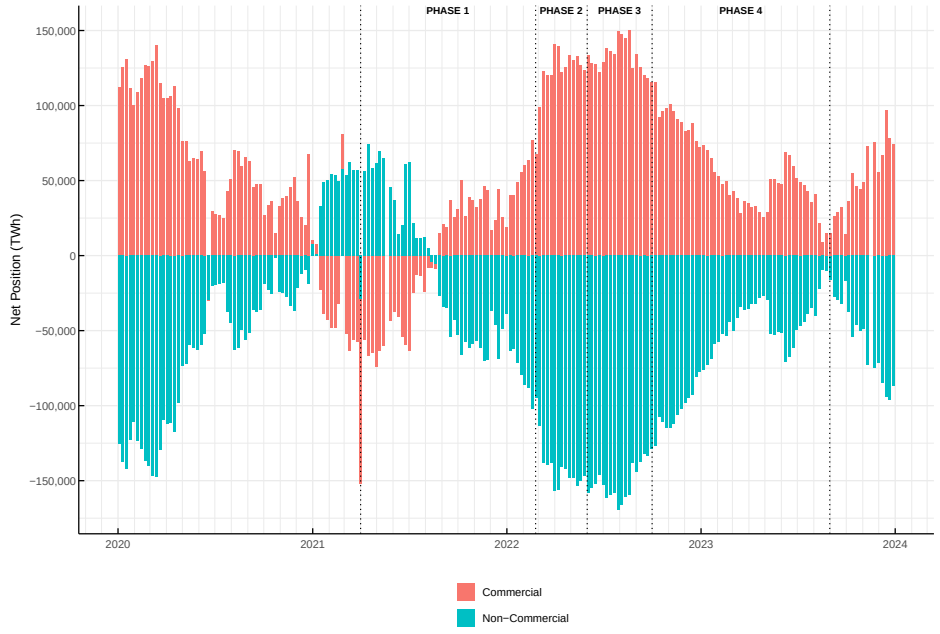
[4]It is possible for a firm to be categorized as an operator with compliance obligations under the ETS report for an emissions allowance contract or derivatives thereof while it must be categorized as a commercial undertaking for holding a position on another asset class of commodity derivatives contract (i.e. metals, oil, coal, gas, power, etc.).

Figure 5: Stacked Bar Chart of Total Net Positions on TTF contracts.



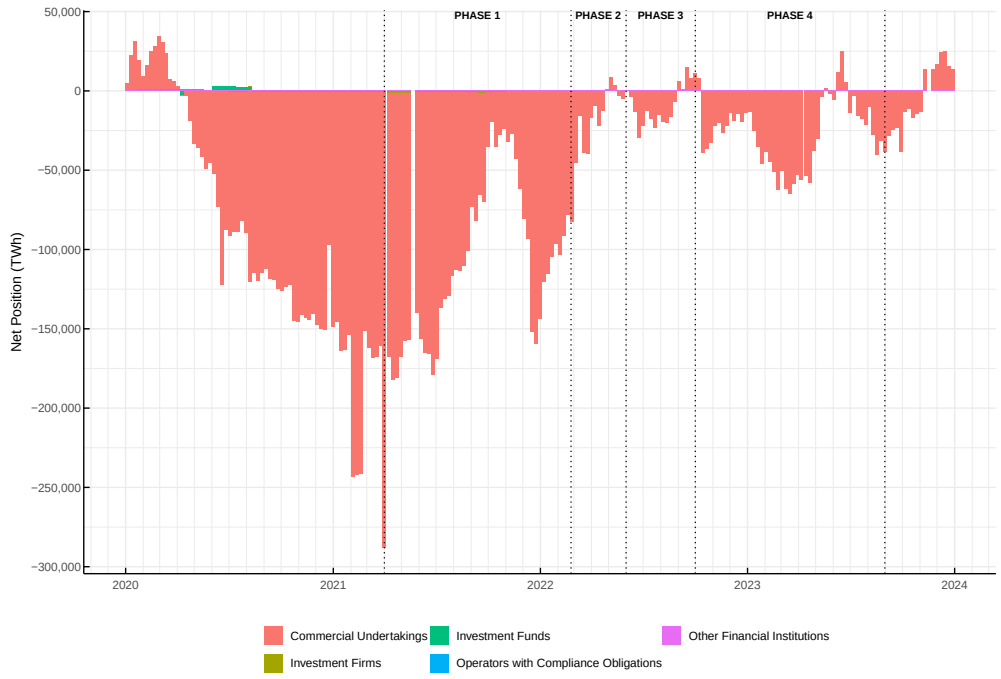
Source: ESMA.

Figure 6: Stacked Bar Chart of Commercial and Non-Commercial Total Net Positions on TTF contracts.

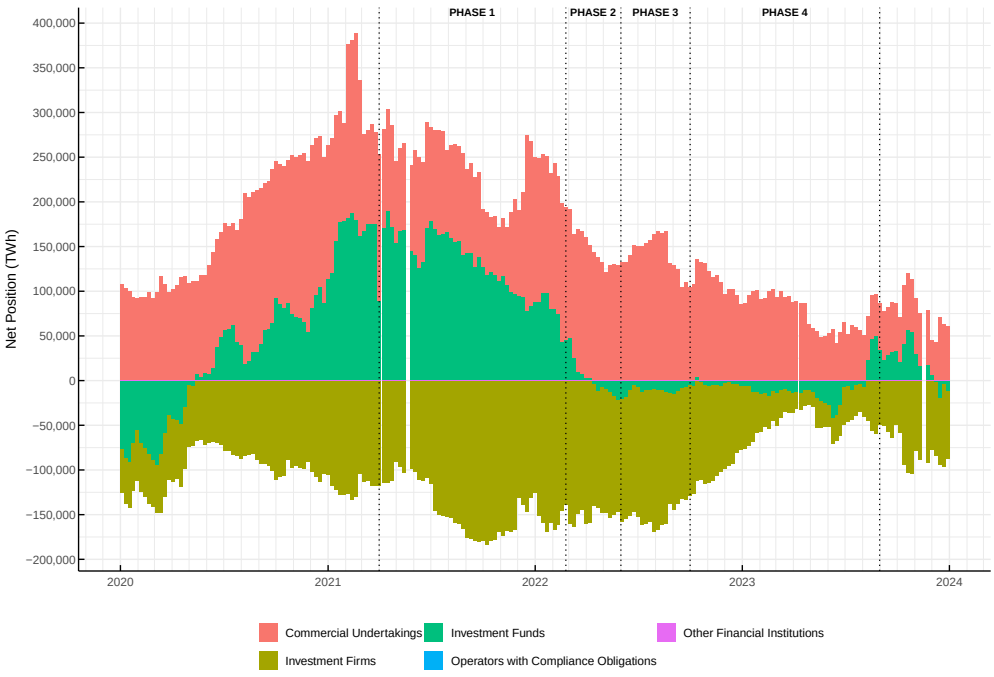


Source: ESMA.

Figure 7: Stacked Bar Chart of Risk Reducing and Other Net Positions on TTF contracts.



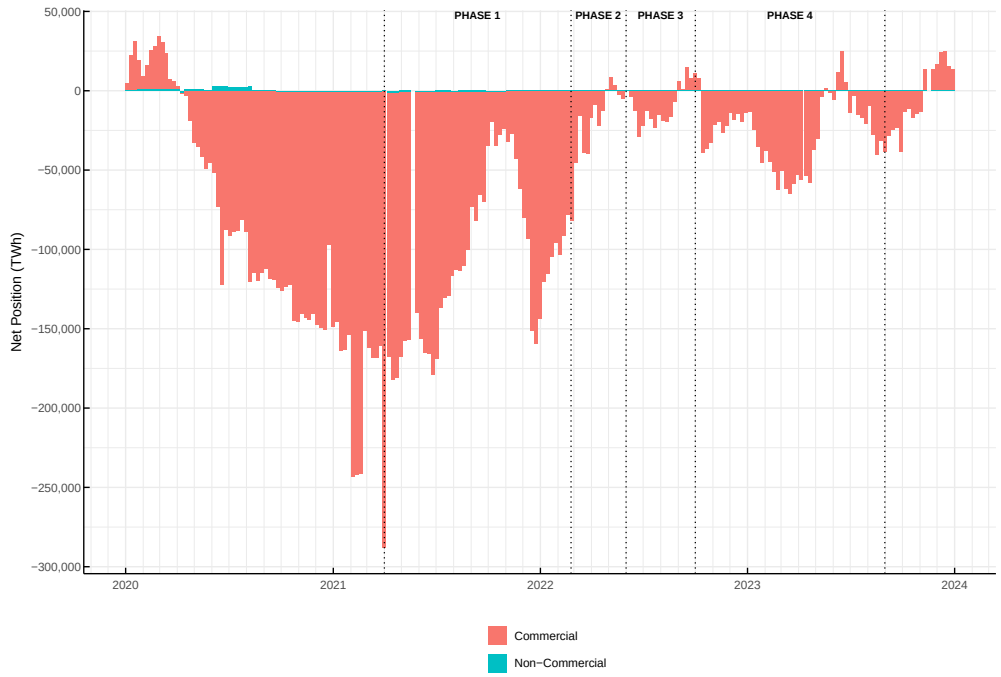
(a) Risk Reducing Positions



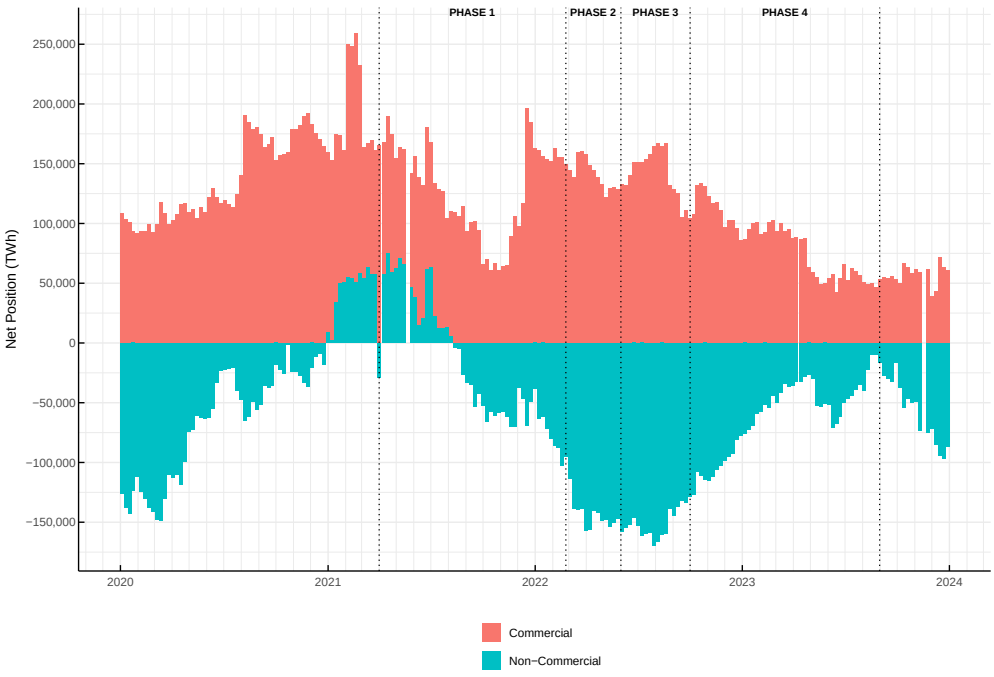
(b) Other Positions

Source: ESMA.

Figure 8: Stacked Bar of Commercial and Non-Commercial Net Positions on TTF contracts.



(a) Risk Reducing Positions



(b) Other Positions

Source: ESMA.

5. Speculative Activity

To perform a more in-depth analysis of speculative activity, we employ a range of established indicators that quantify the level of speculation in the market. These indicators typically express the ratio of speculative to hedging positions. Their values are influenced by the criteria used to classify positions as either speculative or hedging, which can be based either on the trader typology or on the underlying intent behind the trades. In light of the evidence presented above, focusing on traders' motives offers a more accurate representation of speculative behavior, since classification by trader type tends to overlook speculative positions held by commercial participants.

If one differentiates by trader type, the total number of speculative positions in the market is computed by summing up the positions of all non-commercial traders. By analogy, the total number of hedging positions in the market is computed by summing up the positions of all commercial traders. Conversely, if one differentiates by trading motives, the total number of speculative positions in the market is computed by summing up all positions that are not held for risk-reducing purposes, regardless of who holds these positions. The total of hedging positions is then again computed analogously as the sum of all positions that are held to reduce risk.

We now consider three different measures of speculation, distinguished by trader typology and trading motive. If the two approaches produce strongly different results for the same speculation metric, this is a clear sign that one of them, presumably the one that differentiates by trader type, either grossly under- or over-estimates the level of speculation in the market.

The first speculation metric, which has been used by Manera et al. (2016), is referred to as the total share of speculation T, and is computed as:

$$T_t = \frac{SL_t + SS_t}{SL_t + SS_t + HL_t + HS_t} \tag{12}$$

where SL_t and SS_t denote the long and short positions of speculators in week t, while HL_t and HS_t denote those of hedgers.

The second measure, which, following Bohl et al. (2019), we call the long share of speculation L, only focuses on the amount of long speculation in the market, and is defined as follows:

$$L_t = \frac{SL}{SL_t + HL_t} \tag{13}$$

Finally, the last measure is the most common index of excessive speculation, Working's

T-index Working (1962), W, which is computed as follows:

$$W_t = \begin{cases} 1 + \frac{SS_t}{HS_t + HL_t} & \text{if } HS_t \geq HL_t \\ 1 + \frac{SL_t}{HS_t + HL_t} & \text{if } HS_t < HL_t \end{cases} \tag{14}$$

This index is bounded below by unity, which resembles a situation where the positions of hedgers are perfectly offset by the opposing positions of speculators. The index deviates from unity if the number of opposing positions more than offsets the net position of hedgers. In case of $HS_t > HL_t$, that is, when hedgers take an aggregate net short position, the index increases with the number of short positions of speculators, SS_t. In contrast, in the case of $HS_t < HL_t$, when edgers are net long in the aggregate, W increases with the number of long positions of speculators SL_t. The term "excessive" should therefore not be understood normatively, instead it merely refers to the "excess supply" of speculative positions in the market.[5]

Figure 9 compares the three above measures of speculative activity as distinguished by type and motive. Although the three measures denote a relatively stable trend around the four phases, we can recognize a notable difference between the classification of positions by type and motive. In particular, classification by type consistently underestimates the degree of speculative activity in the market. To test whether this difference is statistically significant, we apply the Wilcoxon test. Table 2 shows the average measures of speculation by type and motive. The difference is statistically significant at the 99.9% level.

Table 2: Measure of Speculation by Motive and Type.

Measure	Average by Motive	Average by Type	Difference
T	0.56	0.30	0.26^{***}
L	0.59	0.26	0.33^{***}
W	1.60	1.19	0.42^{***}

[5]Note that, computing the Working's T index according to the trading motive, allows us to overcome one of its main limitations.

Figure 9: Measure of Speculations by Type and Motive.



Source: ESMA.

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