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Speculation or Fundamentals? European Natural Gas Price Swings Post 2020

by

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ABSTRACT

We investigate the role of speculation in the European natural gas market over the period 2020–2024, a period marked by extreme price volatility driven by the energy crisis following Russia’s invasion of Ukraine. Replicating the framework of Knittel and Pindyck (2016), we disentangle the contribution of speculative activity from that of market fundamentals using data on production, consumption, inventories, spot prices, and convenience yields across four distinct phases of the crisis. We find that speculation accounts for only a modest fraction of observed price movements in all periods, with market fundamentals—particularly supply disruptions and policy-driven storage dynamics—remaining the dominant drivers throughout. The speculative component is largest during Phase 1 (April 2021–February 2022), though a large speculative component indicates only that the model cannot exclude speculation as a contributing factor, not that it was responsible for it. The concurrent inventory drawdown and rising convenience yields point instead to genuine supply scarcity as the primary force. In Phase 3 (June 2022–September 2022), the clearest speculative signal is likely attributable in part to EU-mandated storage filling rather than profit-motivated hoarding, a distinction the framework cannot resolve. Across the price cycle, speculation appears to have modestly amplified the run-up and dampened the collapse, consistent with a stabilizing rather than destabilizing role, even during a crisis of the severity experienced in European natural gas markets.

JEL Codes: G13; G23; Q41; Q43

Keywords: Financial economics; Financial markets; Speculation

1. INTRODUCTION

The debate surrounding the role of speculation in driving these price movements has intensified in the wake of unprecedented volatility, particularly during the 2022 energy crisis. Yet, no consensus has emerged on whether speculative forces were a primary driver or merely an amplifier of fundamentally-driven price changes.

Recent contributions point to different directions. Anderl and Caporale (2025) examine the extent to which expectations and speculative dynamics influenced the US natural gas prices using a structural VAR model, finding that shocks to the futures term structure interpretable as expectation-driven or speculative demand may account for as much as half of the variation in real natural gas prices during the period. Regulators, however, offer a more cautious interpretation.

The European Securities and Markets Authority (Fennell et al. 2023) concludes that gas futures markets continued to function effectively during the August 2022 price surge, with no evidence of systemic manipulation or structural breakdown, suggesting that prices were largely consistent with legitimate risk-management responses to a severe supply shock. The European Central Bank (Chitu, Minesso, and Manu 2024) similarly acknowledges that while energy prices exhibited sensitivity to shifts in market sentiment and geopolitical risk premiums during the crisis, the Working T index—a common metric for detecting excess speculative activity—remained relatively stable when gas prices spiked in the summer of 2022, with the correlation between the speculation index and natural gas prices appearing limited overall.

The literature further highlights the deep financialization of European gas markets as a structural feature that complicates the standard speculation narrative. As pipeline gas from Russia was replaced by LNG, gas supply became increasingly mediated by financial markets rather than production costs, with pricing largely determined by derivatives markets where prices reflect trading conventions, portfolio strategies, and expectations (Tropeano 2025). The shift from long-term, oil-indexed contracts to short-term spot contracts indexed to hub prices—already underway before the war in Ukraine—amplified price volatility independently of changes in underlying supply conditions (Rogers 2017; Fulwood 2024). At the same time, the distinction between commercial and non-commercial actors has become increasingly blurred: large commodity trading firms, formally classified as non-financial corporations, combine physical trading with extensive derivative positions in ways that can influence prices through portfolio rebalancing and storage decisions even in the absence of physical supply or demand changes (Financial Stability Board 2023; Bouveret et al. 2023; Heather 2023). From this perspective, price increases can be triggered endogenously by

financial dynamics—volatility, margin calls, and liquidity shortages—rather than by genuine physical scarcity.

Taken together, these contributions suggest that speculation should be treated neither as the dominant nor as a negligible factor, but as one element interacting with fundamentals, policy uncertainty, and an unprecedented geopolitical environment. Disentangling these forces requires a framework that is transparent about what it can and cannot establish. In this paper we apply the commodity price speculation model of Knittel and Pindyck (2016) to the European natural gas market over the period 2020-2024. The framework jointly analyzes spot prices, inventories, and convenience yields to identify whether observed price movements are consistent with speculative activity or are better explained by shifts in market fundamentals.

A key feature of the approach is that the inference it supports is asymmetric: a small speculative component allows one to confidently exonerate speculation as a significant driver, while a large speculative component indicates only that the model cannot exclude it. The framework is therefore better suited to ruling out speculation than to establishing its presence, and we interpret our results accordingly.

We find that speculation accounts for only a modest fraction of observed price movements across all phases of the crisis, with market fundamentals—particularly supply disruptions and policy-driven storage dynamics—remaining the dominant drivers throughout. Where the speculative component is largest, the behavior of inventories and convenience yields is inconsistent with speculation as the primary mechanism, pointing instead to genuine supply scarcity. The analysis also reveals an important limitation specific to this market: EU-mandated storage filling ahead of winter 2022–2023 generates inventory and convenience yield dynamics that are observationally equivalent to speculative hoarding in the model, a distinction the framework cannot resolve and which we discuss explicitly.

The paper is structured as follows. Section 2 summarizes the main features of the European natural gas market in terms of its price and fundamentals. Section 3 develops the theoretical model, which we estimate in Section 4. Section 5 draws the final conclusions.

2. THE DUTCH TITLE TRANSFER FACILITY TRADING HUB

The liberalization of the European Union (EU) natural gas market, beginning in the late 1990s with Directive 98/30/EC and deepening through successive gas market reforms and the EU Gas Target Model, dismantled vertically integrated national monopolies and introduced non-discriminatory third-party access to pipelines and trading infrastructure. This regulatory framework aimed to foster competition, enhance price transparency, and stimulate the development of virtual trading points (VTPs), market hubs where gas could be freely traded independent of physical entry points. As gas contracts shifted away from traditional long-term, oil-indexed supply agreements toward short-term, gas-on-gas pricing, numerous hubs emerged across the EU. These hubs reflect the intent of EU liberalization to create multiple competitive regional price signals and allow market participants to hedge risk and manage short-term supply and demand dynamics more transparently (Hirschhausen 2018).

Among these hubs, the Dutch Title Transfer Facility (TTF) has become the principal benchmark and trading venue for European natural gas. Established in 2003 and operated by Gasunie Transport Services, the TTF grew slowly until the implementation of comprehensive liberalization measures, including standardized gas quality, market-based balancing, and enhanced third-party access. It recorded a dramatic increase in liquidity from around 2009 onward (Lise 2016). Its success is partly attributable to the Netherlands' central geographic position in Northwest Europe, extensive interconnection capacity with neighboring markets, and significant LNG import and storage facilities that anchor physical supply. As a result, TTF traded volumes today far exceed those of other EU hubs.

According to Heather (2024), TTF volumes are over four times greater than all other hubs combined, more than ten times larger than the next most traded hub (UK National Balancing Point), and account for roughly 80 percent of natural gas trading in the EU and UK market in terms of volume and liquidity. These characteristics have attracted a broad spectrum of participants—from utilities to financial traders—in both spot and forward contracts, further reinforcing the TTF's market depth and price discovery role. Consequently, TTF prices have become the principal benchmark used in European supply contracts and LNG destination decisions, a role likened to the “Brent of natural gas” (Bland 2025).

Figure 1 shows the evolution of the TTF front-month contract, the most actively traded of all TTF maturities in terms of open interest and average daily volume, from January 2020 to December 2024. According to the Agency for the Cooperation of Energy Regulators (ACER 2023), the mar-

ket progression during this period can be segmented into four phases with distinct characteristics, which we analyze below.

Phase 1, which goes from May 2021 to February 2022, captures the original the surge in prices following the COVID 19 pandemic. Following the last week of May 2020, when the TTF reached historical lows of 3.059 EUR/MWh, the market entered a sustained upward trajectory. This marked the beginning of a prolonged rally in the front-month future price, characterized by a sequence of unexpected shocks that substantially altered both wholesale price dynamics and the broader trading environment.

The first major price surge materialized in early October 2021, when TTF prices peaked to approximately 116 EUR/MWh, reflecting tightening global gas balances, below-average storage levels, and strong post-pandemic demand recovery. A second and more pronounced peak occurred in December 2021, with prices reaching 180 EUR/MWh. This episode coincided with the reversal of flows in the Yamal-Europe pipeline (an infrastructure route transporting Russian gas to Central and Western Europe) which temporarily operated in the opposite direction amid heightened regional demand and constrained supply conditions.

After a brief phase of partial market readjustment, geopolitical developments introduced a further structural break in price dynamics, captured by the second phase, which extends from February to May 2022. On 24 February 2022, the Russian invasion of Ukraine triggered acute uncertainty in European energy markets. In March 2022, Russia publicly threatened to reduce or suspend natural gas deliveries to Europe via the Nord Stream pipeline. These events drove the TTF to a new peak of approximately 227 EUR/MWh. This escalation was followed by actual supply curtailments and the implementation of policy measures aimed at safeguarding energy security, including mandatory storage filling requirements in June and August 2022.¹

Throughout the rest of 2022, the evolving conflict and progressive reduction of Russian gas exports to Europe generated persistently elevated and highly volatile price levels, captured by the third phase from June to September 2022. A new all-time high was recorded at the end of August 2022, when the TTF front-month price reached 339 EUR/MWh, coinciding with the Nord Stream 1 pipeline maintenance and cessation of supplies due to geopolitical tensions. The interruption of pipeline deliveries significantly amplified scarcity concerns and market fragmentation across

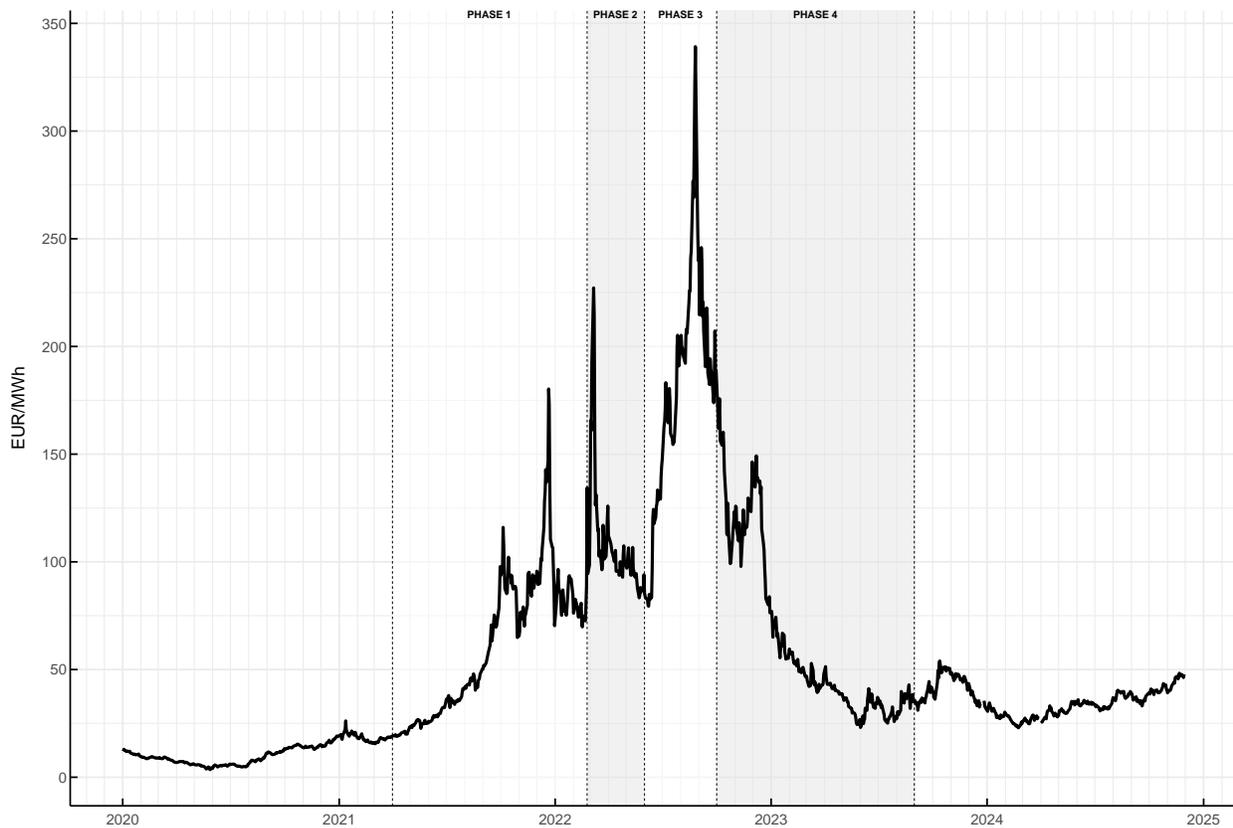
1. In June 2022, the EU introduced the Gas Storage Regulation (EU 2022/1032) to strengthen energy security after the drop in Russian gas supplies. It requires Member States with storage facilities to fill at least 80 percent of capacity by November 1, 2022, rising to 90 percent from 2023.

European hubs.

Subsequently, prices moderated during September and October 2022 as EU Member States achieved key storage-filling milestones, alleviating immediate winter supply risks. This led to the fourth phase, from October 2022 to August 2023, where upward pressure emerged at the end of November 2022, when the price level reached 146 EUR/MWh reflecting a cold spell across Europe that increased short-term heating demand in the context of structurally constrained Russian supply.

This sequence of events underscores the heightened sensitivity of the European gas market to geopolitical shocks, infrastructure disruptions, and storage adequacy during the 2021–2022 energy crisis.

Figure 1: TTF Front Month Future Price (Daily).



Source: Bloomberg.

3. THE MODEL

Knittel and Pindyck (2016) develop a simple economic model of commodity price speculation, to distinguish the effects of speculation from the effects of shifts in fundamental drivers of supply and demand of commodities.

At the core of the model is the notion that it is often extremely difficult to distinguish speculative activity—defined as buying or selling an asset in anticipation of a price increase or decrease to realize a capital gain—from investment decisions, where an asset is traded because its expected net present value is positive, or hedging activities. Although the boundary between these concepts is inherently blurred, Knittel and Pindyck (2016, p. 88) clarifies what speculation is *not*: “a change in fundamentals.” Shifts in fundamentals, such as changes in demand or supply, can certainly affect prices, but the model aims to separate these fundamental-driven price movements from those arising from speculative or investment behavior.

The two most common ways of speculating on commodity prices are holding a (long or short) position in the futures market or holding physical inventories of the commodity. The first one is the easiest, lowest cost strategy performed by both institutional and individual investors and it is also the usual explanation for how speculation takes place. On the contrary, speculation through inventories occurs when sufficient storage capacity is available, so that excess inventories are held in expectation of a capital gain. We should note that speculation via the futures market and speculation via inventory accumulation are intertwined. In order for speculative buying of futures to push up the spot price, inventories must also increase, at least temporarily. Likewise, speculative purchases of inventories will affect the cost of storage and thereby affect the futures price.

The logic of the model, which we analyze in what follows, rests on a framework that describes the spot market, the futures market, and the storage market. We should acknowledge that the ultimate 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.

3.1 The Spot Market

Starting with the spot market, we maintain two simplifying assumptions: (i) the supply of gas includes imports and domestic production, which are indistinguishable and respond to price changes in the same way; 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:

$$\Delta N_t = k_S P_t^{\eta_S} - k_D P_t^{\eta_D} \quad (1)$$

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, we do not estimate the supply and demand elasticities η_S and η_D , but instead consider a range of plausible values for these parameters.

We start by dividing both sides of Equation (1) by Q_t :

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

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

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

Assuming that changes in market fundamentals are reflected in a change in k_D and/or k_S , we can use Equation (3) to isolate the speculative component of price changes:

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

To illustrate, suppose that over some extended period of time there are no changes in fundamentals, so that the only changes in price are driven by speculation. When speculators push the price above its fundamental equilibrium level and keep it there for some time, Equation (4) implies that inventories must continuously accumulate.

Starting from equilibrium position, a higher price implies excess supply over demand, leading to inventory growth. As long as the elevated price persists, inventories continue to rise. When the price eventually returns to its original fundamental level, inventory accumulation stops but inventories remain higher than before speculation began. For inventories to return to their initial level, the price must fall below the fundamental level and remain there long enough to get back to equilibrium.

3.2 The Futures Market

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:

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

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

The futures price itself, $F_{t,T}$, is driven by expectations regarding the future spot price, but it also depends on the risk-adjusted rate of return from holding the commodity:

$$F_{t,T} = E_t[P_{t+T}] + (r_T - \rho_T)P_t, \quad (6)$$

where E_t denotes expectations formed at time t , and ρ_T is the T -period expected return on the commodity, which accounts for systematic risk in its price. Since most industrial commodities are pro-cyclical ($\rho_T > r_T$), we have $F_{t,T} < E_t[P_{t+T}]$. It follows that the futures price is a biased estimate of the future spot price.

In a rational expectations equilibrium, $E_t[P_{t+T}]$ reflects expected changes in fundamentals, such as seasonal increases in demand or new production capacity coming online. With speculation, however, $E_t P_{t+T}$ may deviate from this equilibrium as speculators bet on higher or lower future spot prices. Accordingly, we can write

$$E_t[P_{t+T}] = E_t[\bar{P}_{t+T}] + s_t, \quad (7)$$

where $E_t[\bar{P}_{t+T}]$ denotes the expected future spot price under rational expectations—which may be constant or time-varying if fundamentals are expected to change—and s_t is a shifter capturing deviations due to speculative activity.

We treat both $E_t[\bar{P}_{t+T}]$ and s_t as exogenous, implying that $E_t[P_{t+T}]$ is also exogenous. An increase in the futures price can therefore lead to an increase in the spot price of a commodity, although the magnitude of this effect is constrained by activity in the storage market. Moreover, by examining storage behavior—specifically inventories and the convenience yield—we can assess

whether movements in the spot price are driven by structural shifts in demand and supply or by speculative activity in the futures market.

3.3 The Storage Market

The supply of storage is the total quantity of outstanding inventories, N_t . The price of storage is the implicit “payment” for the privilege of holding a unit of inventory, that is the marginal convenience yield (the marginal value of the flow of services accruing from holding the marginal unit of inventory), ψ_t .

In addition to the price of storage, the demand for storage, $N(\psi)$, depends on the price of the commodity itself (one would pay more to store a higher-priced good). Therefore, we can specify the inverse demand for storage as follows:

$$\psi(N_t) = P_t g(N_t) = k_N P_t N_t^{-1/\eta_N}, \quad (8)$$

where $\eta_N > 0$ is the price elasticity of demand for storage.²

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.

Since we are interested in how changes in the futures price affect the spot price, expressing $g(N_t) = \psi/P_t$ allows us to rewrite Equation (5) as follows:

$$[1 + r_T - g(N_t)] P_t = F_{t,T} - c_T \quad (9)$$

Thus, an increase in $F_{t,T}$ requires an increase in P_t —unless there is an increase in N_t (so that $g(N_t)$ falls) and/or an increase in c_T .

Taking logs and first differences of Equation (8) gives:

$$\Delta \ln \psi_t = \Delta \ln k_N + \Delta \ln P_t - \frac{1}{\eta_N} \Delta \ln N_t \quad (10)$$

2. Note that the marginal value of storage is small when the total stock of inventories is large, because in that case an extra unit of inventory will be of little value, but it rises sharply when the total stock becomes small.

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

$$\Delta \ln \psi_t = \Delta \ln k_N + \frac{1}{\eta_S - \eta_D} [\Delta \ln k_D - \Delta \ln k_S] + \frac{1}{\eta_S - \eta_D} \Delta \ln \left(\frac{X_t}{Q_t} \right) - \frac{1}{\eta_N} \Delta \ln N_t \quad (11)$$

We use Equation (11) to isolate the speculative component of changes in the convenience yield:

$$\Delta \ln \psi_t^S = \frac{1}{\eta_S - \eta_D} \Delta \ln \left(\frac{X_t}{Q_t} \right) - \frac{1}{\eta_N} \Delta \ln N_t \quad (12)$$

We use Equations (4) and (12), 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.

3.4 The Impact of Speculation

To understand the role of speculation in the model, let us consider a case in which there is no change in fundamentals, but speculators believe the spot price will rise, and act accordingly by buying futures and/or accumulating inventories. To analyze the impact on prices, inventories and the convenience yield, we distinguish between two scenarios. The first one is associated with speculation in the futures market, and the second one with inventory holding.

Speculation via the Futures Market

If speculators bet on an increase in futures price, this change in beliefs is captured by Equation (7) through an increase in s_t and thus $E_t[P_{t+T}]$, which leads to an increase in $F_{t,T}$. However, since there is no change in fundamentals driving demand and supply, there is no shift in net demand ΔN_t or demand for storage $\psi(N_t)$.

From Equation (9), equilibrium in the spot and futures markets requires an increase in N_t (so $g(N_t)$ falls) and/or an increase in the spot price. With no change in fundamentals, both will occur. The spot price will increase, leading to an increase in inventories and a consequent fall in $g(N_t) = \psi/P_t$, which limits the increase in the spot price.

After a while, the speculative buying of futures will diminish. The expected future spot price ($E_t[P_{t+T}]$) will fall, leading to decrease in the future price $F_{t,T}$. Now the process unfolds in reverse: the spot price declines, inventories are drawn down, and the additional supply exercise further downward pressure on the spot price. As inventories eventually return to the original level,

the convenience yield rises back to the original value, ΔN_t converges toward zero, and the spot price moves back to its starting position.

Speculation via Inventory Holdings

If inventories accumulation is used to speculate on rising prices, this would generate an increase in the spot price P_t and a subsequent decrease in ψ/P , according to Equation (8). Since the inventory accumulation is driven by an increase in $E_t[P_{t+T}]$, $F_{t,T}$ will increase more than P_t , consistent with the drop in ψ from Equation (5).

Eventually inventory accumulation stops, so that $\Delta N_t = 0$ and P_t returns to its original level, so that $E_t[P_{t+T}]$, $F_{t,T}$, N_t and ψ/P_t do the same, too. Then, while $\Delta N_t < 0$, P_t decreases and only returns to its original value when N_t reaches its original level. As a consequence, some speculators may have made money (depending on when they bought and sold), but, on average, speculators will have lost because they will have incurred additional costs of physical storage.

4. DATA AND RESULTS

In what follows, we apply the model to the European natural gas market 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.

4.1 Data Collection

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.³

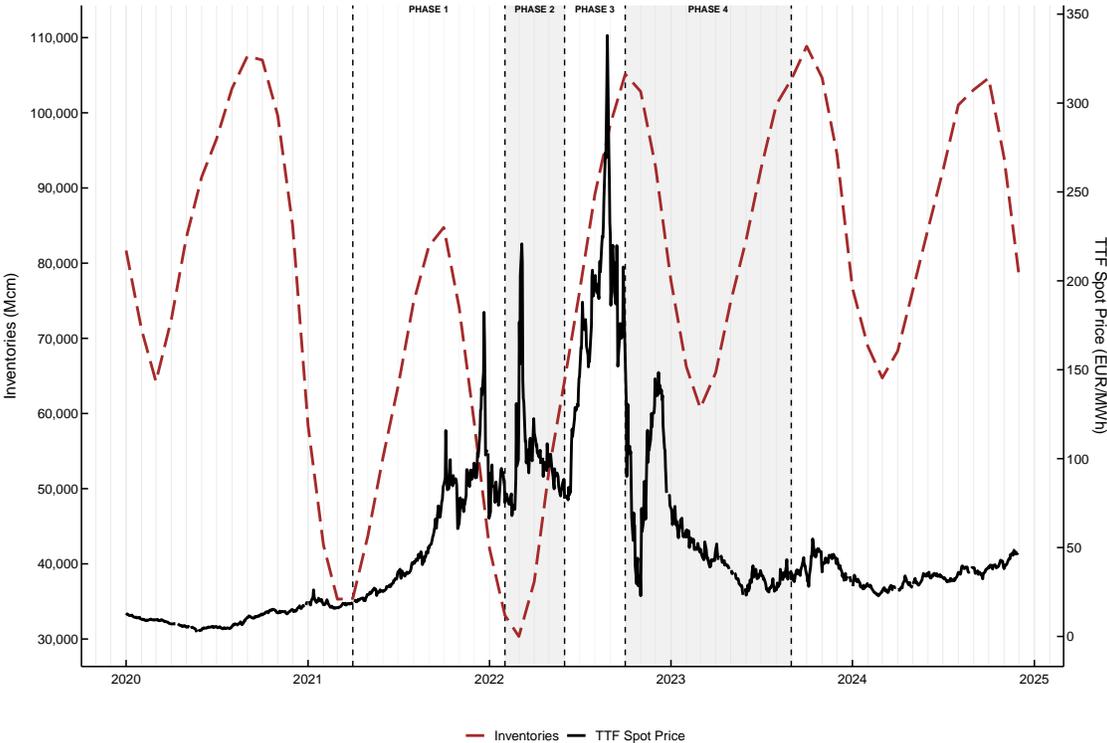
To eliminate the effects of seasonality in demand, we de-seasonalize stocks by first regressing inventories on a set of month dummies and subtracting the coefficients associated with the dummy variables. Thus, consumption is also de-seasonalized given its construction. Finally, we collected

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

daily data on TTF spot price (proxied by the price of the one-day ahead futures contract) and three-month future price from Bloomberg, and then computed monthly averages.

According to the logic of the model, speculative activity that increases spot prices requires a build-up of inventories. Figure 2 captures the relationship between the TTF spot price and the natural gas inventories, at the European level, expressed in millions of cubic meters (Mcm). 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.

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



Source: Bloomberg, Eurostat.

Our ultimate goal is to know whether changes in the speculative component of the spot price 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 changes in the spot price resulting from speculative activity come directly from Equation (4). To compute the cumulative effect of speculative activity, 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:

$$\Delta \ln P_T^S = \ln P_T^S - \ln P_0 = \sum_{t=\text{Jan 2020}}^T \Delta \ln P_t^S \quad (13)$$

To calculate speculation-induced changes in the convenience yield using Equation (12), 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 ($\underline{\psi}_t$) below at 0.4167 EUR/MWh.

The speculative component of the convenience yield is given by Equation (12). 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

$$\Delta \ln \psi_T^S = \ln \psi_T^S - \ln \psi_0 = \sum_{t=\text{Jan 2020}}^T \Delta \ln \psi_t^S \quad (14)$$

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 changes. Note, however, that what matters for our analysis is the sum of the elasticities. Table 1 summarizes the main assumptions for the variables and parameters of the model.

Table 1: List of Variables and Parameters.

Variables	Value	Source
X_t	Supply = Domestic Production + Imports – Exports	Eurostat
Q_t	Demand = Supply – Stock Changes	Eurostat
P_t	TTF Day-Ahead Future Price	Bloomberg
F_t	TTF 3-Month Future Price	Bloomberg
r_T	Euribor 3-month	ECB Data Portal
η_S	0.34; 0.76	(Casoli, Manera, and Valenti 2024; Colombo and Toni 2025)
η_D	-0.47; -0.11	(Casoli, Manera, and Valenti 2024; Colombo and Toni 2025)
η_N	0.6	(Casoli, Manera, and Valenti 2024)
c_T, ψ_t	0.4167 EUR/MWh (per month)	(Taboga 2024)

Casoli, Manera, and Valenti (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 natural gas supply and demand as 0.34 and -0.47. To reflect variations in elasticities, we estimate our model using an inelastic scenario ($\eta_S = 0.34$, $\eta_D = -0.11$) and an elastic scenario ($\eta_S = 0.76$, $\eta_D = -0.47$).

4.2 Results

Before turning to the results, it is important to clarify what the model can and cannot establish. The inference drawn from the speculative component $\Delta \ln P_t^S$ is fundamentally asymmetric. When the speculative component is small relative to actual price changes, one can confidently conclude that speculation was not a significant driver of prices. On the contrary, when the speculative component is large, one cannot conclude that speculation was responsible for that portion of the price change.

A large value indicates only that the model cannot rule out speculation as a contributing factor. It could equally reflect unmeasured fundamental shifts, structural breaks, or policy interventions that appear in the speculative channel because they manifest in the X_t/Q_t ratio. The framework is therefore better suited to exonerating speculation than to establishing its presence.

This follows directly from the construction of the speculative price component:

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

which captures any movement in the production-to-consumption ratio not already accounted for by shifts in the fundamental parameters k_S and k_D . Speculation is one possible source of such residual movement, but it is not the only one.

Figure 3 shows the impact of speculation on the spot price and the convenience yield for the two scenarios over the entire sample, whereas Table 2 reports the associated summary statistics. As we can see, differences in elasticities have an impact on speculative activity, even though in both cases there is no sign of mean reversion.⁴ In particular, the cumulative change in the speculative component of the spot price is negligible as compared to the cumulative change of the spot price itself, in both the elastic and inelastic scenario—despite the inelastic scenario exhibits slightly higher range of variation. According to the model, we can rule out speculation as the major driver of price fluctuations over time.

However, the same reasoning does not apply with respect to the convenience yield. Indeed, both scenario exhibit a remarkable increase in the speculative component across the first three phases, which we investigate in more detail below.

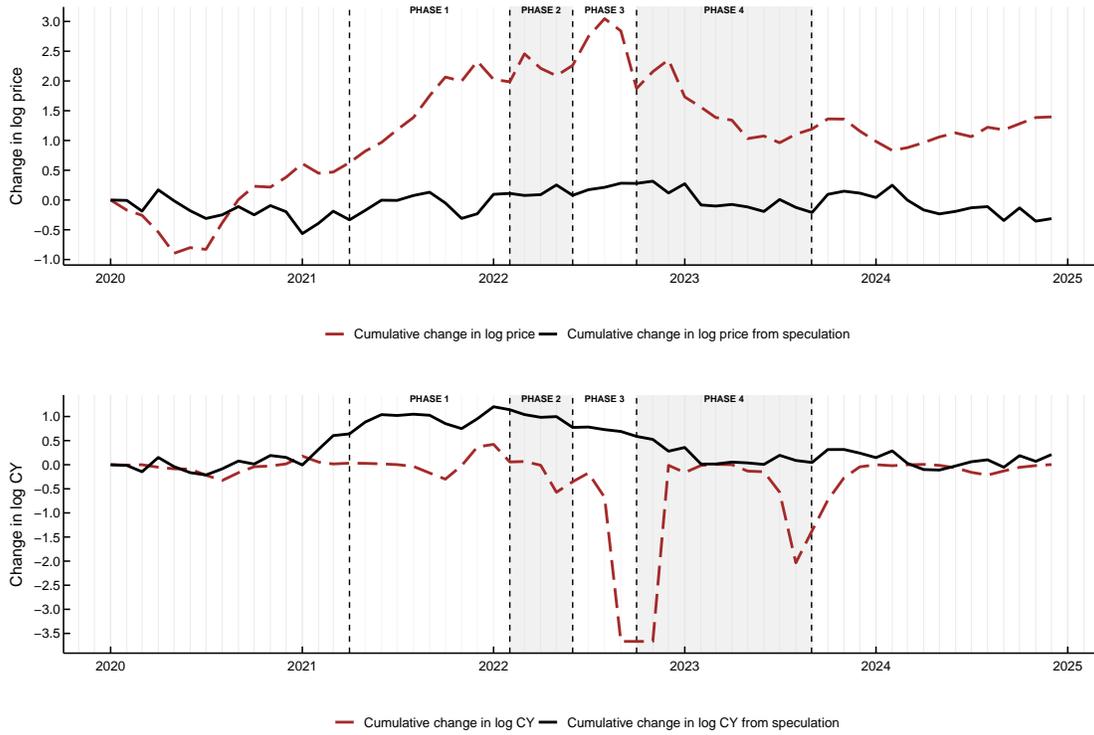
Table 2: Summary Statistics for the Whole Sample.

	Min	Mean	Median	SD	Max
Cumulative Change in log Price	-89.55%	113.87%	116.89%	92.36%	304.73%
Cumulative Change in log Price due to Speculation					
• Inelastic Scenario ($\eta_S = 0.34$, $\eta_D = -0.11$)	-56.45%	-5.55%	-7.92%	19.70%	31.61%
• Elastic Scenario ($\eta_S = 0.76$, $\eta_D = -0.47$)	-20.65%	-2.03%	-2.90%	7.21%	11.57%
Cumulative Change in log Convenience Yield	-366.58%	-32.02%	-3.82%	85.28%	42.26%
Cumulative change in log Convenience Yield due to Speculation					
• Inelastic Scenario ($\eta_S = 0.34$, $\eta_D = -0.11$)	-21.28%	35.47%	19.32%	41.48%	120.31%
• Elastic Scenario ($\eta_S = 0.76$, $\eta_D = -0.47$)	-5.04%	38.99%	21.36%	37.61%	114.22%

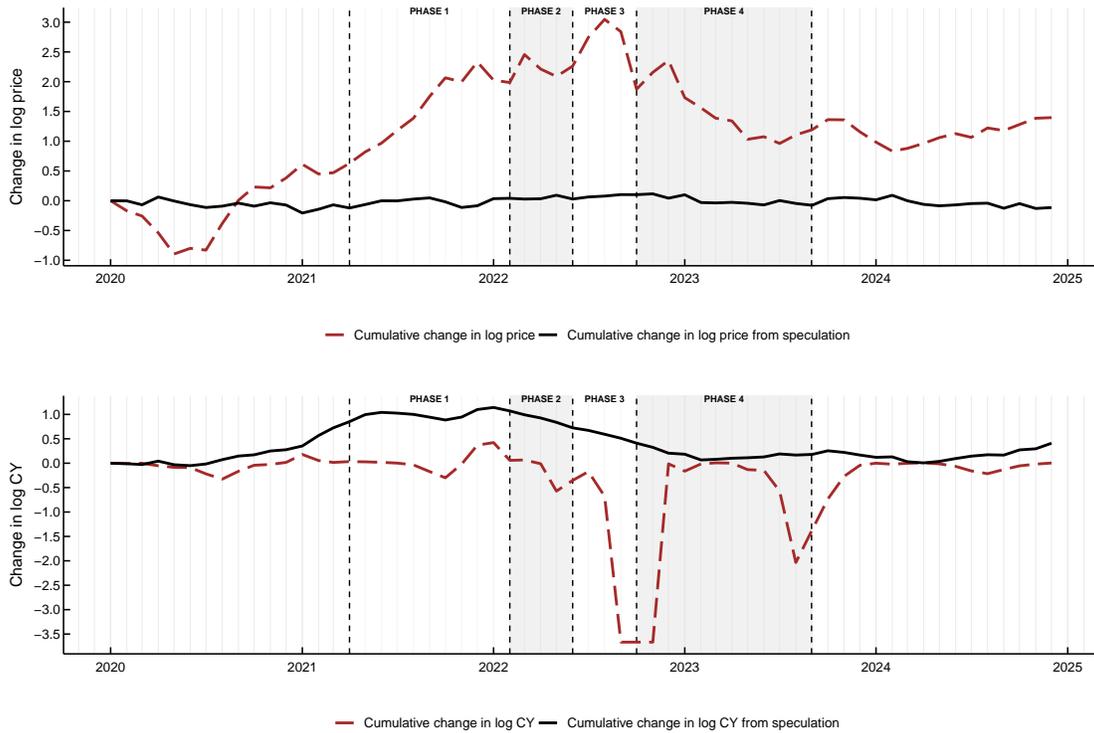
We now examine the individual phases identified in Section 2, summarized in Table 3. We interpret each phase using our key diagnostic criterion: speculative dynamics require simultaneous inventory *buildups* and convenience yield *declines*, occurring alongside rising prices. Our discussion focuses on the inelastic scenario, which represents the more extreme case. The same reasoning applies to the elastic scenario, where the primary difference lies in the magnitude of the estimates.

4. ADF tests for the speculative component of the spot price and the convenience yield are not statistically significant in both scenarios.

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



(a) Inelastic Scenario.



(b) Elastic Scenario.

Phase 1: April 2021 – February 2022

Phase 1 is the most striking. Production fell by 4,690 Mcm, yet consumption contracted far more sharply, declining by 11,887 Mcm. In a standard supply-demand framework, a demand contraction exceeding a supply contraction should exert downward pressure on prices. Instead, prices rose by 135.71 percent . At the same time, inventories fell by 1,532 Mcm and convenience yields rose by 2.52 percent .

According to the model, the speculative component accounts for 44.42 percent of the price change in the inelastic scenario and 16.25 percent in the elastic scenario. However, the inventory decline complicates a straightforward speculation interpretation: pure speculative pressure requires inventory buildups, not drawdowns.

During the period from April 2021 to February 2022, the European natural gas supply landscape underwent a pronounced contraction, driven largely by a reduction in Russian pipeline deliveries. Data indicate that Russian pipeline exports to the European Union were intentionally curtailed in late 2021, with year-on-year decreases of around 25 percent in the fourth quarter of 2021 and a further approximate 37 percent decline in the first seven weeks of 2022, despite available transmission capacity remaining significantly higher (Directorate-General for Energy 2023). This trend resulted in historically low flow levels via major transit routes, including Nord Stream and Ukraine corridors, particularly in January 2022, when aggregate deliveries across main pipelines totaled only 7,100 Mcm—well below typical historical norms. To partially offset these reductions, European markets increased (LNG) inflows, which reached record volumes in early 2022. However, these gains did not fully compensate for the contraction in Russian supply, contributing to a period of sustained supply tightening in the European gas market prior to the onset of the broader energy crisis later in 2022.

As a consequence, the combination of rising prices, falling inventories, and rising convenience yields is instead more consistent with a genuine supply scarcity shock. Even though speculation may have amplified the price response, the evidence suggests fundamental supply constraints were the primary driver.

Phase 2: March 2022 – May 2022

Following Russia's invasion of Ukraine in February 2022, prices fell by 36.80 percent despite enormous market uncertainty. Inventories surged by 6,430 Mcm and convenience yields collapsed by 63.85 percent . Notably, the estimated speculative component is positive (17.65 percent

in the inelastic scenario and 6.46 percent in the elastic scenario) implying that speculative forces were resisting the price decline, pushing prices upward even as fundamentals drove them down. This is consistent with elevated uncertainty and speculative long positioning in the immediate aftermath of the invasion. The inventory buildup, however, likely reflects the beginning of coordinated European efforts to mandate storage fills rather than speculative hoarding, a distinction the Knittel and Pindyck (2016) framework cannot resolve.

With respect to the speculative component of the convenience yield, we can witness a stronger decline in the elastic scenario. This pattern indicates that while inventories were being rebuilt, the marginal value of additional storage declined. We should note that, 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, 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 (10) shows. As the spot price increases, the demand for storage increases, pushing the convenience yield upward.

Phase 3: June 2022 – September 2022

Phase 3 presents the closest analog to speculative dynamics of the model. Prices rose by 57.80 percent, inventories increased sharply by 10,144 Mcm, and convenience yields collapsed by 331.35 percent – the pattern of rising prices, rising inventories, and falling convenience yields that is the model’s signature of speculative activity. The speculative component accounts for 20.39 percent of the price change in the inelastic scenario and 7.46 percent in the elastic scenario.

However, an important structural caveat applies. European Union member states were subject to regulatory mandates requiring storage levels to reach 80 percent of capacity ahead of winter 2022-2023. This policy-driven storage filling would mechanically produce the inventory and convenience yield patterns associated with speculation in the model, even in the complete absence of financial speculative motives. Therefore, the model has no internal mechanism to distinguish policy-mandated from speculative hoarding, which represents a meaningful limitation in this institutional context.

Phase 4: October 2022 – August 2023

In the final phase, prices collapsed by 76.86 percent despite consumption rising by 1,652 Mcm and production falling by 3,390 Mcm—both of which would ordinarily support higher prices. In-

ventories continued to rise by 4,032 Mcm, and convenience yields surged by 163.06 percent as winter demand made storage valuable again.

The speculative component is negative in this phase: -40.34percent in the inelastic scenario and -14.76percent in the elastic scenario. This implies that speculative forces were modestly price-supportive, dampening the price decline even as fundamentals drove prices sharply lower. The price collapse is better explained by the large inventory overhang accumulated during Phase 3, which left European markets well-supplied entering winter despite the adverse fundamental signals.

Overall Assessment

Several findings emerge from the phase analysis. First, speculation plays a quantitatively larger role in European natural gas markets than Knittel and Pindyck (2016) found for crude oil, particularly in Phases 1 and 4. Nevertheless, it still accounts for only a fraction of observed price movements (which is even smaller in the elastic scenario). The dominant drivers across all phases remain fundamental supply and demand shifts.

Second, the asymmetry of the speculative component across the price cycle is notable. Speculation appears to have modestly amplified the price rally in Phase 1 and modestly dampened the collapse in Phase 4, suggesting speculative positions were slow to reverse—a pattern consistent with the stabilizing role that Knittel and Pindyck (2016) attributed to speculation in crude oil markets.

Third, and most importantly for the validity of our application, the European natural gas market exhibits a structural feature absent from the crude oil setting: policy-mandated storage filling. The inventory dynamics in Phases 2 and 3 are substantially shaped by regulatory intervention, which generates convenience yield and inventory signals that are observationally equivalent to speculation in the model but arise from an entirely different mechanism. This limitation should be borne in mind when interpreting the speculative components reported in Table 3.

Table 3: Phase Analysis.

Phase	2021:04–2022:02 (1)	2022:03–2022:05 (2)	2022:06–2022:09 (3)	2022:10–2023:08 (4)
Change in Production (ΔX , Mcm)	-4,690.11	-277.82	-1,908.93	-3,390.72
Change in Consumption (ΔQ , Mcm)	-11,887.35	-2,930.33	-4,317.42	1,652.17
Change in log Price ($\Delta \ln P_T$)	135.71%	-36.80%	57.80%	-76.86%
Change in log Price due to Speculation ($\Delta \ln P_T^S$)				
• Inelastic Scenario ($\eta_S = 0.34, \eta_D = -0.11$)	44.42%	17.65%	20.39%	-40.34%
• Elastic Scenario ($\eta_S = 0.76, \eta_D = -0.47$)	16.25%	6.46%	7.46%	-14.76%
Change in Inventories (ΔN_T , Mcm)	-1,532.38	6,430.23	10,144.48	4,032.17
Change in log Convenience Yield ($\Delta \ln \psi_T$)	2.52%	-63.85%	-331.35%	163.06%
Change in log Convenience Yield due to Speculation ($\Delta \ln \psi_T^S$)				
• Inelastic Scenario ($\eta_S = 0.34, \eta_D = -0.11$)	50.13%	-4.24%	-8.40%	-49.96%
• Elastic Scenario ($\eta_S = 0.76, \eta_D = -0.47$)	21.96%	-15.44%	-21.33%	-24.37%

Note: Production, consumption, and inventories are de-seasonalized.

5. CONCLUSIONS

This paper investigates the role of speculation in European natural gas price dynamics over the period 2020–2024, with particular focus on the unprecedented price movements surrounding the 2022 energy crisis. Replicating the framework of Knittel and Pindyck (2016), we jointly analyze spot prices, inventories, and convenience yields across four distinct phases of the crisis to distinguish between price changes driven by market fundamentals and those attributable to speculative activity.

The central finding is that speculation accounts for only a modest fraction of observed price movements across all phases, with market fundamentals—particularly supply disruptions and policy-driven storage dynamics—remaining the dominant drivers throughout. In Phase 1 (April 2021 – February 2022), the speculative component is largest, ranging between 16 percent and 44 percent of the observed 135 percent price surge, yet the concurrent inventory drawdown and rising convenience yields are inconsistent with speculation as the primary driver and point instead to genuine supply scarcity. In Phase 3 (June – September 2022), the model produces its clearest speculative signal, with prices and inventories rising simultaneously as convenience yields collapse, though this pattern is likely attributable in part to the EU-mandated storage filling rather than speculative hoarding. Across the full price cycle, speculation appears to have modestly amplified the run-up and dampened the collapse, consistent with a stabilizing rather than destabilizing role.

An important methodological point bears emphasis. The inference drawn from the speculative component is fundamentally asymmetric: a small speculative component allows one to confidently exonerate speculation as a significant driver, while a large speculative component indicates only that the model cannot exclude it as a contributing factor. The framework is therefore better suited to ruling out speculation than to establishing its presence, and the results should be interpreted accordingly.

Several limitations of the analysis should be acknowledged. First, the model assumes that supply and demand elasticities are constant over time. Given the structural nature of the 2021–2023 European gas crisis—which involved simultaneous shifts in supply sources, demand patterns, and regulatory environments—this assumption is unlikely to hold uniformly across all phases, and the elasticity scenarios reported in the analysis should be understood as bracketing exercises rather than precise estimates. Second, and more specific to the European natural gas market, the framework cannot distinguish between speculative inventory accumulation and policy-mandated storage filling. EU regulations required member states to reach mandatory storage targets ahead of winter 2022–2023, which would mechanically generate the inventory buildups and convenience yield declines that the model associates with speculative activity, even in the complete absence of financial speculation. Third, the model treats expectations as exogenous and does not account for strategic behavior by large producers or policymakers, which may have played a non-trivial role in the European gas market during this period.

Several directions for future research could address these limitations. A natural extension would be to allow supply and demand elasticities to vary across phases, either through time-varying parameter estimation or through a regime-switching framework, which would better reflect the structural breaks characteristic of the crisis period. Addressing the storage mandate problem likely requires integrating regulatory data on storage targets and obligations directly into the model, allowing policy-driven inventory accumulation to be separated from speculative hoarding. More broadly, the framework could be extended to endogenize expectations, for instance by incorporating futures market positioning data or survey-based expectations, which would allow a sharper identification of the speculative component. Finally, given the increasing integration of gas and electricity markets in Europe, future work could examine whether cross-market dynamics amplified or dampened the speculative pressures identified here.

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