Natural Gas Crisis and Countermeasures

Anthony Papavasiliou

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1. Introduction

Natural gas prices have recently sky-rocketed due to the post-COVID recovery of demand, as well as the invasion of Russia in Ukraine. Since natural gas units are marginal in the European market, this has resulted in electricity prices routinely clearing at unprecedented levels.

The concerns about soaring natural gas and electricity prices relate to the ability of Russia to exert market power in the gas market. This then raises a legitimate question of whether European electricity consumers should suffer the consequences of this monopolistic behavior. The general spirit of the proposed measures has thus been to decouple electricity prices from the prices of the natural gas market.

Some of the measures propose variations to the EU Target Model, whereas others propose a major restructuring of the Target Model. Political positions even include proposals to dissolve electricity markets[1]. In this note I use a quantitative framework in order to describe and analyze a number of these measures.

The models presented in this note are simple, and certainly miss many of the complexities of real-world markets. Nevertheless, I find them useful for organizing my reasoning around the discussion, and more clearly understanding the pros and cons of various alternatives that are under consideration, as well as certain nuances that are not immediately apparent from a purely qualitative analysis.

[1] https://www.news247.gr/gnomes/gianhs-varoyfakhs/ora-na-anatinaxoyme-tis-agores-ilektrikis-energeias.9744425.html

2. Government Interventions

2.1 Two-Markets Approach

Among the proposed measures with the most significant impact on the existing market design, one finds the notion of splitting the market into resources that are non-dispatchable and resources that are dispatchable. Non-dispatchable resources include renewable resources such as wind power or resources that are anyway fully loaded due to their technical and economic features, such as nuclear plants. Dispatchable resources include thermal units, and gas units in particular. The reasoning of the proposal is that non-dispatchable resources should not have access to inframarginal rents because they cannot be controlled and because their cost structure is largely driven by capital costs, whereas dispatchable resources can be cleared at very high prices in order to recover their short-run costs. This view seems to have been voiced, among others, by the president of the European Commission, Ursula Von der Leyen, in a recent speech[2] at the European Parliament.

In fact, the idea of splitting markets is not new, according to Papalexopoulos[3], and has been mobilized in the past in Asian and US markets. A proposal in this spirit has appeared in past academic and industry literature[4]. The Greek government has recently put forth a proposal[5] along these lines, and a variant of the two-market approach[6] has also been advocated for in the UK. Nevertheless, the proposal has also drawn skepticism[7].

The idea of the design, based on what I can surmise from available documentation, is to have non-dispatchable technologies remunerated at a levelized cost of energy (LCOE). The model can thus be described as follows, where we intentionally ignore demand response in order to keep the

[2] https://www.europarl.europa.eu/plenary/en/vod.html?mode=unit&vodLanguage=EN&vodId=b839936a-22b6-fdd1-03bd-487b76155158&date=20220608#

[3] https://www.kathimerini.gr/economy/562025260/klimatiki-allagi-energeiaki-krisi-kai-energeiakes-agores/

[4] Malcolm Keay and David Robinson. The decarbonized electricity system of the future: The two market approach. The Oxford Institute for Energy Studies, 2017.
Malcolm Keay and David Robinson. Market Design for a Decarbonized Electricity System: The Two Market Approach. Chapter in Design of the Electricity Market(s) of the Future, European University Institute, edited by Nicolo Rosetto, ISBN: 978-92-9084-577-5, 2017.

[5] Greek delegation. Proposal for a power market design in order to decouple electricity prices from soaring gas prices, Council of the European Union (11398/22), 2022.

[6] https://www.linkedin.com/pulse/uk-energy-crisis-time-split-power-market-michael-liebreich/

[7] https://www.euractiv.com/section/electricity/opinion/the-greek-market-design-proposal-would-be-the-end-of-electricity-markets-as-we-know-them/.

exposition as simple as possible while still attempting to understand certain relevant properties of the design.

Dispatchable producers: For all resources $g \in G_1$:

$$\begin{aligned} & \max \sum_{t \in T} F_t \cdot (\lambda_t - MC_g) \cdot p_{gt} - 8760 \cdot IC_g \cdot x_g \\ (\mu_{gt}): \quad & F_t \cdot (p_{gt} - x_g) \leq 0, t \in T \\ & p_{gt} \geq 0, x_g \geq 0 \end{aligned}$$

Non-dispatchable producers: For all resources $g \in G_2$:

$$\begin{aligned} & \max \sum_{t \in T} F_t \cdot (\lambda_g - MC_g) \cdot p_{gt} - 8760 \cdot IC_g \cdot x_g \\ (\mu_{gt}): \quad & F_t \cdot (p_{gt} - x_g) \leq 0, t \in T \\ & p_{gt} \geq 0, x_g \geq 0 \end{aligned}$$

Market clearing:

$$D_t - \sum_{g \in G} p_{gt} = 0$$

Government interventions:

$$\lambda_g = \frac{8760 \cdot IC_g \cdot x_g + \sum_{t \in T} F_t \cdot MC_g \cdot p_{gt}}{\sum_{t \in T} F_t \cdot p_{gt}}, g \in G_2$$

The design is interesting, and by construction it can support the optimal mix. Concretely, the LCOE remuneration can support the non-dispatchable capacity, and then the dispatchable resources which come next in the merit order can contribute to price creation by competing against each other. The way to think of the design, therefore, is that the LCOE part takes care of both the investment and fuel cost (if any) of non-dispatchable resources, that come first in the merit order. As long as the optimal amount of non-dispatchable capacity is built, competition between peaking dispatchable units forms the prices for the remaining capacity mix by construction.

This appealing feature of the design can interestingly also raise a major concern: although the design can support the optimal expansion plan, it can also support non-optimal solutions. The intuition of why this is so is that LCOE by construction covers the investment cost of non-dispatchable resources, but it does not fine-tune the optimal capacity. We can thus find a capacity mix with an arbitrarily low or high level of non-dispatchable capacity. This is a sign of trouble. We confirm this problem numerically in section 3.5.

2.2 Tax on Windfall Profits

The idea of this design is to impose a tax on inframarginal units, the profit margins of which are increased significantly relative to their levels before the crisis. In this design, it would be left up to the Member States to decide which consumer classes will be relieved by the taxes that are collected. The model can be described as follows:

Producers: For all resources $g \in G$:

$$\max \sum_{t \in T} F_t \cdot (\lambda_t - MC_g - T_g) \cdot p_{gt} - 8760 \cdot IC_g \cdot x_g$$

$$(\mu_{gt}): \quad F_t \cdot (p_{gt} - x_g) \leq 0, t \in T$$

$$p_{gt} \geq 0, x_g \geq 0$$

Market clearing:

$$D_t - \sum_{g \in G} p_{gt} = 0$$

Note that the tax is technology-specific, and is applied on short-term profits. The way to think of the design is that it essentially modifies the marginal cost of each technology. It can thus potentially result in a long-term capacity mix which deviates from the optimal mix, as we also observe in section 3.6.

One concern that has been raised in terms of the practical implementation of the measure is that it becomes unclear which market the taxes should be applied to. For instance, if the tax is applied to the day-ahead market, then market agents may wait for trading in a market where the windfall tax is not applied. Ways to override this challenge that may be considered include applying the tax consistently throughout all markets, or applying it ex post on the annual reporting of each company.

On a related note, the interaction of the measure with the forward market also matters. Only a small part of energy is traded through the organized markets. Nuclear power, for instance, does not necessarily trade through short-term markets. And this raises the question of how one deals with existing forward contracts that have already been signed. For instance, what if company A has sold forward to company B, which in turns trades in the market? Then company B is taxed, although it does not produce physically.

Legally, it can be a complex matter to apply taxes on market players. The interaction with neighbors also becomes complex. The way in which the measure may be implemented in different Member States may differ, which could lead to a distortion of competition.

The effect of the measure on demand response may depend on when the tax revenues are paid back to consumers. Subsidizing consumers directly through decreased retail rates is likely to mute any reaction from the demand side. Ex-post subsidies entail effort and uncertainty from consumers, and this could thus elicit a certain degree of demand-side response.

2.3 Subsidy on Gas

The idea of a subsidy on natural gas is to emulate the market clearing outcome that would have occurred before the spike of natural gas prices by modifying the marginal cost of natural gas through a subsidy. The model can be described concretely as follows:

Producers: For all resources $g \in G$:

$$\begin{aligned} & \max \sum_{t \in T} F_t \cdot (\lambda_t - MC_g + S_g) \cdot p_{gt} - 8760 \cdot IC_g \cdot x_g \\ (\mu_{gt}): \quad & F_t \cdot (p_{gt} - x_g) \leq 0, t \in T \\ & p_{gt} \geq 0, x_g \geq 0 \end{aligned}$$

Market clearing:

$$D_t - \sum_{g \in G} p_{gt} = 0$$

In principle, and in contrast to the case of taxes that is described in section 2.2, it is straightforward to design subsidies such that the resulting market clearing outcome emulates that of the pre-crisis market. One needs to specifically set the subsidy equal to the difference between the post- and pre-crisis price of natural gas. This is specific to the problem that we are currently facing: since natural gas prices are higher, subsidies move marginal costs in the pre-crisis direction. To the best of my understanding, this proposal seems to be in the spirit of the proposal of the Spanish government.

Concerns[8] that have been voiced relative to the Spanish proposal are certainly pertinent to this model: the model mutes demand response, and the short-run consumption of gas remains at pre-crisis levels.

[8]https://www.euractiv.com/section/energy/opinion/why-spanish-portuguese-proposal-to-intervene-in-wholesale-energy-markets-is-problematic/

2.4 Circuit Breakers

Circuit breakers are described by Papalexopoulos in footnote 3, and have been used in various international markets. A famous example is their use in Texas[9] during the winter crisis of 2021. The idea of circuit breakers is to impose a limit on the profits that can be accrued by inframarginal resources within a reference duration, and pay resources that exceed a certain price cap as bid when this price cap is exceeded, and after the circuit breaker has been activated. The reference duration could be a year, and the threshold profit margin could be two to three times the cost of new entry (CONE).

The measure is interesting, because it balances many counteracting objectives. It sends a signal to demand response, while also ensuring adequate supply in the short run, since natural gas units are able to cover their increased short-run costs, but also limits the exposure of the demand side to high prices.

The implementation of the measure in a portfolio context becomes more challenging. Since bids are not unit-based, one would need to be able to distinguish bids that correspond to gas units from bids that correspond to other resources within a portfolio, or resort to approximations of portfolio supply functions. Moreover, one can expect that the contribution of demand response is decreased once the circuit breaker is activated.

3. Numerical Illustration

3.1 Test System

In this section, we illustrate some of the proposals described above in the context of a relatively simple illustrative model that involves capacity expansion. The numerical model is based on my course notes[10]. We repeat the input data of the model here, for convenient reference.

The system has three load blocks, which are described as follows:

- Base: 7086 MW for 1260 hours
- Medium: 9008 MW for 6000 hours
- Peak: 11169 MW for 1500 hours

There are three candidate technologies in the system:

[9] P. Cramton, Lessons for Peru from the 2021 Texas electricity crisis, March 17, 2021.
[10] https://ap-rg.eu/wp-content/uploads/2020/06/MissingMoney.pdf

- Nuclear (non-dispatchable): marginal cost of 6.5 €/MWh and investment cost of 32 €/MWh
- Coal (dispatchable): marginal cost of 25 €/MWh and investment cost of 16 €/MWh
- Gas (dispatchable): marginal cost of 80 €/MWh and investment cost of 5 €/MWh

3.2 Optimal Mix for $MC_{gas} = 80$ €/MWh

In this solution, the invested capacities are as follows:

- Nuclear: 7086 MW
- Coal: 1922 MW
- Gas: 2161 MW

Prices are as follows:

- Base: 7.62 €/MWh
- Medium: 27.31 €/MWh
- Peak: 109.20 €/MWh

3.3 Short-Run Market Equilibrium when $MC_{gas} = 350$ €/MWh

We now assume that the marginal cost of natural gas rockets from 80 €/MWh to 350 €/MWh. Assuming that the market does not have time to adjust, and is forced to operate with the capacity mix of section 3.2, the market prices[11] become as follows:

- Base: 6.5 €/MWh
- Medium: 25 €/MWh
- Peak: 350 €/MWh

The profit margin of the different technologies is as follows:

- Nuclear: 71.49 €/MWh

[11] Note that these are not the only short-run equilibrium prices, we could also have peak prices at 3000 €/MWh supporting the optimal dispatch.

- Coal: 65 €/MWh
- Gas: 0 €/MWh

We use these values as taxes for the model of section 3.6.

3.4 Optimal Mix for $MC_{gas} = 350$ €/MWh

Given enough time, natural gas units retire and the market reaches a new long-run equilibrium. The optimal mix now becomes as follows:

- Nuclear: 7086 MW
- Coal: 4083 MW
- Gas: 0 MW

Market clearing prices become:

- Base: 7.62 €/MWh
- Medium: 25.00 €/MWh
- Peak: 118.44 €/MWh

Note that the capacity mix now becomes free of natural gas. Note, further, that the market prices recover to 118.44 €/MWh. The marginal cost of natural gas is no longer setting the price, and the market is in long-run equilibrium.

3.5 Two-Markets Approach

We omit wind power or other renewable resources that have uncontrollable output in our example. Instead, in our example nuclear power qualifies for the non-dispatchable category. Our point with the example is to highlight a fundamental issue, which is that the design can support arbitrary (and potentially very different from optimal) levels of non-dispatchable capacity.

We can show that the optimal investment outcome is a solution to this equilibrium problem. The clearing prices for the dispatchable market are as in section 3.2. The clearing price for the non-dispatchable technology is 38.50 €/MWh. By design, this price can support the optimal level of investment in nuclear, and then the market prices for the dispatchable market can support the remaining optimal mix, namely the required mix of coal and gas.

The problem is that, by construction, this design can also support *other arbitrary* levels of non-dispatchable nuclear capacity. This is a sign that the design is offering too many degrees of freedom, and is unable to discover the optimal mix of the market based on decentralized investment decisions of competitive agents. For instance, let us arbitrarily decide to build only 1000 MW of non-dispatchable nuclear capacity, instead of the optimal 7086 MW, so an approximately seven-fold error in the optimal amount of non-dispatchable capacity. Then we can find a solution to the equilibrium model by solving the optimal capacity expansion problem with the remaining load which is not served by the constant output of 1000 MW from the non-dispatchable baseload capacity. This leads us to the following new capacity mix:

- Nuclear: 1000 MW
- Coal: 8008 MW
- Gas: 2161 MW

With prices:

- Base: 25 €/MWh
- Medium: 27.31 €/MWh
- Peak: 109.20 €/MWh

The settlement price for the non-dispatchable nuclear technology is 38.50 €/MWh, as in the case of the optimal mix.

We can show that this is *also* a solution to the long-run equilibrium of the two-market design, although the mix is very notably different from the optimal one, and also notably worse in terms of CO2 emissions. Essentially, the design seems unable to single out the truly optimal capacity of those technologies that are under LCOE remuneration. These capacities have to be decided exogenously, which is in contrast to decentralizing decisions through the market.

3.6 Tax on Windfall Profits

In order to investigate this measure numerically, we focus on the case of section 3.4, where the marginal cost of gas rockets from 80 €/MWh to 350 €/MWh. We use the profit margins of section 3.4 in order to estimate taxes for the non-gas technologies under these conditions. There is no guarantee that this would achieve something desirable (e.g. result in an optimal long-run mix), but the choice is made in order to capture the intuition of certain stakeholders that short-run profit margins should be used as the basis for taxes on windfall profits. The ambiguity[12] of what value should be precisely used, even in this simplified setting, highlights an implementation challenge of the approach.

Concretely, we apply a tax of 65 €/MWh on coal (which implies an effective marginal cost for coal which is equal to 90 €/MWh) and a tax of 71.49 €/MWh on nuclear (which implies an effective marginal cost for nuclear which is equal to 77.99 €/MWh, and which we round to 78 €/MWh in the simulation).

The long-run investment outcome of this model is as follows:

- Nuclear: 0 MW
- Coal: 11169 MW
- Gas: 0 MW

The outcome is clearly suboptimal, and this highlights the fact that the choice of tax is a non-trivial aspect of the design.

3.7 Subsidy on Natural Gas

As discussed in section 2.3, the subsidy can be chosen to be equal to the difference between the post- and pre-crisis marginal cost of gas. This leads to a subsidy of 270 €/MWh on natural gas, which results in the long-run equilibrium being identical to that of section 3.2. Whether this is desirable or not can be discussed. If the crisis persists, the market should be given the incentives to move to a new capacity mix.

4. Conclusions

In what follows, I summarize certain observations that may seem obvious after the fact (indeed, much of the discussion is textbook economics), but were interesting for me to point out while executing the analysis. The exercise

[12] Another interesting source of ambiguity is dual degeneracy in the short-term model of section 3.3, which means that short-run equilibrium prices are not unique, which in turn means that short-run profit margins are not unique. If these short-run profit margins are used for guiding taxation decisions, an ambiguity is introduced in what taxes should be applied.

is by no means claimed to be comprehensive[13], but it has been helpful for me towards organizing my thoughts around the matter, and concentrating interesting remarks that I have gathered from discussions with colleagues during these turbulent past few weeks.

Two-Market Approach. The approach can support the optimal investment outcome. However, the design seems to have too many degrees of freedom (essentially an LCOE that is decided per non-dispatchable technology) and can thus support equilibria that are significantly different from the optimal one, thereby raising questions about whether a decentralized market process can be allowed to reach an optimal degree of penetration of renewable resources in the future. The design also raises important implementation challenges since it proposes a major transformation of the existing European Target Model.

Tax on Windfall Profits. The design raises non-trivial questions about the precise method for choosing taxes, and has no (obvious) guarantee to support an optimal long-run equilibrium. The design further raises concerns about leakage of market participants from the market that is being taxed, and their ability to override the market and thus the tax. Legal concerns and concerns about the implications on existing forward contracts are also raised.

Subsidy on Gas. In our stylized setting, it is in principle straightforward to design a subsidy which results in a pre-crisis market equilibrium. This implies relief of households from high bills, and reduced political pressure. However, this also precludes the market from evolving towards a new mix that is less reliant on gas. The measure diminishes demand response and maintains a high level of consumption of natural gas, at a time when natural gas is extremely expensive.

A. Notation

In this section we describe the notation of the various models.

Sets

T: set of (vertical) blocks in load duration curve

G: set of technologies

G_1: set of "dispatchable" technologies in the two-market model

G_2: set of "non-dispatchable" technologies in the two-market model

[13]Demand response has purposefully been left out of the models. Moving forward, it is interesting to analyze the interaction of the designs with demand response in further detail, and to better understand cross-border effects.

Parameters

F_t: duration of time block t

IC_g: investment cost of technology g

MC_g: marginal cost of technology g

D_t: demand of time block t

T_g: tax on technology g in the tax design

S_g: subsidy on technology g in the subsidy design

Primal variables

p_{gt}: production of technology g in period t

x_g: capacity invested in technology g

Dual variables

λ_t: energy price in time block t

μ_{gt}: profit margin of technology g in time block t

λ_g: LCOE remuneration of technology g in the two-market model