A Theory of Price Caps on Non-Renewable Resources*

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Abstract

What is the optimal response of a resource exporter when a price cap is imposed on its main export? This paper develops a dynamic framework incorporating stochastic prices, financial frictions, and market power to study this novel tool of statecraft. With the right design, a price cap can incentivize increased extraction, stabilizing prices in the global market. But the stabilizing effects diminish when there is leakage outside the cap. Consequently, weak enforcement of the policy worsens the trade-off faced by the sanctioning policymaker. We provide a systematic approach to setting and enforcing an optimal cap level in these circumstances.

JEL: F51, L13, L71, Q41.

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Disclaimer: Both Johnson and Wolfram were involved in the design and implementation of the price cap policy: Johnson as an informal advisor in various policy forums, and Wolfram as the Deputy Assistant Secretary for Climate and Energy at the U.S. Treasury during 2021-22. Rachel has been a member of the Stanford Group on Sanctions since 2022. During that time this group advocated for the price cap policy.

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1 Introduction

Simple economic intuition suggests that binding price controls tend to discourage production. Consistent with this thinking, when a price cap on Russian oil exports was proposed in mid-2022, many policymakers, analysts, and commentators worried that this newly designed G7 policy would reduce the global supply of oil – leading to higher oil prices, more inflation, and perhaps even a worldwide recession.[1]

In this paper, we show that price cap heuristics based on the simplest economic intuition will typically not provide an accurate guide to the behavior of an exhaustible resource producer that has potential market power or that is subject to financial frictions (or both). The Econ 101 model of production-under-price-controls is essentially static, so a lower price today simply means less incentive to produce today. But for an exhaustible resource, dynamic considerations are of paramount importance, including for any petrostate that derives most of its revenue from exports sold into world markets where prices fluctuate a great deal. In the oil market context, the key decision for a large producer is inherently intertemporal and forward looking: run the wells at full capacity today, or "shut-in" some oil and wait for higher prices in the future?

The financial sanctions imposed on Russia following its full-scale invasion of Ukraine in February 2022 created exactly the conditions needed for a price cap to be most effective, because these sanctions severely restricted Russian foreign borrowing and limited access to accumulated official foreign reserves. In the presence of such financial frictions, any petrostate needs to weigh carefully the potential for higher prices in the future against the pressing need for revenue today. These considerations make it much more likely that the sanctioned producer will continue to pump as much oil as possible.[2] And this is essentially what Russia, one of the world's largest oil producers, has done.

Simple static heuristics imply that tougher enforcement of a price cap will increase the risk that the petrostate cuts back on production, but this logic is exactly reversed in a dynamic framework. As we show below, tougher enforcement of a price cap will tend to increase supply, lower oil prices, and reduce volatility in the world oil market. If the sanctioned producer has market power, that only strengthens this finding. Seen through this lens, the

[1]For example, JP Morgan analysts forecast that oil prices could surge to $380 as a result of Russia cutting production in response to the price cap. See https://www.bloomberg.com/news/articles/2022-07-01/jpmorgan-sees-stratospheric-380-oil-on-worst-case-russian-cut?embedded-checkout=true.

[2]The frictionless Hotelling (1931) model predicts perfectly elastic supply, and the analytical literature has emphasized this is far from reality (Anderson et al. (2018)). Our model closely aligns with empirical findings, including the salient facts about Russia's extraction, which are discussed further below.

price cap imposed on Russian oil could have served to reduce revenues for Russia while stabilizing global oil markets. However, enforcement was too weak and, over time, the shadow fleet, which allows Russia to skirt the price cap, has been allowed to grow too large.

A significant conceptual contribution of our paper is to establish that the price cap policy represents a fundamental change to the stochastic environment within which the sanctioned producer operates. The cap eliminates the upside of high prices, making the stock of reserves less valuable and reducing uncertainty.[3] Consequently, the unrestricted supply curve cannot simply be truncated at the price cap level. Instead, the new environment with a price cap requires recomputing the petrostate's policy rules. We follow this strategy and uncover several interesting – and ex ante not obvious – findings about the economics of the cap.

We first study a perfect price cap, i.e., a policy that is tightly enforced and is expected to be permanent. Such a perfect price cap leads to a *more rapid* depletion of reserves, all else equal: i.e., the supply curve shifts outward. The fact that supply expands (or least does not contract, if the producer is already at capacity) is driven by two effects. First, a perfect price cap nullifies the market power of the producer, thus increasing output.[4] Second, it makes the stock of reserves less valuable, which, in the presence of other sources of petrostate revenue, such as general taxation, leads to a more rapid depletion of reserves.

Our finding that the price cap shifts the supply curve outwards has important implications. In particular, a price cap can actually *drive down* world oil prices and act as a *stabilizer* of the global oil market. Such effects are stronger the greater the degree of market power of the producer. A price cap can thus be a potent tool and, perhaps surprisingly, its benefits may actually be greater if it is imposed on a country with significant market share.

Our next set of results concerns the effects of an imperfect price cap, i.e., a cap that applies to only a share of a country's sales of a commodity and/or that is expected to be temporary. The Russian oil price cap was enforced by requiring full compliance for all oil carried on tankers owned, insured, or otherwise serviced by Western companies. At the start of the Russian price cap episode, Western countries owned (or operated or insured) most of the world's large tanker capacity, so a high rate of compliance was entirely plausible.

[3]Our paper builds on papers such as Lee (1978), Lee (1981), and Olson (1989) which highlight that a non-binding constraint can influence behavior in a dynamic setting. Salant et al. (2023) provide experimental evidence consistent with this mechanism. Throughout this paper we use the word "binding" as indicating that the constraint binds contemporaneously at time t (as opposed to affecting time t behavior through the intertemporal channels).

[4]The logic behind this is simple: when the price cap is binding, curbing supply leads to lower volumes but unaltered prices, thereby rendering the use of market power counterproductive, in the sense that the petrostate receives less revenue.

Realistically, however, monitoring and enforcement of any price cap will always be imperfect, and the sanctioning coalition may be able to impact only a certain part of an exporter's sales. Moreover, if the cap is expected to be temporary, the producer might respond quite differently compared with when it is expected to be more permanent.

We find that the effects of a leaky or non-credible price cap are highly state-dependent. If the commodity market is tight and prices are high, the producer may find it optimal to follow a "shut-in" strategy: sharply reduce extraction, further raising global prices, and sell the commodity (at these elevated prices) solely outside the price cap regime. This means that a price cap that is imperfectly enforced and not fully credible can have a destabilizing effect on the world market. But the right response to that situation is to tighten enforcement. Further loosening enforcement is likely to only exacerbate the problems from the perspective of the sanctioning coalition (in the case of the price cap on Russian oil, these are the US, EU, and other G7 countries).

With imperfect enforcement, Western policymakers designing a price cap policy face an important trade-off: harming the sanctioned producer will increase the odds of a commodity price shock. Our model can be used to navigate this trade-off. We introduce a *sanctions possibility frontier* and show how it can be used to set an optimal price cap, for a given set of Western policymaker preferences and depending on the effectiveness of the price cap. Two insights emerge from this analysis. First, the price cap should be less aggressive (i.e., set at a higher level) when the enforcement challenges are more serious. Second, policymakers' preferences (i.e., how they value greater losses for the petrostate vs. increased risk to global oil prices) matter for the optimal price cap level mainly in the intermediate region of price cap effectiveness.

We also present a set of extensions that illustrate the robustness and agility of our setup and which allow us to address specific questions of potential interest to policymakers. We analyze the case of an uncertain yet declining path for the price cap level (e.g., as a result of a form of "forward guidance" on the price cap), as well as a scenario where the leakage is expected to increase over time. We also study the case of a producer that has increasing marginal costs and production capacity constraints. Finally, we discuss whether a price cap can be used as a preventative tool, to credibly discourage a petrostate from committing an act of aggression.

Literature and contribution. A price cap on a non-renewable resource such as oil is a new and live policy, and there is little direct literature on this topic. Our key contribution is to interpret the price cap as a tool that changes the stochastic environment in which the producer operates, and to study the impact on the producer's behavior in a fully structural model. Early analysis of the economics of the price cap on Russian oil appears in Wolfram et al. (2022) and Johnson et al. (2023). In a paper that complements ours with empirical analysis of the cap, Babina et al. (2023) use customs data to provide evidence on the effectiveness of the cap imposed by the G7 on Russia. They find that sanctions have led to a fragmentation of the oil market, with the oil that was destined to Europe trading at steep discounts and below the cap, while the oil sold elsewhere trades at close to global prices. Turner and Sappington (2024) investigate the impact of a price cap in a static two-producer Cournot model. Wachtmeister et al. (2023) consider what different price cap levels imply for net losses of Russia. Almutairi et al. (2025) develop a decomposition of the underlying drivers in the oil market, estimating the monthly shifts in global oil demand and non-OPEC+ supply that have occurred since 2010. They estimate, among other effects, the impact of actions taken by consuming countries against Russia (such as releases from national stockpiles). Baumeister (2023) provides a broader overview of developments in the oil market since the Covid-19 pandemic.

Price caps have also been examined in other contexts, in the industrial organization or urban economics literature – see e.g., Bulow and Klemperer (2012) and Leautier (2018) and references within. More broadly, this paper contributes to the rapidly expanding literature on geoeconomics, which studies the interplay between economic relationships, international politics, and power (see e.g., Clayton et al. (2023) and references within).

The large-scale invasion of Ukraine by Russia has prompted a wave of studies investigating the broader economic impact of sanctions.[5] Consistent with much of the policy discussion and with the focus of our paper, an early study by Bachmann et al. (2022) considers the energy dependence of Europe on Russia, and estimates the short-run effects of disruptions in energy supply to be substantial but manageable. Whether the price cap raises or diminishes the likelihood of such a scenario (and how to mitigate these risks) is one of the key questions we study in this paper. Ghironi et al. (2025) and Ghironi et al. (2024) study sanctions in a dynamic international general equilibrium model. Even though their approach is different from ours, they also highlight the fact that sanctions change the stochastic environment in which an economy operates, and this change is the key channel through which sanctions have an economic effect. Becko (2024) provides a trade-theoretical perspective, viewing sanctions

[5]Contributions that predate the full-scale invasion include Korhonen (2020) and van Bergeijk (2021). Felbermayr et al. (2025) provides a historical overview of sanctions from 1950-2023.

through their effects on terms of trade.[6] Mayer et al. (2025) investigate the potential for trade policy to prevent armed conflict, and Becko and Connor (2025) considers how a country that anticipates conflict should develop its industrial base and international trade linkages. Related to our discussion of the shadow fleet, Egorov et al. (2025a) use product-level data to show that the wave of sanctions imposed on Russia following their invasion of Ukraine had significant adverse effects on Russia's economy, even though roundabout trade and import substitution were substantial.[7]

Our paper also contributes to the literature that studies resource extraction. We construct a new, realistic model of resource extraction that combines three key features. First, we embed in our setting a stochastic process for the oil price that we estimate using oil price data.[8] Second, we study a producer for whom income from oil sales is a large share of government revenues and for whom borrowing might be constrained (e.g., a petrostate facing financial frictions). And third, the producer is large relative to the market, and thus might command significant market power – as is possible for petrostates that account for a large share of global oil sales. By adding these important components, our model has dramatically different implications compared with the canonical Hotelling setting, bypassing many of the shortcomings of that highly influential model. The Hotelling framework has been studied, extended, and criticized in numerous studies.[9] An important contribution to that literature is Anderson et al. (2018), which embeds the geological features of the oil industry, namely the fact that a well's pressure declines as oil is extracted from it. The authors show that extraction from existing wells is not sensitive to economic conditions and is instead largely determined by the binding geological constraints. In contrast, oil well drilling responds more to the underlying market forces. We complement their findings by documenting that financial constraints and market power, in addition to geological constraints, can result in inelastic supply in response to temporary price fluctuations.[10] We do not introduce a

[6] Becko et al. (2025) study the optimal setting of tariffs in presence of geopolitical considerations.

[7] Egorov et al. (2025b) provide some useful stylized facts about trade sanctions based on these data.

[8] Our framework builds on the finance literature (see Cox et al. (1985), Longstaff and Schwartz (1992), Chen and Scott (1993), Duffie and Kan (1996) for models of interest rates, and Schwartz and Smith (2000) and Pindyck (1999) for models of commodity prices).

[9] Classic references include Solow (1974), Stiglitz (1976), Tullock (1979), Dasgupta and Heal (1974), Pindyck (1980), Arrow and Chang (1982), Salant (1976). For an overview of work in the 50 years after the publication of Hotelling's article, see Devarajan and Fisher (1981). Recent work includes van der Ploeg and Withagen (2012), Newell and Prest (2017), Salant (2012) and Gaudet (2013) and most recently Harstad (2023), who considers the dynamic game between successive governments controlling an exhaustible resource.

[10] Notably, our model does so even without explicitly incorporating adjustment costs. Models with adjustment costs can also successfully account for the supply inelasticity. While such costs are undoubtedly important in many problems, there are two reasons why we think it is useful to abstract from these costs

separate drilling decision in our model for parsimony, but still, our model is informative of the economic incentives to extract oil from existing wells and to expand capacity by drilling new wells when the producer is under sanctions.

Our paper analyzes the impact of the price cap on extraction decisions and world oil prices. A complementary paper by Bornstein et al. (2023) develops a quantitative general equilibrium macroeconomic model with an oil production sector and uses it to study the advent of fracking. For a broader overview of the forces that drive oil prices, see Hamilton (2009).

Structure. The rest of the paper is structured as follows. Section 2 describes Russia's oil sector, including its market power and costs, and presents some motivating evidence on the impact of financial frictions on oil production. In Section 3 we construct and solve our model, and in Section 4 we study the effects of the price cap on the producer's decisions and on equilibrium in the oil market. Section 5 considers the case where the producer can partially bypass the price cap. Section 6 establishes a framework for navigating the most important trade-off in designing a price cap (damage to the producer vs. risks to the global economy). Section 7 provides some extensions, illustrating that our framework can be helpful in a variety of circumstances. Section 8 concludes.

2 Motivating facts

This paper's main objective is to develop a dynamic framework to analyze the behavior of a commodity producer under sanctions. While our framework is applicable to any country that exports an exhaustible resource, we are directly motivated by the price cap sanctions imposed on Russia's oil exports in late 2022. Because features of the Russian oil context inform our modeling choices, this section provides a factual background to our analysis. The

in the current context. First, adjustment costs are likely asymmetric, in that it is easier to decrease output than to increase it. Since the sanctioning countries' policymakers are chiefly concerned with the possibility of sharp reductions in supply by the sanctioned producer, the substantial adjustment costs to increase output may be less relevant. Consequently, in the final section of the paper, we explore the cost structure that corresponds to an effective capacity constraint on the level of extraction. Second, adjustment cost models predict inaction regions, where small shocks do not elicit a response, but large shocks do. Economics has developed useful tools to analyze such problems (e.g., Stokey (2009)). However, it is inherently difficult to know, in our context, how large the inaction bands are likely to be with a new policy tool being used (or, relatedly, how to calibrate the adjustment cost in that context). A cautious approach, from the sanctioning policymaker's point of view, is to assume, as we do, that adjustment is free. That way, we learn about the incentives of the petrostate under sanctions without uncertain assumptions about adjustment costs.

section ends with a discussion of a simple empirical exercise that motivates our analysis for the oil industry more generally. The Appendix contains more detail and information about the implementation and enforcement of the price cap in practice.

2.1 Structural features of Russia's oil extraction

Market power. Russia has a significant degree of market power. In early 2022, it was the world's largest exporter of crude oil and oil product combined.[11] The 2022 invasion of Ukraine pushed world oil prices up by nearly 40 percent from the end of February to June 2022, presumably at least in part because participants in the oil market were concerned about potential disruptions to Russian supply.

Russia belongs to the OPEC+ cartel, which influences its market power in two ways. First, the cartel periodically sets production quotas and has considerable influence on world prices; thus, Russia's market power might be wielded through the cartel's decisions, rather than unilateral actions. On the other hand, the extent of Russian market power depends crucially on the reaction of Saudi Arabia and other OPEC+ members, as these producers could increase supply to offset, at least partially, any unilateral changes in Russian supply.

To reflect these considerations, we make the market power of the producer a central component of our framework. We do not explicitly model strategic interactions among the members of the OPEC+, but our estimation of the stochastic process driving oil market shocks implicitly reflects the equilibrium outcome of such historical interactions.[12]

Marginal costs. Naturally, marginal costs are an important element in the producer's decision problem. Most estimates put marginal costs at most Russian fields at between $5 to $20 per barrel.[13] For example, Osintseva (2021) estimates marginal costs across countries and reports Russia's cost of $19 per barrel. At its lowest point at the beginning of the Covid-19 pandemic, the price of oil was around $20-$25 per barrel, which industry reports suggest was above the marginal cost of production.[14] In the main text of the paper, we assume

[11] `https://www.iea.org/reports/russian-supplies-to-global-energy-markets/oil-market-and-russian-supply-2`

[12] For example, we estimate a mean-reversion in the oil price towards the level often understood to be the implicit price target of the cartel. The speed of such mean reversion reflects the historical outcome of interactions and decisions of the cartel.

[13] See Wachtmeister et al. (2023) or the S&P Global: `https://www.spglobal.com/commodityinsights/en/ci/research-analysis/global-crude-oil-curve-shows-projects-break-even-through-2040.html`. The latter also report higher costs relating to future exploration of new oil fields.

[14] See CREA (2023) citing Rosneft (2021).

a constant marginal cost of $19 per barrel, but we explore a richer setting with increasing marginal costs and a capacity constraint in Section 7.4.[15]

State decision-making power, and the federal budget. Like other petrostates, the extraction sector in Russia is effectively a part of the state. To reflect the power of the Russian state over its oil companies and its ability to require payment of ex-post profit taxes, we find it most natural to analyze the problem of a national-level decision maker.

This modeling choice is supported by the significant dependence of Russia's fiscal budget on oil revenues. In 2021, oil (crude and product) was Russia's largest export by category, followed by natural gas and coal.[16] In total, energy represented more than 50% of all export revenues, and oil represented 75% of energy exports. Oil is a significant source of federal budget revenues, accounting for between 35 and 45% over the past decade.[17]

Financial constraints. There are at least three reasons why financial constraints probably play an important role in the decision-making of a sanctioned commodity producer. All of these are applicable to the case of Russia.

First, during a time of geopolitical risks and increased uncertainty, risk-averse international investors are almost inevitably reluctant to lend to a state that is being sanctioned.

Second, a price cap policy is likely to be employed as a result of major act of aggression, and wars are expensive to run. According to its Ministry of Finance, Russia has dramatically increased military spending. Grozovski (2023) reports that in 2023 Russia has dedicated 40% of its budget to military needs. Guriev (2023) estimates military spending to be in excess of 6% of GDP. Such high spending on war puts significant pressure on the budget, heightening the likelihood of financial constraints being binding. Kennedy (2025) emphasizes that around half of Russia's war effort is financed off-budget, and the same author documents heightened pressures in the credit markets as a result of the need to finance the war machine.

Third, a price cap policy might be coupled with financial sanctions, which can diminish the financial war chest and effectively cut off the exporter from international financial

[15]Specifically, we analyze a model with a cost structure that matches the data published by Rystad Energy as reported in Wachtmeister et al. (2023). These data suggest a reverse-L-shaped marginal cost that increases sharply as extraction increases toward a short-run capacity constraint. All our conclusions are robust to this change, although naturally, capacity constraints limit any increases in production in the short-run that are predicted by our model without such constraints. The results we present in the main text can be thought of as better reflecting the medium-term, helping us clearly expose the incentives to increase production in some scenarios.

[16]https://oec.world/en/profile/country/rus

[17]See e.g. Figure 4 in Chanysheva et al. (2021).

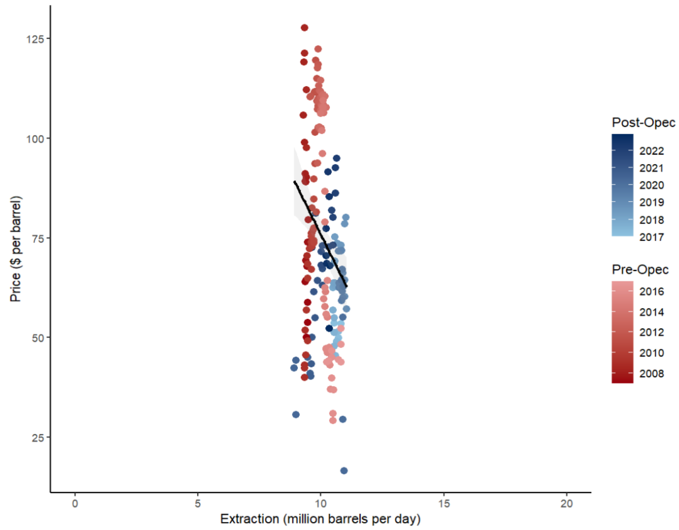

Figure 1: Russia's oil extraction versus Urals price, January 2008 - December 2022. Black line is a least-squares prediction from the univariate regression of price on extraction. Note that Russia joined OPEC+ in late 2016. Source: OPEC, Platts, Argus (price); U.S. Energy Information Administration (extraction).

markets. This is precisely what occurred in the case of Russia in 2022, when Western countries froze $300 billion of Russian central bank reserves almost immediately after the full-scale invasion of Ukraine. In April 2022, the US Treasury Department banned Russia from withdrawing funds held in US banks to pay off its debt obligations. Russian default followed (Itskhoki and Mukhin (2025), Bianchi and Sosa-Padilla (2024), Lorenzoni and Werning (2023)), making borrowing from abroad essentially impossible. And since past saving turned out to be of limited use, the ex post rate of return was negative.

For these reasons, we view the fact that the producer is cash strapped as an integral part of the analysis. In our model, lower revenues translate into lower welfare, as the state is unable to fully isolate consumption from revenue fluctuations. This is further motivated by the literature that has quantified a strong link between sectoral concentration, sectoral shocks, and macroeconomic volatility (Koren and Tenreyro (2007), van der Ploeg and Poelhekke (2009), Aghion et al. (2009)).

Price volatility and price-extraction correlation patterns. In recent decades, Russia's oil extraction has been remarkably insensitive to price fluctuations (Figure 1). Our model is consistent with this important observation.

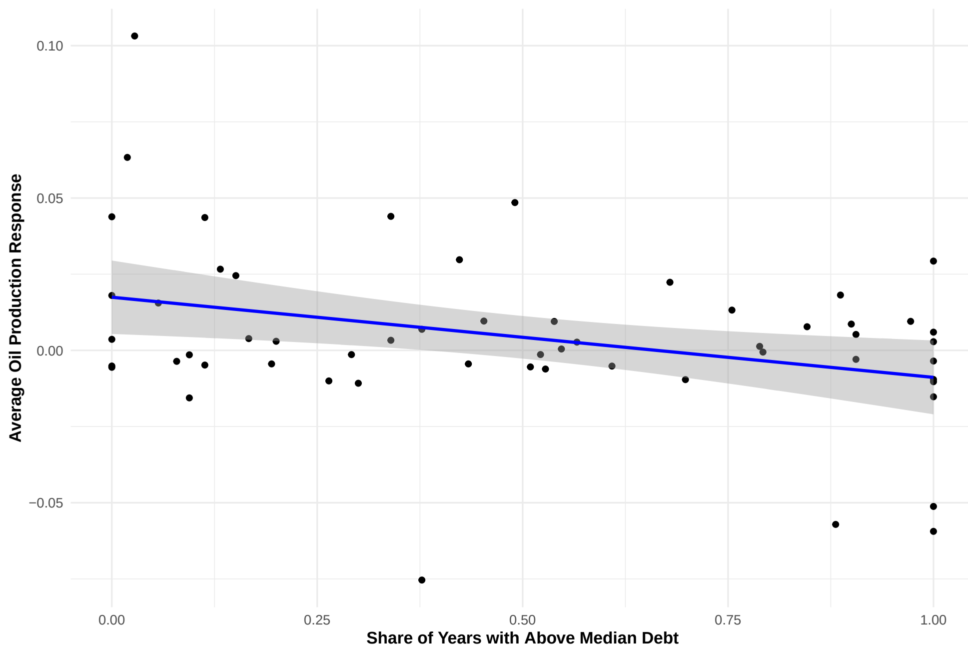

Figure 2: Average oil production response to OPEC announcement as a function of a country's financial conditions. Shaded area reflects 95% confidence interval. See Appendix for details on data sources.

2.2 Cross-country empirical analysis: financial frictions and extraction decisions

One of the predictions of our model below is that financially unconstrained state producers tend to be more sensitive, in terms of their extraction decisions, to price fluctuations. In contrast, the supply schedule of a financially constrained petrostate is predicted to be more inelastic.

To evaluate this proposition, we analyze the oil production decisions of countries as a function of their financial conditions. The basic hypothesis is that countries facing tighter financial constraints will be less sensitive to market factors and will produce the same amount of oil when global prices are low as when prices are high, or perhaps even less when prices are high. We study responses to oil supply news shocks identified by Känzig (2021), who collects OPEC supply announcements. By analyzing production decisions around these announcements, we can isolate how other, non-OPEC countries respond to unexpected price shocks. We use 53 announcements between 1984 and 2017 and examine countries' production in the month following each OPEC decision compared to the month preceding the decision. Our dependent variable is the change in log production multiplied by negative one if the production increased when prices went down or decreased when prices went up.[18]

We measure a country's financial conditions using a dummy variable for whether its government debt to GDP ratio exceeded the median level in a given year. Figure 2 plots country responses to OPEC announcements against the share of years the country had above median debt to GDP levels. There is a negative relationship (coefficient = -.026, std. err. = .010), consistent with the hypothesis that countries facing financial constraints have more inelastic supply responses.[19]

3 Model

In this section, we specify, solve, and estimate a model without a price cap. We refer to this as the laissez-faire solution. The key insight from this analysis is that the supply curve that traces out the producer's extraction relative to equilibrium prices is inelastic – close to vertical – over much of the state space. We carefully unpack this result. In the next section we use this model – and the understanding of its mechanisms – to study the effects of a price cap.

Our setup includes three crucial ingredients. The first is the presence of risk driven by stochastic conditions in the market for a commodity. In the case of oil, the world price fluctuates daily and experiences large swings over time as a result of demand- and supply-side shocks. Because the price fluctuates over time, a price cap fixed at a given level may be binding today, but it might not be binding in the near future if world oil prices decline sufficiently. The opposite is also true: a price cap might not be binding currently but might be expected to bind in some future states. Such future considerations can affect decisions and behavior today.[20] Moreover, we are able to analyze whether the effects of the price cap are state-dependent, i.e., different during times of tight market conditions and high resource prices, compared to when the market has spare capacity and prices are low. Also, an important question that we are able to address with our model is whether the price cap exacerbates or dampens the impact of oil market shocks (from other causes).

[18]Further details about the data used for this analysis, as well as several robustness checks, are in the Appendix. We use observations at the country level since our model focuses on government-level decisions. The results are similar if we exclude countries where the link between oil production decisions and government policy is less strong, such as the United Kingdom and the United States, or if we analyze production decisions six months after the OPEC announcement.

[19]We also examined the relationship between countries' responses to OPEC announcements and the country-level risk premium variable constructed by Damodaran (2022). While slightly noisier, the results also indicate a negative relationship. See Appendix B.

[20]As highlighted by the literature references in footnote 3 above.

The second ingredient we incorporate in our analysis is market power. This is important because the very reason why a price cap, rather than an outright embargo, might be imposed on a petrostate is the fact that the producer is large relative to the market and restricting the flow of the producer's supply into the market can result in a supply shock, and (potentially dramatically) higher oil prices. Whether that happens in equilibrium is one of the key questions that we want to answer with our model.

The third ingredient is an inability of the producer to cushion itself from shocks in the commodity market that drive volatility in prices. The producer whose behavior we analyze behaves in a hand-to-mouth fashion. This could be due to financial frictions, which could, in our context, be caused by financial sanctions. For this reason, we view this as a realistic feature of the environment that we want to study.[21]

3.1 World demand for oil and producer's market power

We denote the world equilibrium price of oil with $p_{w,t}$, and assume that the global demand for oil is isoelastic so that

$$p_{w,t} = \delta(r_t + y_t)^{-\epsilon}, \tag{1}$$

where $\delta > 0$ is a parameter, $\epsilon \geq 0$ is the inverse of the elasticity of demand, r_t is the (residual) supply from the rest of the world, which is stochastic, and y_t is output of the state producer whose behavior is the focus of our study. Fluctuations in r_t capture, in a flexible way, demand, supply, or any other shocks that hit the commodity market.

3.2 Producer's problem

Time is continuous and runs forever. We study a dynamic problem of an agent – e.g. a government of a country, which we refer to as petrostate – endowed with x_0 amount of natural exhaustible resource, such as oil. We normalize $x_0 = 1$. At each instant, profits from resource sales are $\pi_t := p_{w,t}y_t - \mathcal{C}(y_t)$, where $\mathcal{C}(y_t)$ is the total extraction cost. The petrostate

[21] As we demonstrate below, however, the implications of our model of behavior for a large producer are robust to the precise quantification of these frictions, and in particular survive largely unscathed even in a financially frictionless environment. This is no longer the case if the producer is a price taker. The reason is that in a frictionless model, a producer who takes price as given could smooth consumption through borrowing and lending, and hence would optimally extract no resource at low prices, ramping up extraction once prices are sufficiently high. But when the producer has market power, the price moves endogenously against a producer who tries to ramp up production, limiting the desirability of a highly price-responsive extraction strategy. We present quantitative results spanning these possibilities below and report robustness of our results to a wide range of parameter combinations.

has access to income flow unrelated to oil sales, $\tau \geq 0$.

The petrostate chooses how much resource to extract over time to maximize the net present value of the utility from resource rents, subject to a resource depletion constraint, the market conditions, and the demand curve:

$$\max_{y_t} \mathbb{E}_0 \left[\int_0^\infty e^{-\rho t} u(\pi_t + \tau) dt \right] \text{ subject to } dx_t = -y_t dt,\ x_t \geq 0,\ y_t \geq 0, \tag{2}$$

where:

$$\pi_t := p_{w,t} y_t - \mathcal{C}(y_t) = \delta \left(r_t + y_t\right)^{-\epsilon} y_t - \mathcal{C}(y_t). \tag{3}$$

We assume that u is increasing and weakly concave. Note that when u is linear, the producer maximizes the net present value of profits, with the timing of profit flows irrelevant for welfare. This would be the case if the state had access to deep financial markets and was able to smooth its spending through the volatility in revenues from resource sales. Conversely, a strongly concave utility function naturally implies a sharply increasing marginal utility as revenues fall. This is symptomatic of a state that has few options to smooth declining resource revenues and is forced to cut essential spending and/or repress domestic consumption, harming the welfare of its citizens and likely adversely affecting the political popularity of those in power.

We denote by $V(x, r)$ the value of owning reserves x when the market conditions are given by r, with the notation $V_{x \text{ or } r}$ denoting the respective derivative. Writing the problem recursively (and so disposing of the time subscripts), the Hamilton-Jacobi-Bellman equation associated with the problem in (2) is:

$$\underbrace{\rho V(x,r)}_{\substack{\text{required}\\\text{return}}} = \max_y \underbrace{u((p_w(r,y)y - \mathcal{C}(y))}_{\substack{\text{payoff}\\\text{from}\\\text{extraction}}} - \underbrace{V_x(x,r)y}_{\substack{\text{value loss}\\\text{from}\\\text{extraction}}} + \underbrace{V_r(x,r)\mu(r)}_{\substack{\text{value change}\\\text{due to expected}\\\text{price change}}} + \underbrace{\frac{1}{2}V_{rr}(x,r)\sigma(r)}_{\substack{\text{compensation}\\\text{for risk}}}, \tag{4}$$

where $\mu(r)$ and $\sigma(r)$ are the state-dependent drift and variance of the stochastic process for residual supply r, respectively. Equation (4) expresses a balance condition for a petrostate that treats the underground stock of reserves x as part of its national wealth. The left-hand side is the required return the resource must generate given the state discount rate. The right-hand side specifies the elements that this required return is composed of: the instantaneous welfare flowing to citizens when y barrels are extracted and sold at the world price p_w; the loss of value due to reduced stock; the change in value due to the predictable component of the spot price, and the Ito term reflecting a precautionary discount for risk.

Optimal extraction policy sets the marginal welfare from an extra barrel today equal to the cost of resource depletion:

Proposition 1. *The optimal extraction path satisfies the necessary condition*

$$u_\pi \cdot (p_{w,t} \cdot (1 - \varepsilon_{D,t}) - \mathcal{M}(y_t)) = V_x, \tag{5}$$

where

$$\varepsilon_{D,t} := -\frac{\partial p_{w,t}}{\partial y_t} \frac{y_t}{p_{w,t}} = \epsilon \cdot \frac{y_t}{r_t + y_t}. \tag{6}$$

is the effective elasticity of demand and $\mathcal{M}(y_t)$ is the marginal cost.

Equation (5) states that at the optimum the marginal utility of extraction is equal to the marginal value of reserves. Equation (6) shows that the effective elasticity of demand depends on the parameter ϵ as well as the relative size of the producer in world production. The intuition for why market power depends on the market share is similar to that in the Cournot oligopoly model: the larger the producer, the greater its influence.[22]

3.3 Equilibrium

An *equilibrium* is a policy function $y(x, r)$ that solves producer's problem and the price function $p_w(r, y(x, r))$ that clears the market for oil.

We proceed to characterize the equilibrium numerically.

3.4 Parametrization

Our parametrization strategy combines the calibration of some of the parameters of the model with the simulated method of moments where we infer the properties of the stochastic process for $\{r_t\}$ from historical data on real (inflation-adjusted) oil prices. We discuss the two elements in turn.

[22] As in the Cournot oligopoly setup, here too the market power of a producer is increasing in its own market share and decreasing in the absolute elasticity of demand.

3.4.1 Calibration

In our baseline, we assume that the instantaneous utility function is constant relative risk aversion:

$$u(y) = \frac{(\pi + \tau)^{1-\gamma} - 1}{1 - \gamma}. \tag{7}$$

This utility function is widely used in economics to study intertemporal trade-offs, making it a useful benchmark for our dynamic model.[23] Parameter γ reflects both the degree of financial constraints (since access to perfect financial markets implies linear utility and $\gamma = 0$) and the state producer's preferences with regards to the time-varying profile of oil revenues – the (inverse of the) intertemporal elasticity of substitution.

Our calibration reflects a financially constrained producer with intertemporal preferences that reflect those of the population of the state. We view the decisions of the state as having a direct bearing on the consumption and welfare of its citizens (through the tax and transfer system, public goods provision, procurement, and salaries of public sector workers, including the army). To reflect this, we set $\gamma = 2$. This value is consistent with consensus estimates for the (inverse of the) intertemporal elasticity of substitution of households in the literature, and is a benchmark calibration of preferences in models of intertemporal behavior. For instance, this is the mean value in the influential meta-study of Havranek et al. (2015), and is used in many models, see e.g. Moll et al. (2022). This is also the value reported in an (unpublished) manuscript studying intertemporal preferences of the Russian households by Alexander et al. (2013). We report robustness to a wide range of values for γ below.

We set the marginal cost of extraction $\mathcal{M} = \$19$ per barrel, reflecting the estimates of Russia's marginal costs in Osintseva (2021). The constant marginal cost is a useful benchmark often assumed in policy discussions. But our framework is flexible and can handle much more complex settings. To illustrate this, in Section 7 we present the results based on increasing, reverse L-shaped marginal cost, incorporating a short-run capacity constraint.[24]

We set the rate used to discount future payoffs to 3%, to match the level of extraction in Russia of around 2.5-3% of reserves per year. We set $\tau = 2$, which implies that income from commodity sales constitutes a substantial fraction – between 1/3 and 1/2 – of the overall income of the state. Given the estimated process for r we describe below, we set δ to ensure the petrostate's global market share is around 11%, matching that of Russia.

[23] We explore a more flexible parametrization with recursive Duffie-Epstein-Zin preferences in Appendix C. We also analyzed a broader class of HARA utility functions (which nest both CRRA and CARA), and our results are robust to this change.

[24] See also discussion in footnote 15.

Estimating oil demand elasticity is a subject of extensive empirical literature. Meta-analysis in Uria-Martinez et al. (2018) suggests the range for this elasticity in the short run (around one year) is in the $[0.07, 0.14]$ range. However, the recent literature suggests these estimates might suffer from simultaneity bias (see Baumeister and Hamilton (2019) and references within). Moreover, the effective degree of market power of a single producer would in part depend on the reaction of other large producers, not least those in the OPEC cartel: if OPEC offsets some of the extraction decisions of the producer, the effective market power is lower. To reflect these considerations, we set $1/\epsilon = 0.25$ and we extensively discuss below how the results change as we depart from this elasticity in either direction.

3.4.2 Stochastic process for the price of oil

Our objective is to embed the decision problem of the producer in an empirically relevant environment. To do so, we assume that the price follows the Cox–Ingersoll–Ross process (Cox et al. (1985)):

$$dp_t = D(\tilde{p} - p)dt + \varsigma\sqrt{p}dW_t \tag{8}$$

where W_t is the standard Wiener process and $\tilde{p}$, D, and ς are (strictly positive) parameters that satisfy $2D\tilde{p} > \varsigma^2$. The process is mean-reverting, and parameter D determines how quickly the gap between the current price and the average price $\tilde{p}$ closes. Parameter ς determines the volatility of the price.

We estimate this process by maximum likelihood. The model fits the data very well; the estimated distribution is right-skewed and matches well the histogram of historical oil prices (Figure 3).

In terms of the process for r_t, we estimate the model by simulated method of moments, such that the behavior of the equilibrium price $p_{w,t}$ in the laissez-faire equilibrium reflects the process for the oil price observed in the data and displayed in Figure 3.

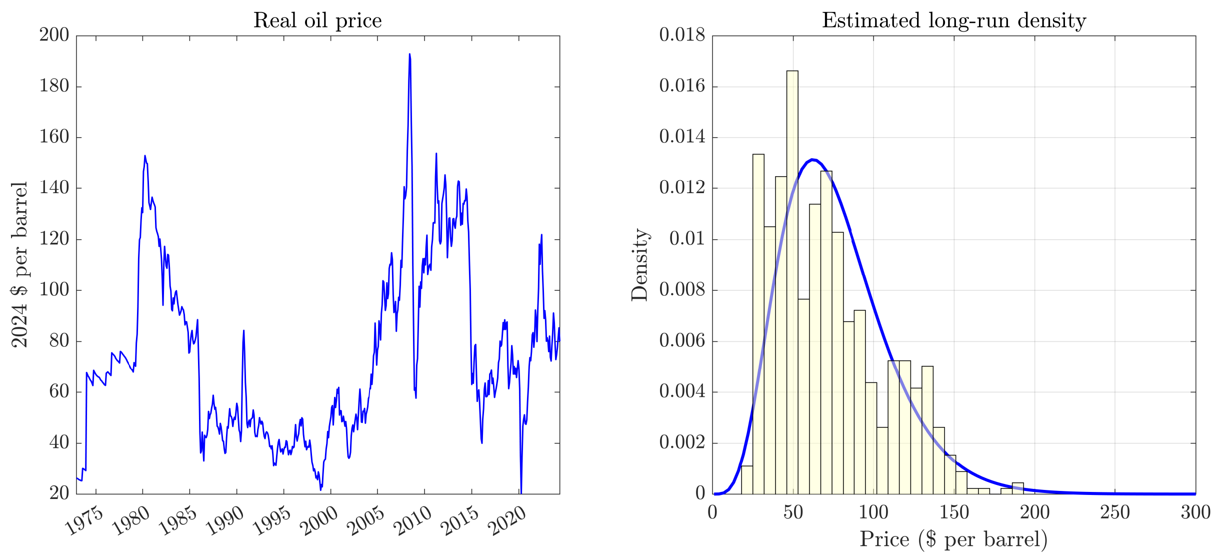

Figure 3: Real oil prices and the estimated distribution

Notes: The left panel shows the data on real oil prices used in the estimation of the price process, and the right panel shows the limiting distribution of the estimated process. The bars in the right panel represent the histogram of historical real oil prices since 1973. The limiting distribution of p_∞ is a Gamma distribution: $f(p_\infty; D, \tilde{p}, \varsigma) = \frac{\beta^\alpha}{\Gamma(\alpha)} p_\infty^{\alpha-1} e^{-\beta p_\infty}$ where $\beta := \frac{2D}{\varsigma^2}$, $\alpha := \frac{2D\tilde{p}}{\varsigma^2}$ and $\Gamma(\alpha)$ is the Gamma function. The variance of the limiting distribution is $\frac{2D\tilde{p}}{\varsigma^2}$. We obtain the data shown in the left panel from the FRED database. We deflate the monthly nominal oil price (code WTISPLC) by the US CPI index (code CPIAUCSL) set to 1 in May 2024. We use maximum likelihood estimation, making use of the numerical implementation of Kladivko (2013). We obtain $\tilde{p} = \$76$ (in 2024 prices), $\varsigma = 2.4$ and $D = 0.2$ (at the annual frequency). The estimated parameters imply a significant degree of persistence in the process for the price, with a half-life equal to $\ln 2/D = 3.6$ years.

3.5 Characterization

The solution to the producer's problem (2) is a value function $V(x, r)$ and policy function $y(x, r)$ which specifies the optimal level of extraction at each price, for any level of reserves.[25] We now study a specific part of the policy function, namely the supply curve at today's level of reserves, $y(1, r)$.

3.5.1 Contemporaneous supply curve

Specifically, the contemporaneous supply curve is a combination of points $(y(1, r), p_w(1, r))$ where $y(1, r)$ is the optimal extraction rate at today's reserves (which we normalized to 1) at any r, and $p_w(1, r)$ is the equilibrium price function.

[25]To solve the HJB equation with market power and to estimate the model, we develop a new algorithm which we describe in the Online Supplementary material.

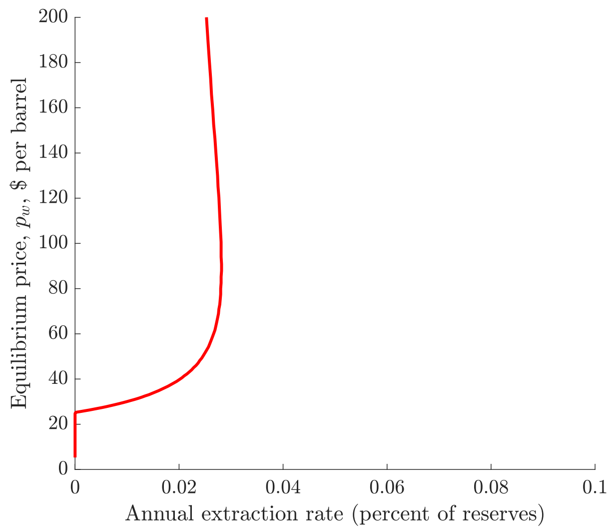

Figure 4: Contemporaneous supply curve

Notes: The figure shows the slice of the policy function $y(1, r)$ plotted against the equilibrium price, i.e. shows the set of points $(y(1, r), p_w(1, r))$.

Figure 4 shows the supply curve implied by the baseline parameterization of our model, with curvature of the utility function given by $\gamma = 2$ and (inverse) demand elasticity given by $\epsilon = 4$. The key result that emerges is that the supply curve is highly *non-linear*, and that for much of the price range it is *inelastic*. Supply falls sharply as prices fall below $40, and reaches zero at values over $20 per barrel, above the marginal cost which we assumed to be $19 per barrel.

This largely inelastic supply curve is consistent with the empirical findings in the literature (Newell and Prest (2017), Caldara et al. (2016), Kilian (2022)) and aligns with the extraction vs. price pattern in the context of Russia (Figure 1). Before turning to the analysis of the price cap in this environment, we account for the shape of the supply curve in the laissez-faire version of our model.

3.5.2 What explains the shape of the contemporaneous supply curve?

We dissect the forces behind our result by solving a series of problems, starting with the simplest case for which an analytical solution is available, and then adding ingredients of our model one by one.

Analytical benchmark. The analytical benchmark we start with is the supply curve of a producer who faces a known and fixed price p and does not have outside income,

$\tau = 0$. It is easy to show that the problem admits a closed form solution: $y_t = \frac{\rho}{\gamma} x_t \forall t$, meaning that each period, the producer extracts a constant fraction $\frac{\rho}{\gamma}$ of remaining reserves. Thus, reserves decline to zero only asymptotically. Since extraction is independent of p, the contemporaneous supply curve is a black vertical line at $\frac{\rho}{\gamma} = 0.015$ in our calibration in Figure 5.

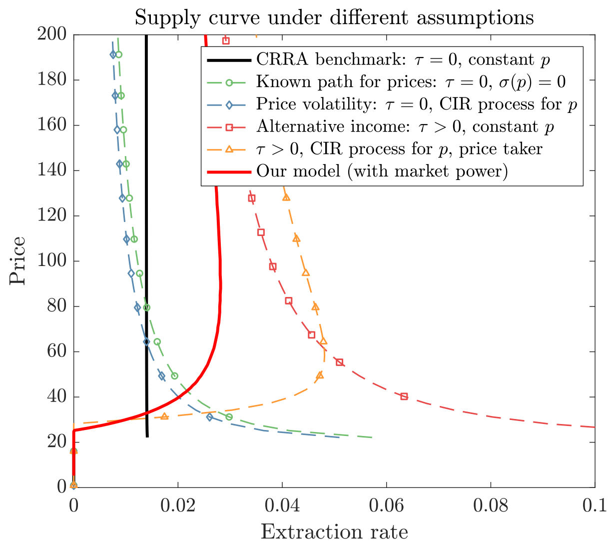

Figure 5: Forces shaping the contemporaneous supply curve

Notes: The figure shows hypothetical contemporaneous supply curves under a series of alternative assumptions about the environment, as described in the main text. The vertical solid black line is the analytical solution with extraction rate given by $\frac{\rho}{\gamma}$. See main text for details.

Revenue smoothing effect. Consider adding to the analytical benchmark the possibility that oil prices move around over time but in a non-random way. Specifically, assume that the price converges deterministically from whatever its current value to its average of $76. Both income and substitution effects are at play. If $\gamma > 1$, as in our benchmark calibration, the income effect dominates, and consequently, when prices are below average today and expected to rise, the producer increases extraction today (relative to the analytical benchmark). Effectively, the producer acts to *smooth revenues* in light of temporary deviations of prices from their average level. With a known price path converging deterministically to the average and $\gamma > 1$, the supply curve is thus downward sloping in the current price (a green dashed line in Figure 5).

Precautionary effect. If instead prices move as in the real world, the mean reversion is coupled with volatility and risk. Heightened uncertainty spurs the additional *precautionary* *effect:* the producer is more conservationist and the supply curve shifts to the left. We find this effect to be relatively small quantitatively (the blue line in Figure 5).

Non-homotheticity effect. When prices are non-stochastic and fixed forever, as in the analytical example, but the producer has access to non-oil income $\tau > 0$, the extraction rate is no longer independent of the price. Instead, optimal extraction is higher the *lower* the fixed price p. This is the *non-homotheticity effect*, denoted by the red-dotted line in Figure 5. Intuition for this effect is best grasped by first noticing that, with an alternative source of income, the producer extracts the entirety of the reserves in finite time.[26] Thus, over time, the extraction rate rises and reaches 100% when the last unit of the commodity is extracted. This pattern of extraction over time means that there is a negative relationship between the value of remaining reserves and the extraction rate. This same relationship between the extraction rate and the value of the reserves is induced by a permanently low price of the resource: low p, if it is permanent, is in this sense equivalent to low reserves. Following this logic, for low p the producer behaves as if they are more impatient, extracting a higher share of the remaining reserves.

Time-the-market effect. When we combine volatile prices with non-oil income, the behavior of the producer changes sharply. This is because, with $\tau > 0$ *and* with volatile prices, there is a strong motive to *time-the-market:* sell at high prices, and conserve reserves when prices are low. The non-oil income τ provides a cushion against sharp increases in marginal utility when revenues are low. Consequently, the producer is able and willing to cut supply sharply when prices are close to marginal cost, and increase output when prices are higher (the orange-dotted line in Figure 5).

Market power effect. When the producer internalizes the effect of its own choices on equilibrium prices, it tends to reduce supply relative to the price taker benchmark, shifting the supply curve to the left (the solid red line in Figure 5).

3.5.3 Comparative statics

The decomposition of the supply curve into these five forces provides us with a better understanding of the comparative statics in our model. Figure 6 illustrates how the results

[26]Effectively, as long as it has access to another source of income, it is not a disaster for the producer to run out of the resource. Consequently, impatience takes over, and extraction is faster.

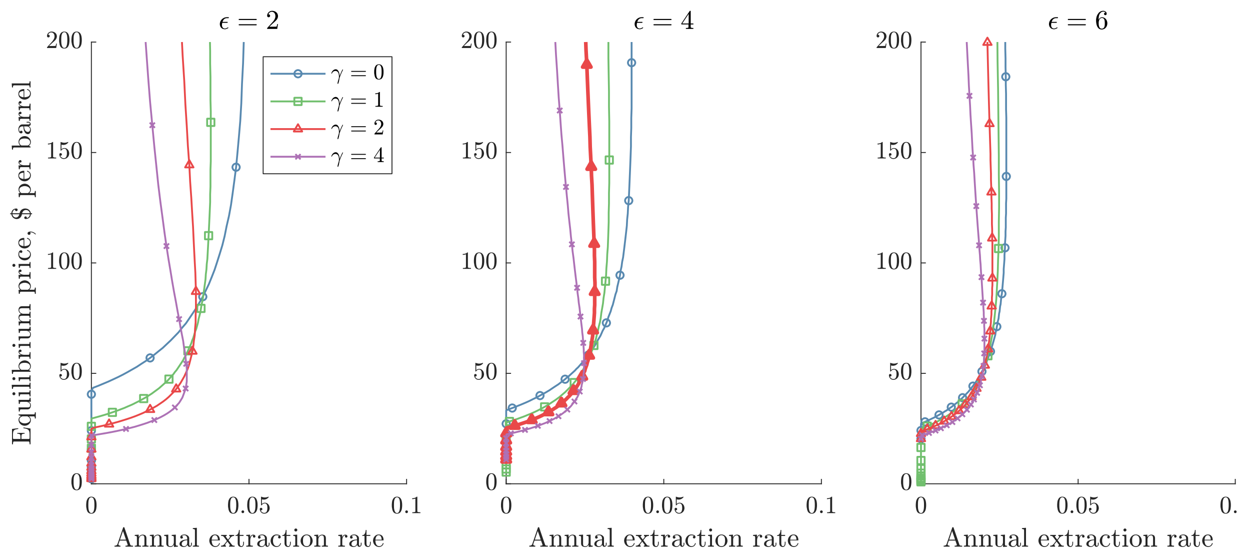

Figure 6: The supply curve under alternative parametrizations of utility curvature γ and demand elasticity ϵ

Notes: The figure shows how the model's result – the contemporaneous supply curve in the laissez-faire case – changes as we vary the degree of market power (across panels) and the degree of financial frictions / curvature of utility (across lines within panels). Higher ϵ and higher γ represent greater market power and more severe financial frictions / more curved utility, respectively. The baseline calibration used elsewhere in the main text is shown as the thick red line with triangles in the middle panel.

change by comparing, across panels, models with different elasticity of demand, and, within every panel, models with varying degrees of curvature of the utility function u, ranging from linearity (the case that can be interpreted as one without financial frictions) to doubling γ to 4.

Consider first how forces we discussed above respond to changes in γ. A lower γ means that the producer cares relatively less about the timing of revenue flows, and cares relatively more about the (net present value of) total revenue received across periods.[27] Thus a lower

[27] This is intuitive, but one way to see this more explicitly is to use the second-order Taylor approximation of (7) in the intertemporal utility. Denoting by $\bar{\pi}$ the average revenue flow, we obtain the following expression for total intertemporal utility:

$$U \approx \underbrace{\frac{1}{\rho} \cdot \frac{(\bar{\pi}+\tau)^{1-\gamma}-1}{1-\gamma}}_{\text{Utility from average flow}} \underbrace{-\frac{1}{2}\gamma(\bar{\pi}+\tau)^{-\gamma-1}\int_0^\infty e^{-\rho t}\left(\pi_t-\bar{\pi}\right)^2 dt}_{\text{Penalty from fluctuations}}$$

We can normalize the mean revenue flow $\bar{\pi}+\tau = 1$, which means that utility from average profit flow is indexed to zero for any γ. Relative to this benchmark, the utility penalty for revenue fluctuations is $-\frac{1}{2}\gamma \cdot Var_\rho \pi_t$, where $Var_\rho \pi_t$ is the discounted variance of the profit flow. The key result is that the penalty for variable profit flow is increasing (in absolute value) in γ.

γ acts to bolster the time-the-market effect, while at the same time reducing the revenue smoothing and precautionary effects. The result: a supply curve that hits zero at higher prices, and is upward sloping rather than inelastic over a larger range of prices (compare the different lines in each of the panels in Figure 6).

Next, consider how changes in ϵ impact the petrostate's actions. Changes in the elasticity of demand alter the degree of market power the petrostate wields. With more inelastic demand (i.e. a higher ϵ), the producer has more market power, and so naturally the market power effect is stronger: the supply curve is shifted inwards (comparison across the panels in Figure 6). And, since the price response works strongly against the producer's attempt to time the market, this effect is weaker and optimal extraction becomes less sensitive to prices for any γ – graphically, the supply curves become more vertical in the right-most panel of Figure 6.

Figure 6 also illustrates the remarkable robustness of our conclusions to a very wide range of parameter values. Specifically, as long as the producer has some market power (e.g. $\epsilon = 2$), then even if they are financially unconstrained ($\gamma = 0$), the supply curve continues to have a shape that is qualitatively the same as in our baseline calibration. We conclude that the key qualitative properties of the supply curve are highly robust to large changes in parameters. The character of optimal behavior changes sharply only as we go to the corner of the parameter space, converging to the canonical Hotelling (1931) model. This corresponds to setting $\gamma = \epsilon = 0$ (which means that the producer has no market power and is completely financially unconstrained) and implies a perfectly elastic – horizontal – supply curve.

4 Perfect price cap

We now use our model to study how the behavior of the petrostate changes when the price cap policy is imposed. Initially, we consider a "perfect" price cap, in the sense that it applies to all of the exporter's sales and is perfectly credible and permanent. This is a useful benchmark that helps build understanding of the workings of this new tool; however, since these assumptions might not be realistic in many contexts, we relax them below.

4.1 How does a price cap affect supply?

A price cap limits the petrostate's exposure to high oil prices. Denoting with p_r the price actually received by the sanctioned state producer when the price cap of $\bar{p}$ is in force, we have:

$$p_{r,t} = \min \{\bar{p}, p_{w,t}\}, \tag{9}$$

where $\bar{p}$ is the level of the price cap and $p_{w,t}$ is the equilibrium price of oil in the world market. Note that, because of market power, $p_{w,t}$ is endogenous and determined by the producer's decisions (as well as by the stochastic realization of the residual supply shock r_t).

A naive way of thinking about the price cap would be to use the supply curve we characterized in the previous section, adjusted with a vertical segment at prices above $\bar{p}$. This approach would miss the fact that the price cap represents a change to the fundamental features of the environment in which the producer operates, and thus has a deep impact on the problem and hence on optimal behavior. Instead, the appropriate way to study the price cap is to use our model to decipher the properties of the extraction function under the cap policy.

We proceed by solving the model with p_r as given by (9), which we incorporate in the producer's problem and in its recursive representation (4). We set the level of the price cap at \$60 per barrel, in line with the G7 price cap on Russian oil.

We plot the main result in Figure 7. The figure shows three curves: the supply curve in the laissez-faire case familiar from the previous section, the supply curve under a price cap of \$60, and a supply curve under a hypothetical case of the producer taking prices as given.[28]

The headline result is surprising: when the cap is imposed, and when it is binding in equilibrium, the supply curve shifts out, so that the producer extracts *more* of the commodity with the cap than without. Why?

Two forces drive this result. First, the price cap limits the use of market power in equilibrium. Although the economics of this is straightforward – with a price cap in place, restricting quantities no longer raises prices, rendering the use of market power ineffective – this insight goes against the popular view that sanctioning a large producer who has substantial market power is necessarily more difficult, or that it risks large adverse market outcomes. In fact, if the price cap is tightly enforced, as we have assumed so far, the opposite is true.

What is more, the supply curve under the cap shifts beyond the no-market-power supply curve, indicating the second mechanism at play. Since the price cap insulates the producer from periods of upward swings in the price, it brings the environment in which the producer operates closer to one without uncertainty and with a lower average price. Consequently,

[28]This final curve provides a useful benchmark to understand the workings of the cap in this environment.

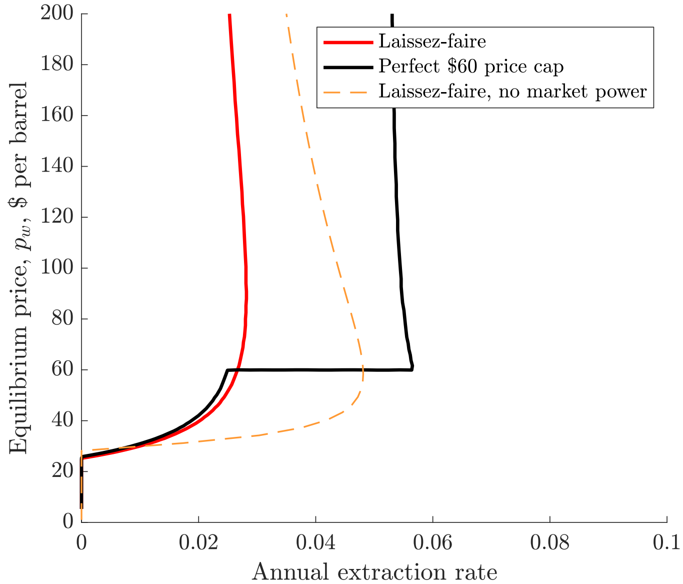

Figure 7: Equilibrium supply in a model with market power with a $60 price cap

Notes: The figure shows the slice of the policy function $y(1,r)$ plotted against the equilibrium price, i.e. shows the set of points $(y(1,r), p_w(1,r))$. The solid red line shows the laissez-faire case, as in Figure 4. The solid black line shows the supply curve under a fully credible and non-leaky price cap set at $60 per barrel. The dashed line shows the hypothetical supply curve in the laissez-faire case, assuming that the producer takes prices as given (and so has no market power).

the optimal behavior resembles more closely that of a producer who faces no uncertainty in the price of the commodity. Recall the intuition: from the producer's perspective, the price cap makes the resources buried underground less valuable. With $\tau > 0$, the less valuable resource implies a higher extraction rate – the core idea behind the non-homotheticity effect. This effect thus explains the additional shift of the supply curve to the right.

The supply curve becomes vertical at equilibrium prices above $\bar{p}$ as the producer receives $\bar{p}$ and not $p_{w,t}$, and so becomes unresponsive to the fluctuations in the latter.[29]

We observe that the supply changes slightly for equilibrium prices below the cap, i.e., when the cap is contemporaneously non-binding. This echos the literature cited in footnote 3. In between these two regions, the producer gradually reduces the extent to which it uses pricing power in equilibrium in a way that maintains the equilibrium price at $p_w = \bar{p}$.

[29]To be precise, the supply schedule is close to but not exactly vertical above $\bar{p}$ because the expected duration of the price being above the cap is different at different levels of $p_{w,t}$.

4.2 Effect of the price cap on equilibrium prices

Given the optimal behavior of the producer we just described, what happens to equilibrium prices as the cap is introduced?

To answer this question, it is useful to define *reference price* $\hat{p}$ as the hypothetical equilibrium price under the assumption that the producer did not use market power. The reference price is simply a transformation of the state variable r. Relative to the equilibrium price p_w, it is cleaned of endogenous decisions of the sanctioned petrostate. Specifically, we calculate:

$$\hat{p} := \delta(r + \hat{y}(r))^{-\epsilon},$$

where $\hat{y}(r)$ is the quantity that a producer would extract, for any r, if it took the price of oil as given.

The headline result from this exercise is that a price cap can lower the global equilibrium price of the commodity, especially when the reference price is high (the right panel of Figure 8). This *stabilization effect* comes about precisely because when the cap is binding, the producer ceases to exercise market power and instead has the incentive to supply larger quantity of the commodity to the market.[30]

It is important to note that these effects are more pronounced when the producer has a substantial degree of market power. This is because the gap between production levels with and without market power naturally increases with the degree of market power, and this gap is what the price cap eliminates.

We summarize these results in the following proposition.

Proposition 2. *When the sanctioned producer has market power, introducing a price cap that applies to all sales has the following effects:*

(1) the cap limits the extent to which the producer exercises market power in equilibrium;

(2) a binding cap thus tends to reduce *equilibrium world price* p_w*;*

(3) the decline in p_w *upon the introduction of the cap is larger the higher is* $\hat{p}$*;*

(4) the cap thus stabilizes *equilibrium world price* p_w*;*

(5) for a high reference price $\hat{p}$*, the equilibrium* p_w *can be below* $\hat{p}$*;*

(6) these effects are more powerful when the producer commands significant pricing power.

[30] In addition to the effects of the price cap, the petrostate that is waging war might be more myopic in its decision-making and discount the future more heavily than usual. Such a higher discount rate would, all else equal, shift the supply curve outwards. We do not show these results in the paper since we find it useful to focus solely on the impact of the price cap itself.

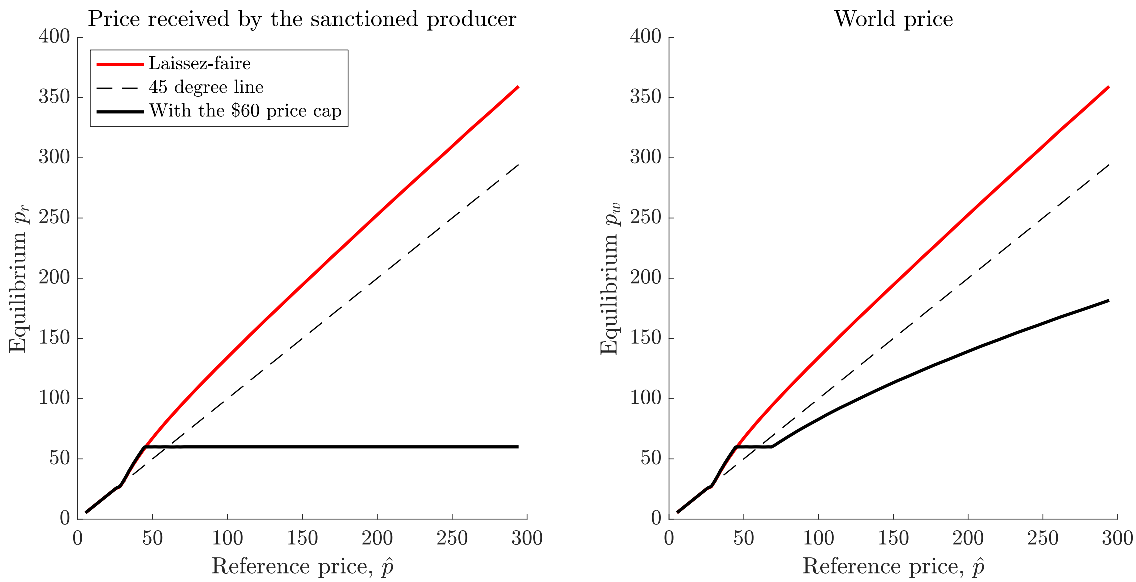

Figure 8: Equilibrium prices in the model with market power, with and without a price cap

Notes: The left panel shows the equilibrium prices received by the sanctioned producer as a function of the reference price $\hat{p}$ (recall that the reference price is the price that that would occur in equilibrium if the producer did not exercise market power – i.e. it is simply an index of prevailing market conditions) in two scenarios: in solid red, the laissez-faire case, and in solid black, a perfect price cap set at $60 per barrel. Note that, because of market power in the laissez-faire case leading to lower extraction, the equilibrium price tends to be above the reference price. The perfect price cap limits the price received by the producer to $60 per barrel. The right panel considers the same scenarios but depicts instead the world market equilibrium price on the vertical axis. In the laissez-faire case, $p_r = p_w$ and so the two red solid lines are identical across the two panels. The fact that the solid black line in the right panel lies below the red line and is flatter implies that a perfect price cap lowers the world market equilibrium price of oil and limits its volatility, relative to the laissez-faire case.

5 Imperfect price cap

Our analysis has so far assumed that the price cap applies uniformly to all sales by the sanctioned producer and is perceived as fully credible, i.e., expected to remain in place indefinitely. These assumptions are unlikely to hold in practice. In reality, the price cap might cover only a fraction of the exporter's oil sales. For instance, the G7 price cap on Russian oil applies exclusively to seaborne oil and oil products that use Western services, such as transportation and insurance. Practical and political frictions in enforcing the price cap can further allow a significant portion of sales to bypass the sanctions regime. Moreover, the producer might expect it to be temporary. In this section, we relax the assumptions of a perfect price cap and explore how this alters the conclusions of our analysis.[31]

5.1 Leaky price cap

Let us represent the percentage of the producer's oil reserves at $t = 0$ that can be exported outside of the cap with parameter $\kappa \in [0, 1]$. For instance, with $\kappa = 0.01$, the producer can export 1% of x_0 per year without being subject to the price cap. $\kappa = 0$ represents the case of a perfect price cap described in the previous section. In the context of Russia, κ can be thought of as the size of the so-called shadow fleet.

With a shadow fleet of capacity κ, the instantaneous profits from oil sales when the price cap is in place are:

$$\pi_t = \begin{cases} y \cdot (p_w(y) - \mathcal{M}) & \text{if } y \leq \kappa \\ y \cdot (p_w(y) - \mathcal{M}) & \text{if } y > \kappa \text{ and } p_w \leq \bar{p} \\ \kappa \cdot (p_w(y) - \mathcal{M}) + (y - \kappa) \cdot (\bar{p} - \mathcal{M}) & \text{if } y > \kappa \text{ and } p_w > \bar{p} \end{cases} \tag{10}$$

where p_w is the world equilibrium oil price. The third line represents profits when extraction is above κ and the cap is binding. In this case the producer receives the world equilibrium

[31] In this section we assume that the capacity to export oil outside the price cap regime is fixed. We explore the implications of increasing degree of leakage in Section 7. This is relevant because sanctioned producers can invest in shipping and logistics to bypass the cap. For example, Russia has made significant investments to develop a "shadow fleet." The International Working Group on Russian Sanctions (2024) estimate that since the cap's implementation, Russia has spent approximately \$10 billion on expanding its fleet. This effort increased the share of Russian crude oil and oil products exported outside the price cap regime from 20% in April 2022 to 67% in August 2024. For a detailed analysis of endogenous decisions to expand shadow fleet capacity within a static model of oil supply, see Cardoso et al. (2025). Fernández-Villaverde et al. (2025) use machine learning methods to measure the extent of the shadow fleet.

price up to the quantity κ, and the price cap for the remaining sales.[32]

5.1.1 The effects of a leaky price cap

The combination of market power and the ability to bypass the price cap provides the producer with a potentially appealing strategy to deal with the sanctions: cut production levels to κ, thereby squeezing the global market and raising equilibrium prices at which the quantity κ is sold. Higher prices in part compensate for the lower quantity. We now show that whether this is indeed an optimal strategy is state dependent: it depends on market tightness and prevailing prices.

Figure 9 illustrates optimal extraction and equilibrium world prices with a price cap that is imposed on the producer who has access to a shadow fleet capable of carrying 1% of its total reserves (i.e., about a third of extraction in normal times). The dashed line in the left panel is the contemporaneous supply curve of such a producer. It is highly non-linear, reflecting the state-dependent behavior of the producer. The right panel shows the equilibrium prices as a function of the tightness of the oil market.

When the oil market is already tight and prices are high, the producer finds it optimal to restrict supply. In that case, the producer reduces production to κ, meaning that it exports only outside the price cap regime. However, when prices are low, the shut-in of supply would be too painful, and the price cap instead leads to an expansion of the desired supply by the producer for the reasons outlined above. Thus, the effects of the price cap are strongly state-dependent. As a result, the cap has stabilizing effects when prices are close to its long-term average of \$76, but a destabilizing effect exactly when world prices are already high. This introduces a meaningful trade-off for the sanctioning policymakers, which we come back to momentarily.

[32]The first order condition of the producer's problem becomes

$$v_x = \begin{cases} u_\pi \cdot (p_w\,(1-\varepsilon_D) - \mathcal{M}) & \text{if } y < \kappa \\ u_\pi \cdot (p_w\,(1-\varepsilon_D) - \mathcal{M}) & \text{if } y > \kappa \text{ and } p_w < \bar{p} \\ u_\pi \cdot \left(\bar{p} + \kappa \frac{\partial p_w}{\partial y} - \mathcal{M}\right) & \text{if } y > \kappa \text{ and } p_w > \bar{p} \end{cases}. \tag{11}$$

When production is low, so that all oil can be transported outside the cap regime (the first row in (11)), the marginal utility of extracting an additional barrel is given by the marginal utility of oil profits times the world price adjusted downward for the impact that this extraction has on the prevailing oil price. This is also true if the marginal barrel is sold using the coalition services and so under the price cap regime, but if the price cap is not binding (the second row). Finally, when the marginal barrel is sold at a cap, the marginal benefit is just the price cap adjusted for the price impact that the sales of a marginal barrel have on the revenues from the sales of the infra-marginal κ barrels (the final row).

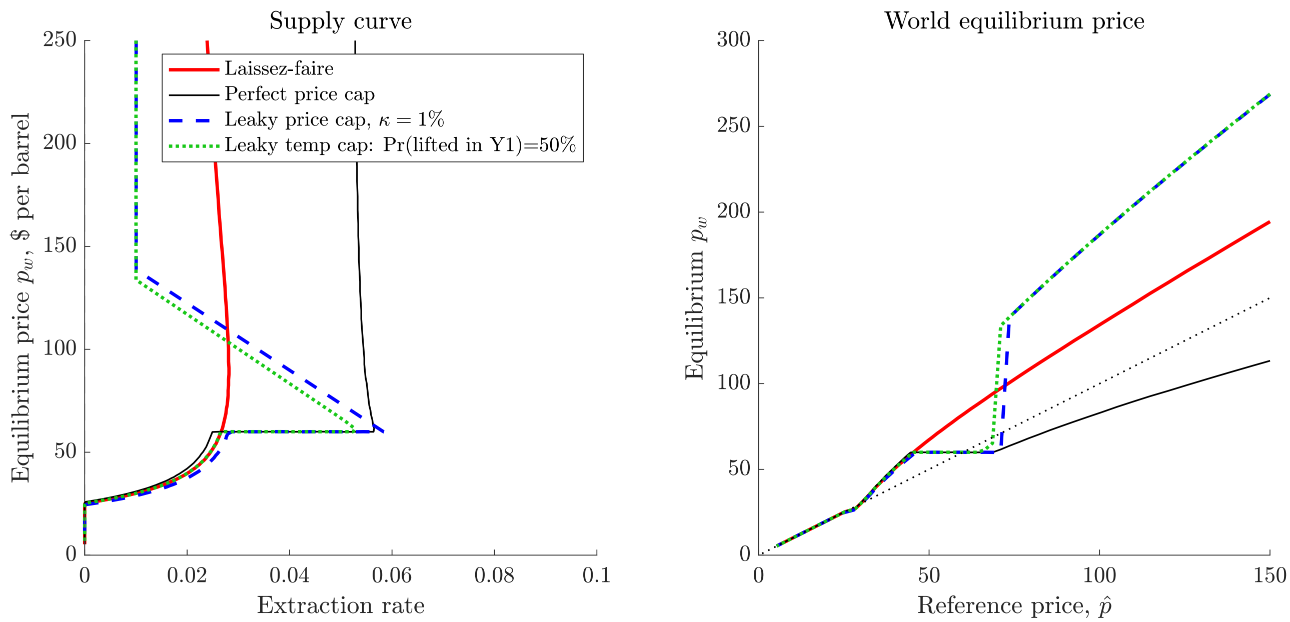

Figure 9: Equilibrium supply and prices with leaky and non-credible price cap

Notes: The left panel shows the contemporaneous supply curve in four scenarios. The first two are familiar from above: the laissez-faire case and the perfect \$60 price cap, and are shown for reference only. The dashed blue line is the supply curve when the price cap is leaky, with the degree of leakage given by $\kappa = 1\%$ of reserves at $t = 0$ (roughly a third of extraction in the laissez-faire case). The solid green line is the supply curve if in addition to a the cap being leaky, it is also expected to be temporary, with 50% chance of being lifted in the first year. The right panel shows the corresponding world market equilibrium oil prices, as a function of the reference price $\hat{p}$.

5.2 Expectation that the price cap is temporary

What if the price cap is expected to only last so long? To answer this question, we now assume that the producer believes that the lifting of the (leaky) cap is a Poisson event with intensity λ, so that the duration of the price cap is an exponentially distributed random variable and $Pr(\text{cap lifted before } t) = 1 - \exp(-\lambda t)$. For concreteness, suppose that the producer perceives that the probability of the cap being lifted in the first year is 50%, implying $\lambda = 0.69$. How does this affect the behavior of the producer?

Figure 9 illustrates how contemporaneous extraction responds to expectations of the cap being lifted (in addition to the cap being leaky) and what the consequences are for global prices. The expectation that the cap is temporary makes the producer more inclined to shut in production, keeping more barrels of oil underground and only extracting them when the price cap is lifted. Thus, as illustrated in the right panel of the figure, the lack of credibility reinforces the leakage and further expands the region of the state space where the cap destabilizes the global market.

5.3 Petrostate's profits and welfare under a price cap

How much does an imposition of a price cap hurt the petrostate? And in particular, is the strategy of reducing output to κ good for the petrostate's profits, and does it cushion the blow to welfare?

Figure 10 contains the answer. Starting from the perfect cap, the thin solid line in the left panel shows that when the producer responds optimally to a perfect price cap, the profit hit relative to the laissez-faire case is very substantial whenever the world prices are high.[33] The corresponding line in the right panel shows that a perfect cap set at \$60 per barrel has large negative welfare consequences: the welfare hit from a perfect price cap is equivalent to a reduction of oil reserves by circa 60%.

The dashed blue and the solid green lines in the left panel of Figure 10 show that when the price cap is leaky and the producer decides to reduce production to $\kappa = 1\%$ to sell only outside of the price cap regime, contemporaneous profits plummet by up to 50% (relative to the profits in the laissez-faire case). Reducing production to κ is optimal not because it increases contemporaneous profits, but because it preserves the oil reserves and so allows for

[33] There is a small boost to contemporaneous profits at intermediate levels of market tightness, where the increase in quantity extracted dominates slightly. Without the price cap, the petrostate would forgo this small increase in contemporaneous profits, which requires a large increase in production, in favor of future profits.

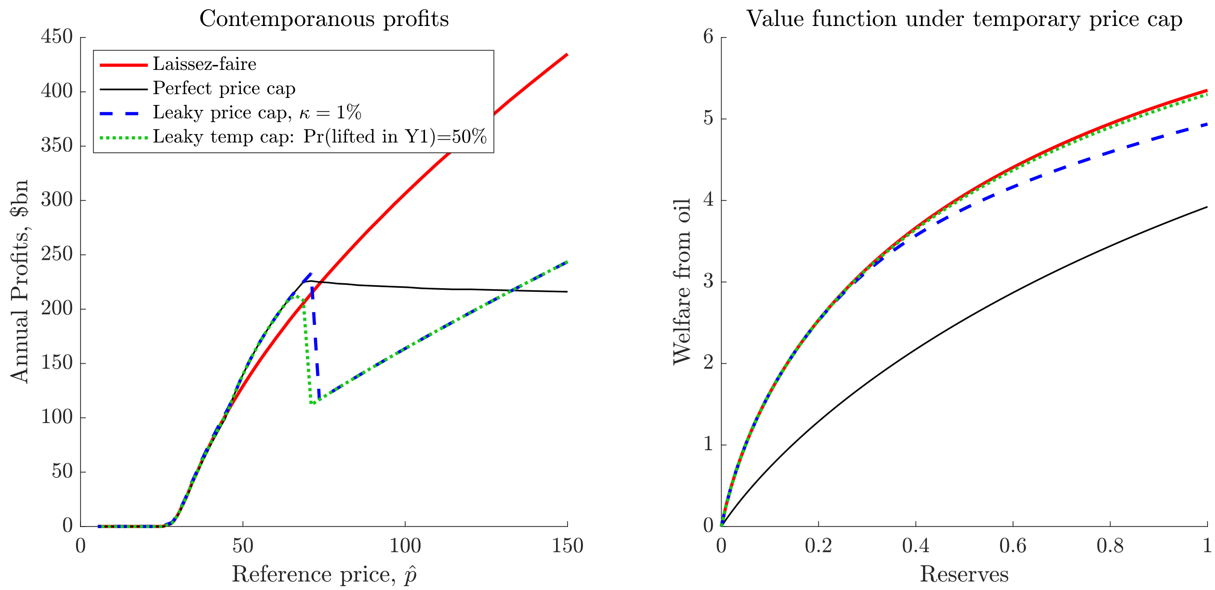

Figure 10: Effects of price caps on producer's contemporaneous revenues and welfare

Notes: The left panel shows annual profits in the four scenarios discussed in the notes of Figure 9. The profits have been rescaled to correspond in magnitude to profits from oil extraction in Russia, using the fact that Russia exports approximately 7 million barrels of oil per day. The right-panel shows the value function rescaled so that the value of having no oil reserves left is zero. The right panel assumes that the price of oil is $80 (but the results are essentially unchanged for any value of the current price).

a more spread-out profile of revenues over time. Indeed, the right-hand panel shows that producer welfare is higher for higher κ: compare the value function under a perfect price cap (i.e. $\kappa = 0$) vs. the value function under a leaky and/or temporary price cap with $\kappa = 1\%$, vs. the laissez-faire case (which is equivalent to a large κ such that the cap never binds). The fact that welfare of the petrostate rises with κ is intuitive: larger κ gives the producer more options to deal with the sanctions, making them less effective. The interesting result here is quantitative, namely that the ability to circumvent the price cap regime very significantly diminishes the degree to which the cap hurts the producer. Compared to a perfect cap, a leaky cap with $\kappa = 0.01$ (i.e. a shadow fleet capable of carrying around a third of extraction in the laissez-faire case) reduces the damage in welfare terms by about $\frac{2}{3}$.

These results reveal the key trade-off for sanctioning policymakers: a price cap hurts the producer but might reinforce the destabilizing shocks in the oil market. Next, we contribute a systematic way to navigate this trade-off.

6 Navigating the trade-off

This section introduces a framework to guide policymakers in setting the price cap at the optimal level. The core trade-off when designing price caps is between the two objectives: depriving the sanctioned country of financial resources and limiting global market volatility. Our contribution is to provide a coherent, model-based tool to quantify and navigate this trade-off.

6.1 Objective for the sanctioning coalition

We assume that the sanctioning coalition (the G7 in the recent episode) aims to minimize an objective that combines two components: a measure of welfare of the petrostate, which we denote $v(\bar{p})$, and a measure of unfavorable market outcomes, $\phi(\bar{p})$,[34] with relative weight between the two determined by policymaker's preferences and denoted by λ. The policymaker chooses the price cap level to solve:

$$\min_{\bar{p}} \quad \underbrace{v(\bar{p})}_{\substack{\text{a measure of} \\ \text{producer's welfare}}} \quad + \lambda \times \quad \underbrace{\phi(\bar{p})}_{\substack{\text{a measure of} \\ \text{adverse outcomes} \\ \text{in the oil market}}} \quad .$$

A higher λ indicates caution: a high-λ policymaker puts a relatively large weight on minimizing adverse outcomes in the oil market. In contrast, a low-λ policymaker is more tolerant of costs and prioritizes the infliction of damage on the petrostate. For simplicity, we assume that the preference map (and hence the indifference curves) is linear, but it is straightforward to see how the analysis would change if, for example, strict quasiconcavity were assumed instead. Rather than trying to pin down the preferences of policymakers precisely, below we explore how different values of λ affect the optimal choices within our framework.

The next step in our analysis is to use our structural model to quantify the functions $v(\bar{p})$ and $\phi(\bar{p})$.

[34] Deliberately, this is a broad term that nonetheless captures the essence of policymakers' concerns when sanctioning a large petrostate. We operationalize our framework with two specific measures of unfavorable market outcomes: frequency of episodes of oil prices above a certain threshold (in this section), and an alternative measure based on variance of equilibrium oil prices (in Section 7). Implicitly, we are assuming here that the main way through which the welfare of the sanctioning states is affected is through the relevant commodity market.

6.2 Quantifying the producer's welfare, $v(\bar{p})$

The measure $v(\bar{p})$ should capture the relative reduction in the welfare of the sanctioned producer due to the price cap. Using the structural model, a natural way to quantify this is via the producer's value function, $V(\bar{p})$, which denotes the value under a price cap $\bar{p}$. The welfare impact of the price cap is then expressed as:

$$v(\bar{p}) := \frac{V(\bar{p}) - V(\infty)}{V(\infty)}$$

where $V(\infty)$ represents the value function when there is no price cap (i.e. $\bar{p} = \infty$). Thus, $v(\bar{p})$ is the proportional welfare loss inflicted by the price cap, normalized by the producer's welfare in the laissez-faire case.[35]

6.3 Quantifying market outcomes, $\phi(\bar{p})$

The measure $\phi(\bar{p})$ reflects the probability of undesirable outcomes in the oil market under a price cap. A simple and plausible candidate measure – which reflects some of the policy discussions in the recent episode – is the (excess) probability of an oil price shock, defined as the price of oil exceeding a certain threshold, such as \$120 per barrel. Indeed, there is evidence that there is a threshold price of gasoline – around \$3.50 per gallon in the United States – which, when breached, results in a significant increase in media reporting of gas prices, tumbling consumer sentiment and confidence, with associated economic and political risks.[36] Over the past 20 years, gasoline prices reached that level when oil prices climbed to circa \$120 (in 2024 dollars).[37] More broadly, there is ample evidence that oil price spikes are economically costly. For example, according to the estimates by Känzig (2021), a 50% increase in oil prices (e.g. to \$120 per barrel from the average price of \$80) increases the 12-month inflation rate in the United States by about 2 percentage points, while lowering industrial production 2-3 years out in the United States and globally by 5% and 2.5%, respectively. Policymakers wary of these risks would likely take them into account when

[35] While this measure emphasizes intertemporal welfare, alternative definitions are possible. For instance, policymakers might instead focus on contemporaneous profits rather than full intertemporal welfare. We explore this possibility in Section 7.

[36] For example, Cummings et al. (2024) find that TV coverage of gas prices ramps up sharply when the nominal gas price hits \$3.50 per gallon and is consistently negative in tone, impacting inflation expectations and consumer sentiment.

[37] A graph charting this is available at `https://fred.stlouisfed.org/graph/?g=1KVNs`. As this graph shows, the gasoline prices were unusually high in the aftermath of the Covid-19 pandemic, likely exacerbating concerns about additional oil price spikes.

designing sanctions.

Correspondingly, we define:

$$\phi(\bar{p}) := \underbrace{Pr(p_w > \$120 \mid \text{price cap of } \bar{p})}_{\text{can compute using the model}} - \underbrace{Pr(p_w > \$120 \mid \text{no price cap})}_{\text{=12\% historically \& in our model}}.$$

The historical- and model-based probabilities of such price shocks are equal (since our model is estimated on historical data) at approximately 12%. The corresponding probability under a specific price cap $\bar{p}$ can then be computed through model simulations, an approach we take below.

Of course, alternative measures of $\phi(\bar{p})$ are feasible and computable within our framework. To illustrate this, we quantify $\phi(\bar{p})$ using an alternative measure based on the variance of equilibrium oil prices in Section 7.

6.4 The sanctions possibility frontier

Our framework introduces a novel concept: *the sanctions possibility frontier*. For a given level of price cap leakage (indexed by the ratio of κ to average extraction in the laissez-faire case), the frontier captures the combinations of (1) damage inflicted on the sanctioned country and (2) the probability of an oil market shock that can be achieved through various price cap levels. It serves as a menu from which policymakers select the optimal price cap, balancing these competing objectives.

6.5 Mapping out the trade-off

The trade-off can be visualized graphically (Figure 11). The horizontal axis represents the metric v (damage inflicted on the sanctioned producer) and the vertical axis encodes the values of ϕ (probability of an oil market shock).

The thick colored lines each represent the possibilities, showing the combinations of v and ϕ achievable under different levels of price caps. The different lines correspond to varying levels of leakage.

The Figure also plots the indifference curves that represent the sanctioning coalition's preferences. Several lessons stand out.

First, if the cap is perfect, there is no trade-off between the two objectives. Lowering the price cap simultaneously inflicts greater harm on the sanctioned producer *and* stabilizes the global oil market. The sanctions possibility frontier is slightly upward sloping. Under these conditions, a sanctioning policymaker should always choose the corner solution of the lowest possible price cap above marginal cost, regardless of their preferences (we mark the optimal choice from the menu we consider with a colored circle in Figure 11).[38]

In the more realistic case of a leaky price cap, there is a trade-off between market stability and the aims of economic warfare: the sanctions possibility frontier becomes downward sloping. Figure 11 shows that the sanctions possibility frontier tends to steepen as κ increases, suggesting that the optimal price cap level is higher (the cap is more lax) the greater the degree of leakage.

Indeed, with a meaningful trade-off present whenever the cap is not watertight, which price cap level is optimal becomes dependent on preferences: for example, if κ is such that the sanctioned producer can carry 1/6th of its normal production levels outside of the sanctions regime, a sanctioning policymaker who is more concerned about the potential impact on world oil prices ($\lambda = 2$ – shown in the Figure) chooses a cap of \$55 a barrel, while a more aggressive policymaker who puts higher relative value on imposing losses on the producer ($\lambda = 1$) implements the \$20 price cap.

Another interesting result is that the schedules in Figure 11 tend to be reverse S-shaped. The implication of this shape is that the intermediate levels of the price cap are dominated by both the low and the high caps. In the case where the cap is $\frac{1}{6}$ leaky, the policymaker is unlikely to choose the cap level to be in the $\$30 - \$40$ range. These price caps heighten the risk of an oil price spike as much as a lower \$20 cap, but their impact on the welfare of the sanctioned state is less severe.

[38] This, of course, is a conceptually useful benchmark that is highly unlikely to be attainable in a real world context. Additionally, the sanctioning policymaker is unlikely to have full information as to the true marginal cost, and such uncertainty would need to be factored into its decision making framework.

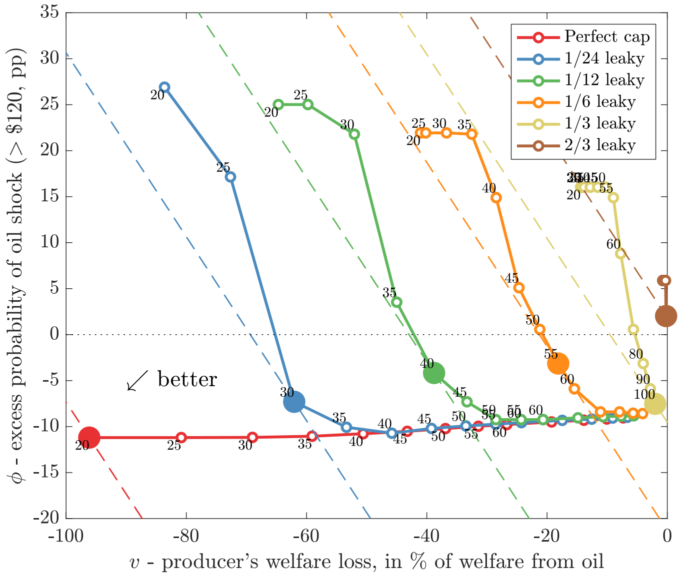

Figure 11: Sanctions possibility trade-off

Notes: The figure shows the sanctions possibility frontier for various levels of leakage (the solid schedules) and indifference curves for $\lambda = 2$ policymaker (the thin dashed lines). A western policymaker wants to be as close as possible to the bottom left corner of the diagram. For a given degree of leakage (i.e. for a given schedule), each circle denotes a different price cap level, from \$20 to \$100 in \$5 increments. From this menu, the colored circles indicate the optimal level of the price cap for a given level of κ, determined as the point of tangency of the schedule with an indifference curve.

Figure 12 illustrates that preferences play a role in driving the optimal price cap choice for intermediate levels of price cap leakage: as the price cap becomes leaky and ineffective, the optimal choice under two preference settings we consider converges to the same value (the maximum price cap in our menu, of \$100 per barrel).

In summary, the policy framework we put forward can help policymakers navigate the complex trade-off when designing sanctions. The key takeaway is that the optimal price cap level increases with the degree of leakage. The corollary is that efforts to reduce leakage – for example, those targeted at strengthening enforcement, or sanctions that discourage the acquisition of oil tankers by any part of the shadow fleet – can meaningfully improve the trade-off faced by policymakers. This naturally leads to the question we discuss next.

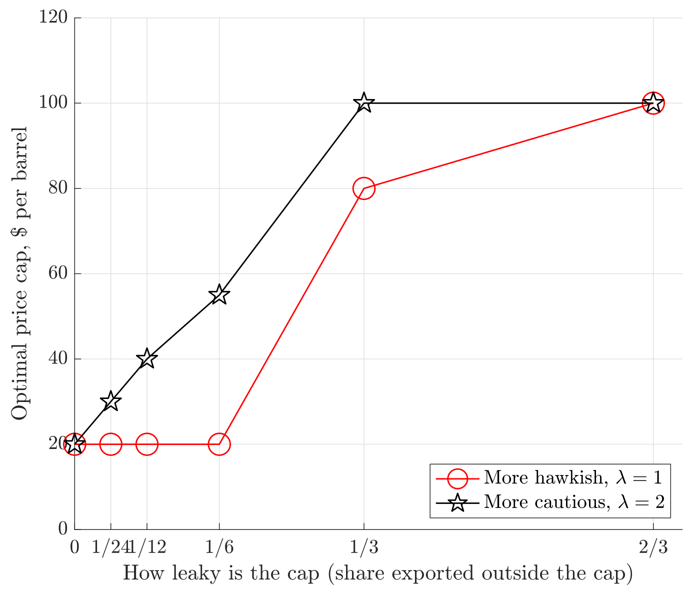

Figure 12: Optimal price cap as a function of leakage

Notes: The figure shows the optimal price cap as a function of leakage, for two sets of preferences. The optimal price cap is determined in each case as the point of tangency of the indifference curve of the sanctioning coalition and the sanctions possibility frontier, as illustrated in Figure 11. A more cautious policymaker finds it optimal to set the price cap at higher levels, with largest differences in the intermediate region of leakage.

6.6 What if there is a cost of enforcing the price cap?

So far we analyzed the problem of setting the optimal cap, taking the degree of leakage κ as given. However, our framework can be extended to accommodate the outer layer of the problem: how well to enforce a given cap if such enforcement is costly? A natural way to answer this question within our framework is to view the problem as choosing between the degree of leakage – i.e. between the different sanctions possibility frontiers in Figure 11.

For example, suppose that costly enforcement efforts could reduce the degree of leakage from $\frac{1}{3}$ to a lower value. Figure 11 shows that the optimally chosen price caps all *reduce* the probability of oil market shocks (as defined above) by a similar amount, about 5-10%. But at the same time, these policies have very heterogeneous impacts on the petrostate, with more tightly enforced policies driving much more significant declines in welfare. Thus, which policy should be chosen (i.e. how much of the costly enforcement effort should be exerted) depends on how the greater losses of petrostate welfare are valued against the cost that needs to be paid to achieve lower leakage. Quantification of both sides of this trade-off is beyond the scope of this paper, and in practice during conflicts it will depend, among other things, on the assessed sensitivity of the petrostate's military actions to the pain inflicted by the price cap.

7 Extensions

We now present several extensions of our analysis.

7.1 Dynamic price cap

So far we have studied a price cap that is fixed (perhaps temporarily) at a given level. This was motivated by the actual policy implemented following Russian war in Ukraine, which fixed the price cap of crude oil at $60 per barrel.[39] However, our model is useful also because it allows for analysis of hypothetical scenarios and policies. We illustrate this by focusing on a policy whereby the price cap is expected to be gradually reduced over time, albeit with some uncertainty as to the precise extent and timing of such decreases.

Specifically, we analyze the optimal behavior of the producer in the situation where the price cap is expected to be reduced from $60 to $30 per barrel over a period of about two years, with a probability distribution around the expected path of the price cap. We consider the situation where the price cap is leaky, with parameter κ set to 1% of time-0 level of reserves, as in the previous analysis. We illustrate the expected path of the price cap and the associated uncertainty around this path in the left panel of Figure 13.

The right panel of Figure 13 shows the effect of the expectation of the declining price cap on producers' actions at time-0 (i.e., when the price cap is still $60 per barrel). Qualitatively, the supply curve under the expectation of falling price cap shifts out and to the right – the producer increases supply today in anticipation of facing a lower price cap in the future. Quantitatively, the effect is substantial: the probability of an oil price spike is significantly reduced. Specifically, the probability that the oil price is above $120 per barrel (while the cap remains at $60 but is expected to decline) is 5 percentage points lower (15% instead of 20%) under the respective price cap policies (versus 11% historically, i.e. without the price cap). This shows that such "forward guidance" on the price cap, if it is credible, can carry substantial benefits.[40]

[39] G7 countries other than the U.S. reduced the price cap to $47.60 in September 2025.

[40] Of course, once the cap is actually lowered, this will spur reaction of the producer and, as we highlighted in the previous section, could lead to additional volatility in the oil price.

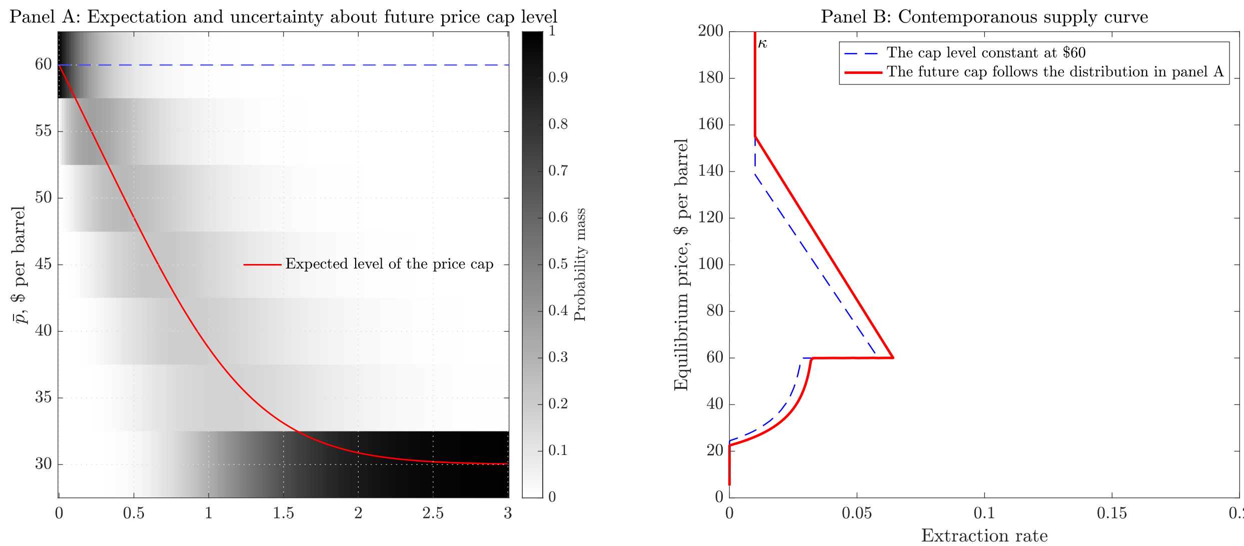

Figure 13: Contemporaneous extraction when the price cap is expected to decline

Notes: The figure depicts the effect of an expectation of future reductions in the price cap on extraction decisions *today*. The left panel shows the time-0 expectation of the path of the price cap over the following 3 years (the solid line) together with probability distribution around that expected path. The darker color denotes greater probability mass, as indicated in the gray scale on the right of the panel. The right panel shows two contemporaneous supply curves: the dashed line corresponds to the expectation of a constant $60 per barrel cap. The thick solid line shows the supply curve when the price cap is expected to evolve stochastically, as depicted in Panel A. In both cases, we assume that the price cap is leaky, with $\kappa = 0.01$. With an expectation of a declining cap, the contemporaneous supply curve is shifted to the right, implying that the sanctioned producer follows the shut-in strategy in strictly tighter market conditions, relative to the case of a constant cap. Thus the forward guidance on the price cap makes the shut-in less probable in equilibrium. See main text for details.

7.2 Increasing leakage

One of the key considerations that we highlighted in the analysis so far is the degree to which the price cap can be bypassed by the sanctioned producer. Given the importance of such leakage for the results, we now explore the extension of our model which allows for the leak to be changing over time, possibly in a stochastic fashion.

Changes in the degree of leakage could be driven by the exporter building up its own capacity to trade the commodity with neutral countries, or by dynamically changing enforcement of the policy. We consider the scenario where the degree of leakage is expected to nearly double over the three-year horizon, from 1% to 2% of time-0 reserves (equivalently, from around a third to around two-thirds of the ex-ante, laissez-faire production). Such a scenario is realistic, given that it is in the interest of the producer to make efforts to increase κ (see the welfare analysis above), and given that the petrostate might expect that sanctions fatigue among the sanctioning coalition could set in, easing enforcement. Yet, the precise path for the build-up of this capacity might be uncertain, and we take such uncertainty into account. What impact does the expectation of greater leakage have on the incentives to extract today?

Figure 14 shows, in the left panel, the evolution of the probability distribution of κ over time in the scenario that we study. In the right panel we show the supply curves consistent with this scenario. The different lines show the supply curve for a specific value of κ along the transition. Focusing on the supply curve corresponding to $\kappa = 0.01$ but expected to increase (the darkest red solid line in the right panel), we observe that, relative to the constant-κ case we analyzed previously, the producer is more willing to restrict supply (i.e., restricts supply over a larger range of the state space), in anticipation of the policy becoming less constraining in the future. Over time, as κ increases, the supply curve converges back to the laissez-faire schedule, with the vertical portion at high prices shifting out (the shut-in occurs at κ, which is increasing), and the portion at the price cap shifting in (as the producer regains market power with ever higher κ).

7.3 Price cap as a preventative measure

Can a mere threat of a price cap being imposed on a potentially rogue state prevent an act of aggression? This is the question we turn to in this section.

While our framework is obviously not well suited to answer this question comprehensively – we do not attempt to model the underlying causes of war, and clearly factors beyond

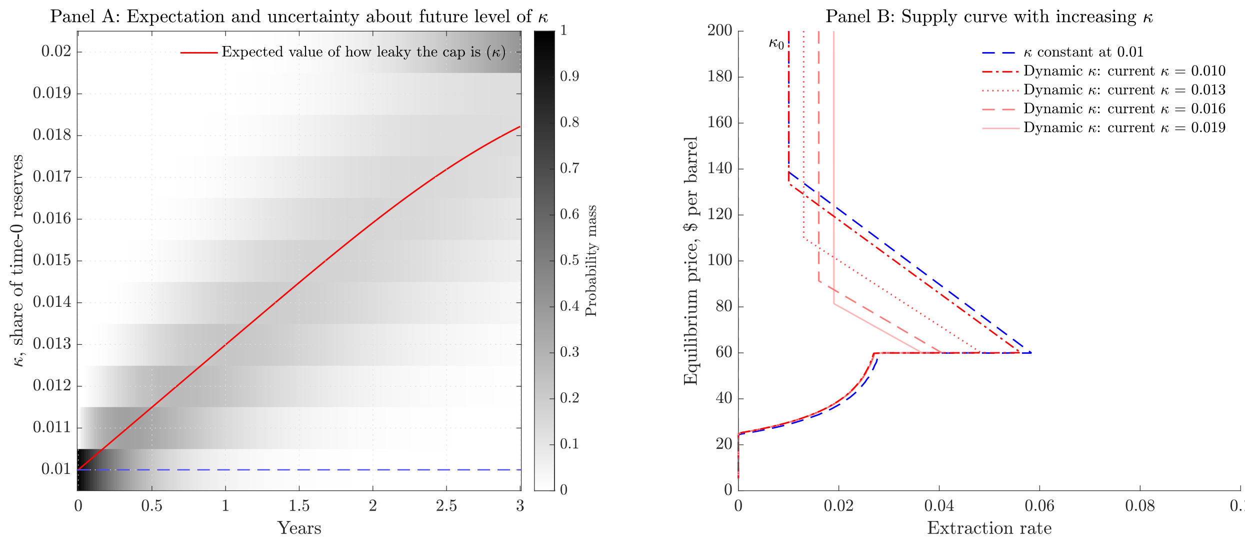

Figure 14: Extraction when the degree of leakage (κ) is expected to increase

Notes: The left panel shows the time-0 expectation of the degree of leakage κ measured in the share of current reserves that can be exported outside of the price cap regime (the solid line) together with probability distribution around that expected path. The right panel shows the supply curves. The dashed line corresponds to the expectation of a constant \$60 per barrel cap. The red lines correspond to the increasing κ scenario, and each line shows extraction at different levels of current κ.

economics play an important role – the model can help us understand how an ex-ante price cap alters the financial and economic calculation of the sanctioned producer.

To do this, we first focus on the scenario where the price cap is credible but leaky, with $\kappa = 1\%$ as in the analysis in Section 5 above. If the petrostate is rational and forward-looking, a sufficient statistic for the welfare impact of the price cap is the change in the value function upon the imposition of the policy. As Figure 10 shows, a leaky price cap with $\kappa = 1\%$ lowers welfare as much as a loss of around a fifth of total oil reserves. This is a very substantial loss, but this calculation assumes that the cap, while it has some leakage, is fully credible and will last for a long time. The same figure shows that the welfare impact of a cap, which is expected to be lifted in the next couple of years, is much smaller. This highlights the importance of credibility of the cap, possibly stretching beyond the duration of the war itself, in making the threat of the cap significant ex-ante.

It seems plausible, however, that the petrostate considering the invasion would pay particular attention to the flow of contemporaneous profits, rather than the fully-forward-looking measure of welfare. And, if a threat of a price cap is credible, then the policy alters the future distribution of profits upon invasion (Figure 15). The price cap effectively makes episodes of high profits exceedingly rare. Calibration to Russia suggests that the right tail

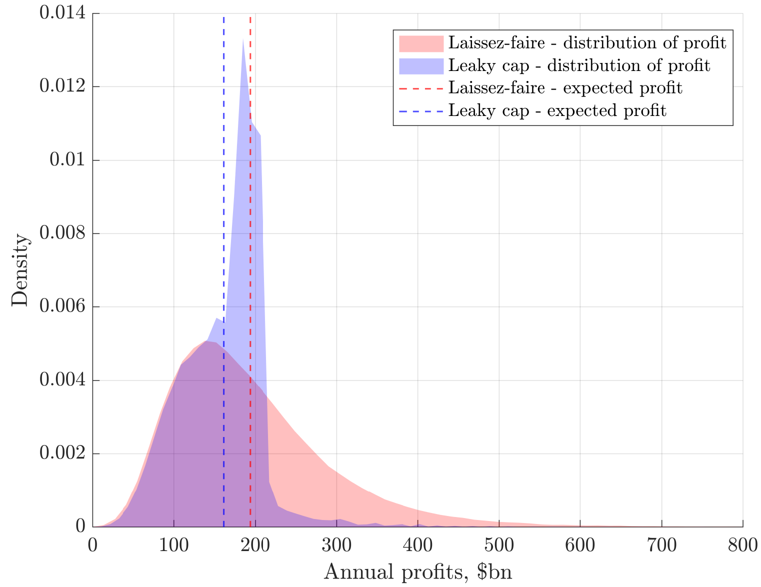

Figure 15: Distribution and average expectation of profits with and without the price cap

Notes: The areas represent the estimated probability density functions of annual profits of Russia under no price cap and under a leaky ($\kappa = 1\%$) \$60 per barrel price cap. The darker area is where the two densities overlap. Calibration assumes the reverse L-shaped marginal costs, as discussed in Section 7.4. Similar results hold with constant marginal costs.

of the profit distribution, above around \$220 billion annually, is dramatically curtailed. As a result, expected profit drops by around a fifth, or \$40 billion annually. This is the annual cost of the price cap which should enter the calculus when the sanctioned state ponders the invasion decision.[41]

Using the price cap preemptively comes with an added challenge: the petrostate, anticipating that the policy could be used against it, would likely put effort into preparing for the policy. In our model, this would translate into efforts to increase κ. If successful, such efforts would make the price cap less effective. Thus, any preemptive policy must weigh the risk of having a less effective tool ex post against the benefit of using the tool ex-ante.[42]

[41]By comparison, Russia's National Wealth Fund was estimated to hold less than \$40 billion in liquid assets in June 2025, down from almost \$115 billion in early 2022, according to media reports (see, for example, the Moscow Times article: `https://www.themoscowtimes.com/2025/06/09/russias-national-welfare-fund-at-risk-of-depletion-by-2026-economists-warn-a89395`).

[42]Chupilkin et al. (2025) make a similar point when empirically investigating how the change in the currency of invoicing involving Russia's trade has changed following sanctions. They find that sanctions have led to adoption of currencies other than the US dollar in invoicing, lessening the dependence of these countries on the dollar-based international financial architecture and thereby potentially making future sanctions less effective.

7.4 Increasing marginal costs and capacity constraints

So far we made a simple assumption about the marginal cost of the producer under sanctions: we assumed it is constant and equal to \$19 per barrel. We now explore how an alternative formulation, with increasing marginal cost and a short-term capacity constraint, affects our results. This exercise shows that our framework is flexible and can accommodate a range of assumptions about the production technology of the producer.

We assume that the marginal cost increases in the extraction rate. Specifically, we target the marginal cost curve estimated by Rystad Energy and reported in Wachtmeister et al. (2023). We assume that, measured in dollars per barrel, the marginal cost is

$$\mathcal{M}(y) = 1.5 + \frac{0.25}{\sqrt{0.03 - y}}.$$

The blue curve in the left-most panel of Figure 16 illustrates this cost curve: at low extraction rates, marginal cost is low and quite flat, but increases sharply as production approaches the capacity constraint (set at 3% of time $t = 0$ reserves).

The remaining three panels compare the baseline results with this alternative. The bottom line is that all our results are robust to such a change in the cost structure. One natural change is that whenever our framework predicts extraction above the capacity constraint of 0.03, the model now predicts the producer to be at the corner, producing at capacity (see, e.g., the third panel, which shows the effect of a perfect price cap).

We opted for the variant with the model with constant marginal cost in the main text since that model better illustrates the unconstrained incentives to increase extraction as a result of the cap. But if the producer is bound by short-term capacity constraints, there will be a limit on how much the actual extraction rate can increase.

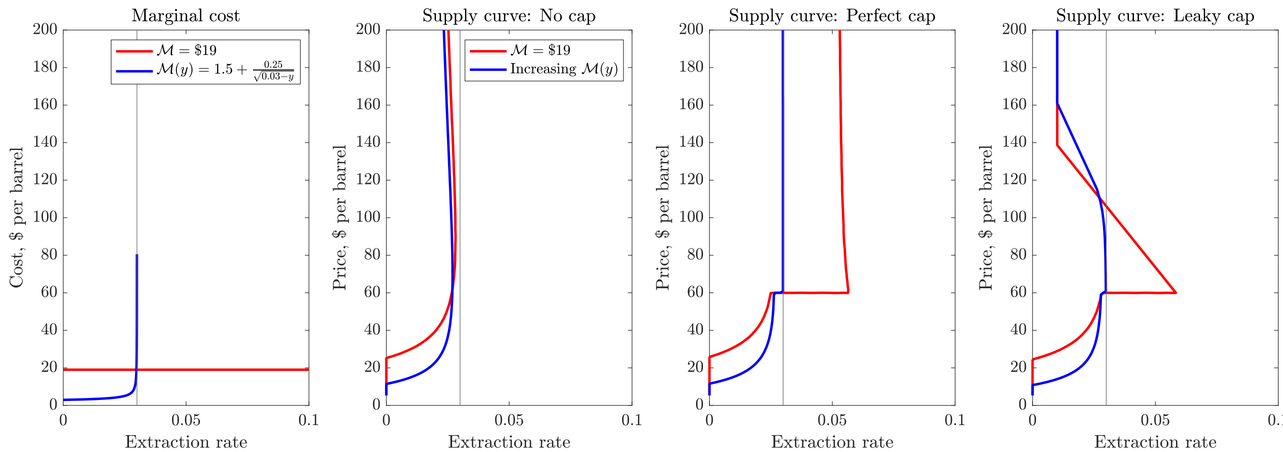

Figure 16: The results with increasing marginal cost and a capacity constraint

Notes: Across the four panels, the red lines show the baseline results presented elsewhere in the paper. The blue lines assume instead an increasing marginal cost schedule and a capacity constraint. The first panel shows the marginal cost, illustrating that the calibration assumes that the capacity constraint is set at 3% of the current level of reserves. See the discussion in the main text for details and sources for this calibration of the cost structure. The second panel shows the contemporaneous supply curve in the laissez-faire case (i.e. with no cap) under the two cost structures. The third panel shows the respective supply curves under a perfect price cap. The fourth panel shows the supply curves under a leaky price cap, with the leakage of 1% of time-0 reserves.

The inability of the producer to ramp up production when faced with a price cap has important implications for the choice of the optimal instrument by the sanctioning coalition. This is because the capacity constraint limits the producer's appetite to withhold production, effectively lowering the shut-in risks to the sanctioning coalition (see the right panel of Figure 16). The intuition for why this is the case is that the sharply declining marginal cost raises the opportunity cost of shutting in, hence making the shut-in more gradual.

Recomputing the sanctions possibility frontier with the reverse L-shaped marginal cost structure reveals that, for positive but moderate leakage, very low price cap levels continue to be optimal. In other words, capacity constraints on production diminish the shut-in risks and hence suggest that the price cap should be set at a lower level, all else equal (Figure 17).

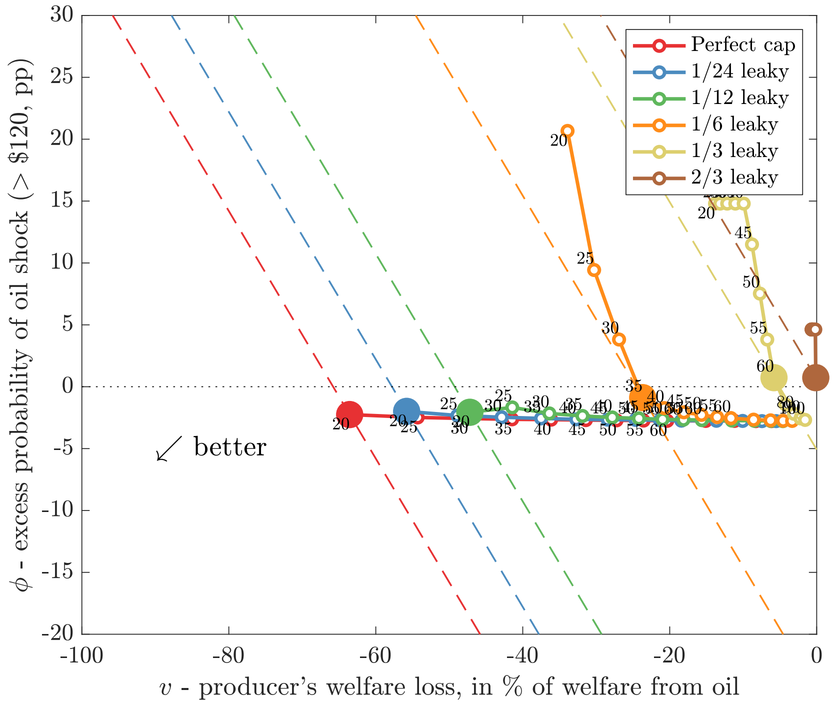

Figure 17: Sanctions possibility trade-off with reverse L-shaped marginal cost structure

Notes: The figure shows the sanctions possibility frontier when the marginal costs are reverse L-shaped, i.e. described by the schedule in the left panel of Figure 16. The colored circles indicate the optimal level of the price cap for a given level of κ, out of the menu of price caps between $20 and $100 per barrel. See notes under previous figures for details.

7.5 Alternative conceptualization of the sanctioning coalition's objective

In Section 6 we presented a model-based framework able to help policymakers think through the optimal price cap design. We parametrized the objective function of the policymaker with specific measures of adverse outcomes in the oil market ϕ (frequency of oil prices reaching highs above $120 per barrel) and adverse consequences to the producer v (loss of value). These, of course, are not the only possibilities. To illustrate the versatility of our framework, we now present the analysis for a set of alternative assumptions about these measures.

As an alternative measure of adverse outcomes in the oil market, we can focus on changes in the variance of the equilibrium world oil prices caused by the imposition of the price cap. We can also replace the measure of petrostate's welfare with (expected) short-term profits of the producer. We think it is plausible that both the petrostate and the sanctioning coalition might be focused on measures of short-term liquidity of the petrostate in the event of a war, as opposed to focusing entirely on the full dynamic welfare.

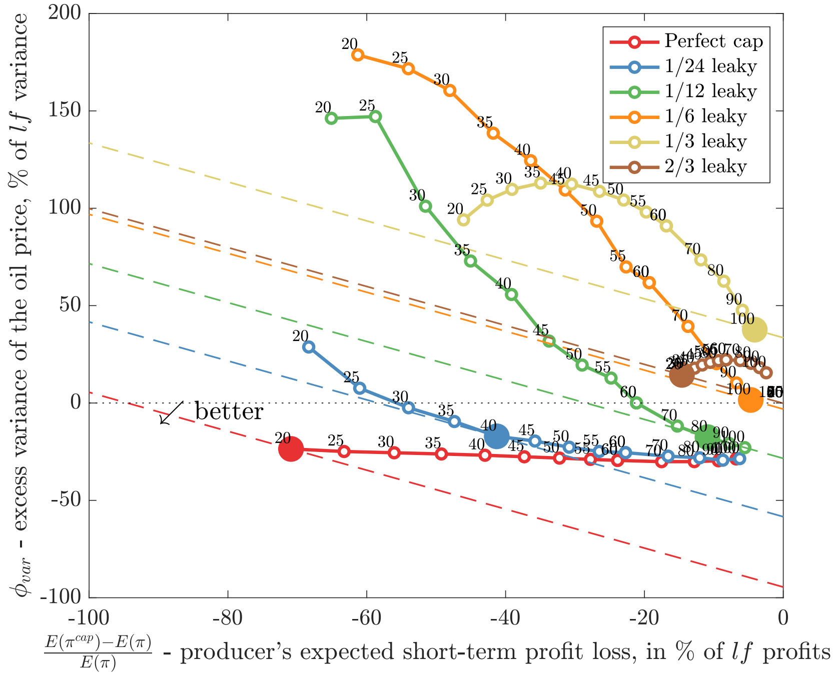

Figure 18: Sanctions possibility trade-off with alternative objective measures

Notes: The figure shows the sanctions possibility frontier for various levels of leakage (solid lines) and indifference curves for $\lambda = 2$ policymaker (of course now λ indexes policymakers' tolerance in terms of different measures of costs and benefits). The underlying model assumes reverse L-shaped marginal costs as in Figure 17, but assumes different measures of the cost of the price cap policy (here it is the additional variance of the equilibrium oil price) and the damage done to the petrostate (here this is defined in terms of the expected value of short-term profits).

Figure 18 shows the sanctions possibility frontier when the components of the objective are measured in this alternative way. Using the framework, one can again devise the schedule of optimal price caps, one for each κ. For the most part, the optimal price cap level increases with leakage; although interestingly, once the cap becomes $\frac{2}{3}$ leaky, a low price cap becomes optimal again since it lowers profits but has no adverse bearing on the variance of the oil price.[43]

[43] The intuition for this is as follows: with a highly leaky, ineffective cap set at a tight level that is essentially always binding (like 20 USD per barrel), the producer shuts in production regardless of market conditions. This "stable" behavior of the producer can decrease the variance of the global market equilibrium oil price (for example, relative to a situation where the price cap is set at a higher level and the producer shuts in only when the cap is binding). Of course, this behavior results in oil prices that are stable but also much higher, as reflected in the results in Figure 17.

8 Conclusions

The main contribution of this paper is a simple dynamic model that helps us understand the economic incentives of a large, financially constrained producer of a non-renewable resource. Our application and focus have been on the effects of the new instrument of international policy – a price cap.

The analysis uncovered economic forces and intuitions that matter for the discussions of the price cap. In particular, our model highlights the importance of financial frictions, market power, and the optimal dynamic behavior of the producer in this context. It emphasizes the role of alternative sources of funds or other sources of non-homotheticity in producer's preferences. And it illuminates the fact that the price cap reduces the use of market power in equilibrium, which leads to a stabilizing effect of the price cap on the global commodity market, as long as the price cap is not too leaky.

Finally, we have used the estimated model as a building block of a framework for designing optimal policy. This device is useful because it allows policymakers to think through trade-offs in a consistent manner. The main substantive conclusion from this exercise is that effective enforcement of the cap tends to improve policymakers' trade-off and is a precondition for a low level of the cap itself.

Our paper opens up several avenues for future research. Some new research has already built on this analysis by explicitly considering the endogenous decision to expand the capacity of the shadow fleet. Our setting explored the use of the price cap tool in the context of non-renewable resources. But future work might want to consider a setting in which trade of products or exchange of technologies is taking place between the sanctioning and the sanctioned state. Another useful avenue for future research would be to explicitly embed the setting developed here within a general equilibrium model of a world economy, with strategic interactions across participating states. More broadly, the tools developed here could naturally be used in other contexts where a producer faces stochastic market conditions and intertemporal choices.

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Appendix

A Background on Russian oil

A.1 Oil extraction in Russia historically

In the 1970s and 1980s, Russia was the largest global oil producer, peaking at over 11 million barrels per day. The collapse of the Soviet Union triggered a dramatic decline in oil production, which fell to as low as 6 million barrels per day (left panel of Figure 19). Beginning in the mid-1990s, major investment, including access to western oil field services, helped restore production to more than 10 million barrels per day by 2019; making Russia the world's third largest oil producer (after the US and Saudi Arabia), with about 10 percent of world production. In recent years, most Russian production has been exported (7.5-8 million barrels per day, from production of 10-10.5 million barrels per day). The right panel

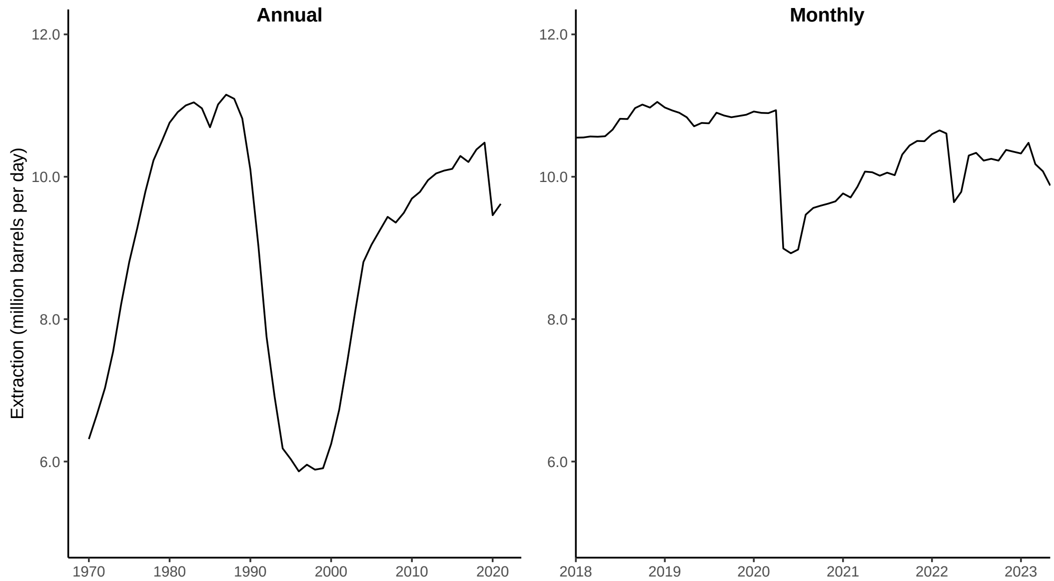

Figure 19: Russia's oil extraction historically: annual, 1970-2020 (left panel) and monthly, January 2018-March 2023 (right panel). Source: CEIC (https://www.ceicdata.com) (left) and U.S Energy Information Administration (right).

of Figure 19 plots monthly production from January 2018 to March 2023, highlighting the major disruption around the pandemic and the gradual recovery since then. The drop in extraction that coincided with the invasion of Ukraine in February 2022 was relatively small and short-lived.

Of the 7.5 million barrels per day exported by Russia in 2021, crude oil accounted for 4.7 million barrels and refined products for the remaining 2.8 million barrels.[44,45] Most Russian oil is produced in Western Siberia and transported by pipeline to refineries and shipping facilities in Russia's Baltic and Black Sea ports. Before the war, Russia's largest oil customer was the European Union, receiving 0.7 million barrels of crude oil per day by pipeline and 1.5 million barrels by sea in 2021. The EU also bought 1.2 million barrels of oil product, almost all of which arrived by sea. Overall, the EU imported almost half of Russia's total oil exports. Most of the tankers carrying these fossil fuels to the EU departed from three

[44] https://iea.blob.core.windows.net/assets/9aea25c1-5450-49db-8e1f-a67c0212720c/-16MAR2022_OilMarketReport.pdf

[45] A single barrel of crude oil can be processed to produce multiple refined products such as gasoline, diesel, jet fuel, and other derivatives of oil. Refineries can be designed to produce different mixes of refined products. The scope to change this is limited, especially in the short run. As of 2021, Russia's refining industry had the capacity to serve domestic gasoline and diesel demand and the country exported the remaining products. Substituting between exporting crude and exporting refined products is possible to some degree, but the infrastructure differs and there are pipeline and port constraints.

sets of ports: in the Black Sea, the Baltic Sea, and Murmansk in the far north.

China was also an important customer and received 1.6 million barrels of crude per day in 2021, half by pipeline and half by sea. Before February 2022, China did not purchase significant amount of Russia's refined product.

A.2 Russian oil exports since the start of the war

Figure 20 plots Russia's seaborne crude oil exports by destination from January 2022 to September 2023.[46]

Shortly after the invasion of Ukraine in February 2022, Russia's energy exports to the US and the UK quickly collapsed; both countries swiftly implemented embargoes, but neither represent a large market for Russian oil. Exports to the EU, Russia's largest customer, diminished much more gradually, and reached practically zero only after the implementation of the embargo on crude oil in December 2022 and on oil product in February 2023. The overall level of Russian oil-related exports has remained steady, however, with significant substitution away from the European market towards buyers in Asia, most notably India, which previously imported very little oil from Russia.

We discuss the design and implementation of the price cap policy in more detail below. However, it should be noted that the continued steady level of exports from Russia to the global market was the intended outcome of the policy mix implemented by the G7 and other coalition countries. The goal of the US-EU-G7 countries was to reduce Russian revenues from oil sales without taking Russian supply off the global market, thus avoiding the risk of a damaging global oil supply shock.

A.3 The G7 price cap on Russian oil: implementation details and enforcement challenges

The G7 price cap on Russian oil operates by setting terms and conditions for the provision of western financial and shipping services. Specifically, services can only be provided for the shipment of Russian oil by companies located in countries in the price cap coalition if the price paid to Russia is at or below the cap.[47] The caps were initially set at $60 per barrel for

[46] It does not reflect the approximately 1.5 million barrels of crude oil per day exported via pipeline, roughly half of which used to go to the EU and half to China. Data for oil products paint a similar picture.

[47] In addition to the G7, EU and Australia, Albania, Bosnia and Herzegovina, Iceland, Liechtenstein, Montenegro, North Macedonia, Norway, Switzerland and Ukraine have all pledged to follow EU sanctions against Russia.

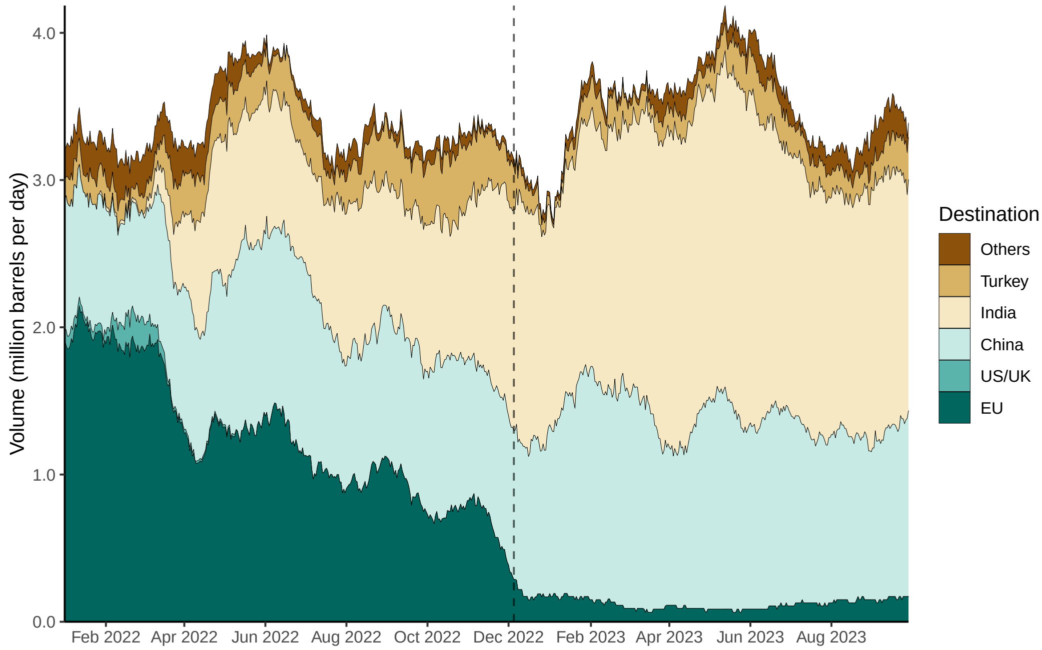

Figure 20: Russia's seaborne crude oil exports by destination, January 2022 - September 2023. Dashed line indicates the start of the price cap policy for crude oil on December 5, 2022. Source: CREA.

crude, $100 per barrel for high value refined products (including diesel, gasoline and kerosene) and $45 per barrel for low value refined products (including fuel oil and naphtha).[48] The price cap was implemented in response to the EU's 6th sanctions package, which would have banned the provision of services for the shipment of Russian oil altogether and could have considerably reduced the supply of Russian oil to the world markets (Wolfram (2024)). The price cap effectively allows for an exception to that outright ban.

Several studies examine some of the impacts of the price cap, including Hilgenstock et al. (2023a), Hilgenstock et al. (2023b), O'Toole et al. (2023), Rosenberg and Van Nostrand (2023), and Kilian et al. (2025). The cap appears to have been largely successful in keeping the supply of Russian oil on the market, as documented above. As we discuss below, in the initial phases the cap policy applied to large volumes of Russian oil trade. Consistent

[48] This design of the policy means that if an entity, e.g., in India, buys crude at or below the cap, it is allowed to sell the refined product at world prices. This arrangement is expected to encourage the flow of Russian oil and helps explain why Russian deliveries to the world market are largely unchanged. But who earns the rents from the difference (world price minus capped price) remains shrouded in some mystery. As an example, an article *Wall Street Journal* in April 2023 cited evidence that Saudi Arabia and the United Arab Emirates were importing Russian oil products at low prices and making high profits (Faucon and Said (2023)), but there is no systematic accounting of where the rents have gone.

with that, the implementation of the price cap and the EU embargo has coincided with an increase in the discounts on Russian oil (more so for Urals and less so for ESPO).

However, more recently, several important developments appear to have limited the effectiveness of the price cap. First, the price cap has not been strictly enforced. Although CREA data[49] suggest that in April 2023, about 60% of crude oil shipments and 75% of product shipments from Russia's ports were covered by insurers from the EU, G7, or Norway, lack of clear verification procedures has meant that, during the periods when the price cap was binding (i.e., when the market price of oil was above the cap), a significant share of exports have been sold at prices above the cap. Shapoval et al. (2024) report that, in the fourth quarter of 2023, up to 95% of all Russian seaborne crude oil exports took place above the $60 per barrel threshold, indicating that some actors break the rules imposed by the price cap regime.

Furthermore, Russia has increased its capacity to transport its oil. Based on industry data, Shapoval et al. (2024) assess that the share of oil carried by non-coalition tankers has increased from around a fifth in early 2022 to two-thirds and one-third for crude and product, respectively (see also Kennedy (2023)). The same report argues that a significant share of this capacity consists of old tankers that are likely unfit to pass through international waters, e.g. through the territorial waters of Finland, Estonia, and Denmark in the Baltic Sea. Stronger enforcement of environmental and safety standards, such as those imposed by the UN's International Maritime Organization, would therefore indirectly strengthen the degree to which the price cap is binding.

B Supplementary information on empirical analysis

Figure 2 relies on country-level data on oil production and financial constraints plus data on OPEC pricing decisions. This appendix describes the data and reports several robustness results for the relationship plotted in Figure 2.

B.1 Oil production and oil pricing decision data

The analysis uses a country-level data set comprising 70 non-OPEC countries and 53 OPEC announcements that span 1984 to 2017. The OPEC announcements come from Känzig (2021), who sources post-2002 dates from publicly available announcements and derives

[49] See https://energyandcleanair.org/russia-sanction-tracker/

pre-2002 dates from OPEC resolutions and Bloomberg news reports. The monthly oil production data from the US Energy Information Administration (EIA) enables the calculation of production changes between the month following each OPEC pricing decision and the preceding month. The oil production data set includes 106 countries. Of these, 26 countries—Algeria, Angola, Azerbaijan, Bahrain, Brunei, Congo-Brazzaville, Ecuador, Equatorial Guinea, Gabon, Indonesia, Iran, Iraq, Kazakhstan, Kuwait, Libya, Malaysia, Mexico, Nigeria, Oman, Qatar, Russia, Saudi Arabia, South Sudan, Sudan, the United Arab Emirates, and Venezuela—were OPEC or OPEC+ members for at least part of the analysis period and were excluded. Additionally, countries with minimal production levels—Belize, Taiwan, Barbados, Morocco, Slovakia, Senegal, Tajikistan, Jordan, Sweden, and Slovenia—were removed. The analysis focuses on the remaining 70 countries with substantial production levels outside OPEC. Guyana is excluded because it began oil production after December 2019, and the latest OPEC announcement is in 2017.

For each country-OPEC decision pair, we calculated the change in log production multiplied by negative one if the production increased when prices went down or decreased when prices went up. Figure 2 plots the average for each country.

B.2 Financial conditions data

We measure a country's financial conditions using the debt-to-GDP ratio. The debt-to-GDP ratio data are sourced from the IMF‘s Global Debt Database[50] and represents the total stock of debt liabilities issued by the central government as a share of GDP. We construct a dummy indicating whether the value is above or below the median and then average these over the relevant time period. Twelve countries (Burma, China, Congo-Kinshasa, Cuba, Egypt, Former Serbia and Montenegro, Former USSR, Former Yugoslavia, Georgia, Netherlands, Philippines, and Uzbekistan) are excluded due to missing debt data, leaving 57 countries represented in Figure 2.

B.3 Robustness checks

Recall that the relationship in Figure 2 reflects a coefficient on the share of years with above median debt = -.026 and standard error = .010. The negative relationship is robust to additional specifications, including:

[50] https://www.imf.org/external/datamapper/CGDEBTGDP@GDD/CHN/FRA/DEU/ITA/JPN/GBR/USA

- Using the country risk premium developed by Damodaran (2022) as the independent variable. The country risk premium, available starting in 2001, reflects the default spread on a government bond. In this case, the coefficient on country risk premium is = -0.152, standard error = 0.137 (n = 56). For the 50 countries for which we have both country risk premium data and debt-to-gdp data, the coefficient on risk premium is = -0.253, standard error = 0.139 (n = 50).

- Using a six-month forward change in oil production. The coefficient on share of years with above median debt is = -0.029, standard error = 0.022 (n = 57).

- Dropping the 4 countries characterized as "liberal democracies" by the V-Dem Institute, as governments in these countries would have less control over oil production.[51] The coefficient on share of years with above median debt is = -0.028, standard error = 0.010, (n = 53).

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C Duffie-Epstein-Zin preferences

In addition to the robustness of our results to different values of γ under the assumption of CRRA utility that we presented in the main text, we explore here how our results change as we flexibly parametrize the petrostate's relative risk aversion and its intertemporal elasticity of substitution. Specifically, we consider a class of recursive preferences in continuous time, as introduced by Duffie and Epstein (1992).

The producer's utility function is given by the Stochastic Differential Utility (SDU), which is the continuous-time equivalent of recursive utility of Epstein-Zin. Let V_t denote the petrostate's SDU, expressed as:

$$V_t = \mathbb{E}_t \left[\int_t^\infty f\left(\pi_s + \tau, V_s\right) \, ds \right], \tag{12}$$

where π_t denotes the extraction profit and τ is the lump-sum transfer. The aggregator $f(\cdot)$ is defined as:

$$f(\pi_t + \tau, V_t) = \frac{1}{1-\delta}(1-\gamma)V_t \left[(\pi_t + \tau)^{1-\delta} \left((1-\gamma)V_t\right)^{\frac{1-\delta}{1-\gamma}} - \rho \right], \tag{13}$$

[51]See https://v-dem.net/documents/54/v-dem_dr_2025_lowres_v1.pdf.

for $\gamma \neq 1$ and $\delta \neq 1$. Here, γ is the coefficient of relative risk aversion (RRA), and $1/\delta$ is the elasticity of intertemporal substitution (EIS). The parameter $\theta = (1-\delta)/(1-\gamma)$ governs substitution across time and states. When $\gamma = \delta$, which implies $\theta = 1$, Duffie-Epstein-Zin preferences collapse to time-additive CRRA utility that we used in the main text. However, the key advantage of these preferences is that they allow us to explore the sensitivity of the results to the IES and risk aversion separately.

Figure 21 shows, against our benchmark CRRA calibration of $\gamma = 1/\delta = 2$, a set of results when the producer is (i) more risk averse than in the baseline and (ii) is also less willing to tolerate changes in the profit flow over time (perhaps representing greater cost of bearing the financial frictions that the producer faces, and/or perhaps political ramifications at home that come with revenue volatility). In the three panels we present the contemporaneous supply curve in three environments: the laissez-faire case, perfect price cap of \$60 per barrel, and a leaky price cap set at the same level.

Turning to the results, we observe that all the conclusions from our baseline continue to hold. The largest quantitative difference that arises as a result of this more flexible and different parametrization is that the producer makes more effort to cushion the blow from very low prices (producing large quantities when prices are even only just above the marginal cost). The petrostate is even more cautious in terms of increasing supply when the market is tight and prices are high.

Generally, we find that what tends to drive larger quantitative changes in petrostate behavior is the variation in the elasticity of intertemporal substitution, while risk aversion plays less of a role. This is consistent with the decomposition of the supply curve in Figure 5, where the channels that worked through risk played less of a role than the forces that relied on the allocation of resources across time.

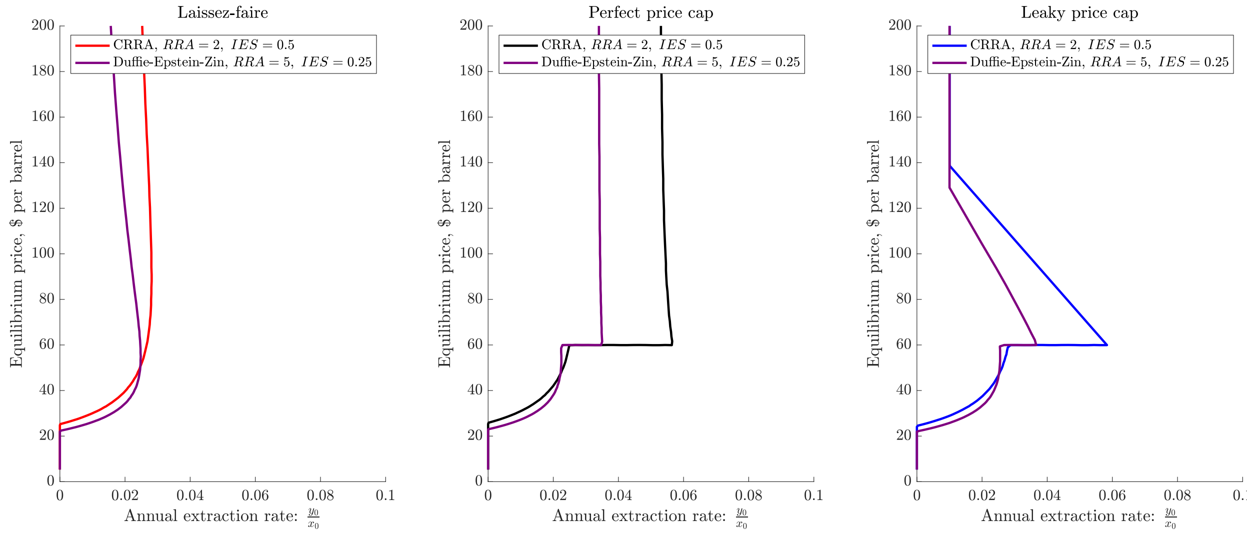

Figure 21: Results under Duffie-Epstein-Zin preferences

Notes: The Duffie-Epstein-Zin results assume that the producer is more risk averse and less willing to intertemporally substitute the revenue flows, compared to the baseline. The notation in the figure corresponds to RRA: relative risk aversion; IES: intertemporal elasticity of substitution.