Supplemental Appendix

A Theory of Price Caps on Non-Renewable Resources

By Lukasz Rachel

Background on Russian oil

A1. *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 A1). 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 of Figure A1 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.

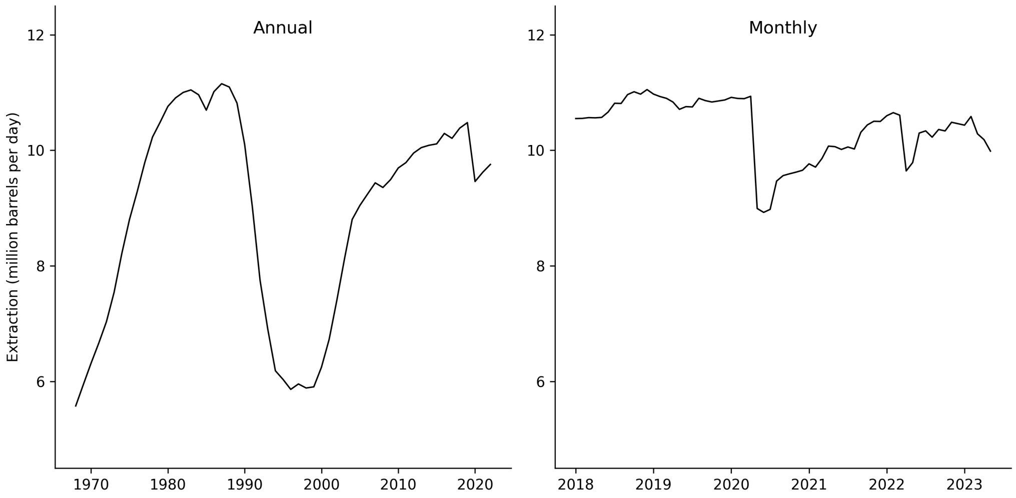

Figure A1. Russia's oil extraction historically

Note: Data are 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 (2024) (right).

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.[45,46] 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 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.

A2. Russian oil exports since the start of the war

Figure A2 plots Russia's seaborne crude oil exports by destination from January 2022 to September 2023.[47]

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.

---

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

[46] 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.

[47] 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.

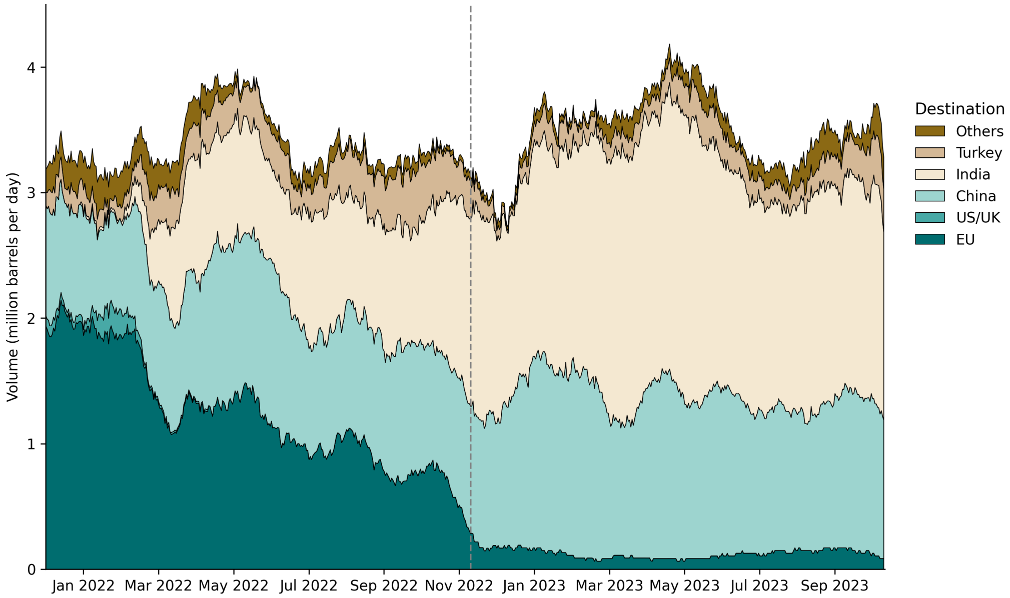

Figure A2. Russia's seaborne crude oil exports by destination

Note: January 2022 - September 2023. Dashed line indicates the start of the price cap policy for crude oil on December 5, 2022. Source: CREA (2024).

A3. 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.[48] The caps were initially set at \$60 per barrel for 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).[49] 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

---

[48] 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.

[49] 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.

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. (2023*a*), Hilgenstock et al. (2023*b*), O'Toole et al. (2023), Rosenberg and Van Nostrand (2023), and Kilian, Rapson and Schipper (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 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 (CREA, 2024) 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.

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.

B1. 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*b*) (Känzig, 2021*a*), who sources post-2002 dates from publicly available announcements and derives pre-2002 dates from OPEC resolutions and Bloomberg news reports. The monthly oil production data from U.S. Energy Information Administration (2024) 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.

B2. 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 (International Monetary Fund, 2024) 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.

B3. 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:

- 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.[50] The coefficient on share of years with above median debt is = -0.028, standard error = 0.010, (n = 53).

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:

$$V_t = \mathbb{E}_t \left[\int_t^{\infty} f\left(\pi_s + \tau, V_s\right)\, ds \right], \tag{C1}$$

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

$$f(\pi_t + \tau, V_t) = \frac{1}{1-\delta}(1-\gamma)V_t \left[(\pi_t + \tau)^{1-\delta} \left((1-\gamma)V_t\right)^{\frac{1-\delta}{1-\gamma}} - \rho \right], \tag{C2}$$

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 C1 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

---

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

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.

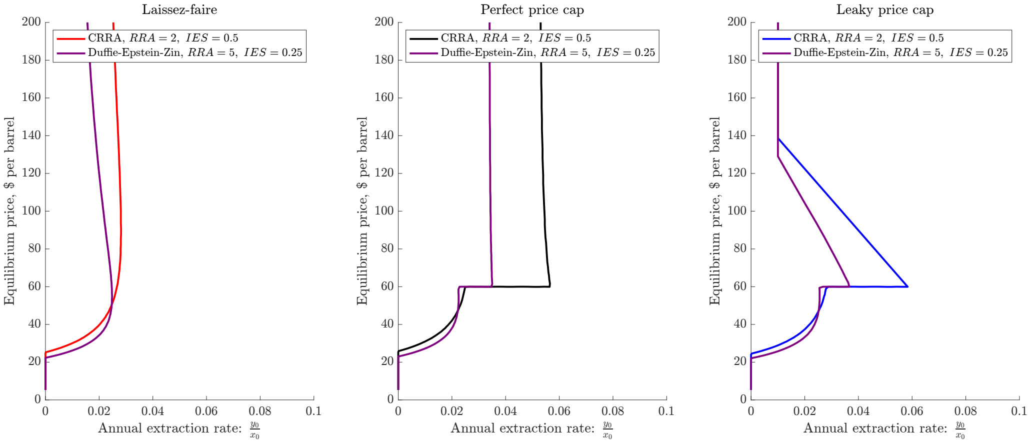

Figure C1. Results under Duffie-Epstein-Zin preferences

Note: 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.