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ABSTRACT

THE GEOPOLITICAL EXTERNALITY OF CLIMATE POLICY*

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This paper formalizes the geopolitical externality of climate policy and estimates its plausible magnitudes. Specifically, domestic reductions in fossil fuel demand depress global prices, thereby lowering export revenues for resource-rich autocracies – many of which allocate substantial resources to military spending. As a result, climate policy reduces geopolitical and security burdens on Western democracies, offering a "peace dividend" as a co-benefit. Using the European Union's oil consumption and its support to Ukraine as a case study, we highlight the relevance of this externality. We estimate that each euro spent on oil in the EU generates geopolitical costs of 0.37 [0.01 - 4.7] euros related to Russia's war on Ukraine. Based on our central estimate, a carbon price of 62 euros per ton of CO_2 would be required to internalize these costs. Even under conservative assumptions, our analysis highlights that the geopolitical externality offers a compelling argument for strong unilateral efforts to reduce fossil fuel demand in the EU.

Keywords: geopolitical externality; climate policy; co-benefit; EU climate policy; Russia's invasion of Ukraine

JEL classification: F18; F51; F52; H23; H56

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1 Introduction

Climate policy seeks to address the market failure of global warming caused by greenhouse gas emissions, primarily by reducing the supply and demand of fossil fuels. A substantial body of literature has emphasized the non-climate related externalities, or co-benefits, of these policies – including improved public health (e.g. Gao et al., 2018), increased energy security (e.g. Kim et al., 2025; Kruse-Andersen, 2023; Schwanitz et al., 2015), and fiscal benefits from recycling revenues generated by climate policies (e.g. Bento & Jacobsen, 2007; Bento et al., 2018; Siegmeier et al., 2018).[1] Beyond these well-documented co-benefits, climate policy also has a geopolitical externality.

At the end of the Cold War, Ward and Davis (1992) coined the concept of a "peace dividend", describing how reduced geopolitical tensions lower military spending and free public budgets for civil society. In this paper, we demonstrate that climate policy can similarly create a security dividend. A significant share of the world's fossil fuel resources is concentrated in autocratic nations (Ross, 2012), sometimes with high military expenditures (Do, 2021; Edenhofer et al., 2023), which impose security and military costs on Western democracies (e.g. Hauenstein et al., 2021). By reducing dependence on fossil fuels, climate policy has the potential to diminish these costs, generating what we define as the geopolitical externality of climate policy.

While previous work has qualitatively identified and explored the links between climate policy and geopolitics (Charbonnier, 2024; Mercure et al., 2021; Moore, 2024)[2], our paper formalizes the geopolitical externality of climate policy, decomposes it in four quantifiable causal steps, and provides a tentative quantification in a study case.

Specifically, we analyze the relationship between the EU's oil consumption and the costs it incurs from Russia's ongoing war in Ukraine, offering a policy-relevant case study.

[1] Karlsson et al. (2020) categorize co-benefits of climate policy into six areas: improved (i) air quality, (ii) diet and physical activity, (iii) soil and water quality, (iv) biodiversity, (v) economic and organizational performance, and (vi) energy security. We expand on a seventh category and provide a quantitative assessment of its impact.

[2] Reciprocally, Zhang et al. (2024) shows that geopolitical risks already motivates the deployment of renewable energy.

Our findings demonstrate how reduced fossil fuel demand in the EU lowers oil revenues for Russia, thereby reducing military-related expenditures borne by the EU.

Our central estimate suggests that each euro of reduced oil consumption in the EU generates approximately 37 cents in geopolitical co-benefits by lowering EU expenditures related to Russia's war in Ukraine, with a plausible range from 1 cent to 4.7 euros. This corresponds to an implicit carbon price on oil of 62 [1 - 786] euros per tonne of CO_2, solely to internalize the EU's geopolitical costs.

The remainder of this paper is organized as follows. Section 2 defines the concept of a geopolitical externality of climate policy and its decomposition into measurable components. Section 3 provides a quantification of the geopolitical externality and contextualizes it within the broader range of (co-)benefits associated with climate policy. Section 4 concludes with a critical discussion of our findings.

2 Conceptual definition

In this section, we define the concept of the geopolitical externality of climate policy, outlining its scope and significance. To establish a clear methodological framework, we break down the causal mechanism underlying this externality into four distinct steps. For each step, we reference supporting evidence from existing literature, followed by an illustrative quantification in the subsequent section.

We define the geopolitical externality of climate policy as its indirect impact on geostrategic security, mediated through fossil fuel markets. This externality arises because ambitious climate policies lower global demand for fossil fuels, thereby reducing fossil fuel prices. In turn, this diminishes the economic resources – and, thus, the military power – of fuel-exporting autocratic countries. Ultimately, climate policy could generate a peace dividend (Ward & Davis, 1992) by decreasing geopolitical and military risks.[3]

[3] It is likely that fuel-exporting countries can anticipate that climate policies in fuel-importing countries will ultimately reduce their future revenues. As a result they may decide to hasten their military buildup while fossil fuel incomes are still high – essentially extending the concept of the Green Paradox to war preparation. However, this second-order effect does not change the rationale of the geopolitical externality

The geopolitical externality of climate policy unfolds through four causal steps, as illustrated in Figure 1.

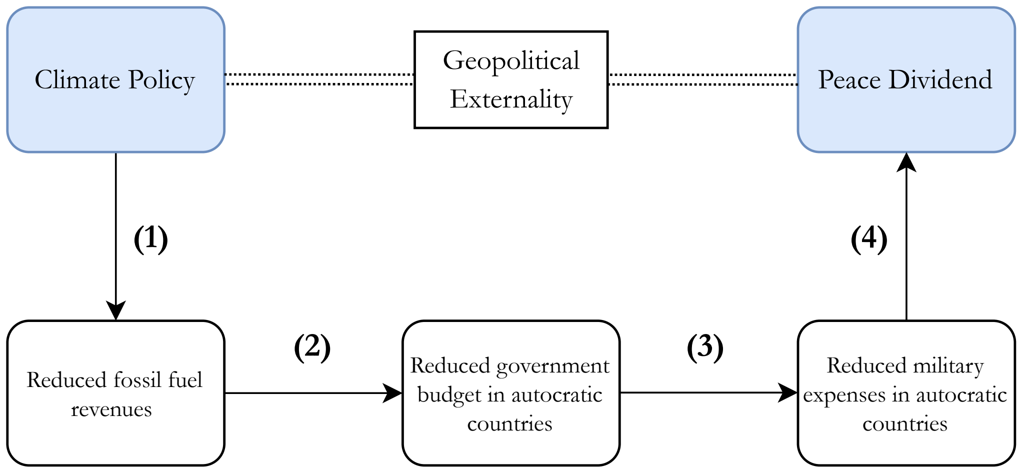

Figure 1: Conceptual steps of the geopolitical externality

Mathematically, we denote the geopolitical externality for country A, mediated by an oil-producing country B, as $\beta_{A\to B}$[4]. We define it as the marginal change in country A's military expenditures ME_A, in response to a marginal change in its fossil fuel consumption X_A:

$$\beta_{A\to B} \equiv \frac{d(ME_A)}{d(X_A)}. \tag{1}$$

Following Figure 1, we decompose Equation (1) into four ratios:

$$\beta_{A\to B} = \frac{d(W_B)}{d(X_A)} \times \frac{d(GOV_B)}{d(W_B)} \times \frac{d(ME_B)}{d(GOV_B)} \times \frac{d(ME_A)}{d(ME_B)}. \tag{2}$$

The first ratio relates a change in fossil fuel consumption within country A, $d(X_A)$ to a reduction in country B's fossil fuel rent $d(W_B)$, as detailed in Section 2.1. The second ratio converts the change in fossil fuel rent, $d(W_B)$, into a change in government budget,

for the importing country: reducing fossil fuel demand still allows to limit the military buildup in fuel exporting country.

[4] More generally, the total geopolitical externality of climate policy in country A is the sum of the geopolitical externalities mediated through all other countries B: $\beta_A = \sum_B \beta_{A\to B}$.

$d(GOV_B)$, covered in Section 2.2. Third, the changes in country B's government budget, $d(GOV_B)$, influence its military expenses, $d(ME_B)$, discussed in Section 2.3. Fourth, the additional military expenses of country B, $d(ME_B)$, raise the security costs for country A, $d(ME_A)$, as presented in Section 2.4. As illustrated in Section 3, combining estimates for the four ratios allows quantifying the geopolitical externality of fossil fuel consumption.

2.1 From climate policy to fossil fuel rents

The first link in this causal chain is the climate policy-induced reduction in global demand for fossil fuels, which exerts downward pressure on fossil fuel prices. This combination of reduced demand and lower prices results in decreased fossil fuel revenues for resource-rich countries. This effect is well-documented and poses two primary challenges for ambitious climate policy: carbon leakage, where reduced domestic consumption is partially offset by increased consumption in countries without stringent climate policies (Grubb et al., 2022; Jakob, 2021); and the difficulty of securing an international climate agreement with disproportionately affected resource-rich countries (Kalkuhl & Brecha, 2013).

In this paper, however, we emphasize a potential benefit of reduced fossil fuel revenues, contrasting these challenges. In addition to a terms-of-trade improvement – where fuel-importing countries like the EU benefit from lower global fossil fuel prices driven by their own demand reduction (see Section 3.2) – the decline in fossil fuel revenues of resource-rich countries marks the first step toward a geopolitical externality of climate policy.

2.2 From fossil fuel rents to state budgets

The second link in the causal chain is the reduction of government budgets in resource-rich, often autocratic countries, driven by declining fossil fuel revenues. These countries rely heavily on revenues from resource extraction and export revenues to fund their budgets, drawing income through profit taxes, licensing fees, and, more directly, state-owned enterprises (Nan Tian, 2017).

Figure 2 illustrates the significance of resource rents – defined by the World Bank's

World Developments Indicators (WDI) as income exceeding estimated production costs – as share of GDP for countries most dependent on these revenues. The figure highlights that resource rents from oil and natural gas are particularly important for autocratic countries, where the average share exceeds 12.5%, compared to less than 1.2% in democratic countries. These resource rents are particularly high in the Middle-East and North African (MENA) region, Kazakhstan, and Russia, with the majority – nearly 90% on average in autocratic countries – derived from crude oil production.

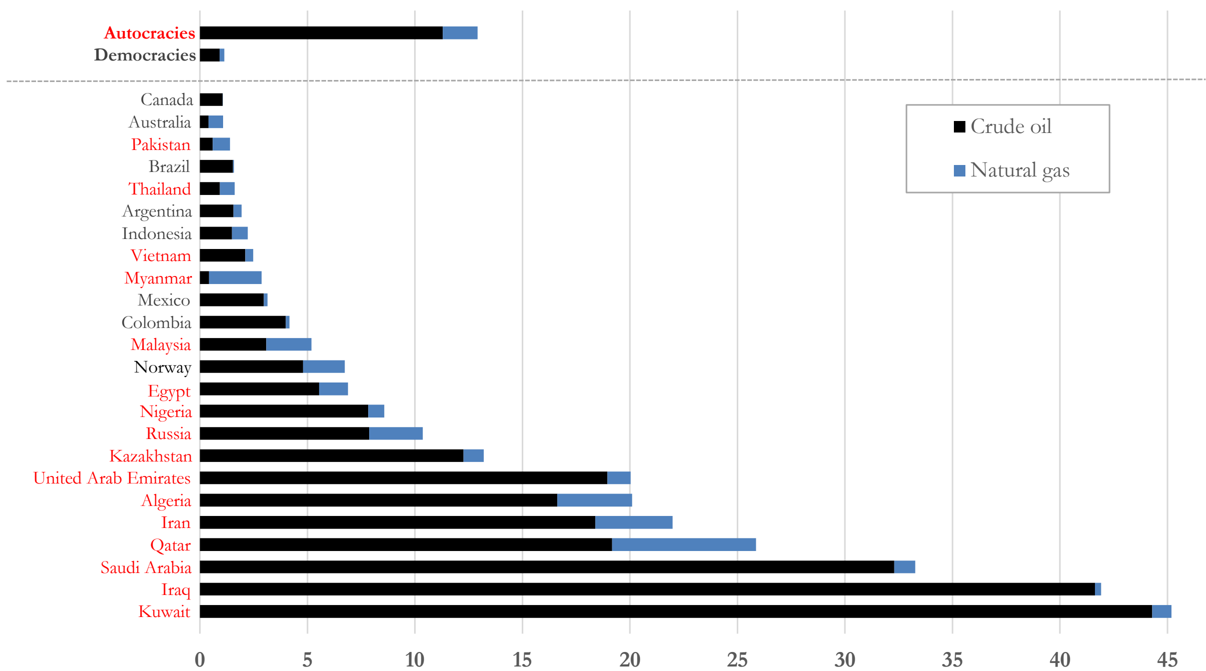

Figure 2: Resource rents as a share of GDP (in %)

Note: Shares represent the 2010-2020 average. Country names in red indicate non-democratic (autocratic) regimes, based on the "Boix-Miller-Rosato Dichotomous Coding of Democracy" classification for 2020 (see Miller et al., 2022). Only countries with a resource rent share from oil and natural gas of more than 1% of GDP and a GDP greater than 100 billion USD in 2020 (at 2015 constant prices) are included. Source: Own illustration based on Edenhofer et al. (2023).

2.3 From state budgets to military spending

The third link in this chain driving the geopolitical externality is the induced decrease in military expenditures, which constrains these countries' abilities to pursue aggressive geopolitical strategies. Levels of military expenditures derive from a complex interaction of factors (Bachtiar et al., 2024) and only indirectly relate to the political nature of the regimes and their resource rent (Do, 2021). Nonetheless, reductions in government budgets due to lower resource income significantly impact the military capacity of states involved in open conflicts (Spiro, 2025; Vandenbroucke, 2024) and more broadly the geopolitical ambitions of fuel exporting countries (Nan Tian, 2017).

2.4 From military spendings to global security costs

The final link in this chain is the diminished geopolitical influence or threat posed by fossil fuel-rich autocratic countries, enabling climate-ambitious Western democracies to lower their own expenditures on geostrategic security (Hauenstein et al., 2021; Yesilyurt and Elhorst, 2017). This may include reduced military spending and decreased financial support – covering military, economic, and reconstruction efforts – for allies directly at war with resource-rich countries. This argument also applies in the absence of open conflicts, by reducing the costs of deterrence (Powell, 1991). By alleviating these security burdens, climate policy can generate a peace dividend, allowing resources to be redirected away from costly arms races. In addition, the effects extend beyond direct military threats, impacting international trade, the stability of global supply chains, and migration flows – including refugees from conflict zones (Federle et al., 2024).

3 Case study: EU oil demand and Russia's invasion of Ukraine

Since Russia's illegal occupation of Crimea in 2014, the EU and Russia have been in conflict over Ukraine's territorial integrity (Meister, 2022). Despite these tensions, Russia remained the EU's largest oil supplier until its full-scale invasion of Ukraine in February 2022 (Eurostat, 2024a). Meanwhile, the EU has adopted ambitious climate targets that necessitate a significant reduction in oil consumption (European Commission, 2021). This specific set of interactions between the EU and Russia offers a compelling case study on the intersection of climate policy and geopolitical risks.

3.1 Quantification of the geopolitical externality

In this section, we estimate the geopolitical externality associated with the EU's oil consumption in relation to the Russian war in Ukraine.[5] We provide range estimates for the four ratios defined in Equation (2), and subsequently contextualize our estimate of the geopolitical externality within the range of other well-documented (co-)benefits of climate policy in Section 3.2.

3.1.1 Estimating Russia's revenue losses from oil exports

First, we quantify how a one-euro reduction in oil consumption by the EU translates into rent losses for Russian exporters. Employing the definition of supply and demand elasticities (ϵ_S and ϵ_D, respectively), we estimate that for every euro reduction in oil demand in the EU, the market value of global oil production decreases by $1/[\epsilon_S - (1 - \mu_{EU})\epsilon_D]$ euros, where μ_{EU} is the EU share in global oil use.[6] For a competitive global oil market, the loss for Russian exporters is calculated by weighting this price reduction by Russia's market share in the oil market:[7]

$$\frac{d(W_{RUS})}{d(X_{EU})} = \frac{\text{RUS oil exports}}{\text{World oil production}} \frac{1}{\epsilon_S - (1 - \mu_{EU})\epsilon_D}. \tag{3}$$

Global long-run elasticities are estimated between -0.23 and -1.1 on the demand side, with a central estimate of -0.45; on the supply side, estimates range from 0.05 to 0.2, with

[5] Our analysis focuses on the impact of reduced oil consumption in the EU, abstracting from the impact of EU climate policy on other fossil fuels, particularly coal and natural gas.

[6] A formal proof of this relationship is provided in Appendix A.1, where we employ the static demand-supply model of Gars et al. (2022).

[7] We assume a perfectly competitive oil market, implying that losses from price decreases are evenly distributed. As a result, this approach does not account for gravity patterns in international oil trade, where closer trade partners are more affected by demand shocks (cf. Farrokhi, 2020). Since Russia was the EU's largest oil supplier prior to its invasion of Ukraine (Eurostat, 2024a), reductions in EU oil consumption likely have a disproportionately larger impact on Russia compared to other exporters.

a central estimate of 0.13 (Gars et al., 2022). Russian net exports and EU oil consumption contribute to 7% and 11% of the world oil supply, respectively (EIA, 2024).

Using these values, we estimate that each euro reduction in EU oil consumption leads to proportional profit losses for Russian exporters, given by[8]:

$$\frac{d(W_{RUS})}{d(X_{EU})} = \mathbf{0.13}\,[0.06; 0.27]. \tag{4}$$

3.1.2 Effect on the government budget

The second causal link of the geopolitical externality examines the relationship between Russian oil rents and the Russian government budget. Empirically, the Russian government heavily relies on tax revenue from the oil and gas sectors. In 2023, these sectors generated approximately \$108 billion in taxes, accounting for up to 32% of the Russian state budget (Yermanokov, 2024, p. 9). Notably, 80% of this fiscal revenue is derived form oil rents, mainly through the Mineral Resource Extract Tax (MRET) and an export tax on oil (Yermanokov, 2024).

Given that the operating costs of the fossil fuel industry are largely fixed in Russia (Spiro et al., 2024), the Russian government can fully tax any additional turnover. Consequently, each euro lost in oil revenue directly translates into a one-euro reduction in the government budget:

$$\frac{d(GOV_{RU})}{d(W_{RUS})} = 1. \tag{5}$$

3.1.3 Linking the Russian government budget to military expenses

The third step examines the part of the government budget allocated to military spending. In 2023, Russian security expenditures were estimated at 9.6 trillion rubles, accounting for

[8] The EU implemented trade sanctions in response to Russia's invasion of Ukraine, including a price cap on Russian crude oil exports (Becker et al., 2024). These sanctions do not directly affect our results. First, the price cap as proved largely ineffective in reducing the Russian oil income (Kilian, 2022; Spiro et al., 2024). Second, the modeled revenue reduction arises from a global oil price effect, regardless of whether the EU imports oil from Russia or other countries (e.g., the US or Iraq). Unlike sanctions targeting specific trade flows, the impact of a global price reduction cannot be circumvented by Russia.

32% of the total government spending (Cooper, 2023). Our analyses focuses on how an additional rouble of Russian fiscal revenue, $d(GOV_{RU})$, is allocated to military expenditures, $d(ME_{RU})$. To assess this relationship, we propose three distinct approaches.

Proportional expenses: Here, we assume a direct linear relationship between the total government budget and military spending. Under this assumption, reductions in the Russian government budget are evenly distributed across all public expenditures. Thus, a one-ruble decrease in government revenue translates into a 0.3-ruble reduction in military expenses, corresponding to the military's 30% share of the budget.

One-to-one reduction: Here, we assume that every additional ruble of oil export revenue is allocated entirely to military expenditures. This assumption is plausible, as oil exports generate foreign currency needed to import dual-use goods and technical equipment necessary for the military but unavailable domestically. Under this method, the military budget increases in direct proportion to the Russian government budget.

Intertemporal budget: In the short term, the Russian war effort might be largely independent of government revenue, such that the multiplier between the Russian government budget and the Russian military expenditure is close to zero.[9] Indeed, Russia benefits from vast stocks of Soviet-era military equipment, available at a negligible price. As a result, the Russian war effort may depend more on these historical stocks than on the current government resources (Vandenbroucke, 2024). Similarly, the Russian government can finance its military expenses by contracting debt or reducing other government expenditures, thereby abstracting from the short-term revenue constraints.

However, this does not imply that Russia's overall intertemporal military expenditure is unaffected by changes in the government budget. Over time, the depletion rate of military stocks constrains the potential duration of the war and, in turn, the intertemporal military spending in Ukraine. Appendix B illustrates this effect with a stock-flow modeling

[9] This could hold if Russia had sufficient domestic resources to sustain the war without relying on external incomes, which we cannot completely exclude.

approach linking the yearly average spending on the war in Ukraine to the real military expenditures m (including stock depletion) and the current military budget g. In this framework, a reduction in the available government budget has a multiplier effect on the intertemporal spending in the war:

$$\frac{d(ME_{RUS})}{d(GOV_{RU})} = \frac{m}{m-g}. \tag{6}$$

If a one-euro reduction in the annual government budget shortens the war by one day – because it hastens the depletion of the Russian resource stocks – the corresponding reduction in cumulative spending does not only entail this one-euro reduction in each year of the war, but also the total budget that would have been spent on the avoided day of war, which might largely exceed one euro. Appendix B proposes a calibration of the model based on the observed losses in military equipment (Seohina, 2024; Wratling & Reynolds, 2024), leading to a multiplier of 4.[10]

Based on the different approaches, we get the following range of estimates linking marginal Russian military expenditures to marginal changes in the government budget:

$$\frac{d(ME_{RUS})}{d(GOV_{RU})} = \begin{cases} 0.3 & \text{(proportional)} \\ \mathbf{1} & \text{(one-to-one)} \\ 4 & \text{(intertemporal)} \end{cases} . \tag{7}$$

We adopt the one-to-one estimate as a baseline, reflecting a realistic assumption of how Russia allocates government revenue to military expenditures.

[10] This quantification draws on strong assumptions regarding the commitment of Russia to the war in Ukraine, the quantification of the overall Russian war effort, and the exhaustibility of the Russian military (and potentially fiscal) reserves. However, the mechanism by which current government budgets constrain long-term military capabilities is well-established in the literature (Vandenbroucke, 2024) and sufficient to rule out the hypothesis that the Russian military effort is completely independent from its government budget.

3.1.4 EU spendings in reaction to the Russian war in Ukraine

As the final step in our causal chain, we assess the ratio of changes in Russian military expenses in Ukraine, $d(ME_{RUS})$, to the corresponding European response, $d(ME_{EU})$. This scaling factor depends on the scope of expenses considered on both sides. Throughout this analysis, we assume that EU support to Ukraine is proportional to Russia's military spending – in other words, each additional bomb financed by Russia causes an equal burden on the EU through its support to Ukraine.

Between 2022 and 2024, the Russian government allocated 29,215 trillion rubles – about 350 billion USD – to its military. However, the fraction of this budget directly allocated to the war in Ukraine is largely unknown (Cooper, 2023). In September 2023, the RAND research center projected that direct Russian war spending would reach at least 131 billion USD by the end of 2024 (Shatz & Reach, 2023), while statements at the end of 2024 from US Defense Secretary Lloyd Austin suggested a figure "above 200 billion USD" (Kosoy, 2024). Based on available information, we thus estimate Russian spending on the war in Ukraine at 131 to 350 billion USD, with a central estimate of 200 billion USD.

From the onset of the war, the EU has provided Ukraine with direct financial, humanitarian, and military support. As of December 2024, EU member countries and institutions had allocated a total of 113 billion euros (122.5 billion USD) in such assistance (Trebesch et al., 2024). However, this figure significantly understates the overall cost of Russia's war for the EU. Reconstruction needs following the large-scale damages to Ukraine's infrastructure and economy are currently estimated to 524 billion USD (World Bank, 2025). Assuming that reconstruction costs are shared between the EU and other European allies in proportion to their relative contributions to Ukraine – and excluding US participation in reconstruction – we estimate the EU's additional burden to be 448.2 billion USD. Adding this to the 122.5 billion USD in already allocated direct support yields a total EU cost of about 571 billion USD.

Beyond the specific case of the Russian war in Ukraine, historical evidence provides a conservative estimate of military budget spillovers. Yesilyurt and Elhorst (2017) show that the post-cold war defense budgets in one country are substantially influenced by the military spending of neighboring countries, with all countries being affected by the spending of UN Security Council members such as Russia. They estimate that a 1% increase in military spending as a share of GDP in one country results in a 0.24% increase in neighboring countries' military spending per unit of GDP in the short term. Given that the EU's GDP is about nine times larger than Russia's (World Bank, 2024), this implies that a one-euro increase in Russia's military budget translates into an estimated 2.16-euro increase in EU military expenditures under this conservative assumption.

Taken together, these approaches yield the following range of the ratio between the EU's military expenditures and support to Ukraine and Russian military expenditures:

$$\frac{d(ME_{EU})}{d(ME_{RU})} = \mathbf{2.9}\,[0.35; 4.4]. \tag{8}$$

Depending on the scope for the Russian military effort in Ukraine and on the range of costs included on the EU side, each euro of Russian military spending in Ukraine imposes between 35 cents and 4.4 euros in costs on the EU. Using our preferred estimates – 200 billion USD in Russian military spending and 571 billion USD in total EU support to Ukraine – we derive a central ratio of 2.9.

Importantly, the upper bound of this estimate is highly sensible to the geopolitical context. In the case of a complete withdrawal of the US support, preliminary estimates suggest that EU countries would need to increase their annual military spending by an additional mounting 250 billion euros (Burilkov & Wolff, 2025), substantially increasing the multiplier. Moreover, our estimate does not account for other indirect costs of Russia's war in Ukraine, such as the strong reduction in EU economic growth.

3.1.5 Total geopolitical externality

In the previous four subsections, we quantified the individual steps required to estimate the geopolitical externality in the context of the EU's oil consumption and its connection to the Russian war in Ukraine. By combining the four components of the analysis – as detailed in Equation (2) and summarized in Table 1 – we estimate the marginal geopolitical externality at 37 cents per euro of EU oil consumption, with a range between 1 cent and 4.7 euros. Put differently, each euro spent on oil in the EU generates 37 cents (central estimate) in geopolitical costs for the EU due to Russia's aggression.

The estimates depend on assumptions about supply and demand elasticities (Section 3.1.1), Russian taxation system and effectiveness (Section 3.1.2), Russian military expenditures as a function of the government budget (Section 3.1.3), and the scope of EU expenses in response to Russia's invasion of Ukraine (Section 3.1.4). The latter two estimates appear as the most difficult to quantify, with estimates in both cases spanning a full order of magnitude. Despite these uncertainties, our central estimate is based on plausible and relatively conservative assumptions.

Table 1: Geopolitical externality from EU oil consumption.

	Ad-valorem estimate		
Causal step	Low	Central	High
(A) Impact on Russian oil revenues	0.06	0.13	0.27
(B) Impact on Russian government budget	1	1	1
(C) Impact on Russian military expenses	0.3	1	4
(D) Cost of the war for the EU	0.4	2.9	4.4
Total geopolitical externality	**0.01**	**0.37**	**4.70**

Note: Ad-valorem estimates are expressed in monetary cost per monetary unit of oil used. Number in parenthesis indicate the range of estimate.

Under the strong assumption that the marginal geopolitical costs of EU oil consumption scale linearly, the 282 billion euros spent on oil in 2023 in the EU (Eurostat, 2024b) are estimated to result in indirect geopolitical costs ranging from 1.7 to 1,324 billion euros, with a central estimate of 104 billion euros.

3.2 The geopolitical externality in perspective

The geopolitical externality complements other externalities associated with the consumption of oil. In this section, we compare the geopolitical benefits of reducing the EU's domestic oil consumption to the terms-of-trade effect of reduced oil imports and to the benefits of climate mitigation.

As a net importer of fossil fuels, the EU benefits from reduced fossil fuel consumption through lower world market prices, which improve its terms of trade. We quantify this externality by applying the reasoning of section 3.1.1 (see Appendix A.1 for the proof):

$$\text{terms-of-trade externality} = \frac{\mu_{EU}}{\epsilon_S - (1 - \mu_{EU})\epsilon_D}. \tag{9}$$

Using an EU use share of 11% of global oil consumption (EIA, 2024) and the demand and supply elasticities from Section 3.1.1, we estimate the terms-of-trade benefits of reducing EU oil consumption by one euro to range between 12 and 54 cents, with a central estimate at 26 cents.

Combining the terms-of-trade and geopolitical externalities, we estimate the self-inflicted externality of one euro of oil consumption to 0.55 euros – more than half of its market value – with a plausible range between 0.09 and 5.08 euros (see rows (1) to (3) of Table 2).

Table 2, rows (4) to (6), also presents estimates of the social cost of oil use in the EU based on the two identified externalities.[11] Under our most conservative estimate, these externalities justify a carbon price of 15 Euro/tCO_2 – about a quarter of the current permit price under the EU Emission Trading Scheme (EU ETS). Our central estimate reaches 93 EUR/tCO_2 (62 EUR/tCO_2 for the geopolitical externality alone), suggesting that the current EU ETS price is too low to internalize the terms-of-trade and geopolitical externality of EU oil consumption. The upper bond is evaluated at 850 EUR/tCO_2 and supports a strong reinforcement of the EU climate policies.

Notably, these estimates do not account for the costs of climate change. The US Environmental Protection Agency (EPA) estimates the Social Cost of Carbon (SCC) at

[11] Based on current oil prices and standard assumptions on the carbon intensity of oil we estimate that each euro reduction in EU oil consumption results in approximately 6 kg of avoided CO_2 emissions within the EU. This estimate is based on an oil price of 70 euros per barrel, an emission intensity of 2.65 $kgCO_2/l$, and a barrel capacity of 158 liters (Freund et al., 2018).

Table 2: The geopolitical externality compared to the terms-of-trade externality of oil use in the EU.

Metrics	**Geopolitical externality**	**Terms-of-trade externality**	**Total**
Ad-valorem estimate			
Low (1)	0.01	0.08	0.09
Central (2)	**0.37**	**0.18**	**0.55**
High (3)	4.7	0.38	5.08
Social cost estimate (EUR/tCO_2)			
Low (1)	1	14	15
Central (2)	**62**	**31**	**93**
High (3)	786	64	850

Note: Ad-valorem estimates are expressed in monetary cost per monetary unit of oil used. The social cost equivalents are estimated using an oil price of 70 euros and an emission intensity of 2.65 kgCO_2/l.

190 EUR/tCO_2 for 2020, using a 2% discount rate (EPA, 2023).[12] The SCC reflects the global damages from climate damages, only a fraction of which will occur in the EU. While this argument is sometimes used against unilateral climate mitigation, the geopolitical and terms-of-trade externalities affect exclusively the EU and constitute strong arguments for unilateral climate action.

4 Conclusions

This paper formalizes and provides a first quantification of the geopolitical externality of climate policy: by reducing reliance on fossil fuels, climate policy can indirectly generate a peace dividend for fuel-importing Western democracies. Specifically, we highlight a causal mechanism where reduced fossil fuel revenues constrain government budgets in fuel-exporting autocratic countries, ultimately leading to lower military expenditures for fuel-importers. Building on a broad literature, this paper decomposes this externality into quantifiable components, evaluates it for the EU in the context of the Russian war in

[12] Recent econometric studies suggest a much higher SCC (Bilal & Känzig, 2024; Wenz et al., 2024), with estimates reaching up to 2,000 euro per tCO_2.

Ukraine and highlight its significance in comparison to other co-benefits of climate policy.

Our central estimate is that a one-euro reduction in oil consumption within the EU lower the cost of the Russian war in Ukraine to the EU by 0.37 euros. At the upper bound of our estimates, the geopolitical externality is valued at 4.7 euros, indicating that the indirect geopolitical costs of oil consumption in the EU may exceed its current market value. The geopolitical externality in this specific context translates into a carbon price on oil of 62 EUR/tCO_2 (central estimate). This highlights a compelling case for ambitious EU climate policies, even without accounting for additional gains from climate change mitigation and related co-benefits, or benefits accruing to other countries.

This central estimate is subject to considerable uncertainty. Our plausible range spans two order of magnitudes (0.01; 4.7). It is particularly sensitive to the evolution of military expenditures per unit of increased government budget and the indirect costs of war on western democracies (step 3 and 4 of our analysis, respectively), highlighting the need for further research on these questions.

The relationship between the EU and Russia, characterized by asymmetrical trade and open geopolitical conflict, offers a striking example of how climate and geostrategic objectives can align. While the quantification presented in this paper only applies to a specific geopolitical and historical context, the concepts introduced here are not limited to the EU's support for Ukraine against Russia. However, in other contexts, the magnitude and direction of the geopolitical externality may be more nuanced and less straightforward.

As the global energy transition reshapes resource demands and dependencies, the geopolitical externality could also be mediated by other key resources, such as critical minerals and green technologies. With geopolitical tensions are on the rise, this paper provides an additional step for understanding the complex link between climate change, international trade and geopolitics.

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Appendix

A.1 A heuristic derivation of the impact of reducing oil demand

Suppose there is a a globally integrated market for oil. Let us use the following notations:

p = price of oil on the world market

$D(p)$ = world aggregate oil demand

$S(p)$ = world aggregate oil supply

Also, let us denote by σ an infinitesimal reduction in the oil demand (whose impact we want to evaluate). The world market clearing condition is: $D(p) - \sigma = S(p)$.

Differentiating with respect to σ yields:

$D'(p)\frac{dp}{d\sigma} - 1 = S'(p)\frac{dp}{d\sigma}$.

Rearranging gives us: $\frac{dp}{d\sigma} = \frac{-1}{S'(p)-D'(p)}$.

Let us denote $\mu_{Russia} = \frac{\text{Russian net oil exports}}{\text{world oil production}}$, by ϵ_S the global price elasticity of supply and by ϵ_D the global supply elasticity of demand. By the envelope theorem, the marginal change in social surplus for Russia is:

Russian oil exports $\times \frac{dp}{d\sigma} = \mu_{Russia} S(p)\frac{dp}{d\sigma} = \mu_{Russia} S(p)\frac{-1}{S'(p)-D'(p)} = \mu_{Russia} p \frac{1}{\epsilon_S - \epsilon_D}$.

Now suppose that the unit for measuring oil is chosen such that one unit costs \$1. Then we obtain: Reducing demand for oil by 1 dollar worth of oil deprives Russia of $\mu_{Russia}\frac{1}{\epsilon_S-\epsilon_D}$ dollars of net revenue or, more generally, social surplus. Similarly, it gives the EU $-\frac{\mu_{EU}}{\epsilon_S-\epsilon_D}$ dollars in social surplus due to the lower world market price, where $-\mu_{EU}$ is the share of net EU imports relative to global oil production.

The next section will show that the formulae derived here heuristically are a good approximation to the exact formulae.

Now let us also use our result that $\frac{dp}{d\sigma} = \frac{-1}{S'(p)-D'(p)}$ to compute the fraction, denoted l, of the demand reduction σ that gets offset by increases in oil use everywhere the world. This we obtain as follows: $l = \frac{dp}{d\sigma}D'(p) = \frac{-D'(p)}{S'(p)-D'(p)} = \frac{-\epsilon_D}{\epsilon_S-\epsilon_D}$.

A.2 A formal derivation of the unilaterally optimal ad valorem taxes in a canonical Walrasian model

Lemma 1. *Let ϵ^D and ϵ^S denote the global price elasticities of supply and demand for oil. Let ϵ^D_{EU} denote the price elasticity of demand for oil in the EU. Let η_{EU} denote the climate damages accruing to the EU per ton of CO2. Let p denote the price of oil per quantity corresponding to 1 ton of CO2. Let $l := \frac{-\epsilon^D}{\epsilon^S-\epsilon^D}$. Let $G'(W_{Russia})$ denote the marginal damage that the EU suffers per unit of additional social surplus accruing to Russia from increased world oil prices.*

The EU's ad valorem tax rate on oil use that maximises the EU's economic surplus is characterized by the following equation:

$$x_{EU}^{optimal} = \frac{1}{1 - l\frac{-\epsilon^D_{EU}}{-\epsilon^D}\frac{D_{EU}}{D_{World}}}\left((1-l)\frac{\eta_{EU}}{p} + \frac{\frac{D_{EU}-S_{EU}}{D_{World}}}{-\epsilon^D+\epsilon^S} - G'(W_{Russia})\frac{\frac{S_{Russia}-D_{Russia}}{D_{World}}}{-\epsilon^D+\epsilon^S}\right)$$

Thus the formula is as suggested by the heuristic derivation, with one notable modification: The multiplication by the factor $\frac{1}{1-l\frac{-\epsilon^D_{EU}}{-\epsilon^D}\mu_{EU}}$.

Proof. Consider a region k (e.g. the EU) that implements climate policy via an ad valorem tax on oil use at rate x_k. Let p denote the price of oil on the world market. Let $D_k((1+x_k)p)$ denote the demand for oil in the region k, given that the consumers there face the after-tax oil price of $(1+x_k)p$. Let $D_{-k}(p)$ denote the oil demand in the rest of the world: $D_{-k} = \sum_{j\neq k} D_j((1+x_j)p)$. We take the taxes in the rest of the world (-k) to be exogenous. Let $S_k(p)$ and $S_{-k}(p)$ denote the oil supply in k and the rest of the world, respectively, and $S(p) = S_k(p) + S_{-k}(p)$.

World market clearing means:

$$D_k((1+x_k)p) + \sum_{j\neq k} D_j((1+x_j)p) = S(p)$$

Since we want to look at the effect the change of the ad valorem tax in region k has on the world market price, we differentiate with respect to x_k:

$$(p + \frac{dp}{dx_k}(1+x_k))D'_k((1+x_k)p) + \frac{dp}{dx_k}\sum_{j\neq k}(1+x_j)D'_j((1+x_j)p) = \frac{dp}{dx_k}S'(p)$$

Dividing by $S(p)$ and using the world market clearing condition again yields:

$$(p + \frac{dp}{dx_k}(1+x_k))\frac{D'_k((1+x_k)p)}{D_k((1+x_k)p)}\frac{D_k}{D} + \frac{\frac{dp}{dx_k}}{p}\sum_{j\neq k} p(1+x_j)\frac{D'_j((1+x_j)p)}{D_j}\frac{D_j}{D} = \frac{dp}{dx_k}\frac{S'(p)}{S(p)}$$

Let us use the following notations for the demand and supply elasticities of oil in region k and -k respectively. ϵ^D_k denoting the demand elasticity in region k:

$$\epsilon^D_k := (1+x_k)p\frac{D'_k((1+x_k)p)}{D_k((1+x_k)p)}$$

$$\epsilon^S := p\frac{S'(p)}{S(p)}$$

Furthermore, we introduce an expression of the share the demand in region k (and -k respectively) has of the overall demand. $\mu_k := \frac{D_k}{D_k+D_{-k}}$

$\mu_{-k} := \frac{D_{-k}}{D_k+D_{-k}}$.

Using this notation in the equation from above yields:

$$(\frac{1}{1+x_k} + \frac{\frac{dp}{dx_k}}{p})\epsilon_k^D \mu_k + \frac{\frac{dp}{dx_k}}{p} \sum_{j \neq k} \epsilon_j^D \mu_j = \frac{\frac{dp}{dx_k}}{p} \epsilon^S$$

$$\frac{\frac{dp}{dx_k}}{p}(\epsilon_k^D \mu_k + \sum_{j \neq k} \epsilon_j^D \mu_j - \epsilon^S) = -\frac{\epsilon_k^D}{1+x_k}\mu_k$$

$$\frac{\frac{dp}{dx_k}}{p} = \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon_k^D \mu_k - \sum_{j \neq k} \epsilon_j^D \mu_j + \epsilon^S}$$

$$\frac{\frac{dp}{dx_k}}{p} = \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon_k^D \mu_k - \sum_{j \neq k} \epsilon_j^D \mu_j + \epsilon^S}$$

Now since the market-share-weighted sum of demand elasticities equals the aggregate elasticity, we obtain:

$$\frac{\frac{dp}{dx_k}}{p} = \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D + \epsilon^S}$$

Now consider social surplus in region k

$$W_k = \underbrace{\int_{v=(1+x_k)p}^{\infty} D_k(v)dv}_{\textbf{consumer surplus}} + \underbrace{p x_k D_k((1+x_k)p)}_{\textbf{tax revenue}} + \underbrace{\int_{v=S_k^{-1}(0)}^{p} S_k(v)dv}_{\textbf{producer surplus}} - \underbrace{\eta_k S(p)}_{\textbf{climate damages}}$$

So far, all is standard. However, let us now assume that there is another region, denoted z that inflicts a geopolitical externality on k. (In our motivating example, Russia inflicts damages on the EU due to its invasion of Ukraine.) Specifically, let us assume that these damages depend on the social surplus accruing in z:

$V_k = W_k - G(W_z)$

This specification is motivated by the view that any social surplus accruing to people in Russia due to changes in the world market oil price can be captured by the Russian government by adjustments in the tax and transfer system. Thus changes in the world market oil price effectively translate into changes in the Russian government's budget constraint and therefore W_{Russia} is a sufficient statistic for how the war outcomes are affected.

Maximizing social surplus in region k using the equations from above will yield the optimal ad-valorem tax on oil.

$$\frac{dW_k}{dx_k} = (-(p + \frac{dp}{dx_k}(1+x_k)) + p + x_k\frac{dp}{dx_k})D_k((1+x_k)p) + px_kD_k'((1+x_k)p)(p + \frac{dp}{dx_k}(1+x_k))$$
$$+ S_k(p)\frac{dp}{dx_k} - \eta_k\frac{dp}{dx_k}S'(p)$$
$$\frac{dW_k}{dx_k} = -\frac{dp}{dx_k}D_k((1+x_k)p) + px_kD_k'((1+x_k)p)(p + \frac{dp}{dx_k}(1+x_k)) + (S_k(p) - \eta_kS'(p))\frac{dp}{dx_k}$$
$$\frac{dW_k}{dx_k} = -\frac{dp}{dx_k}D_k + \frac{px_k}{(1+x_k)p}D_k\epsilon_k^D(p + \frac{dp}{dx_k}(1+x_k)) + (S_k(p) - \eta_kS'(p))\frac{dp}{dx_k}$$
$$\frac{dW_k}{dx_k} = \frac{dp}{dx_k}(S_k - D_k - \eta_kS'(p)) + \frac{px_k}{(1+x_k)}D_k\epsilon_k^D(1 + \frac{\frac{dp}{dx_k}}{p}(1+x_k))$$
$$\frac{\frac{dW_k}{dx_k}}{pD} = \frac{\frac{dp}{dx_k}}{p}\frac{S_k - D_k - \eta_kS'(p)}{D} + \mu_k\epsilon_k^D(\frac{x_k}{(1+x_k)} + \frac{\frac{dp}{dx_k}}{p}x_k)$$

Setting this to 0 yields the optimal ad valorem rate for region k:

$$0 = \frac{\frac{dp}{dx_k}}{p}\frac{\frac{S_k - D_k - \eta_kS'(p)}{D}}{\mu_k\epsilon_k^D} + (\frac{x_k}{(1+x_k)} + \frac{\frac{dp}{dx_k}}{p}x_k)$$

Substituting in $\frac{\frac{dp}{dx_k}}{p} = \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D + \epsilon^S}$ yields:

$$0 = \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{\epsilon^D + \epsilon^S}\frac{\frac{S_k - D_k - \eta_kS'(p)}{D}}{\mu_k\epsilon_k^D} + (\frac{x_k}{(1+x_k)} + \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D + \epsilon^S}x_k)$$

$$0 = \frac{\frac{S_k - D_k - \eta_kS'(p)}{D}}{-\epsilon^D + \epsilon^S} + (x_k + \frac{\epsilon_k^D\mu_k}{-\epsilon^D + \epsilon^S}x_k)$$

$$x_k = \frac{1}{1 - \frac{-\epsilon_k^D\mu_k}{-\epsilon^D + \epsilon^S}}\frac{\frac{D_k - S_k + \eta_kS'(p)}{D}}{-\epsilon^D + \epsilon^S}$$

Now using that $D = S$ by global market clearing, we get:

$$x_k = \frac{1}{1 - \frac{-\epsilon_k^D\mu_k}{-\epsilon^D + \epsilon^S}}(\frac{\frac{D_k - S_k}{D}}{-\epsilon^D + \epsilon^S} + \frac{\epsilon^S}{-\epsilon^D + \epsilon^S}\frac{\eta_k}{p})$$

Now let us consider the case with the geopolitical externality. We now get:
$\frac{dV_k}{dx_k} = \frac{dW_k}{dx_k} - G'(W_z)\frac{dW_z}{dx_k}$

To compute $\frac{dW_z}{dx_k}$, we can use the envelope theorem, given our assumption that the country z chooses its tax policy and extraction policy so as to maximize its social surplus:
$\frac{dW_z}{dx_k} = \frac{dp}{dx_k}(S_z - D_z)$

Using the above results yields:

$$\frac{\frac{dv_k}{dx_k}}{pD} = \frac{\frac{dp}{dx_k}}{p}\frac{S_k - D_k}{D} + \mu_k \epsilon_k^D \left(\frac{x_k}{(1+x_k)} + \frac{\frac{dp}{dx_k}}{p} x_k\right) - G'(W_z)\frac{\frac{dp}{dx_k}}{p}\frac{S_z - D_z}{D}$$

Substituting in $\frac{\frac{dp}{dx_k}}{p} = \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D + \epsilon^S}$ again yields:

$$(1+x_k)\frac{\frac{dv_k}{dx_k}}{pD} = \frac{\epsilon_k^D \mu_k}{-\epsilon^D + \epsilon^S}\left(\frac{S_k - D_k}{D} - G'(W_z)\frac{S_z - D_z}{D}\right) + \mu_k \epsilon_k^D \left(x_k + \frac{\epsilon_k^D \mu_k}{-\epsilon^D + \epsilon^S} x_k\right)$$

The region k's optimal ad valorem tax rate is thus given by:

$$x_k = \frac{1}{1 - \frac{-\epsilon_k^D \mu_k}{-\epsilon^D + \epsilon^S}} \frac{\frac{D_k - S_k}{D} - G'(W_z)\frac{S_z - D_z}{D}}{-\epsilon^D + \epsilon^S}$$

This is the ad valorem tax that exactly internalizes the pecuniary externality and the geopolitical externality.

Recall our notation from the heuristic derivation: $\mu_{Russia} = \frac{\text{Russian oil exports}}{\text{world oil production}}$. With that, we can write our expression for the EU's ad valorem tax that exactly internalizes the pecuniary externality and the geopolitical externality as follows:

$$x_k = \frac{1}{1 - \frac{-\epsilon_k^D \mu_{EU}}{-\epsilon^D + \epsilon^S}} \left(\frac{\frac{D_{EU} - S_{EU}}{D_{World}}}{-\epsilon^D + \epsilon^S} - G'(W_{Russia})\frac{\frac{S_{Russia} - D_{Russia}}{D_{World}}}{-\epsilon^D + \epsilon^S}\right)$$

□

Let us put this result in perspective to the formulae suggested in the heuristic derivation. Consider the first term in the sum, $\frac{1}{1 - l\frac{-\epsilon_{EU}^D}{-\epsilon^D}\mu_{EU}}(1-l)\frac{\eta_{EU}}{p}$. $\frac{\eta_{EU}}{p}$ is the marginal climate damage that the EU suffers per unit of oil that is worth 1 Euro. A first guess for the Pigouvian component in the EU's optimal ad valorem tax to internalise the damages it incurs from climate change is to set it to $\frac{\eta_{EU}}{p}$. However, per unit of demand reduction, global emissions only decline by $1-l$, given leakage on the global oil market, as derived in the preceding heuristic subsection of this appendix. Thus the heuristic approach might suggest that the climate damage internalising ad valorem rate is $(1-l)\frac{\eta_{EU}}{p}$. However, this is not correct. To see why, consider a (purely hypothetical) sequence of expansions of the EU that converges to the entire world. Then clearly the optimal carbon price due to the climate damages is simply the marginal global climate damages. Leakage must thus disappear from the formula in the limit. As a consistency check, we see that this is indeed what happens in the exact formula, as $lim_{EU \to World}\frac{1}{1 - l\frac{-\epsilon_{EU}^D}{-\epsilon^D}\mu_{EU}}(1-l) = 1$.

Now let us interpret the Lemma in terms of its application. The equation gives a necessary condition for an ad valorem tax rate to be optimal, coming out of the first order condition for the EU's ad valorem tax rate setting problem. We do not need to impose functional forms or make any approximations. The elasticities on the right hand side are evaluated at the global Walrasian equilibrium resulting from the ad valorem tax rate. Thus in general they will be affected by the ad valorem tax rate itself. However, it seems plausible that this effect will not be that large which justifies our approach of using elasticity estimates from the literature (presumably capturing elasticities around the *status quo* tax policy instead of around the optimal policy).

The first factor in this expression, $\frac{1}{1-\frac{-\epsilon^D_{EU}\mu_{EU}}{-\epsilon^D+\epsilon^S}}$ does not seem to have a clear intuitive explanation. However, it is close to 1. In our calibration with the central elasticity estimates it is 1.10. If we ignore this factor, then we get an interpretation of the formula in line with the heuristic derivation from the preceding subsection: The ad valorem tax rate that exactly internalizes the terms-of-trade and the geopolitical externalities can (to good approximation) be computed by tracing the causal effects of reducing oil demand by a quantity worth a dollar: Firstly, it benefits the EU via the lower world oil price that is by $\frac{\frac{D_{EU}-S_{EU}}{D_{World}}}{-\epsilon^D+\epsilon^S}$ dollars lower as a result. Secondly, it reduces oil rents accruing to Russia by $\frac{\frac{S_{Russia}-D_{Russia}}{D_{World}}}{-\epsilon^D+\epsilon^S}$ which gets translated at the rate $G'(W_z)$ into damages for the EU. In the main text we pick up from here and compute $G'(W_z)$ via the chain rule.

Lemma 2. *Let us define the "leakage rate for policy to reduce oil demand in region k" as* $\frac{\frac{-dD_{-k}}{dx_k}}{\frac{dD_k}{dx_k}}$*, i.e. the increase in oil use in the rest of the world per unit of reduction in oil use in region k. We have:* $\frac{\sum_{j\neq k}\frac{D_j}{D}\epsilon^D_j}{-(\epsilon^D-\epsilon^D_k\frac{D_k}{D})+\epsilon^S}$

Proof.

$$\frac{\frac{dp}{dx_k}}{p} = \frac{\frac{\epsilon^D_k}{1+x_k}\mu_k}{-\epsilon^D+\epsilon^S} \tag{A.1}$$

From Lemma 1 we know:

$$\frac{dD_k}{dx_k} = D'_k((1+x_k)p)(p+(1+x_k)\frac{dp}{dx_k}) \tag{A.2}$$

$$\frac{dD_k}{dx_k} = D'_k((1+x_k)p)p(1+(1+x_k)\frac{\frac{dp}{dx_k}}{p}) \tag{A.3}$$

$$\frac{dD_k}{dx_k} = D'_k((1+x_k)p)p(1+(1+x_k)\frac{\frac{\epsilon^D_k}{1+x_k}\mu_k}{-\epsilon^D+\epsilon^S}) \tag{A.4}$$

$$\frac{dD_k}{dx_k} = D'_k((1+x_k)p)p(1+\frac{\epsilon^D_k\mu_k}{-\epsilon^D+\epsilon^S}) \tag{A.5}$$

$$\frac{dD_k}{dx_k} = D'_k((1+x_k)p)p(\frac{-(\epsilon^D-\epsilon^D_k\mu_k)+\epsilon^S}{-\epsilon^D+\epsilon^S})\epsilon^S) \tag{A.6}$$

$$\frac{dD_k}{dx_k} = D_k \frac{\epsilon_k^D}{1+x_k}\left(\frac{-(\epsilon^D - \epsilon_k^D \mu_k) + \epsilon^S}{-\epsilon^D + \epsilon^S}\right) \tag{A.7}$$

$$\frac{dD_{-k}}{dx_k} = \sum_{j \neq k} D_j'((1+x_j)p)(1+x_j)\frac{dp}{dx_k} \tag{A.8}$$

$$\frac{dD_{-k}}{dx_k} = \sum_{j \neq k} D_j'((1+x_j)p)(1+x_j)p\frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D + \epsilon^S} \tag{A.9}$$

$$\frac{dD_{-k}}{dx_k} = \sum_{j \neq k} D_j \epsilon_j^D \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D + \epsilon^S} \tag{A.10}$$

$$\frac{\frac{dD_{-k}}{dx_k}}{\frac{dD_k}{dx_k}} = \frac{\sum_{j \neq k} D_j \epsilon_j^D \frac{\frac{\epsilon_k^D}{1+x_k}\mu_k}{-\epsilon^D+\epsilon^S}}{D_k \frac{\epsilon_k^D}{1+x_k}\left(\frac{-(\epsilon^D - \epsilon_k^D \mu_k)+\epsilon^S}{-\epsilon^D+\epsilon^S}\right)} = \frac{\sum_{j \neq k} D_j \epsilon_j^D \frac{\epsilon_k^D}{1+x_k}\mu_k}{D_k \frac{\epsilon_k^D}{1+x_k}(-(\epsilon^D - \epsilon_k^D \mu_k) + \epsilon^S)} \tag{A.11}$$

$$= \frac{\sum_{j \neq k} \frac{D_j}{D}\epsilon_j^D}{-(\epsilon^D - \epsilon_k^D \frac{D_k}{D}) + \epsilon^S} = \frac{\sum_{j \neq k} \frac{D_j}{D}\epsilon_j^D}{-(\epsilon^D - \epsilon_k^D \frac{D_k}{D}) + \epsilon^S} \tag{A.12}$$

□

A.3 Endogenizing other countries' tax rates on oil

The model in the previous section assumed that the other countries tax rates are not affect by the EU's tax rates. However, higher EU tax rates might induce other countries to have higher tax rates as well. One reason for this is that fossil fuel use taxation might be limited due a constraint that says that the total consumer price (i.e. net of taxes) must not exceed a given threshold, lest it cause popular discontent. More generally, if the political cost of high fuel prices are a function of the overall consumer price then the EU's greater climate policy ambition would cause other countries to increase their tax rates, given that the world market price gets reduced. This would imply that the formulae from the previous section would get adjusted upward: Both the terms of trade effect and the geopolitical externality would get amplified, as the EU's greater climate policy ambition would crowd in greater ambition by countries limited by the political cost of high overall fuel prices.//

B On the long term sensitivity of military expenses

This appendix introduces a model for estimating the cumulative spendings on war depending on current government resources and a stock of resource that the government can mobilize to fund the war effort. Section B.1 introduces a basic formulation of the model, with constant spendings and a fixed resource stocks. Section B.2 introduces an alternative formulation with an endogenous resource stock. Section B.3 generalizes the model to the case where military spendings and government resources vary over time.

B.1 Basic model

We note m_t the real Russian military expenditures for the war in Ukraine and g_t the fiscal resources that the Russian government can use for the war at time t. If the Russian resources do not fully cover the military expenses, the Russian government can draw in a stock of resources $S(t)$ (e.g., historical military stocks, human resources, military support from allies, fiscal space).

The depletion of the stock S at time t, $\frac{\delta S_t}{\delta t}$, is thus the quantity of military expenses not covered by the government own resources:

$$\frac{dS_t}{dt} = (g_t - m_t). \tag{B.1}$$

We suppose that the war ends at time T, when the aggressor or the defender cannot sustain the war anymore because the military stock S is exhausted: $S(T) = 0$. By definition, we then have:

$$S(0) = \int_{t=0}^{T} m_t - g_t dt. \tag{B.2}$$

Assuming the military expenditures m_t and the government revenues g_t are constant over time, the length of the war directly depends on the ratio between the initial resource stock S_0 and the gap in military spendings:

$$T = \frac{S_0}{m - g}. \tag{B.3}$$

We note M the cumulative resources spent during the war. By definition, it is:

$$M = \int_{t=0}^{T} m_T dT = mT. \tag{B.4}$$

In Section 3.1.3, we are interested in the sensibility of the annual military spendings, $\frac{1}{T}M(T)$, to a marginal change in government budget g_t. From our model, we derive this multiplier as:

$$\frac{1}{T}\frac{dM}{dg_t} = \frac{1}{T}\frac{dM}{dT}.\frac{dT}{dg_t}. \tag{B.5}$$

By definition, equation B.4 implies that a marginal increase in war duration increases the total cumulative expenditures by the value m:

$$\frac{dM}{dT} = m. \tag{B.6}$$

Using Equation (B.3), we find than an additional unit of government budget increases the war duration by:

$$\frac{dT}{dg} = -\frac{S_0}{(m-g)^2}. \tag{B.7}$$

The current military expenses thus increase by a coefficient $\frac{S_0}{T}\frac{m}{(m-g)^2}$ for each additional unit of income available. According to Equation (B.3), the first ratio, $\frac{S_0}{T}$, equals the current budget gap, $m - g$. Thus, the end-of-war multiplier depends only on the share of military expenses covered by the current government budget:

$$\frac{1}{T}\frac{dM}{dg_t} = \frac{1}{1-\frac{g}{m}}. \tag{B.8}$$

If Russia had no available budget for the war ($g = 0$), the war effort would exclusively rely on the available stock, and any additional government revenues would increase military spendings – implying a multiplier of 1. As the share of real military spendings covered by the Russian budget increases, the sensitivity of the war effort to the government budget increases as well.

In the first six months of the war, approximately 10.7 billion USD of Russian military equipment was destroyed (Shatz & Reach, 2023), with about 80% replaced by depleting soviet equipment reserves (Seohina, 2024; Wratling & Reynolds, 2024). Over the course of one year, this translates to an estimated 18 billion USD in military equipment drawn from the stocks and unreported in the military budget. In addition, the Russian government reported a 17 billion USD fiscal deficit in 2023 (Cooper, 2023), further reducing its capacity of taking more debts in the future. These stocks depletion add to the 109 billion USD official defence budget, which thereby represent about 75% of the real military expenditures. Using Equation (6), a unit decrease in the Russian government revenue translates into four units of reduction in intertemporal military spendings.

B.2 Endogenous resource stock

This model assumes that the "non-budgeted" resources $S(t)$ are fixed in quantity. By modifying Equation (B.1), the model can be extended to dynamic stocks, reflecting e.g. interests rates or demographic evolution. If we note r the interest rate (or population growth rate), Equation (B.1) becomes:

$$\frac{\delta S_t}{\delta t} = (g_t - m_t) + rS_t. \tag{B.9}$$

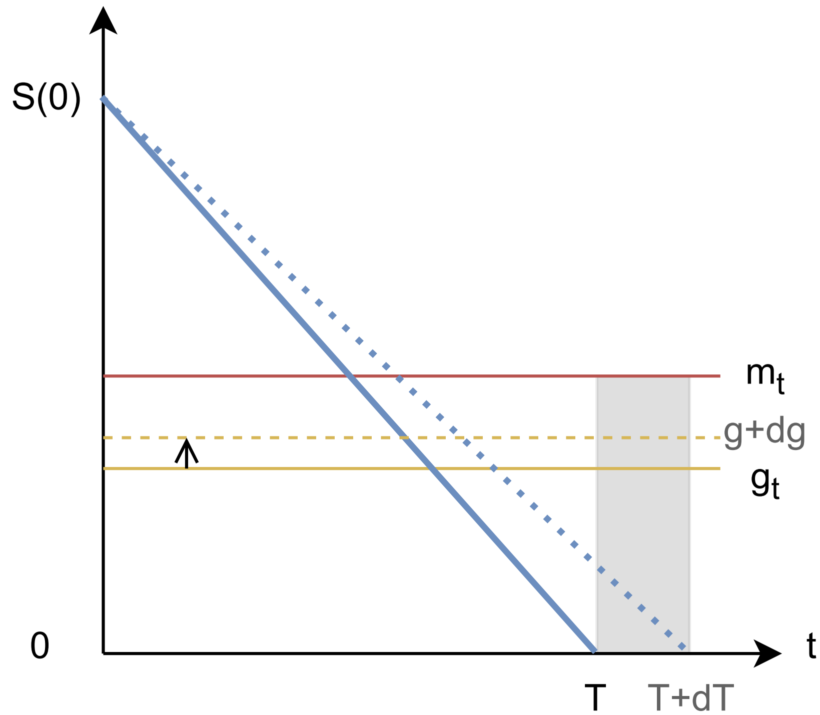

Figure B.1: Graphical representation of the end-of-war model. The yellow line g figures the current income the government can spend on the war and the red line m is the effective war effort. The blue curve S represents the evolution of the resource reserves during the time of the war. As the current government revenues do not cover all the effective war expenses, it draws from the stock of resources $S(0)$, at a rate $(m - g)$. The war ends at time T, when the resource stock is fully exhausted. The dotted lines represent the effect of an increase dg of the government revenues: increasing the current government revenue decreases the rate of the stock depletion (dotted blue curve), effectively delaying the end of the war $(T + dT)$. The extension of the duration of the war dT allows an increase of $dT * m$ in inter-temporal military spendings (grey area). Such marginal military spendings do not depend on the size of the initial stock $(S(0))$ nor on the duration of the war (T), but only on the stock depletion rate.

Solving this equation at the end-of-war T introduces an additional parameter e^{rT} reflecting the endogenous evolution of the stock, which eventually appears in the definition of the multiplier:

$$\frac{1}{T}\frac{dM}{dg_t} = \frac{1}{1-\frac{g}{m}}e^{rT}. \tag{B.10}$$

B.3 Endogenous spending path

The formulation of Equation (B.3) assumes that government and military spendings are constant over time. Our modelling approach also applies to other paths of spendings over time. In that case, Equation (B.8) becomes:

$$\frac{1}{T}\frac{dM}{dg_t} = \frac{1}{1-\frac{g_T}{m_T}}. \tag{B.11}$$

In this case, the change in intertemporal spendings only depends on the income gap *at the time the war ends*. This approach allows for an alternative calibration of the model: from a fiscal perspective, we can estimate the current government deficit that would trigger a sovereign default and - in turn - the end of the war. In 1998, the Russian government defaulted on its public debt with a fiscal deficit of 55% of its current revenues (Khara et al., 2001). Assuming the same level of fiscal deficit would trigger a default in contemporary Russia, the end-of-war multiplier would reach 1.8.