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Partners, Not Rivals: The Power of Parallel Supply-Side and Demand-Side Climate Policy

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Brian C. Prest is a fellow at Resources for the Future specializing in climate change, electricity markets, and oil and gas economics. Prest uses economic theory and econometric models to improve energy and environmental policies by assessing their impacts on markets and pollution outcomes. His recent work includes evaluating the impacts of federal tax credits for coal use. He is also working to establish an empirical basis for determining discount rates used in the social cost of carbon. His past work includes econometric analysis of US oil and gas industry, understanding the economic effects of rising temperatures, modeling the market dynamics of climate change policy under policy uncertainty, and assessing household responses to time-varying electricity pricing. His work has appeared in the *Journal of the Association of Environmental and Resource Economists*, *Energy Economics*, and *The Energy Journal*.

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Abstract

Policies to reduce greenhouse gas emissions can be categorized as demand-side measures, which reduce the consumption of fossil fuels, or supply-side measures, which reduce fossil fuel extraction. Most governments have relied primarily on demand-side approaches to emissions reductions while largely eschewing supply-side policies, even though policy commitments thus far remain insufficient to limit global temperature rise to 1.5°C. The focus on demand-side policies may stem from a common perception by policymakers and economists that supply-side policies are vulnerable to emissions "leakage"—in which reduced domestic fossil fuel production (and hence emissions) is simply offset by increased production and emissions elsewhere—to which demand-side policies are supposedly immune. This paper shows that leakage is a concern for both supply- and demand-side policies alike when pursued on their own, as is commonly done. However, when supply- and demand-side policies are pursued in parallel with similar vigor, leakage can be mitigated or even eliminated. As a result, supply- and demand-side policies are complementary in their goals of reducing greenhouse gas emissions. Far from being rivals, these two kinds of policies can be partners.

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1. Introduction

Despite recent progress in securing international commitments to fight climate change, such as the Paris Agreement, current climate policies remain far from sufficient to limit global temperature rise to 1.5°C. While this indicates more aggressive steps are needed, many policy levers remain underutilized. By and large, the policies pursued thus far have focused on demand-side measures, such as fuel economy standards, that directly reduce the consumption of fossil fuels, whereas supply-side measures that directly reduce fossil fuel extraction have received relatively little attention. This lopsided focus is at odds with the International Energy Agency's 1.5°C-consistent pathway, which entails "no investment in new fossil fuel supply projects" starting immediately.[1] Similarly, Welsby et al. (2021) calculate that the same target would require leaving 60 percent of existing oil and gas reserves and 90 percent of coal reserves in the ground. Such reserves would seem to be a natural focus of climate policy. In the United States, greenhouse gas emissions associated with federally owned fossil fuels are equivalent to about 24 percent of annual US emissions (Merrill et al. 2018; Ratledge et al. 2022), giving the federal government direct control over the extraction of these resources. Abroad, even larger shares of fossil fuel reserves are directly owned by governments. Yet governments have largely eschewed policies that directly reduce fossil fuel extraction.

Climate mitigation policies can generally be classified as either demand-side, directly reducing the consumption of fossil fuels and hence greenhouse gas emissions, or supply-side, directly reducing fossil fuel extraction. Historically, policymakers have overwhelmingly focused on demand-side measures. For example, in the United States, the Obama administration primarily pursued demand-side policies such as fuel economy standards and power plant regulations but did relatively little to directly reduce the production of fossil fuels. That focus on the demand side may stem in part from a common perception by policymakers and economists that supply-side policies are vulnerable to emissions "leakage"—in which reduced domestic fossil fuel production (and hence emissions) is simply offset by increased production and emissions elsewhere—to which demand-side policies are supposedly immune. But is that truly the case? Are these types of policies fundamentally different? More specifically, what are the major differences between these policies with respect to key outcomes such as leakage and, ultimately, global emissions reductions? This paper explores those questions and shows that the two types of policies are not fundamentally different with respect to leakage concerns. Although both types of policies can induce leakage on their own, when pursued jointly, they are in fact complementary, mitigating or even eliminating leakage.

Critics frequently dismiss supply-side policies based on a notion that leakage undermines their effectiveness in reducing emissions globally. However, it is commonly overlooked that leakage is an issue for demand-side climate actions as well. For example, whereas analyses of the effects of federal oil and gas development

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[1] **https://www.iea.org/news/pathway-to-critical-and-formidable-goal-of-net-zero-emissions-by-2050-is-narrow-but-brings-huge-benefits.**

frequently emphasize the potential for leakage of production to other regions, analyses of demand-side policies like fuel economy standards typically do not consider the analogous potential for leakage of *consumption* elsewhere.[2] On their own, demand-side policies generate leakage by reducing the price of fossil fuels, making it cheaper for other consumers, such as those in other countries, to burn them. Supply-side policies analogously generate leakage by increasing the price of fossil fuels, encouraging more production elsewhere. The climate benefits of either supply- or demand-side policies are each reduced by emissions leakage, or substitution, just via different mechanisms. Despite this symmetry, leakage concerns are disproportionately raised in the context of supply-side policies.

Leakage is not inevitable, though. Standard neoclassical economic theory shows that leakage can be avoided if supply- and demand-side policies are implemented in tandem and with equal ambition, in a quantitative sense in terms of the direct number of barrels of oil of consumption and production reduced. Intuitively, leakage is a problem either when demand-side policy suppresses global fossil fuel prices, making it cheaper for other countries to emit, or when supply-side policy boosts those prices and thereby makes it more profitable for other countries to produce more fossil fuels. But if both types of policies are implemented in parallel and in equal magnitude, these two effects can exactly offset each other: reduced supply is offset by reduced demand, muting or even eliminating the effect on global prices and hence the leakage problem. Conversely, a lopsided policy approach that addresses only demand or only supply will continue to generate leakage, demonstrating how the two kinds of policies can create synergies if pursued with similar ambition.

In this study, I consider leakage under both types of climate policies and argue that these policies are better thought of as partners that complement each other, and not rivals or alternative policies, as they are commonly seen. I demonstrate this point using standard neoclassical economic theory. This exercise demonstrates conceptually symmetric leakage effects from both demand-side and supply-side policies—if each type of policy is pursued alone. But when both types of policies are pursued in parallel, their individual weaknesses become synergies, mitigating leakage.

I first demonstrate this effect using a simple theoretical model that shows the effects of each policy type on the regional distribution of fossil fuel production and consumption. It shows how leakage can be reduced or eliminated, demonstrating that leakage can be eliminated by pursuing supply- and demand-side policies in tandem and with equal ambition.

In addition to this theoretical exercise, I use an empirically calibrated model of US and global markets for oil and gas, developed in Prest (2022), to conduct a quantitative exercise of the synergies produced by pursuing supply-side policies (such as reduced development of oil and gas on US federal lands and waters) in parallel with the more commonly implemented demand-side ones (such as fuel economy standards). The

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[2] Compare, for example, US EPA (2016), which analyzed US offshore federal oil and gas leases and assumed perfect leakage, with US EPA (2021), an analysis of US vehicle fuel economy standards that did not consider leakage.

results demonstrate how such policies complement each other by mitigating or even potentially eliminating leakage.

Beyond the issue of leakage, I outline other benefits of pursuing parallel policies, from both economic and political economy perspectives. I also discuss how the demand-centric structure of existing emissions accounting systems inefficiently skews policymakers' incentives away from supply-side actions and in favor of demand-side ones. Overall, supply-side policies represent underappreciated tools for reducing greenhouse gas emissions, given their complementarities with more commonly pursued demand-side policies. This underappreciation is a contributor to the disproportionate focus by policymakers and economists alike on demand-side policies like fuel economy standards and power plant emissions intensity regulations.

Literature

Although academic research commonly focuses on demand-side climate policies, a growing literature has promoted the value of supply-side policies. In a seminal study, Sinn (2008) noted that demand-side policy is effective only if suppliers actually react by reducing production, and further, a "green paradox" can arise if producers actually accelerate production in response to anticipated weakening demand in the future. This suggests a role of supply-side policy to target fossil fuel production directly, rather than indirectly through the channel of demand. Harstad (2012) made the case for climate coalitions to engage in supply-side policies by buying up foreign fossil fuel deposits and retiring them.

Countries can also reduce supplies domestically. In most countries, this policy approach is theoretically straightforward to implement because mineral rights are commonly owned by the government, although naturally the prospect of forgone revenue can create political disincentives to reducing production. Even though mineral rights ownership is more dispersed in the United States, about one-quarter of fossil fuels are nonetheless extracted from lands and waters owned by the federal government.[3] Recent studies suggest that these kinds of US supply-side policies could indeed lead to substantial emissions reductions, even after accounting for potential production leakage (see, e.g., Prest 2022; Prest and Stock 2022; Gerarden et al. 2020; Erickson et al. 2018; Erickson and Lazarus 2014, 2018). These are frequently discussed supply-side policies, but other examples of demand-side and supply-side policies are shown in Table 1. Both IEA (2021) and Welsby (2021) find that substantial declines in fossil fuel production are needed globally to have even-odds of limiting global warming to 1.5°C, suggesting that supply-side policy can play a substantive role in reducing emissions.

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[3] See, for example, **https://www.eia.gov/analysis/requests/federallands/pdf/table1.pdf**; **https://revenuedata.doi.gov/query-data/**; and Prest (2022). Correspondingly, life-cycle emissions from fossil fuels produced from US federal lands and waters amount to about 24 percent of annual US emissions (Merrill et al. 2018). Absent policy changes, this share is expected to remain stable through at least 2030 (Ratledge et al. 2022).

Table 1. Examples of Fossil Fuel Supply- and Demand-Side Policies

Supply-side policies		**Demand-side policies**	
Policy	**Effect**	**Policy**	**Effect**
Limiting extraction of publicly owned fossil fuel reserves	Lower supply of all fossil fuels	Fuel economy standards	Lower oil demand
Purchasing and retiring coal mines (e.g., Harstad 2012)	Lower coal demand	Subsidies for electric vehicles	Lower oil demand
Carbon tax levied at point of fossil fuel extraction	Lower supply of all fossil fuels	Carbon tax levied at point of emissions	Lower demand for all fossil fuels
Other taxes on fossil fuel extraction (e.g., severance taxes)	Lower supply of all fossil fuels	Investments in clean electricity	Lower coal and gas demand
Removal of fossil fuel subsidies	Lower supply of all fossil fuels	Energy efficiency	Lower demand for all fossil fuels

Some argue that supply-side policies may also be easier to implement, both practically and politically (see, e.g., Green and Denniss 2018). Practically, supply-side policies may have lower monitoring costs to the extent that there are fewer producers than consumers, reducing administrative and implementation costs. Politically, supply-side policies place the focus on fossil fuel production, which many people closely relate to the full suite of negative externalities, such as air pollution and land degradation. By contrast, the end goals of demand-side climate policy (reduced environmental harms) may be commonly perceived as only indirectly connected to a consumer's energy use. It is also likely that consumers perceive supply-side policies to primarily burden fossil fuel producers rather than consumers (Green and Denniss 2018).

The literature on supply-side policies has frequently focused on supply-side policies alone; relatively little focus has been given to the appropriate balance of supply-side and demand-side policies. One notable exception is Fæhn et al. (2017), who find that in Norway, optimal policy calls for a relatively balanced mix of supply- and demand-side policies (about two-thirds supply, one-third demand).

This paper contributes to the literature by demonstrating in a general model the conditions under which leakage can be eliminated. One such case highlights the benefits of pursuing, in tandem, supply- and demand-side policies with similar levels of ambition. The next section demonstrates the economic complementarities of these two kinds of policies, first through a theoretical model and second through an empirically calibrated, dynamic simulation model of US and foreign oil and gas supply and demand. That simulation compares two real-world supply- and demand-side policies: 1) an end to oil and gas leasing on federal lands and waters, and 2) fuel economy standards for light-duty vehicles. Finally, I discuss other benefits and complementarities of pursuing parallel policies and the diverging incentives for demand- and supply-side policies under existing emissions accounting systems.

2. Leakage in Supply- and Demand-Side Policy

In this section, I demonstrate the symmetries and complementariness that demand-side and supply-side policies have regarding leakage. First, I develop a simple, general model of international trade in oil and gas, based on standard neoclassical economic theory. This model demonstrates a conceptual symmetry for leakage when each policy is pursued independently, but also the potential for leakage to be mitigated or even eliminated when both policies are pursued in parallel.

Theoretical example

The theoretical model developed here is based on standard neoclassical economic theory. Although the model is fully general and allows for multiple products (oil and gas) from an arbitrary number of producing and consuming regions, for expositional clarity I focus on the case of a single fuel (oil) with two regions: domestic and foreign. For concreteness, I choose model parameters that roughly reflect the current state of the global oil market. For example, business-as-usual global supply and demand are taken to be 100 million barrels of oil per day (mb/d), of which 12 mb/d is supplied by US ("domestic") producers. I assume that 3 mb/d is removed by supply-side policy. This value corresponds to 25 percent of the 12 mb/d domestic supply, approximately in line with the share of oil produced from federal lands and waters. The full set of parameter assumptions is shown in Appendix Table A4. Because the chosen parameters reflect simple approximations of the current state of the market, the numerical results should be interpreted as illustrative of the economic mechanisms driving supply- versus demand-side policies, not as explicit estimates of the effect of any specific policy.

The result is a series of curves representing domestic, foreign, and global supply and demand. Economic equilibrium is achieved at the price and quantity levels at which total quantity supplied equals total quantity demanded. Figure 1 illustrates this equilibrium under four domestic scenarios:

1. No policy, or business as usual, shown as solid lines.
2. Supply-side policy, which entails an exogenous inward shift (i.e., a reduction) in the domestic oil supply curve, and hence a shift in the global supply curve by the same amount. This lower domestic oil supply is shown as the dashed blue line, and the reduced global oil supply is shown as the dashed brown line.
3. Demand-side policy, which entails an exogenous inward shift (i.e., a reduction) in the domestic oil demand curve, and hence in the global oil demand curve. This lower global oil demand is shown as the dashed purple line.

4. Both supply- and demand-side policy in equal ambition, which entails simultaneous inward shifts of both domestic supply and domestic demand curves (and hence the global ones) in items 2 and 3 above. These are assumed to be equal in magnitude.

The effect of a policy on greenhouse gas emissions depends on how much it reduces equilibrium global oil consumption. The no-policy equilibrium is indicated by the red dot in panel (a) of Figure 1 at the intersection of the solid purple and brown lines (global supply and demand). The "both policies" case is the green dot at the intersection of the dashed lines, leading to lower oil consumption as measured by the horizontal distance between the indicated points. Note that in the "both policies" case, the full 3 mb/d of reduced domestic supply and demand translates into a full 3 mb/d of reduced consumption globally.

By contrast, under either a demand-only or a supply-only approach, leakage means global effects are substantially smaller than the 3 mb/d direct effects of either policy. The points are shown in panel (b) of Figure 1, which is an inset of panel (a) zoomed in on the area around the global equilibria. The yellow and orange dots represent the equilibria under supply-only and demand-only policies, respectively. In either case, the global effect of the 3 mb/d direct reduction is smaller than 3 mb/d because of supply-side or demand-side leakage. The general direction of consumption and production by region under each policy approach is shown in Table 2. Under a supply-only approach, leakage occurs through increased foreign production, whereas under a demand-only approach, it occurs through increased foreign consumption.[4]

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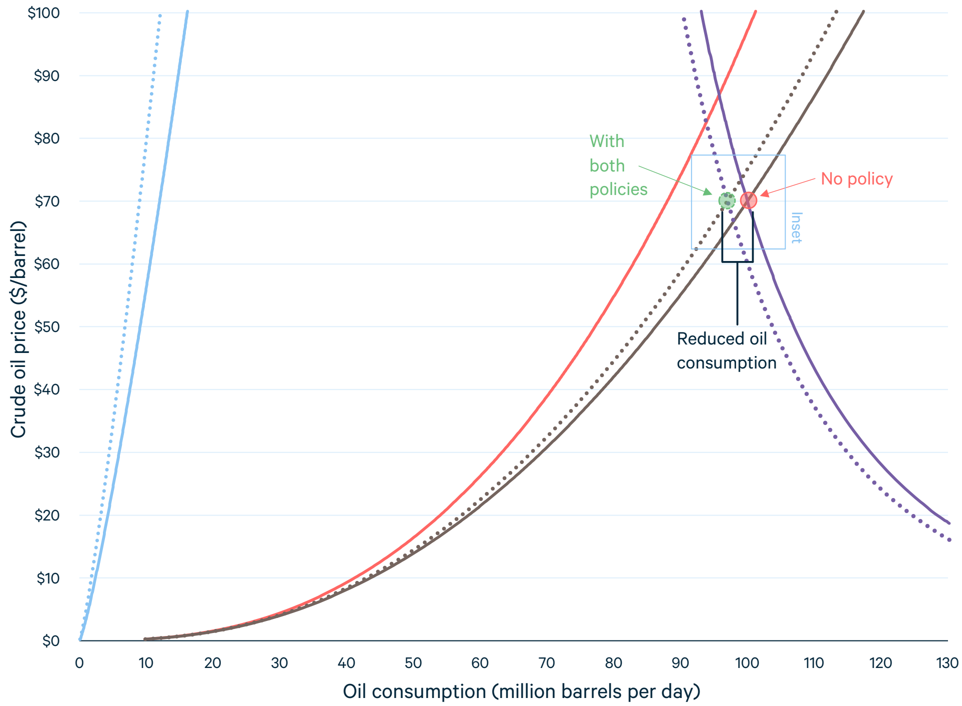
[4] Appendix Figure A1 includes a more detailed version of this figure, depicting the price effects and domestic demand curve.

Figure 1. Illustrative Effects of Supply- and Demand-Side Policies on Global Oil Markets

Panel (a): Supply and Demand Curves and Equilibrium Points



Panel (b): Inset of Panel (a) around Equilibrium Points

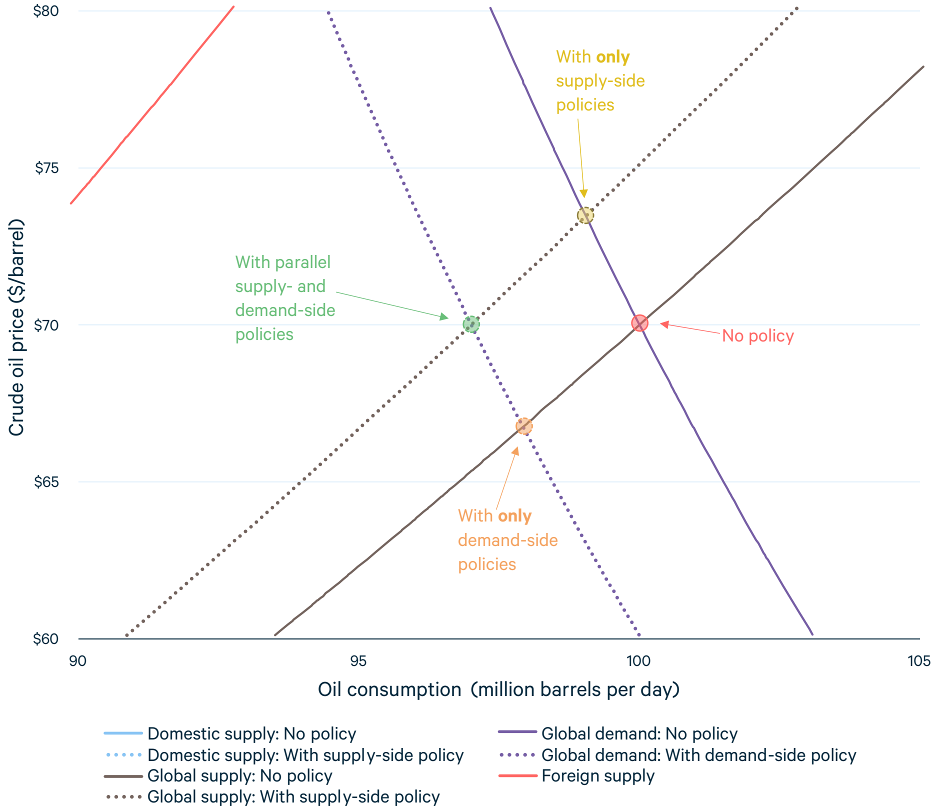


Table 2. Examples of Fossil Fuel Supply- and Demand-Side Policies on Oil Consumption, Production, and Associated Emissions

	Domestic	Foreign	Global
Supply-wide policy only			
Change in oil consumption and emissions	⬇	⬇	⬇
Change in oil production and emissions	⬇	⬆	⬇
Demand-side policy only			
Change in oil consumption and emissions	⬇	⬆	⬇
Change in oil production and emissions	⬇	⬇	⬇
Parallel policies, equal ambition			
Change in oil consumption and emissions	⬇		⬇
Change in oil production and emissions	⬇		⬇

More generally, the model (discussed in detail in the Appendix) derives a very general equation that represents the amount of leakage to be expected when supply-side and demand-side policies are pursued simultaneously, possibly at unequal levels of ambition. In particular, if a one-unit (e.g., 1 barrel of oil or 1 ton of CO2) direct reduction in consumption driven by a demand-side policy is simultaneously accompanied by a supply-side policy that drives a β-unit direct reduction in production (where β is between 0 and 1, with 0 corresponding to no supply-side policy and 1 corresponding to equivalently strong supply-side policy), then the resulting amount of leakage is given by the expression

$$Leakage = \frac{\bar{\varepsilon}_c}{\bar{\varepsilon}_s + \bar{\varepsilon}_c}(1-\beta) \qquad (1)$$

where $\bar{\varepsilon}_s$ and $\bar{\varepsilon}_c$ represent global average oil supply and demand elasticities, respectively, in absolute value. This result mirrors one appearing in Erickson and Lazarus (2014, 2018), with an additional term. The intuition for equation (1) is as follows: if demand-side policy is pursued on its own (β=0), this lower domestic demand drives down the global price of oil by an amount that depends on how far supply and demand fall to absorb the lower demand (the elasticities in the denominator, $\bar{\varepsilon}_s + \bar{\varepsilon}_c$). The less elastic supply and demand are (a smaller denominator), the more prices must decline to induce lower production and higher consumption to levels that restore market equilibrium. How much this price decrease translates into leakage—higher consumption largely outside the domestic market—depends on the global demand elasticity, given by $\bar{\varepsilon}_c$ in the numerator. In other words, demand-side leakage is driven by reduced prices, encouraging greater consumption in proportion to the global elasticity of demand, $\overline{\varepsilon}_c$. The mechanism is reversed in supply-side policy: reduced supply increases prices, encouraging more production in unregulated regions.

More generally, supply-side policy results in more leakage than demand-side policy when supply is more elastic than demand; that is, $\overline{\varepsilon}_s > \overline{\varepsilon}_c$. Conversely, if demand is more elastic, demand-side policies are leakier than supply-side ones. With equal elasticities, both approaches yield leakage rates of exactly 50 percent. This demonstrates a conceptual symmetry in leakage between the two policy types if each is pursued alone.

An inspection of equation (1) shows two ways in which leakage can be eliminated. First, leakage in demand-side policy is zero if global demand is perfectly inelastic ($\overline{\varepsilon}_c=0$), meaning there is no scope for a consumption response to lower prices, or if global supply is perfectly elastic ($\overline{\varepsilon}_s=\infty$), meaning production immediately and fully contracts in response to reduced demand. Neither case is a reasonable approximation of reality, nor are the elasticity parameters necessarily in the direct control of policymakers. The second way to eliminate leakage is to choose $\beta=1$, corresponding to a supply-side policy pursued at the same level of ambition as the demand-side policy. Intuitively, when demand and supply fall by the same amounts, there is no net pressure on the market price of oil, thereby inducing no increase in production or consumption abroad.

Quantitative example: US federal leasing ban and fuel economy standards

Although the model summarized in Figure 1 is helpful for illustrating the conceptual similarities and differences between supply- and demand-side policies, it is nonetheless highly stylized, and the numerical results should not be interpreted as the effects of any specific policy proposal. In this section, I provide more concrete and quantitatively rigorous estimates of the effects of actual, recently proposed policies.

I use the dynamic model of oil and gas supply developed in Prest (2022). That model entails a global representation of oil and gas supply and demand, with a detailed treatment of US oil and gas supply that disaggregates wells along three dimensions: federal versus nonfederal, onshore versus offshore, and oil-directed versus gas-directed wells. The model is calibrated econometrically to represent the dynamic response of drilling to oil and gas prices, and the corresponding time pattern of oil and production in response to changes in drilling over time. The model also accounts for how changes in supply and demand would affect global equilibrium oil and gas prices, including shifts in consumption and production between the United States and the rest of the world.

I use that model to estimate the effects of two specific US policies recently considered: a phaseout of US oil and gas leasing on federal lands and waters (a supply-side policy) and US corporate average fuel economy ("CAFE") standards for light-duty vehicles (a demand-side policy).

The first policy, the so-called leasing ban, was previously analyzed in Prest (2022), and the details of its implementation in the model can be found in that paper. That model accounts for leakage of production from federal lands and waters to both nonfederal domestic and foreign producers. The additional inclusion of CAFE, either on its own or alongside a leasing ban, is new to this study. Implementing this demand-side policy in the Prest (2022) model is straightforward and involves shifting the domestic oil (and hence global) demand curve in each year by the amount estimated in economic analysis by the US Environmental Protection Agency (EPA), which amounts to about 0.5 mb/d of reduced oil consumption annually (values in this section reflect annual averages over the 2020–2050 window, unless stated otherwise).[5] This is substantially smaller than the estimated supply reduction of 1.2 mb/d that would be directly achieved by an end to federal leasing, illustrating that the leasing ban is about 2.4 times as ambitious as the fuel economy standards.[6] Therefore, I also run an "equal ambition" scenario in which the oil demand reductions projected for CAFE standards are assumed to be larger each year by a factor of about 2.4 to bring the direct supply and demand reductions into approximate alignment. To simplify exposition, I focus on emissions from oil consumption in the analysis below, but it should also be noted that reduced gas production also generates additional emissions reductions that I don't include in the results (both for expositional simplicity and because the CAFE standards do not correspondingly reduce demand for natural gas). Although this does not affect the qualitative conclusions, it means that the emissions reductions presented here represent lower bounds on realistic effects.

The results of this quantitative exercise are shown in Figure 2, whose four panels reflect the four policy scenarios. Within each panel, the change in oil production is depicted in red, with the solid red bar indicating effects on US domestic production and the hatched red bar indicating effects on foreign production. Analogously, the effects on US domestic and foreign consumption are shown in solid and hatched blue. The first panel depicts supply-side policy implemented alone (a leasing ban), showing that the substantial reduction in domestic production of about 1 mb/d[7] is offset by an increase in foreign production by about 0.6 mb/d, meaning the net reduction in oil demand is only about 0.4 mb/d. The right-hand axis shows that the resulting global emissions reductions from reduced oil consumption amount to 55 million metric tons

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[5] Specifically, I use the estimated reduction in US fuel consumption from Table 5-7 of US EPA's (2021) regulatory impact analysis. Because the Prest model is on a monthly time step whereas EPA's estimates are annual, I convert to production rates (barrels per day) and linearly interpolate to the monthly time step.

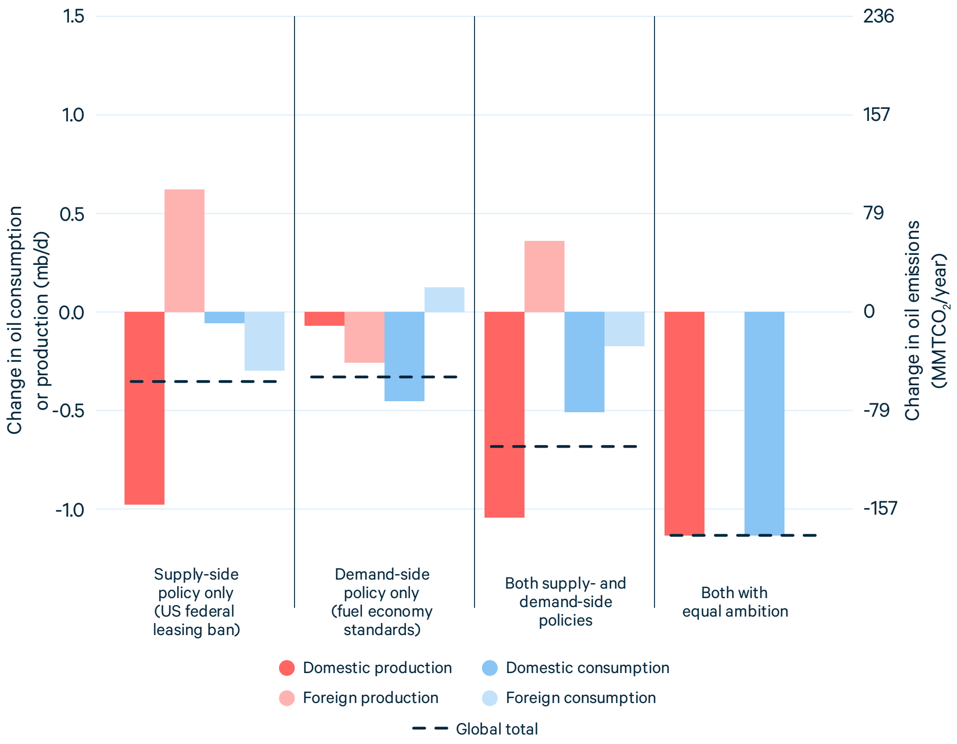
[6] This large difference in magnitude may be surprising, given policymakers' greater attention to fuel economy standards than to the federal oil and gas leasing program. In a subsequent section, I explore some factors driving this disproportionate emphasis on demand-side policies, such as existing emissions accounting systems.

[7] This 1.0 mb/d reduction in domestic production includes about 1.2 mb/d of reduction from federal lands and waters, offset by an increase of about 0.2 mb/d from state, private, and tribal lands.

of CO2 (MMTCO2) annually (each 1 mb/d is equivalent to 157 MMTCO2/year in emissions[8]).

As shown in the second panel, the demand-side policy pursued alone delivers similar reductions but is likewise subject to leakage. The direct reduction in domestic consumption of about 0.45 mb/d is undermined by an increase of about 0.12 mb/d abroad as the lower prices spur more consumption abroad, leading to a net reduction of about 0.33 mb/d, which causes a net emissions reduction of 52 MMTCO2.

Figure 2. Emissions and Leakage under Parallel Supply-and Demand-Side Policies



Notes: All values are 2020–2050 annual averages. The global total lines correspond to the sum of the change in domestic and foreign production. Since production equals consumption in equilibrium, it is also equal to the sum of the change in domestic and foreign consumption. The supply-side policy modeled in the first panel is an end to new oil and gas leasing on federal lands and waters. The demand-side policy in the second panel is the 2021 light-duty vehicle fuel economy standards. The third panel models both policies. The fourth panel, "Both with equal ambition," corresponds to a more aggressive demand-side policy that directly reduces US oil demand by the same amount that the leasing ban directly reduces federal oil supply (1.2 mb/d on average).

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[8] I use an emissions rate of 0.43 $MMTCO_2$ per barrel, meaning each 1 mb/d of production leads to emissions of 157 $MMTCO_2$/year ($= 1 \text{ mb/d} \times 0.43 \frac{\text{metric tons CO2}}{\text{barrel}} \times 365.25 \text{ days/year}$).

The third and fourth panels show how pursuing demand and supply-side policies in tandem can mitigate leakage. In the third panel, coupling supply-side policy with relatively modest demand-side policy shrinks the degree of leakage to foreign production, and in this case, consumption falls both domestically and abroad in response to higher prices. Leakage is not eliminated, however, because the direct reductions in oil consumption projected for the demand-side policy modeled—CAFE standards—are less than half the supply-side reductions from a leasing ban. With leakage mitigated, the overall reductions in oil consumption and emissions are much larger: 0.7 mb/d and 107 MMTCO2, respectively.

Finally, the fourth panel shows the result for a hypothetical set of more stringent demand-side policies—such as more stringent CAFE standards, electric vehicle deployment, or sustainable aviation fuels—that are commensurate in scale with the direct supply reduction from a leasing ban (both –1.2 mb/d).[9] The result is the same as in the theoretical model: no change in foreign production or consumption, since the domestic reductions in supply and demand lead to no net change in oil import demand and hence no effect on international oil prices, consumption, or production. With both policies pursued in tandem and with equal ambition, leakage is eliminated, and global emissions from oil are cut by 178 million tons of CO2 annually.

Although the focus of the exercise is oil, as mentioned previously, an end to federal oil and gas leasing would also reduce gas emissions. The model also includes natural gas emissions, where leakage remains an issue because I did not model a parallel policy reducing gas demand. After accounting for leakage, emissions reduction from gas amount to 30 MMTCO2e, bringing the overall emissions reductions from these two parallel policies to 208 million tons of CO2e per year. Further demand-side policies aimed at curbing gas consumption, such as deployment of electric heat pumps to substitute for gas furnaces, could further mitigate leakage and lead to larger emissions reductions.

Additional emissions reductions would be expected if these policies were also paired with reduced federal coal leasing, which is not included in my model. For example, Gerarden et al. (2020) estimated that reduced federal coal leasing could reduce emissions by 260 MMTCO2 in 2030, accounting for substitution between coal and gas in the power sector. Neither that study nor this one accounts for additional interactions between reducing federal coal and federal gas leasing. Just as parallel supply- and demand-side policies are complementary, reducing federal gas leasing would complement reduced federal coal leasing by discouraging substitution between those two fuels in the power sector—yet another unmodeled benefit of parallel policies. This highlights how reducing leakage requires not only simultaneously pursuing different types of policies (supply-side and demand-side) but also

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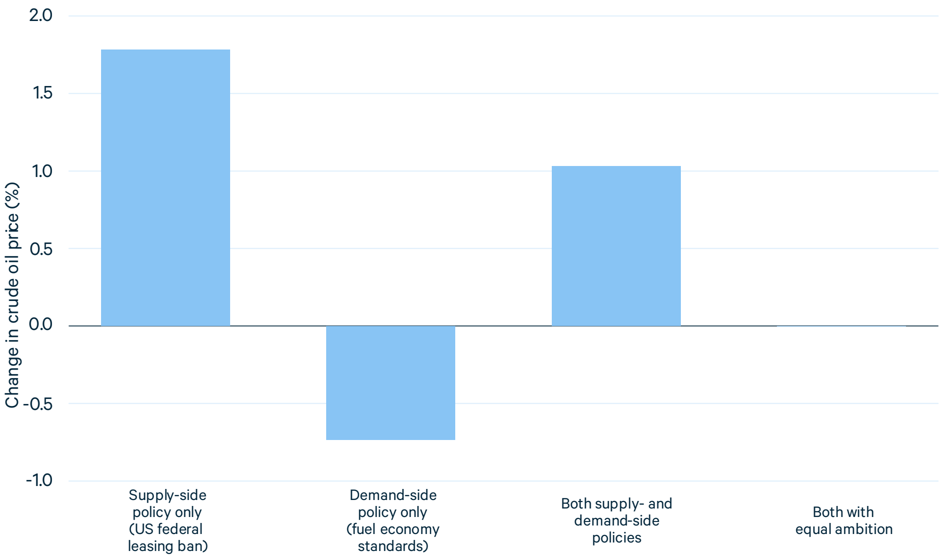
[9] This would require policies leading to an additional 0.7 mb/d reduction in oil consumption on top of the 0.5 mb/d reduction projected for the CAFE standards alone. **Bloomberg New Energy Finance** recently estimated that an aggressive deployment of electric vehicles could reduce oil demand by about this amount by 2030, and much more beyond that point.

simultaneously addressing emissions from different sources of emissions (coal, oil, and gas) to mitigate substitution across those sources.

Finally, Figure 3 shows the effect of each policy scenario on oil prices. The effects on global oil prices are generally small (less than 2 percent), and with parallel policies of equal ambition, oil prices are effectively unchanged, consistent with the result from the theoretical model depicted in Figure 1.

Figure 3. Effects of Each Policy Scenario on Oil Prices



Other benefits of parallel demand- and supply-side policies

Although the above analysis demonstrates how implementing supply- and demand-side policies in parallel can mitigate leakage, this is purely an economic feature; parallel policies have other advantageous features that address the common objections raised to supply-side policies. These include mitigating price impacts, diplomatic benefits, and the potential for reducing inequities in environmental consequences across countries.

Parallel policies address common objections to supply-side policy

Parallel policies can address several frequently raised criticisms of supply-side policy. First, as shown in Figure 3, parallel policies mitigate potential effects on energy prices. The mechanism for this is clear in Figure 1, where the parallel policies shift both supply and demand by the same, offsetting amount, leading to no net change in energy prices. This addresses commonly raised political concerns that supply-side policy could harm consumers by raising energy prices (and analogous concerns from energy producers about depressed prices).

Second, parallel policies render irrelevant the common objection that reallocated production or consumption could be shifted to dirtier producers. This argument, frequently raised in the United States in objection to supply-side policies, alleges that fossil fuel production is cleaner in the United States than in other countries (in terms of life-cycle CO2e per barrel of oil, or a similar metric for gas and coal).[10] Under this argument, leakage to more emissions intensive foreign producers could undermine the goal of reducing emissions. Extreme forms of this assertion allege that supply-side climate policies could even increase global emissions despite lower production.[11] Such an increase in emissions is conceptually possible, but its likelihood is frequently overstated in public debate; the best estimates of the amount of leakage and the degree of regional variation in the emissions intensity of fossil fuels are simply too small for this effect to dominate the overall reduction in consumption.[12] Regardless of the practical validity of this charge against supply-side policies, it simply does not apply when supply-side and demand-side policies are pursued in parallel and with equal ambition: leakage is eliminated, neither foreign production nor foreign consumption increases, and any regional differences in emissions intensities are irrelevant.

Parallel policies enhance credibility for diplomatic leverage in obtaining emissions commitments

Parallel policies can also be valuable from a diplomatic perspective by building credibility that can be leveraged in international climate negotiations. Countries pursuing a demand-only or supply-only strategy can be justifiable targets of criticism, since critics could allege insufficient dedication to efforts to reduce emissions across all major sectors.

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[10] This argument, typically raised against supply-side policies, is also conceptually relevant for demand-side policies. For example, an analogous outcome is possible with demand-side policy, such as if reduced demand for coal diverts coal consumption from a relatively efficient coal plant to an inefficient one.

[11] See, for example, Richards (2021) and Bureau of Ocean Energy Management (2016).

[12] See Carnegie Endowment Oil-Climate Index (**http://oci.carnegieendowment.org/#supply-chain**); Brian C. Prest, Written Testimony to US House Committee on Natural Resources, March 9, 2021 (**https://naturalresources.house.gov/imo/media/doc/Testimony%20-%20Mr.%20Brian%20Prest%20-%20EMR%20Leg%20Hrg%2003.09.21.pdf**); and Prest (2022).

A country that makes no substantial efforts to reduce its consumption of fossil fuels may be seen as unserious about pursuing aggressive climate policy, even if it is winding down its fossil fuel production. Although that perspective is perhaps widely appreciated, it is less apparent that the same charge can apply in reverse. A country that makes no substantial efforts at reducing its fossil fuel extraction is liable to be seen as unserious about achieving global climate goals, even if it is reducing its fossil fuel consumption. Such a country (e.g., Canada, Norway) is setting itself up to be a large oil exporter, which may be seen as inconsistent with long-term international climate goals. Even if emissions from domestic combustion of oil decline, the oil it exports will be combusted elsewhere and with the same climate impact as if it were consumed domestically. In that sense, such a country could be reasonably accused of simply exporting its emissions responsibility to others. Meanwhile, a country's growing fossil fuel export industry could develop strong financial incentives to resist a broader global energy transition. Supply- and demand-side policies pursued in parallel, however, can demonstrate a country's commitment to reducing emissions jointly on both sides of the ledger, generating credibility useful for winning additional emissions commitments in international negotiations.

Mitigating inequities in environmental harms across countries

Reductions in conventional environmental harms from reduced fossil fuel consumption and production—also called co-benefits—also have implications for the differential effects of supply- and demand-side policies on inequities in environmental damages across countries. In this context, it is important to distinguish "upstream" co-benefits associated with reduced production (e.g., reduced water contamination near oil and gas wells, and alternative land uses like conservation) from "downstream" co-benefits associated with reduced consumption (e.g., reduced conventional air pollutants from vehicles).

This distinction is important because of the diverging implications of supply- and demand-side policies for the geographic distribution of consumption and production (recall Table 2). For example, a demand-side policy targeting domestic oil consumption leads to downstream domestic co-benefits from reduced conventional air pollution but higher conventional air pollution damages in other countries, where consumption rises. For a relatively wealthy country like the United States, this means demand-side policy, pursued on its own, could exacerbate inequities in environmental exposure across countries from downstream sources. By contrast, supply-side policies reduce consumption both domestically and internationally, leading to broadly shared environmental improvements from downstream effects.

On the other hand, the upstream benefits from supply-side policies such as land conservation are enjoyed only domestically, and production leakage results in upstream damages internationally. On net, the implications of either supply-only or demand-only for environmental equity depend on the relative importance of upstream and downstream co-benefits, domestically and abroad. Although the relative merits of supply-only and demand-only policies for environmental equity are therefore ambiguous a priori, the effects of both policies pursued in parallel are clear: solely domestic co-benefits, with no adverse upstream or downstream effects "exported" to other countries.

Perverse incentives under international emissions accounting systems

Despite the symmetries and synergies of supply- and demand-side policies, they are nonetheless not treated equally by international emissions accounting systems. Country-level emissions accounts are predominantly focused on emissions measured at the point of demand. More specifically, countries' measured emissions accounts and nationally determined contributions (NDCs) are generally based on emissions released inside a country's territorial boundaries.[13] Naturally, this does not account for the full life-cycle effects of the fossil fuels a country exports. This structure can therefore inadvertently create perverse incentives for policymakers to discount supply-side policies and instead focus solely on the demand side.

Although counting life-cycle emissions at both the point of demand and the point of supply would double-count emissions, the choice of focusing on the point of demand is not a neutral one. This choice provides insufficient incentive for policymakers to pursue emissions-reducing supply-side policies, even if they would be cost-effective.

For example, even though President Biden campaigned on a supply-side policy of winding down oil and gas production on federal lands and waters, his administration has instead proposed modest changes to royalty rates on new leases. One apparent reason for this softening stance is political, but another perhaps more subtle one is that the emissions reductions resulting from that policy would occur largely in other countries: the vast majority of the emissions reductions (80–139 million tons CO2e annually; see Prest 2022) that would result from ending federal oil and gas leasing would occur outside the United States if those emissions are measured at the point of consumption, as is common. Similarly, the first panel of Figure 2 shows that nearly all the reduced oil consumption from a leasing ban comes from reduced foreign consumption. Those reductions, while real, would not count toward the US NDC or the administration's goal of cutting US emissions by 50 to 52 percent by 2030.[14] The administration thus has only a weak political incentive to pursue supply-side policies to achieve its NDC targets. Indeed, the US 2021 NDC does not mention US fossil fuel production except in one place, regarding domestic emissions from methane leaks in fossil fuel infrastructure.[15] Piggot et al. (2018) encourage countries to include supply-

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[13] Measuring emissions at the point of consumption of fossil fuels is also known as territorial accounting, compared with extraction-based accounting, in which emissions are measured at the point of supply (Piggot et al. 2018). I use the terms demand-based and supply-based accounting synonymously with territorial and extraction-based accounting, respectively.

[14] **https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/.**

[15] The United States of America Nationally Determined Contribution, Reducing Greenhouse Gases in the United States: A 2030 Emissions Target, April 21, 2022, **https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/United%20States%20of%20America%20First/United%20States%20NDC%20April%2021%202021%20Final.pdf.**

side goals in their NDCs but note that there is little incentive for a country to do so absent a supply-side accounting system.

Although the emissions reductions achieved by supply-side policies are generally understated by demand-side emissions accounting, a perhaps more perverse result is that a country receives credit for the full amount of demand-side reductions achieved domestically even if demand-side leakage means those emissions are effectively exported to other countries, which may then have more difficulty in meeting their own emissions goals. This occurs because demand-side leakage is not typically reflected in NDC goals. The relative benefits of demand-side policies, if pursued alone, are thereby overstated. From an economic perspective, this leads to inefficient, distorted incentives for policymakers that bias policy choices away from supply-side policies toward demand-side ones.

The current demand-based accounting skews incentives, but simply switching to a supply-based one would not necessarily be better. Supply-based emissions accounting would have the reverse effect of discouraging demand-side policies. One proposed alternative would be to deploy both accounting systems in parallel and consider both when evaluating potential policies (see, e.g., Piggot et al. 2018; Steininger et al. 2016; Harrison 2015).[16] If summed, those two parallel accounting systems could double-count emissions (e.g., a barrel of oil's life-cycle emissions would be counted both when it is extracted and again when it is consumed), but taken together, they correctly account on the margin for the direction of the consequences of both demand- and supply-side policies. Either both accounting systems could be considered separately, or alternatively, they could be averaged. The benefit of a simple average of a country's emissions measured at both the point of extraction and the point of consumption would not suffer from double-counting, nor would it distort relative incentives between supply- and demand-side policies. Although the simple average approach is admittedly imperfect,[17] it would nonetheless reduce that inefficient distortion.

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[16] The use of parallel greenhouse gas (GHG) accounting systems from different perspectives is not new. For example, GHG accounting protocols for estimating indirect emissions from an organization's electricity consumption include both location-based measures of GHG emissions (based on the emissions intensity of the local grid) and market-based measures (based on an organization's green power contracting). Organizations are encouraged to quantify and report both such metrics (US EPA 2020).

[17] This imperfection arises because of incomplete crediting of emissions reductions under the simple average approach. For example, a simple average of demand-side emissions (E_D) and supply-side emissions (E_S) would yield an emissions measure of $(E_D + E_S)/2$. As a result, the marginal credit of 1 ton of reduced emissions is 1/2, regardless of whether that reduction is from reduced demand or from reduced supply. This illustrates that there is no relative distortion across the two policy types, but the credit is only ½ ton, far less than the 1 ton reduced. An accounting metric that reflected the sum of the two emissions measures, $E_D + E_S$, would give full and equal credit but at the cost of double-counting emissions.

3. Conclusion

Critics of supply-side climate policies frequently object that leakage will undermine—or even completely offset—the intended emissions reductions. This criticism is often raised against supply-side policy, but the same scrutiny is not typically applied to demand-side policies. I have argued that both policies lead to conceptually symmetric effects for leakage, and that the two types of policies can be complementary when pursued in tandem.

Beyond mitigating leakage concerns, the complementarities include less disruption in market prices, diplomatic benefits useful in international negotiations, and improved environmental equity. Despite this, most policy approaches typically emphasize demand-side solutions, in part because of policymakers' skewed incentives resulting from the emphasis on demand-side emissions measurements used in current emissions accounting systems, such as those used in countries' nationally determined contributions toward climate change targets. Pairing the existing demand-side accounting approach with a supply-side one would be a step toward reducing the current distorted incentives that favor demand-side policies.

In short, policies that reduce fossil fuel supply and those that reduce fossil fuel demand, when pursued in parallel and with similar ambition, are complementary in their goals of reducing global emissions. Far from being rivals, these two kinds of policies can be partners.

4. References

Bureau of Ocean Energy Management, 2016. OCS Oil and Natural Gas: Potential Lifecycle Greenhouse Gas Emissions and Social Cost of Carbon. U.S. Department of the Interior, Washington, DC. November. **https://www.boem.gov/sites/default/files/oil-and-gas-energy-program/Leasing/Five-YearProgram/2017-2022/OCS-Report-BOEM-2016-065---OCS-Oil-and-Natural-Gas---Potential-Lifecycle-GHG-Emissions-andSocial-Cost-of-Carbon.pdf**.

Erickson, Peter, and Michael Lazarus. 2014. Impact of the Keystone XL Pipeline on Global Oil Markets and Greenhouse Gas Emissions. *Nature Climate Change* 4(9): 778–81.

———. 2018. Would Constraining US Fossil Fuel Production Affect Global CO2 Emissions? A Case Study of US Leasing Policy. *Climatic Change* 150(1): 29–42.

Erickson, Peter, Michael Lazarus, and Georgia Piggot. 2018. Limiting Fossil Fuel Production as the Next Big Step in Climate Policy. *Nature Climate Change* 8(12): 1037–43.

Fæhn, Taran, Cathrine Hagem, Lars Lindholt, Ståle Mæland, and Knut Einar Rosendahl. 2017. Climate Policies in a Fossil Fuel Producing Country—Demand Versus Supply Side Policies. *Energy Journal* 38(1).

Gerarden, Todd D., W. Spencer Reeder, and James H. Stock. 2020. Federal Coal Program Reform, the Clean Power Plan, and the Interaction of Upstream and Downstream Climate Policies. *American Economic Journal: Economic Policy* 12(1): 167–99.

Green, Fergus, and Richard Denniss. 2018. Cutting with Both Arms of the Scissors: The Economic and Political Case for Restrictive Supply-Side Climate Policies. *Climatic Change* 150(1): 73–87.

Harrison, Kathryn. 2015. International Carbon Trade and Domestic Climate Politics. *Global Environmental Politics* 15(3): 27–48.

Harstad, Bård. 2012. Buy Coal! A case for supply-Side Environmental Policy. *Journal of Political Economy* 120(1): 77–115.

International Energy Agency (IEA). 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector. May. **https://www.iea.org/reports/net-zero-by-2050.**

Merrill, Matthew D., Benjamin M. Sleeter, Philip A. Freeman, Jinxun Liu, Peter D. Warwick, and Bradley C. Reed. 2018. Federal Lands Greenhouse Gas Emissions and Sequestration in the United States: Estimates for 2005-14. US Department of the Interior, US Geological Survey, Washington, DC.

Piggot, Georgia, Peter Erickson, Harro van Asselt, and Michael Lazarus. 2018. Swimming Upstream: Addressing Fossil Fuel Supply under the UNFCCC. *Climate Policy* 18(9): 1189–202.

Prest, Brian C. 2022. Supply-Side Reforms to Oil and Gas Production on Federal Lands. *Journal of the Association of Environmental and Resource Economists*.

https://www.journals.uchicago.edu/doi/10.1086/718963. Preprint available at: **https://www.rff.org/publications/working-papers/supply-side-reforms-oil-and-gas-production-federal-lands/.**

Prest, Brian C., and James H. Stock. 2022. Climate Royalty Surcharges. Working Paper. Washington, DC: Resources for the Future. **https://www.rff.org/publications/working-papers/climate-royalty-surcharges/.**

Ratledge, Nathan, Laura Zachary, and Chase Huntley. 2022. Emissions from Fossil Fuels Produced on US Federal Lands and Waters Present Opportunities for Climate Mitigation. *Climatic Change* 171(1): 1–8.

Richards, Heather. 2021. Would Biden’s Oil Freeze Increase Emissions? E&E News, September 16. **https://www.eenews.net/articles/would-bidens-oil-freeze-increase-emissions/**. Sinn, Hans-Werner. 2008. Public Policies against Global Warming: A Supply Side Approach." *International Tax and Public Finance* 15(4): 360–94.

Steininger, Karl W., Christian Lininger, Lukas H. Meyer, Pablo Muñoz, and Thomas Schinko. 2016. Multiple Carbon Accounting to Support Just and Effective Climate Policies. *Nature Climate Change* 6(1): 35–41.

US Environmental Protection Agency (EPA). 2016. OCS Oil and Natural Gas: Potential Lifecycle Greenhouse Gas Emissions and Social Cost of Carbon. Washington, DC. November.

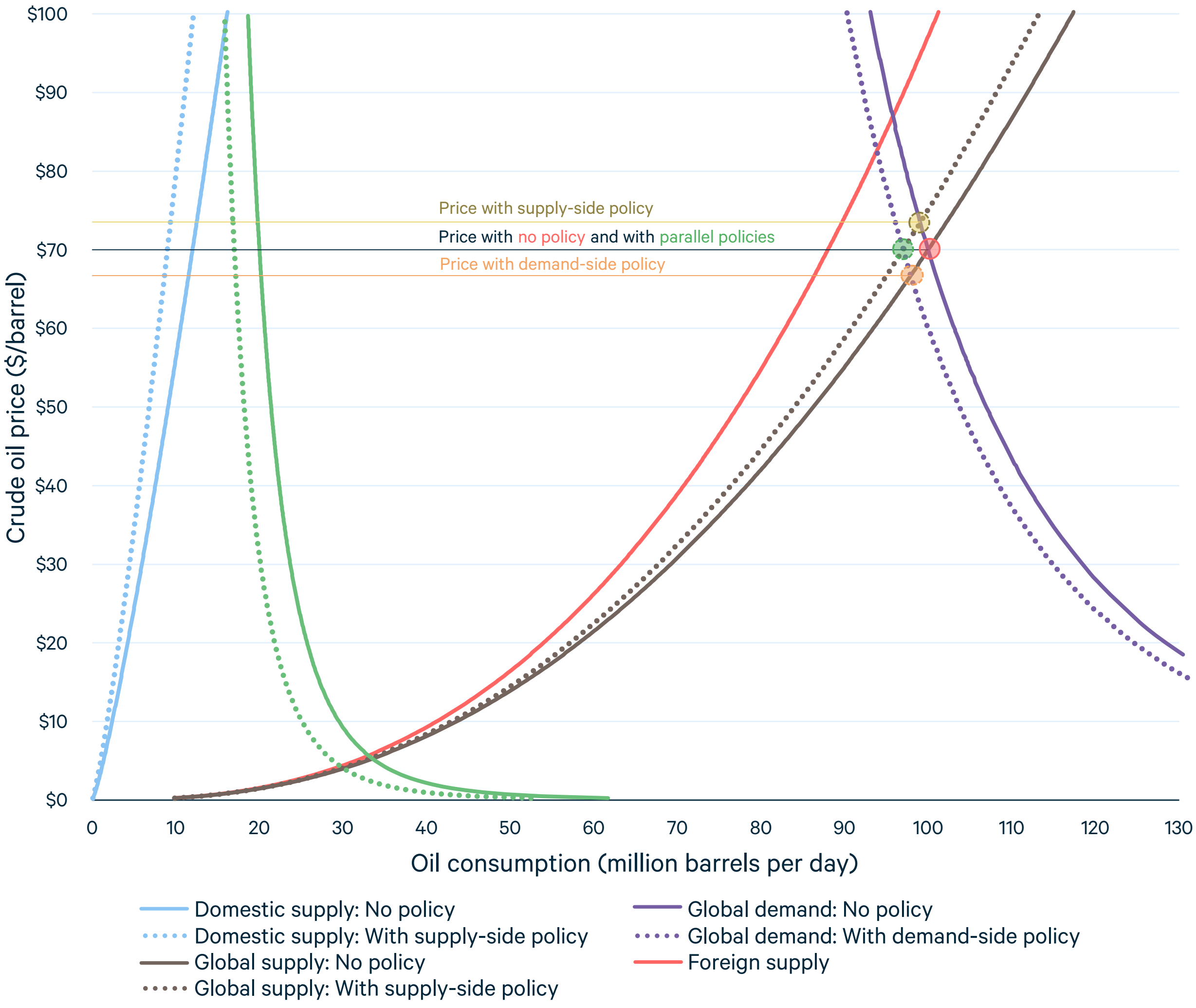
———. 2020. Greenhouse Gas Inventory Guidance: Indirect Emissions from Purchased Electricity. Washington, DC. December.———. 2021. Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards: Regulatory Impact Analysis. Washington, DC. August.

Welsby, Dan, James Price, Steve Pye, and Paul Ekins. 2021. Unextractable Fossil Fuels in a 1.5 C World." *Nature* 597(7875): 230–34.

5. Appendix

Extended Version of Figure 1

Figure A1. Extended Illustrative Impacts of Supply-and Demand-Side Policies, with Domestic Demand and Equilibrium Prices Shown



Theoretical Model

The following is a simple two-region model of supply and demand for an internationally traded commodity, such as oil, that produces life-cycle emissions E. I will focus on the example of oil, but the lessons from the model also hold for other fossil fuels.

The two regions, domestic and foreign, both produce (supply) and consume (demand) the good, denoted q. I denote as $q_{s,d}$ the number of barrels supplied (s) by domestic (d) suppliers, and $q_{s,f}$ for foreign (f) suppliers. Domestic and foreign consumption (c) are denoted as $q_{c,d}$ and $q_{c,f}$ respectively. The good has life-cycle emissions proportional to the amount consumed at a rate denoted e (e.g., measured in tons CO_2e per barrel of oil), so global emissions (in tons CO_2e) are denoted $E = e(q_{c,d} + q_{c,f})$.

Each region has a supply function of the forms:

$$\text{Domestic supply: } q_{s,d} = \gamma_d + s_d(p) \tag{1}$$

$$\text{Foreign supply: } q_{s,f} = \gamma_f + s_f(p) \tag{2}$$

where the γ_d and γ_f terms are supply shifters and the $s_d(p)$ and $s_f(p)$ terms are functions that describe how supply shifts with the price of oil (p). The $s_d(p)$ and $s_f(p)$ functions can be very flexible, indicating that very little structure has been imposed in this model. The only assumptions are that the $s_d(p)$ and $s_f(p)$ functions are differentiable and that they are increasing in price, reflecting upward-sloping supply curves. The supply shifters, γ_d and γ_f, are included as "levers" for us to shift to examine the effects of supply-side policies that exogenously decrease production, but they otherwise start at values of zero.

Each region has a consumption (or demand) function of analogous forms:

$$\text{Domestic consumption: } q_{c,d} = \lambda_d - c_d(p) \tag{3}$$

$$\text{Foreign consumption: } q_{c,f} = \lambda_f - c_f(p) \tag{4}$$

where I use the subscript c for consumption instead of d for demand, to avoid potential confusion with the d subscript for "domestic." The $c_d(p)$ and $c_f(p)$ terms reflect the relationship between consumption and demand. Similar to the supply functions, the $c_d(p)$ and $c_f(p)$ functions are assumed to be differentiable and increasing in price, which when subtracted in the consumption equations imply negative relationships between consumption and price (downward-sloping demand curves). The λ_d and λ_f terms reflect demand shifters (at initial values of zero, analogously to the supply shifters).

Economic equilibrium arises when the market clears, meaning total global production (supply) equals global consumption (demand):

$$q_{s,d} + q_{s,f} = q_{c,d} + q_{c,f} \tag{5}$$

Market clearing and the shape of the supply and demand curves uniquely determine the equilibrium oil price, and regional consumption and production.

Leakage under Supply-Side Policies

I can calculate the leakage rate of supply-side or demand-side policies (or both in tandem) with no further assumptions. To start, let us consider the effect of a domestic supply-side policy that changes the domestic supply shifter γ_d slightly, corresponding with an exogenous increase or decrease in domestic oil production A small increase in supply will decrease global prices somewhat, and we can solve for an equation for the decrease in the oil price—that is, solving for $\frac{dp}{d\gamma_d}$. I start by differentiating both sides of equation (5) with respect to a small change in the supply shifter, γ_d,

$$\frac{d}{d\gamma_d}(q_{s,d} + q_{s,f}) = \frac{d}{d\gamma_d}\left(q_{c,d} + q_{c,f}\right)$$

$$\left(1 + \frac{\partial s_d}{\partial p}\frac{dp}{d\gamma_d}\right) + \frac{\partial s_f}{\partial p}\frac{dp}{d\gamma_d} = -\frac{\partial c_d}{\partial p}\frac{dp}{d\gamma_d} - \frac{\partial c_f}{\partial p}\frac{dp}{d\gamma_d} \tag{6}$$

From here it is straightforward to solve for the change in equilibrium prices, which depends on the slopes of the supply and demand curves:

$$\frac{dp}{d\gamma_d} = \frac{-1}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}} < 0 \tag{7}$$

$\frac{dp}{d\gamma_d}$ is the change in the price of oil from a 1-unit increase in increase in domestic supply. Naturally, the expression is negative: more supply reduces prices. Mathematically, this can be seen because the numerator on the right-hand side is negative, and its denominator contains only positive terms (recall that the supply curves slope upward and the demand slopes are represented in absolute value). This reflects the effect of a 1-unit increase in domestic supply; the result for a 1-unit decrease in supply would simply reverse the sign. In terms of magnitude, larger slopes of supply or demand in the denominator mitigate the price effect, as more of the effect of changed domestic supply is absorbed by additional consumption or reduced production elsewhere.

I can use this expression to easily find expressions for the effects on regional production and consumption. For example, the change in foreign production is

$$\frac{dq_{s,f}}{d\gamma_d} = \frac{\partial s_f}{\partial p}\frac{dp}{d\gamma_d} = \frac{-\frac{\partial s_f}{\partial p}}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}} < 0,$$

which simply reflects the price effects mediated by the slope of the foreign supply curve. The other effects are analogous and are shown in Table A1.

Table A1. Effects of 1-Unit Increase in Domestic Supply on Regional Production and Consumption (in Barrels)

	Production	Consumption
Domestic	$1-\frac{\frac{\partial s_d}{\partial p}}{\frac{\partial s_d}{\partial p}+\frac{\partial s_f}{\partial p}+\frac{\partial c_d}{\partial p}+\frac{\partial c_f}{\partial p}}\ (+)$	$\frac{\frac{\partial c_d}{\partial p}}{\frac{\partial s_d}{\partial p}+\frac{\partial s_f}{\partial p}+\frac{\partial c_d}{\partial p}+\frac{\partial c_f}{\partial p}}\ (+)$
Foreign	$\frac{-\frac{\partial s_f}{\partial p}}{\frac{\partial s_d}{\partial p}+\frac{\partial s_f}{\partial p}+\frac{\partial c_d}{\partial p}+\frac{\partial c_f}{\partial p}}\ (-)$	$\frac{\frac{\partial c_f}{\partial p}}{\frac{\partial s_d}{\partial p}+\frac{\partial s_f}{\partial p}+\frac{\partial c_d}{\partial p}+\frac{\partial c_f}{\partial p}}\ (+)$
Total	$\boldsymbol{\frac{\frac{\partial c_d}{\partial p}+\frac{\partial c_f}{\partial p}}{\frac{\partial s_d}{\partial p}+\frac{\partial s_f}{\partial p}+\frac{\partial c_d}{\partial p}+\frac{\partial c_f}{\partial p}}}\ (+)$	

The effect on total global oil consumption is given in the last row of the table. Although the expressions in the table relate to slopes of supply and demand curves in terms of *barrels per dollar* (e.g., change in production per dollar change in price), it is often more intuitive to think in percentage terms—that is, in terms of supply and demand *elasticities*. A close relationship exists between slopes and elasticities based on the very definition of elasticities. For example, in this context, the domestic supply elasticity is defined as $\varepsilon_{c,d} = \frac{\partial s_d}{\partial p}\frac{p}{s_d}$. The other supply and demand elasticities are defined similarly. This close relationship allows us to convert the expression in the final row of Table A1 into one based on elasticities. That final row, representing the global change in oil consumption from a 1-unit change in domestic supply, can be written more simply in terms of elasticities as

$$\frac{dq_c}{d\gamma_d} = \frac{\bar{\varepsilon}_c}{\bar{\varepsilon}_s + \bar{\varepsilon}_c},$$

where $\bar{\varepsilon}_c$ is the global, consumption-weighted average of regional demand elasticities (in absolute value), and $\bar{\varepsilon}_s$ is the global, production-weighted average of the regional supply elasticities. In fact, this result holds for any number of regions, not just the special case of two regions in this simple model. In other words, for a 1-barrel increase in domestic supply, global oil consumption increases by $\frac{\bar{\varepsilon}_c}{\bar{\varepsilon}_s+\bar{\varepsilon}_c}$. By the same logic, a 1-barrel *decrease* in domestic supply *reduces* global oil consumption by $\frac{\bar{\varepsilon}_c}{\bar{\varepsilon}_s+\bar{\varepsilon}_c}$ barrels. The difference between that full barrel and the net effect represents the leakage rate. In other words, supply-side policies, undertaken alone, have a leakage rate of

$$L_S = 1 - \frac{\bar{\varepsilon}_C}{\bar{\varepsilon}_S + \bar{\varepsilon}_C} = \frac{\bar{\varepsilon}_S}{\bar{\varepsilon}_S + \bar{\varepsilon}_C}.$$

Leakage under Demand-side Policies

It is straightforward to show that demand-side policies also generate leakage. The algebraic manipulations are analogous to the exposition above, except I consider the effect of a small change in the domestic demand shifter, λ_d, instead of the supply shifter, γ_d. The effect of a 1-unit increase in demand on oil prices is simply the same expression as equation (7) but with the opposite sign:

$$\frac{dp}{d\lambda_d} = \frac{1}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}} > 0$$

This leads to the pattern of regional production and consumption shown in Table A2, where domestic consumption rises but foreign consumption declines.

Table A2. Effects of 1-Unit Increase in Domestic Demand on Regional Production and Consumption (in Barrels)

	Production	Consumption
Domestic	$\frac{\frac{\partial s_d}{\partial p}}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}}\,(+)$	$1 - \frac{\frac{\partial c_d}{\partial p}}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}}\,(+)$
Foreign	$\frac{\frac{\partial s_f}{\partial p}}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}}\,(+)$	$\frac{-\frac{\partial c_f}{\partial p}}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}}\,(-)$
Total	$\boldsymbol{\frac{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p}}{\frac{\partial s_d}{\partial p} + \frac{\partial s_f}{\partial p} + \frac{\partial c_d}{\partial p} + \frac{\partial c_f}{\partial p}}}\,(+)$	

As in the supply-side policy case, one can rewrite the leakage rate of demand-side policies as

$$L_D = \frac{\bar{\varepsilon}_C}{\bar{\varepsilon}_S + \bar{\varepsilon}_C}.$$

Each barrel of reduced demand reduces global consumption by only $\frac{\bar{\varepsilon}_S}{\bar{\varepsilon}_S + \bar{\varepsilon}_C} < 1$ barrel. In a symmetric manner to the result with supply-side policies, the rest is lost to leakage, since reduced oil prices make it cheaper for other countries to consume oil. This symmetric result demonstrates that there is no fundamental difference between the two policies regarding leakage—only the mechanism varies.

The relative magnitudes could differ, however. Comparing the expression for leakage under supply-side policies, $L_S = \frac{\bar{\varepsilon}_S}{\bar{\varepsilon}_S+\bar{\varepsilon}_C}$, with that for leakage under demand-side policies, $L_D = \frac{\bar{\varepsilon}_C}{\bar{\varepsilon}_S+\bar{\varepsilon}_C}$, shows that there is a simple comparative relationship. Supply-side policies feature less leakage when supply is less elastic than demand ($\bar{\varepsilon}_S$ smaller than $\bar{\varepsilon}_C$). Intuitively, if reduced domestic supply is not easily offset by other suppliers, then the net effect is primarily to reduce consumption rather than increase production elsewhere. Alternatively, if demand is relatively inelastic, then reducing domestic demand doesn't simply free up fossil fuels to be consumed by other countries—the demand-side policy form of leakage. Although both policies feature leakage, the mechanisms are actually opposite: supply-side policies increase energy prices, inducing more production, whereas demand-side policies decrease energy prices, inducing more consumption. This suggests that mitigating leakage could be as simple as pursuing both policies, which can minimize the effects on energy prices and hence leakage.

Leakage under Both Supply- and Demand-Side Policies

The previous discussion suggests an alternative approach to combating leakage. Instead of choosing either supply-side or demand-side policy, policymakers could instead pursue both simultaneously. Suppose we pair a supply-side policy with a demand-side policy that is α percent as ambitious. Or, alternatively, we pair a demand-side policy with a supply-side one that is β percent as ambitious. The resulting expressions for leakage are shown in the second column of Table A3. The third column shows illustrative leakage rates in the case where supply and demand are equally elastic. In this case, when only one type of policy is deployed, leakage is 50 percent, but it is much lower when both policies are deployed in tandem. Even when merely modest supply-side policies (50 percent as ambitious) accompany demand-side policy, the leakage rate is cut in half, to 25 percent. Leakage is eliminated when $\alpha = 100 \text{ percent}$ or $\beta = 100 \text{ percent}$—that is, when both types of policies are deployed with equal levels of ambition. The intuition for this result is that if there is undue weight placed on one policy, its mechanism for leakage dominates. If too much emphasis is placed on a demand-side policy, oil prices are depressed, encouraging oil use outside the regulated region. If too much emphasis is placed on a supply-side policy, oil prices rise, encouraging additional production outside the regulated region. By balancing policy approaches, leakage can be eliminated.

Table A3. Leakage under Alternative Policy Emphasis on Supply- and Demand-Side Policies

Scenario	Leakage	Illustrative Value (assuming $\bar{\varepsilon}_S = \bar{\varepsilon}_C$)
Only supply-side policy (L_S)	$\frac{\bar{\varepsilon}_S}{\bar{\varepsilon}_S + \bar{\varepsilon}_C}$	50%
Only demand-side policy (L_D)	$\frac{\bar{\varepsilon}_C}{\bar{\varepsilon}_S + \bar{\varepsilon}_C}$	50%
Both policies, unequal ambition ($L_{S+\alpha D}$) (supply-side policy paired with α% as ambitious demand-side policy)	$\frac{\bar{\varepsilon}_S}{\bar{\varepsilon}_S + \bar{\varepsilon}_C}(1-\alpha)$	25%
Both policies, unequal ambition ($L_{\beta S+D}$) (demand-side policy paired with β% as ambitious supply-side policy)	$\frac{\bar{\varepsilon}_C}{\bar{\varepsilon}_S + \bar{\varepsilon}_C}(1-\beta)$	25%
Both, equal ambition (L_{S+D}) ($\alpha = 100\%$ or $\beta = 100\%$)	0	0%

Note: The illustrative values in the third column assume elasticities of equal magnitude ($\bar{\varepsilon}_S = \bar{\varepsilon}_C$) and 50% as ambitious as the accompanying policy ($\alpha = 50\%, \beta = 50\%$).

Although elasticities determine the degree of leakage from policies that shift supply or demand, those elasticities are not immutable constants but can themselves be driven by policy in the long run. For example, if a supply-side policy not only shifted the supply curve but also reduced its elasticity (smaller $\bar{\varepsilon}_S$), the leakage rate in the first row of Table 3 would decline.

Extension to Two Fuels and N Regions

The model can be extended to multiple fuels (oil and gas) and an arbitrary number of regions ($i = 1, \dots, N$). Compared with the single-fuel case, I now need more notation to account for additional effects that arise in the case of multiple fuels. Previously, I assumed that a 1-unit reduction of oil demand is accompanied by an α-unit reduction in oil supply. Analogously, I assume that a 1-unit change in domestic demand for oil is accompanied by a change in gas demand of θ^{gas} and changes in oil and gas supply of β^{oil} and β^{gas}. In this case, the effect of a 1-unit change in oil demand (accompanied by the other effects) on final consumption of both goods can be written as

$$\begin{bmatrix} Global\ Change\ in\ Oil\ Consumption \\ Global\ Change\ in\ Gas\ Consumption \end{bmatrix} = \begin{bmatrix} 1 \\ \theta^{gas} \end{bmatrix} - \mathbb{E}^c(\mathbb{E}^c + \mathbb{E}^s)^{-1} \begin{bmatrix} 1 - \beta^{oil} \\ \theta^{gas} - \beta^{gas} \end{bmatrix}$$

where $\mathbb{E}^c$ and $\mathbb{E}^s$ are the Jacobian matrices of the demand and supply curves, respectively, representing how oil and gas demand and supply respond to oil and gas prices.[18] This more general result nests the single fuel model above; in the special case of no cross-price effects (e.g., oil supply and demand are not affected by gas prices), the diagonal elements of $\mathbb{E}^c$ are equal to their pointwise inverse, and the remaining terms are zero, in which case the top-left element of $(\mathbb{E}^c + \mathbb{E}^s)^{-1}$ has the same form as equation (7).

The $\mathbb{E}^c(\mathbb{E}^c + \mathbb{E}^s)^{-1}$ term plays a similar role as the ratio of elasticities $\frac{\bar{\varepsilon}_c}{\bar{\varepsilon}_c + \bar{\varepsilon}_s}$ plays in Table A4, row 4. If demand is perfectly inelastic, $\mathbb{E}^c = \mathbf{0_{2x2}}$, then the second term vanishes and consumption changes by the same amount as the demand-side policies shift oil and gas demand (1 and θ^{gas}). Similarly, if supply is perfectly elastic, $\mathbb{E}^s = 0$, then $\mathbb{E}^c(\mathbb{E}^c + \mathbb{E}^s)^{-1} = \mathbf{I_{2x2}}$ and the change in consumption reflects the full amount of the direct effects of the supply side policy (β^{oil} and β^{gas}). Further, if global supply and demand have the same elasticities, $\mathbb{E}^c = \mathbb{E}^s$ and $\mathbb{E}^c(\mathbb{E}^c + \mathbb{E}^s)^{-1} = \frac{1}{2}\mathbf{I_{2x2}}$ and the change in oil and gas consumption is only half as large of the direct effects ($0.5 + 0.5\beta^{oil}$ and $0.5\theta^{gas} + 0.5\beta^{gas}$). Finally, with all policies applied in equal ambition ($\beta^{oil} = \theta^{gas} = \beta^{gas} = 1$), the last vector in that equation is zero and the full force of the direct supply- and demand-side reductions is felt globally.

Assumptions for Application of Theoretical Model in Figure 1

Table A4 shows the input parameters underlying the simple static model depicted in Figure 1. These parameters are baseline production and consumption levels reflecting the current state of the oil market and supply and demand elasticities. The input parameters correspond approximately to those in Prest (2022), except for the assumed direct effects of the stylized supply- and demand-side policies, chosen to improve clarity of exposition. The demand elasticity represents the base (conservative) elasticity considered in Prest (2022). The supply elasticities correspond to the responsiveness of domestic and foreign production to a simulated exogenous 1 percent increase in oil prices, on average over the full model horizon (2020-2050).

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[18] Namely, the (j, k) element of $\mathbb{E}^c$ is $\sum_{i=1}^{N} \frac{\partial c_i^j}{dp^k}$ for $j, k \in \{oil, gas\}$, and the analogous element of $\mathbb{E}^s$ is $\sum_{i=1}^{N} \frac{\partial s_i^j}{dp^k}$.

Table A4. Baseline Input Assumptions to Model in Figure 1

Variable	Domestic	Foreign	Global
Baseline oil price ($/barrel)	$70	$70	$70
Baseline oil production (mb/d)	12	88	100
Baseline oil consumption (mb/d)	20	80	100
Demand elasticity ($-\bar{\varepsilon}_c$)	-0.2	-0.2	-0.2
Supply elasticity ($\bar{\varepsilon}_s$)	0.83	0.39	0.44
Direct effect of supply-side policy (mb/d)	-3	0	
Direct effect of demand-side policy (mb/d)	-3	0	

Notes: The oil price is the same across countries. Global consumption and production values represent the sum of domestic and foreign. Global supply and demand elasticities represent production-weighted and consumption-weighted averages of domestic and foreign values, respectively.