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The fuel security and climate policy nexus*

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Abstract

Swedish transportation has a high reliance on biofuels, accounting for approximately 20% of total energy demand in 2019 for transportation, excluding electricity. This makes Sweden an exceptional opportunity to study the interaction between climate policy and fuel security objectives in a small open economy with no domestic oil production. Despite this high reliance, we estimate Sweden's fuel security premium to be upwards of 0.065 EUR per liter diesel equivalence (or 12.6 USD/barrel) of imported oil, which is comparable although lower than similar estimates for the USA. We then discuss fuel security policy related to specific fuels including HVO/FAME, biomethane, and electricity. We conclude that electricity, and to some extent biomethane, are the most promising in terms of their potential to support fuel security objectives and reduce greenhouse gas emission.

Keywords: Fuel security premium, renewable fuel, climate policy, biofuels, electricity

JEL: Q42 - Alternative Energy Sources; Q43 - Energy and the Macroeconomy; Q58 - Environmental Economics: Government Policy.

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1 Introduction

Shortages in fuel supply cause economic losses that go beyond the direct impacts of the market price of fuels. These losses are external to the price of fuel (Brown, 2018). It is an externality in that the consumption of an additional unit of fuel imposes costs on others that are not taken into account by those consuming the marginal unit of fuel. Countries would be willing to pay a premium to better secure their fuel supply and minimize these losses. The fuel security premium is an attempt to quantify this externality at the national level.

At the same time, many economies are shifting transportation away from fossil fuels to fuels that are potentially less carbon intensive such as biofuels and electricity, which we refer to as *alternative fuels* (hereinafter AFs). An important motivation for these efforts is of course related to climate policy objectives. However, some suggest that AFs can help countries achieve energy security objectives as well. The reasoning is intuitive: shifting towards AFs could help countries reduce their dependence on fossil fuel imports. To varying degrees, AFs can be produced locally. This means they can provide an opportunity for some countries to diversify their fuel portfolio, which would support both climate protection and energy security objectives. The fuel security premium and the social cost of carbon could complement each other, strengthening the rationale for policy support for the transition from fossil fuel.

This is not a new idea but the volatility of global oil markets over the last few years arising from the COVID-19 pandemic, Russia's invasion of Ukraine, and increasing tensions in the Middle East, have helped renew interest in the issue. Increasingly reports on climate change have spurred interest further.

Sweden is an exceptional opportunity to study the interplay of fuel security and climate change objectives. In Sweden, AFs are already an important source of energy for the transportation sector. In 2019, Sweden had Europe's largest share of AFs in the transport sector, increasing by around 300% from 2010 to roughly 20% of total transport fuel demand on an energy basis (Mossberg et al., 2021; Lundberg et al., 2023). The increase in demand for AFs was largely driven by Sweden's blending mandate policies.

In this paper, we focus on the role that increasing AF use can play in terms of reducing the macroeconomic losses associated with global oil supply shocks. We first estimate Sweden's fuel security premium using monthly GDP and oil market data from 2010.01–2023.04, following the methodologies outlined by (Kilian, 2009) and (Brown, 2018). We then discuss extent to which AFs have had an impact on Sweden's fuel security premium, focusing on the role played by biodiesels, electricity in transport, and biomethane, which together accounted for almost all of the AFs consumed by Sweden's transport sector in the years leading up to 2023. Despite Sweden's AF use, it is (*ex ante* our analysis) unclear how Sweden's fuel security premium would compare to other economies such as the USA. There are convincing arguments that can be made for a higher or lower (or no) Swedish fuel security premium.

One view is that that domestic fuel supplies have limited scope to reduce the impact of fuel price shocks unless they can be produced in sufficient quantities to affect global fuel market outcomes (Nordhaus, 2009). Sweden's economy, and production and consumption of fuels, is small enough to ensure that there little scope to impact global fuel markets. Higher fuel prices abroad would be a powerful incentive to Swedish producers to export their fuel, which would mean the Swedish fuel price is determined abroad irrespective of the level of domestic fuel production volumes. In this world of perfectly competitive, friction-free fuel trade, domestic policy is unable to impact domestic fuel markets, and boosting domestic production of AFs would provide little benefit in terms of avoiding Swedish GDP losses from global fuel supply shocks.

However, there is convincing evidence suggesting small economies (such as Sweden) may be able to affect domestic fuel markets with domestic policy. For example, (Balmaceda and Soruco, 2008) investigate oligopoly power in fuel markets and show how prices adjust more slowly with increasing market power. Similar results are reported in recent work, e.g. (Byrne, 2019) and (Tsvetanov and Slaria, 2021). Moreover, AFs have supply chain, distribution, and technical characteristics that make them distinct from petroleum based fuels. Electricity for example is gaining ground as a transportation energy source and electricity distribution has characteristics of its own (which we discuss below). The degree to which various AFs can be a substitute for petroleum based fuels, and the face that fuel market frictions would appear to matter suggest the Nordhaus view of fuel security may not hold always hold with respect to some AFs.

Our paper's contribution lies at the nexus of fuel security and climate policy. To the best of our knowledge, our analysis is the first to bring empirical estimates of the impact of oil market shocks to a small open economy with a relatively high share of renewable fuel use. Unlike our paper, much of the related work approaches this topic theoretically and/or qualitatively, such as the earlier work by (Vedenov and Wetzstein, 2008) and (Chevalier et al., 2006), and more recent work by (Chiaramonti and Maniatis, 2020) and (Hache, 2018).

In other related work, (Awerbuch and Sauter, 2006) provide an early estimate of the

GDP losses that could be avoided by increasing the share of renewable energy in the US, the EU and other OECD countries. (Gunatilake et al., 2014) report estimates from a computable general equilibrium analysis of the potential benefits to the Indian economy from increasing the share of biofuels. (Su et al., 2021) studies the interplay between geopolitical risk and the shift towards renewable fuel supply chains.

Our paper also makes a technical contribution by obtaining estimated GDP responses to oil supply shocks using monthly GDP time series for Sweden and the U.S. recently provided by the OECD (Woloszko, 2020). We thereby avoid aggregating GDP and oil market time series to quarterly observations, which is the approach taken in the literature (see e.g. Kilian and Murphy, 2012, 2014; Baumeister and Hamilton, 2019; Lippi and Nobili, 2012; Baumeister and Peersman, 2013). With monthly GDP data, our analysis captures shorter-run GDP responses that are missed by estimates based on quarterly time-series data.[1]

In the next section, we describe the methodology used to estimate the fuel security premium. Section 3 reports the results of SVAR analysis and fuel security premium computations. In Section 4 we discuss the promise and pitfalls associated with each AF type for supporting fuel security objectives in a small, open economy. Section5 provides policy recommendations and Section 6 concludes.

2 Methodology and data

The analysis was performed in two steps. The first step was to obtain an estimate for the response of Swedish GDP to fuel supply shocks. The second step used this estimate to compute the GDP losses of oil supply shocks and the associated fuel security premium.

(Kilian, 2009) decomposes the real price of crude oil into three components: crude oil supply shocks; global demand shocks; and demand shocks specific to crude oil market. This method was used to estimate a Structural Vector Auto-regressive (SVAR) model of the global oil market based on the vector of t monthly observations $z_t = (\Delta prod_t, rea_t, rpo_t)'$. $\Delta prod_t$ is the change in global fuel production, rea_t is an index capturing monthly global GDP growth computed by (Kilian, 2009), and rpo_t is the real price of oil.

For comparability, variables were transformed and deflated from the same sources used by (Kilian, 2009), with $\Delta prod_t$ expressed in terms of the percentage change in

[1] For insights on the methodologies used to estimate the macroeconomic impacts of fuel shocks see the review by (Kilian, 2022).

global crude oil production, and rea_t and rpo_t expressed in logs. The analysis is based on monthly data covering the period from 2010.1–2023.4. rea_t and rpo_t are obtained from US Federal Reserve System, and $\Delta prod_t$ is obtained from the International Energy Agency. The SVAR representation is

$$A_o z_t = \alpha + \sum_{i=1}^{L} A_i Z_{t-i} + \epsilon_t \tag{1}$$

ϵ_t is a vector of residuals that capture the serially and mutually uncorrelated structural oil price and oil production shocks. These are unexpected shocks to the global oil market, which are used to calculate the elasticity of Swedish GDP to fuel supply shocks (which is done in the next step). The number of lags L was determined using standard information criteria. (Kilian, 2009) includes $L = 24$ lags in the regression but the lag length is not discussed in the paper. The shorter time-series used in this paper requires a more parsimonious specification, although the sensitivity of the findings was considered by varying L. A_o^{-1} has a recursive structure, which means the errors decomposed to $e_t = A_o^{-1}\epsilon_t$

$$e_t \equiv \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \epsilon_t^{Q_{oil}} \\ \epsilon_t^{Y} \\ \epsilon_t^{P_{oil}} \end{pmatrix} \tag{2}$$

As (Kilian, 2009) points out, a key assumption for identification is that the short-run supply curve of fuel is vertical. This is motivated by assuming that quantity of global fuel supply cannot respond to fuel demand within the same month because of it takes time to adjust oil production and because of the difficulty in obtaining information about the state of the fuel market within the same month. Likewise, rea_t does not depend on rpo_t. The exclusion restriction is that variation in rpo_t will not immediately affect global economic activity, but will with a delay of at least a month. These assumptions suggest the triangular structure of A_o^{-1}.

The structural shocks are projected on time-series GDP. In the existing literature, a challenge is that national GDP statistics are reported at quarterly intervals, whereas the model and its assumptions are based on monthly time series. The solution employed by (Kilian, 2009) and others has been to aggregate the structural shocks obtained from the

SVAR to the quarterly level.[2]

In this study, monthly GDP estimates derived by (Woloszko, 2020) was instead used, which uses a novel methodology to track GDP using inputs from Google Trends to capture within quarter variations in GDP. Therefore, it was possible to project the monthly structural shocks directly on *monthly* GDP observations for Sweden. In this way, the need for aggregation to the quarterly-level was bypassed and more granular GDP response estimates were obtained.

Monthly oil supply shocks $\hat{\varepsilon}_t^Q$ were projected on month-to-month growth rates of Swedish GDP Δy_t and real oil price Δop_t according to

$$\Delta y_t = \alpha_1 + \sum_{j=0}^{M} \beta_{1,j} \hat{\varepsilon}_{t-j}^Q + \eta_{1,t} \tag{3}$$

$$\Delta op_t = \alpha_2 + \sum_{j=0}^{M} \beta_{2,j} \hat{\varepsilon}_{t-j}^Q + \eta_{2,t} \tag{4}$$

These were estimated with OLS, and $\beta_{.,j}$'s captured the impulse response coefficients of Swedish GDP and real price of oil to structural supply shocks. The impact of the structural shocks on Swedish GDP were computed with

$$\Phi_t(h) = \frac{\sum_{k=0}^{h} \frac{\partial \Delta y_{t+k}}{\partial \hat{\varepsilon}_t}}{\sum_{k=0}^{h} \frac{\partial \Delta op_{t+k}}{\partial \hat{\varepsilon}_t}} \tag{5}$$

In the final step of the analysis, the methodologies of (Brown and Huntington, 2015) and (Brown, 2018) were adopted to compute Sweden's fuel security premium. Relative to the USA, Sweden is a small economy with little domestic fuel production capacity. This simplifies the computations considerably, as the equivalent computations for the U.S. need to account for the impact of domestic US fuel production on global fuel markets.

Note that the effect of COVID-19 figures prominently in all three time series variables. These shocks were first driven by the collapse in demand for fuel as responses to the pandemic took hold, restricting mobility and thereby demand for fuel. Fuel prices dropped and oil producers responded by cutting oil production, which resulted in fuel prices rebounding. Table 1 summarizes the shape of the key variables.

[2] See also (Kilian and Murphy, 2012), (Kilian and Murphy, 2014), (Baumeister and Hamilton, 2019), and (Lippi and Nobili, 2012).

Table 1: Summary statistics for monthly data used in the analysis from 2010.1 – 2023.4.

Variable	Mean	Std. Dev.	Min.	Max.	N
$\Delta prod_t$	0.007412	0.0176107	-0.0265139	0.0582688	119
rea_t	0.0236807	0.0122435	-0.0011428	0.0613667	119
rpo_t	0.000787	0.077372	-0.2177068	0.2384565	119

3 Analysis Results

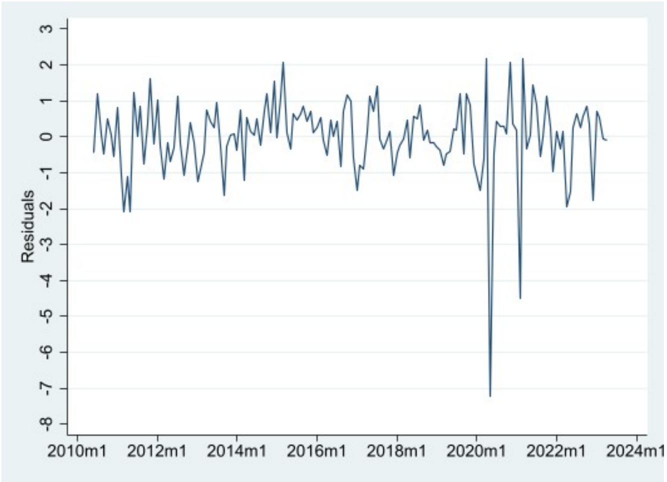
3.1 Estimating the elasticity of Swedish GDP to a fuel supply shock

The historical evolution of the structural shocks from the SVAR model ϵ_t were obtained from Equation 1 We plot the historical evolution of these shocks in Figure 1.[3]

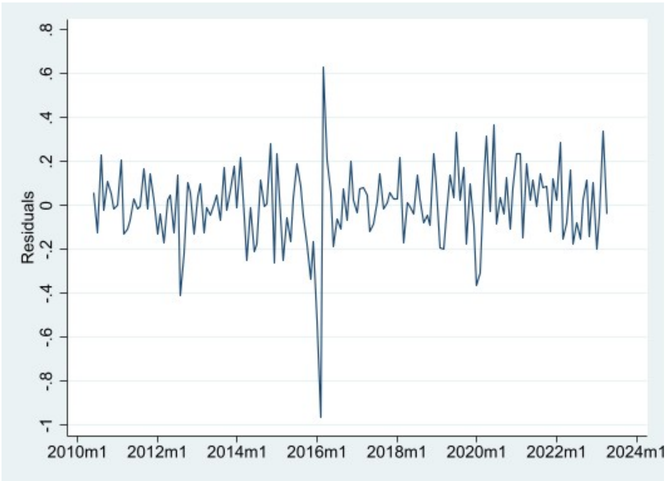
Figure 1a and 1c illustrate the evolution of global oil production and price as they respond to unexpected shocks. The COVID-19 pandemic shows up as a significant negative (positive) shock to oil supply (price), eclipsing even Russia's February 2022 invasion of Ukraine. OPEC's 2016 cutback on oil production also shows up as a positive oil-specific demand shock. The economic turmoil of 2015-2016 shows up as a large negative shock in Figure 1b.

We projected the residuals reported in Figure 1a on a monthly time-series of Swedish GDP. We also projected on a monthly time-series of U.S. GDP to provide a reference point, and to compare with the results reported by (Kilian, 2009) and (Herrera and Rangaraju, 2020). Figure 2 reports the estimated $\beta_{\cdot,j}$'s obtained from estimating Equations 3 and 4.

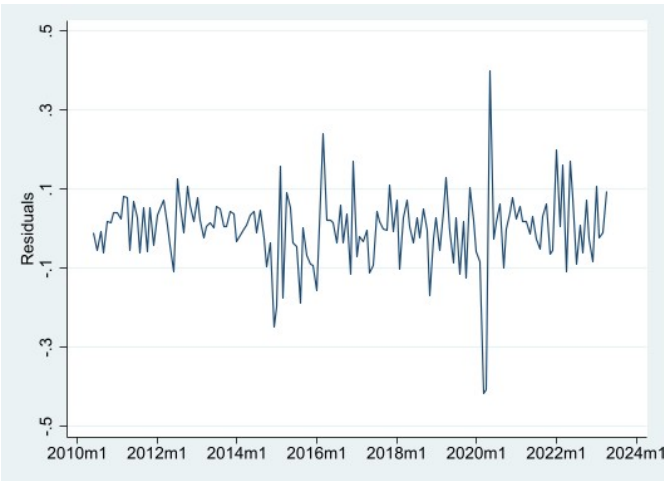
[3]The impulse-response functions obtained from the SVAR model in Equation 1 were comparable to those reported by (Kilian, 2009), and they should be as they were obtained using the same method applied to data from the same sources. A difference were that the estimates were based on the period 2010.10–2023.04 versus the 1973.1–2006.10 period covered by Kilian.



(a) Oil supply shock

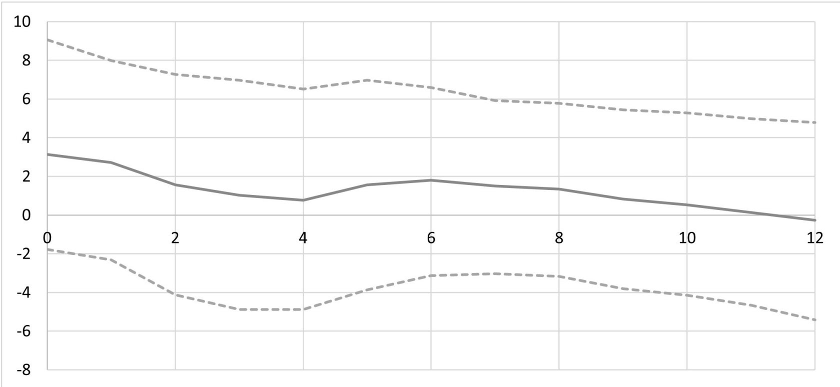


(b) Aggregate demand shock

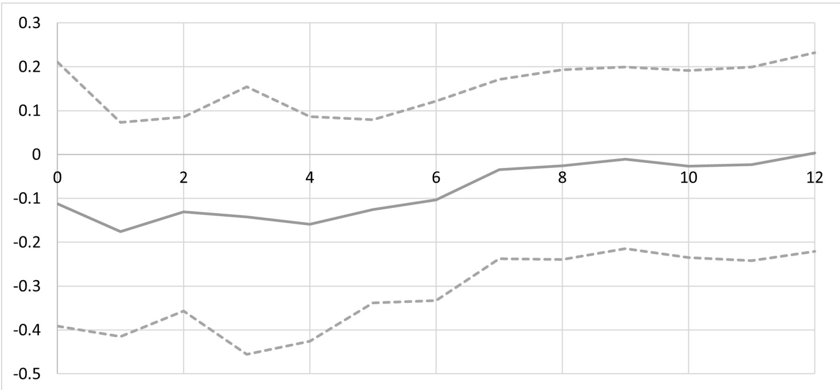


(c) Oil-specific demand shock

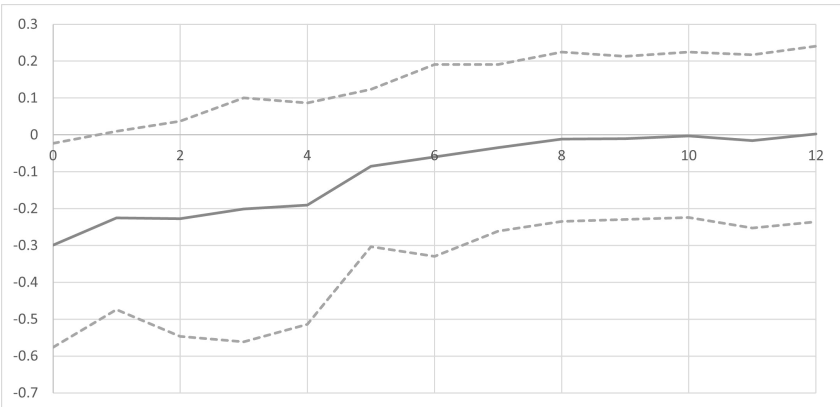
Figure 1: The historical evolution of structural shocks 2010-2023



(a) Real price of oil



(b) Real Swedish GDP



(c) Real U.S. GDP

Figure 2: The monthly response in percent of the Real Price of Oil, and Swedish GDP, and U.S. GDP to an unexpected 1% decline in world oil supply obtained from Equations 3 and 4, for 2010.01-2023.04. The dotted lines are the 90% error bands constructed using a block bootstrap with block size 6 and 10000 bootstrap replications.

Together, Figures 2b and 2c suggests that Swedish and U.S. GDP both fall in response to a 1% unexpected decline in world oil supply and that the U.S. response is larger in the short-run. The figures also suggest that both economies revert to pre-shock levels after around 6 months. The short-run impact on U.S. GDP is around .33 %in the same month of the oil supply shock, and around 0.11 in the same month for Sweden. None of the estimated $\beta_{1,j}$'s estimated from Equation 3 are statistically significant from zero at the 10% level. The difference between the estimated $\beta_{1,j}$'s for Sweden and the USA are not estimated with enough precision to be significantly different from one another.

Figure 2a reports the response of the global price of oil to a 1% unexpected decline in world oil supply. The short-run impact of the 1% decline in oil supply increases global oil price with 3.42% in the same month of the shock, with the impact reverting to zero within 6 months.[4]

We computed the dynamic multiplier defined in Equation 5 using the estimated betas reported in Figure 2 at $h = 1$ and $h = 12$ months, and report these key estimates in Table 2.

Table 2: Summary of monthly estimates to a decline in world oil supply

Parameters	**Coefficient**	**90% Confidence Interval**
Impact response Real GDP in percent: $\beta_{1,j}$		
Sweden - 1 month after shock	-0.176	(-0.454,-0.280)
Sweden - 12 months after shock	0.003	(-0.237, 0.234)
U.S. - 1 month after shock	-0.225	(-0.641,-0.105)
U.S. - 12 months after shock	0.002	(-0.247, 0.245)
Dynamic multiplier: $\Phi_t(h)$		
Sweden $h = 0$	-0.036	
Sweden $h = 6$	-0.075	
Sweden $h = 12$	-0.065	
U.S. $h = 0$	-0.095	
U.S. $h = 6$	-0.090	
U.S. $h = 12$	-0.081	

Note: $\beta_{1,j}$ obtained from Equation 3 and $\Phi_t(h)$ computed with Eq. 5.

The dynamic multiplier for Sweden is -0.036, -0.075 and -0.065 at $h = 0$, $h = 6$ and

[4] The patterns reported in Figures 2c and 2a are qualitatively similar to those reported by (Herrera and Rangaraju, 2020), although their results are based on quarterly time-series over the period 1973.1 to 2016.12.

$h = 12$, respectively. As a reference, we estimated the dynamic multiplier for the U.S. at -0.095, -0.090 and -0.081 at $h = 0$, $h = 6$ and $h = 12$, respectively. Taken at face value, these estimates suggest that Swedish GDP is less sensitive to global oil supply shocks than U.S. GDP in the short run.[5]

For comparison, Herrera and Rangaraju (2020) use the same method to estimate the dynamic multipliers for the U.S. for quarterly GDP data over the period 1973.1–2016.12 at -0.098 and -0.023 for zero quarters and 4 quarters after the shock, respectively. These estimates are lower than the estimates we report using more recent monthly GDP data but the U.S. impact at a one year horizon lies within the range of other estimates reported in the literature, which are between -0.012 and -0.12 (Jones et al., 2004), and is close albeit slightly higher than the level used by the U.S. Department of Energy, which is between -0.025 and -0.055. (Brown, 2018) discuss the fact that more recent estimates are smaller because of improved monetary policy responses, an economy that is better at adjusting to fuel supply disruptions, improved modelling methods and/or a lack of a major oil supply disruption. On this last point, it is worth noting that our period of analysis, while shorter, includes the COVID-19 pandemic, Russia's invasion of Ukraine and the 2015-2016 global recession, which disrupted oil supply. Moreover, (Oladosu et al., 2018) review a wide variety estimates and point out that much of the variability in the estimates is indeed due to differences in empirical methodology.

Interestingly, our estimates reported in Figures 2a, 2b, and 2c suggest that the oil supply shock's effect on Swedish and U.S. GDP, and oil prices after around 6 months, which is significantly faster than the estimates reported by (Kilian, 2009). This is likely the result of the monthly GDP data used in our analysis versus the quarterly GDP data used in past studies.

It is not clear *a priori* on which side of the U.S. estimate Sweden would fall. Several factors suggest that the Swedish economy would be more sensitive to oil supply shocks than the U.S. For one, Sweden is a small open-economy, which would expose it to this type of commodity shock via macroeconomic and trade-linkage spillovers (see (Jung and Park, 2011) and (Buckle et al., 2007)). Another factor that could make Sweden's GDP more responsive is that Sweden has practically zero capacity to affect global fuel prices, domestic US fuel production probably dampens the effects as suggested by (Bodenstein et al., 2011) and (Brown and Huntington, 2013). These factors which would suggest a more negative $\Phi_t(h)$ for Sweden.

[5]We run the computations to exclude the COVID-19 pandemic, for the period 2010.01-2019.12. The estimates for $\Phi_t(h)$ are lower when the pandemic is excluded.

The fact that the elasticity of Swedish GDP to oil supply shocks is negative suggests that Sweden would be willing to pay a premium to avoid these GDP losses. In the next subsection we use the estimated $\Phi_t(h)$ to compute the magnitude of Sweden's fuel security premium.

3.2 The fuel security premium

We calculated Sweden's fuel security premium following the methodology outlined by (Brown, 2018). Their methodology was derived to capture the GDP losses to the US economy, which needs to consider domestic US fuel production and consumption. In contrast, Sweden is a small open-economy, which means Swedish domestic production and consumption of oil based fuels and its close substitutes is essentially negligible in a global context and can thus be ignored. This simplifies the calculations and reduces the number of parameters, and assumptions, required for the calculation.

The theory links a disruption in the quantity of fuel supplied to Swedish GDP, through the price of fuel. For a given disruption in fuel supply D_i, the resulting loss in GDP in given year is

$$\Delta Y_i = Y_{SE}\left[\left[\frac{Q_w - D_i}{Q_w}\right]^{\frac{\eta_{GSE}}{\eta}} - 1\right] \tag{6}$$

Y_{SE} is Swedish GDP in 2022, and η_{GSE} is dynamic multiplier for Swedish GDP with respect to oil prices for a one year horizon ($h = 12$) estimated in the previous section (see Table 2). Q_w is the global quantity of fuel consumed and D_i is the size of the oil supply disruption.

$$\eta \equiv \eta_{DROW} + \eta_{YROW}\eta_{GROW} - \eta_{SROW} \tag{7}$$

Where η captures global fuel market dynamics, where η_{DROW} is the elasticity of fuel demand in the rest of the world, η_{YROW} is the rest of the world's income elasticity of fuel demand, η_{GROW} is the elasticity of global GDP with respect to fuel prices, and η_{SROW} is the short-run price elasticity of Rest of World (ROW) oil supply.

These elasticities capture global fuel market characteristics and can be obtained from the literature (see (Brown and Huntington, 2015) for a discussion and more recent work by (Foroni and Stracca, 2019)). These equations together with the parameter estimates in Table 3 disruptions in fuel supply to Swedish GDP losses.

Table 3: Parameter values used in the calculation of Swedish GDP losses resulting from global disruptions in fuel supply obtained from (Brown, 2018) unless noted otherwise

Parameter	Value	Comments
η_{GSE}	-0.075	$\Phi_t(12)$ of Table 2.
η_{DROW}	-0.1 to -.25	
η_{YROW}	0.55 to 0.75	
η_{GROW}	-0.006 to -0.029	
η_{SROW}	0.00 to 0.075	Lower range from SVAR model assumption
Q_w	94 M barrels	US Energy Information Administration, 2022
Y_{SE}	590 billion USD.	Statistics Sweden (SCB), 2022

Integrating the damage function over the probability distribution of global fuel supply disruptions yields the expected Swedish GDP losses for any given supply shock event characterized by its size in millions of Barrels of oil per day (BPD) and an annual probability, see Appendix Table A.1, columns 1 and 2, respectively. (Brown, 2018) provide the annual probability distribution, which we used to calculate the expected gross domestic product (GDP) losses for any given year.

The estimated damages increase with the size of the fuel supply disruption, but the probability falls with the size of the disruption. Sweden's expected annual GDP loss resulting from fuel disruptions ranges from USD 0.8 billion to USD 2.5 billion for the higher and lower range of parameter estimates in Table 3.[6] The corresponding security premium follows directly from these calculations and is around 4.0 to 12.6 USD/barrel. For comparison, (Brown, 2018) report the U.S.'s fuel security premium for US oil imports ranging up to 15.4 USD per barrel, and (Krupnick et al., 2017) reports fuel security premiums of a similar magnitude.

To give the magnitude of these estimates context, consider that the International Energy Agency estimated oil markets could lose around 3 million bpd following Russia's invasion of Ukraine. Over a month, a negative shock of this size would result in around USD 1 billion in economic losses for Sweden.

These GDP losses based on the assumption that global fuel supply and demand follow market forces, i.e. prices adjust and markets are cleared and the GDP losses arise through the higher price of fuel paid and the resulting impact on the economy. The elasticities used to calculate this damage, including but not limited to the elasticity of GDP to fuel

[6]Current 2022 USD are reported throughout this paper.

price shocks, is estimated around the market "equilibrium" and damages are a function of these elasticities that capture the interaction between the global fuel market and the aggregate economy.

What is not captured are the GDP losses arising from fuel disruptions that are severe enough to limit the capacity of essential services or to fuel the military. Discussions of fuel security often revolve around uncertain but potentially very damaging events, which may arise from conflict, war or other catastrophes. Damages arising from catastrophic events are probably increasing at an increasing rate, i.e., massive fuel supply disruptions have a disproportionately large economic impact.

The intuition for these increasing damages is straightforward: essential functions which are very valuable to society (by definition) cease to operate in cases of extreme fuel shortages. Damages from a stop in essential services are hard to quantify in monetary terms and their probability of occurring is also difficult to quantify. The "traditional" approach to protecting the economy from global fuel supply shocks is to maintain strategic fuel reserves. The fact that the Swedish Energy Agency manages and maintains a strategic fuel reserve would suggest that policymakers are aware of the role played by fuel market frictions.[7] As confirmation of this awareness, strategic fuel reserves are often released in a controlled manner designed to keep opportunistic fuel traders from simply exporting fuel reserves abroad, in coordination with other countries.[8] To the extent that strategic oil reserves support the fossil-based status quo, they do not align with climate policy objectives in the longer-run.[9] Such reserves could be reduced, to the extent AFs can support fuel security objectives.

4 Have AFs increased Sweden's fuel security?

Our aim with this section is to reconcile Sweden's fuel security premium (estimated above) with the state of the rapidly evolving transportation fuel market, and to clarify the potential contribution AFs have made to Sweden's fuel security objectives. Swedish demand for AFs is met mainly with bio-diesel, and relatively small shares of biomethane

[7] Sweden follows the recommendations made by the International Energy Agency (IEA) and the EU to maintain a 90 day fuel reserve.

[8] The Swedish Energy Agency publishes information on Sweden's contingency plans for oil stocks, see `https://www.energimyndigheten.se` Likewise, the Swedish Civil Contingencies Agency provides information about contingency stocks in general including oil stocks, see `https://www.msb.se`.

[9] One can argue that strategic oil reserves provide a back up option that can facilitate the development of renewable energy supplies during the transition to a renewable economy.

and electricity. There is also a small and declining share of ethanol that we do not discuss, but for an overview of the biofuel market in Sweden see (Mossberg et al., 2021).

The view that AFs in a small open economy, like Sweden's, have little potential to contribute to domestic fuel security objectives is probably too strict. Each AF has characteristics that make it more, or less, promising in terms of their potential contribution to fuel security.

Hydrotreated Vegetable Oil (HVO) and Fatty Acid Methyl Esters (FAME) are the most important AFs in Sweden's renewable fuel mix. HVO contributed about 15% of total Swedish fuel demand, in 2022. In 2023, Sweden's blending mandate required fuel distributors to mix in biofuels to achieve at least a 30.5% reduction in greenhouse gas emissions. The cost of HVO production is high enough relative to fossil based diesel that the blending mandate is binding. As of 2024, the blending mandate was relaxed to 6% to help lower the retail price of diesel, which increased significantly with Russia's invasion of Ukraine. FAME is second to HVO in Sweden's renewable fuel mix with a share of about 4% of total Swedish fuel demand in 2022.

HVO is a drop-in fuel, which means it can be blended with conventional diesel or replace it completely. HVO's chemical properties mean it can be used in existing diesel infrastructure and vehicles. The competitiveness of foreign HVO production has meant that most of Swedish demand for HVO is met with imports (Lundberg et al., 2023). A factor that distinguishes FAME and HVO is that chemical differences mean that most diesel engines have an upper limit FAME they can tolerate in the fuel mix.

HVO technology is largely mature, but a barrier to scale is feedstock availability. Most HVO is produced using imported feedstocks (see Brown et al., 2020). According to the Swedish Energy Agency, around 95% of the HVO sold in Sweden is produced using imported feedstocks from Indonesia, Malaysia, Germany and the USA. Moreover, Sweden is the dominant source of global HVO demand, consuming around 35% of world production and about 65% of European HVO production in 2021 (Mossberg et al., 2021).

The main feedstock for domestic Swedish HVO production is tall oil derived from pulp and paper industrial residues, but other feedstocks are also important including food processing wastes (from slaughterhouses), rapeseed oil, and similar. There is scope for increasing the scale of Swedish HVO production, and several initiatives are underway but further increases in Swedish consumption of HVO and FAME will probably rely on imported fuel or feedstocks (Mossberg et al., 2021). Another barrier to wider use of HVO is that it is currently more expensive relative to fossil based diesel. FAME feedstocks are largely the same as those used to produce HVO.

Electricity is powering an increasing share of Sweden's transportation fleet. Between December 2022 and December 2023, the number of electric vehicles on Swedish roads increased by 30% to 600 000, representing about 11 percent of the total vehicle fleet. Of these approximately half are chargeable hybrid vehicles and half are battery-electric vehicles.[10]

A factor that makes electricity important in terms of fuel security is that Swedish prices for electricity are determined on the Nordic electricity market, Nord Pool. This means the relationship between the electricity price and oil prices are quite complicated, in part because the Nordics have a fairly high reliance on hydro power, wind power, and nuclear power.[11] Another feature of the electricity market is that domestic Swedish electricity production does to a fairly high degree determine its electricity price.[12] Moreover, price of electricity in Sweden is low relative to other transport fuels. These factors suggest that the recent increase in the share of electric vehicles in Sweden's transport fleet has probably help reduce Sweden's exposure to oil market shocks.

Biomethane use in transportation increased steadily over the period 2006-2014 and thereafter plateaued, and in 2021 contributed to a few percent of total Swedish fuel demand. As a transport fuel, biomethane is a chemically perfect substitute for natural gas. Moreover, Sweden has a significant domestic production capacity of biomethane from the digestion of sewage sludge, food waste, industrial residues, and agricultural residues such as manure and crop residues, as well as dedicated energy crops (Lindfors et al., 2022). While there is scope to increase biomethane production, it is relatively costly to transport domestically because of limited gas distribution infrastructure.[13] If biomethane is liquified (LBG) its long-distance shipping will become more affordable — similar to LNG. By virtue of the transport costs involved in shipping, domestic biomethane production can probably affect local market outcomes.

The upshot is that Sweden's AF mix has likely provided some fuel security benefits. For one, Sweden has a relatively high share of AF use, and the AF mix is quite diversified

[10]See `https://powercircle.org/elbilsstatistik/`.

[11]For recent example of research on determinants of Nordic electricity prices see (Lyu et al., 2024).

[12]Sweden's electricity grid is connected to other European countries, which means the price is determined not only by local electricity demand, but also the electricity markets in these other countries. However, transmission cost means prices vary across the market.

[13]biomethane requires dedicated distribution infrastructure, see LARA et al. (2021) for an assessment.

including a range of different fuel types. Moreover, the fact that electric vehicles are a non-negligible, and increasing, share of Sweden's transportation fleet might also have had an appreciable effect on Sweden's exposure to oil market shocks. Biomethane, by virtue of transportation costs, is largely locally produced and consumed. Also recently, HVO/FAME are have been the most important AF in Sweden and have also probably helped reduce Sweden's exposure to oil supply shocks, to the extent that fuel market frictions and other market distortions are a factor. Taken together, Sweden's AF use to date has probably helped helped dampen the shorter-run impacts of oil market shocks.

An insight from the analysis undertaken in Section 3, is that an important part of Sweden's GDP response (see Figure 2 Panel (b)) extends from 2 to 12 months after an oil supply shock, which could be caused by macroeconomic and trade-linkage spillovers from other countries: the impact of the fuel supply shock is likely to take some time to make their way through foreign supply chains and/or foreign macroeconomic outcomes. Domestic AF use and related policies probably have little scope to affect the transmission of fuel supply shocks through these types of channels.

5 Policy Recommentations

Our analysis points to several recommendations on how AFs can be deployed to support fuel security objectives in Sweden and other small, open economies.

- Sweden's fuel security premium corresponds to 0.065 EUR per liter diesel equivalence (or 12.6 USD per barrel), which suggests there is scope for policy to support AFs that target both fuel security and climate protection objectives.

- Biodiesels (HVO and FAME) are chemically similar to fossil based diesels, but restricted capacity and their high price reduce their potential to improve fuel security. Moreover, these fuels are relatively easy to transport (as easy as their fossil counterparts), which could lead fuel exporters to take advantage of higher diesel prices abroad in the event technological advances reduce production costs. This would work against their contribution to fuel security.

- Electricity is relatively more difficult to transport internationally due to capacity constraints and associated costs. Electricity is also already price competitive relative to petroleum based fuels and Sweden has significant domestic electricity production capacity. These factors make it an attractive option in terms of fuel security even though it requires hybrid or specialized vehicle drive trains.

- Likewise, biomethane is also difficult and costly to transport internationally, and it is also price competitive. Domestic production of biomethane is less likely to be exported and would thereby potentially enhance security of supply, to the extent production capacity can be scaled.

- Trade-linkage spillovers limit the scope for AFs to protect the domestic economy. By definition, an open economy is exposed to shocks to trade partners, (see (Friberg and Sanctuary, 2022) and (Di Giovanni et al., 2018)). GDP losses from such global shocks cannot be completely avoided even if AFs fully displaced oil based transport fuels if the impact of shocks to trade partners spills over to the domestic economy. AF policy support for fuel security should therefore more effective with coordination between main trade partners.

6 Concluding remarks

Our analysis quantifies Sweden's economic losses arising from a global oil price shock. With data covering the period 2010.10–2023.4, we estimate Sweden's short-run cumulative GDP impact of a 1 % decline in world oil supply at -0.036, which can be compared to the corresponding estimate for the US at -0.095. The cumulative impact after 12 months is -0.065 and -0.081 for Sweden and the U.S., respectively. Sweden's short run response to a shock is also lower relative to the US short run response. The estimated coefficients are consistent with Sweden's relatively high share of AFs in total fuel demand, which it would seem help dampen the impact of unexpected oil supply shocks. We also report that an important part of Swedish GDP response extends from 2 to 12 months after the oil supply shock.

We used the estimated GDP elasticity to compute Sweden's fuel security premium to be up to 12.6 USD per imported barrel in 2022. Reported U.S. fuel security premium for US oil imports range up to 15.4 USD per barrel.

These estimates provide insight on the magnitude of the economic losses resulting from fuel supply shocks. For example, based on the estimates reported, the cost to the Swedish economy from the 2022 disruptions to global fuel markets arising in part from Russia's invasion of Ukraine were on the order of 1 billion USD per month.[14] In terms of

[14]This rough calculation assumes a 3 million bpd negative supply shock, which was in fact an estimated

future losses, we compute the annual *expected* GDP losses from fuel supply shocks to be around 2.2 billion USD per year for a given year. These estimates are derived during a period excluding acute fuel shortages that might undermine military or hospital services. Including catastrophic aspects to the fuel security discussion would magnify the losses.

It was unclear *a priori* if Sweden would even have a positive fuel security premium, given its already relatively high share of AF use, and the diversification of fuel types, over the time period studied. The fact that Sweden has a positive fuel security premium, despite this, suggests that there is scope for the government to support increased AF production and consumption to reduce GDP losses arising from dependence on crude oil based fuels. As a reference, consider that the average carbon price under the EU Emission Trading System (in which Sweden participates) was around 80 USD/ton in 2022, which is equivalent to 40.6 USD/barrel of oil. At up to 12.6 USD/ton, Sweden's fuel security premium could be of a non-trivial magnitude. This would suggest that there is scope for a positive interaction between fuel security and climate objectives.

Increasing Sweden's reliance on AFs will increase Sweden's exposure to supply disruptions affecting other fuel types. Domestic fuel production can only support fuel supply security to the degree that production or supply shocks are uncorrelated across domestic and foreign fuel types. Having an economy that depends on different fuel types that are produced from distinct supply chains will help protect the economy against shocks to the supply of one fuel.

Policies to support AFs for fuel security would need consider measures to manage fuel trade similar to those governing the distribution of strategic fuel reserves. Currently no such measures are in place to secure Sweden's domestic AF supply, which would be especially important in times of crisis.

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Appendix

Table A.1: The GDP losses associated with each supply disruption D_i, and the expected GDP losses over the probability distribution of the disruptions

D_i M BPD	**Annual** probability	**GDP loss** Million USD	**Expected losses** Million USD
0.0	0.89958	0.0	0.0
1.0	0.00369	-4532.8	-16.7
2.0	0.01215	-9079.0	-110.3
3.0	0.01503	-13638.7	-205.0
4.0	0.01646	-18212.2	-299.7
5.0	0.00978	-22799.6	-223.0
6.0	0.00876	-27401.1	-240.0
7.0	0.01048	-32017.0	-335.5
8.0	0.00801	-36647.5	-293.7
9.0	0.00499	-41292.7	-206.1
10.0	0.00259	-45953.0	-119.0
11.0	0.00312	-50628.4	-157.8
12.0	0.00213	-55319.4	-117.8
13.0	0.00087	-60026.0	-52.0
14.0	0.00046	-64748.5	-30.0
15.0	0.00053	-69487.3	-36.6
16.0	0.00013	-74242.5	-10.0
17.0	0.00013	-79014.5	-10.6
18.0	0.00011	-83803.5	-8.9
19.0	0.00012	-88609.7	-11.0
20.0	0.00002	-93433.6	-2.3
21.0	0.00011	-98275.3	-10.4
		Total	**-2496.5**