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Commentary

Not only a mild winter: German consumers change their behavior to save natural gas

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INTRODUCTION

By the start of the 2022/2023 heating season, Germany and many other European countries found themselves facing a potential gas supply shortage in the wake of Russia's invasion of Ukraine. In search of a response, authorities called on residential and commercial sectors to save natural gas. Exploiting winter 2022/23 as a "natural experiment," we shed light on the magnitude of behavioral gas savings using open data and a machine learning method. Despite being exposed to incomplete price signals, we find significant behavioral gas savings by German households and businesses, contributing to closing the supply gap. We uncover temperature-dependent saving dynamics and discuss the potential roles of different drivers of this change. Finally, we highlight the pivotal role of a timely and continuous provision of openly accessible data and analysis to inform the general public as well as policymakers.

CONTEXT

The Russian invasion of Ukraine in February 2022 has created an unprecedented supply crunch in European natural gas markets. Up until February 2022, Russia had been Europe's largest supplier of natural gas, expanding its position in prior years. Doubting the reliability of Russia's gas supplies, the question of whether enough gas would have been supplied to the European market led to spiraling wholesale gas prices. At the end of August 2022, prices peaked at over 300 Euro per megawatt hour (MWh) at the benchmark hub Title Transfer Facility (TTF) after Russia stopped delivering gas through its Nord Stream 1 pipeline.[1] Slowly rising in the months prior to the invasion, prices had been fluctuating around 20 Euro per MWh in recent years.[1] Following the closure of Nord Stream 1, the security of supply was called into question with respect to the upcoming winter of 2022/23.[2]

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Within a year, (Central) Europe's gas supply structure changed radically. While historically around 40% of all gas imported to Germany had been coming through Russian pipelines, this number dropped to almost 0% by the end of 2022.[3] Much of the Russian supply was substituted by additional pipeline imports from Norway and liquefied natural gas (LNG) shipments from other countries. The remaining potential shortfall gave rise to a discussion on how much gas could and would be saved by whom.

With respect to gas consumption, there are three principal groups: gas-fired power plants, large industrial consumers, and the residential and commercial sectors, which comprise households and small- and medium-sized businesses. Gas-fired power plants consume gas for electricity production, yet some also supply heat to district heating networks. Large industrial consumers use gas either as feedstock or source of process heat. The residential and commercial sectors need gas predominantly to satisfy heat demand.

These consumer groups are different in terms of the price signals they receive, as well as the potential for and consequences of gas demand reductions or enforced curtailment. Gas-fired power plants usually buy gas short-term to serve peak electricity demand and thus react immediately to price signals in both electricity and gas markets. Provided there is sufficient alternative electricity supply, e.g., from coal-fired power plants, gas demand from the power sector is rather flexible. Large industrial consumers, unless protected by long-term gas supply contracts or comprehensive hedging, are similarly exposed to price changes in the spot market and therefore have an incentive to reduce gas consumption in case of a supply crunch. At least in the short run, the industry can reduce its gas consumption by curbing production, substituting the energy carrier, or buying alternative upstream products. Mostly supplied under fixed-price contracts, residential and commercial consumers do not bear the consequences of rising prices in the spot market until a contract has to be renewed. Even in the case of an acute gas shortage, it is not clear whether a controlled gas curtailment of supply to residential and commercial sectors in the distribution grids would have been possible, as it would have been challenging to implement for various technical[4,5] and political reasons.

In the face of a looming gas shortage, the public debate initially concentrated on industry halting production, leading to a strong economic downturn, the size of which was debated controversially among economists.[6,7] To avoid dire economic consequences of production cutbacks of industrial consumers and because of limited means for the government to impose rationing, voluntary savings by residential and commercial sectors eventually gained importance in closing the gas supply gap.

GAS SAVINGS FROM CHANGES IN BEHAVIOR

Since the beginning of the gas supply crunch, Germany has been the focus of discussion due to its large economy and relatively high dependence on Russian gas imports. In September 2022, the German Federal Network Agency, *Bundesnetzagentur*, announced that a 20% reduction in gas consumption (compared to the average consumption of the preceding 4 years) would have been necessary to avoid an acute gas shortage.[8]

In the following, we aim to shed light on the efforts by residential and commercial sectors to save gas. The strong dependency of residential and commercial gas demand on weather conditions implies that relatively warmer or colder weather has a large effect on whether the target is actually achievable or not. Building on a rich literature on the relationship between heat demand, gas demand, temperatures, and prices,[9–12] we use a very flexible machine learning method to isolate those gas demand drivers that are not governed by weather variations. We subsume these drivers as the behavioral component.

The method used in this commentary to estimate savings is a causal forest, which has two important features: (1) it is fully non-parametric and data driven, and (2) it allows isolating savings effects differentiated by temperature. Causal forests[13] extend a classic machine learning algorithm, random forests.[14] The general idea of random forests is to partition the dataset based on values of explanatory variables and fit local models within these partitions, which are together capable of representing non-linear relationships without having to specify a functional form. Causal forests extend this concept by using the same logic as a tool to identify local saving effects. We provide extensive explanations, details, and robustness checks of our model in the supplemental information sections SI.2–SI.4. The causal forest model enables us to predict daily behavioral savings depending on the weather conditions of the day. In order to control for weather conditions, we include mean, minimum, and maximum temperatures of a given day as well as several lags to control for thermal inertia. Irradiation effects are proxied by sunshine duration, and we include month and weekend/holiday indicators to account for behavioral variations.

Our model allows us to recover two alternative scenarios of estimated consumption. The first scenario is the estimated actual consumption, including behavioral savings. The second scenario is the estimated counterfactual consumption, which would be expected in the absence of the savings. By design, the difference between these two scenarios yields our estimate of behavioral savings. By focusing on

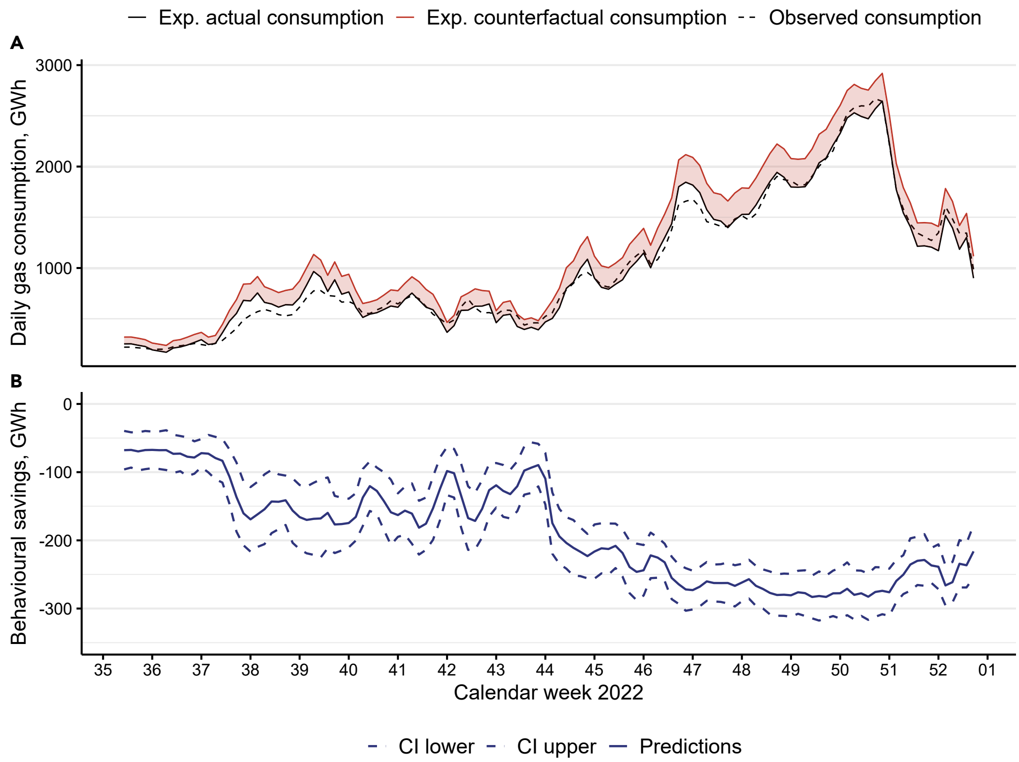

Figure 1. Daily actual and counterfactual gas consumption

(A) The modeled actual and counterfactual daily gas consumption paths from September 2022–December 2022.

(B) The solid line gives the estimated daily behavioral savings (corresponding to the shaded area in (A). The dashed lines define the 95% confidence interval of the estimated savings.

estimated counterfactual consumption and estimated actual consumption (instead of observed consumption), we ensure a like-for-like comparison and that our savings are not driven by random error. This assumes implicitly that the model errors, given by the difference between the estimated actual consumption and the observed consumption, would have been the same in the absence of behavioral savings.

In Figure 1A, the estimated actual consumption is depicted as a solid black line, while a solid red line represents the estimated counterfactual consumption (in the absence of savings). The dashed black line gives the observed consumption. We start measuring the savings effect as of September 2022, when the risk of a supply shortage became pressing with the start of the heating period and the end of Nord Stream deliveries. Nonetheless, our model allows for the possibility of behavioral savings from the beginning of the Russian invasion of Ukraine on February 24, 2022. We discuss the implications of this assumption in detail in the supplemental information section SI.4.

Gas consumption has been going up as expected with colder temperatures (Figure 1). With the beginning of the heating season in September, we see that German residential and commercial sectors have consistently saved between 66 and 285 GWh of gas per day. As revealed in Figure 1B, estimated savings are statistically significant for all days in the September to December period. December 2022 was exceptionally cold, also reflected by spiking gas demands. Around the Christmas period, savings efforts diminished. Cumulatively, we estimate that households and commercial sectors have saved ca. 23 TWh (95% CI: 18.7; 27.3) by changing their behavior from the beginning of September until the end of December 2022.

Relying on the results above, we can attribute the differences in gas consumption between 2022 and the average of the period 2018–2021 to different effects (Figure 2). The weather effect (gray) is computed as the difference between the estimated 2018–2021 average consumption and the estimated counterfactual consumption in 2022. Behavioral savings (red) result from the difference between estimated actual and counterfactual consumption. The sum of weather and behavioral savings does not add up to the total difference in consumption, represented by the solid line, due to the unobserved error component discussed above. The 20% savings target defined by German Federal Network Agency is reflected by the dashed line.

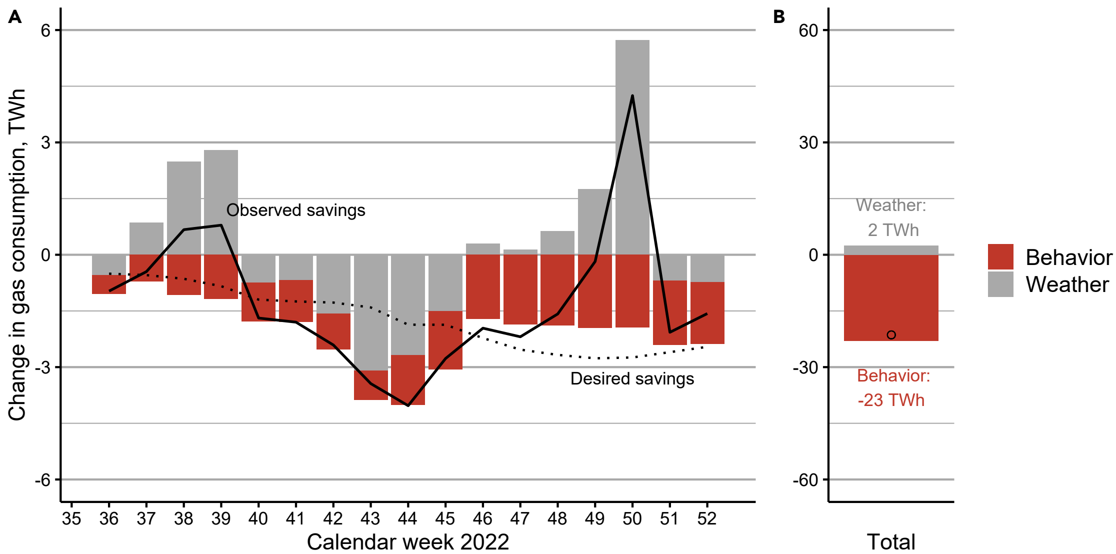

Figure 2. Gas savings disaggregated into weather and behavioral components versus 2018–2021 average
Gas savings in 2022 compared to 2018–2021 consumption, disaggregated into behavioral (red) and weather component (gray). The solid black line represents total savings and the dashed line the savings goal of 20%. (A) provides a weekly view, while the (B) shows the accumulated savings for the calendar weeks 36–52 2022.

Total savings compared to the average of 2018–2021 varied substantially between different weeks (Figure 2). This variation is mostly driven by the weather component. Meanwhile, the behavioral component remains relatively stable, slightly increasing over time. Compared to 2018–2021, we observe two cold spells: one in September (as of calendar week 36) and one in mid-December (as of calendar week 50), in which the weather component drove up gas consumption. Even in these colder periods, estimated behavioral savings did not change much. In the last 2 weeks of the year, savings decreased slightly compared to the previous weeks. This may be explained either by the Christmas period or by a reduced urgency, as it became increasingly evident by December that a gas shortage in the winter of 2022/23 would be rather unlikely. Gas storage levels remained well above the range of previous years.

On aggregate, we find that the weather effect alone did not play a significant role when comparing the September to December 2022 gas consumption with previous years (Figure 2B). At least for the first half of the winter, this is possibly at odds with other analyses asserting that a comparably mild winter induced most savings.[15] Consistent behavioral savings contrast highly variable weather-related savings. Especially the cold spell in December offset most of the savings by weather due to milder temperatures in the weeks before. However, the weather may have had an indirect effect, as a colder winter would have made it even harder for households to save gas in the same way.

The winter months of 2022 also shed light on the savings dynamics of the residential and commercial sectors relative to temperatures. We find a negative relationship between relative gas savings, defined as absolute gas savings divided by estimated counterfactual consumption, and temperature (Figure 3B). The residential and commercial sectors seem to relatively easily suppress their heating demand when temperatures are rather mild. These levels of relative savings cannot be carried over to lower temperatures. If outside temperatures are around 12°C, decreasing heating efforts by a certain amount will have a much lower effect on room temperatures compared to a situation when outside temperatures range around 0°C.

Regarding the relevance of averting a gas shortage, relative savings are, however, only of minor importance. Therefore, we highlight the substantial and consistent absolute savings during cold temperature days (Figure 3A). Although they fell short of the targeted 20% goal by the federal regulator, they added more to averting a gas shortage than the higher relative savings in autumn.

CONCLUSIONS AND OUTLOOK

Winter 2022/23 happened to be a "natural experiment" for Europe and Germany on how the economy would react to a gas supply crunch or even a looming shortage. It tested the capacity and willingness of households and commercial consumers to cut gas demand mainly used for heating. Using a data-driven causal forest model, we can show that residential

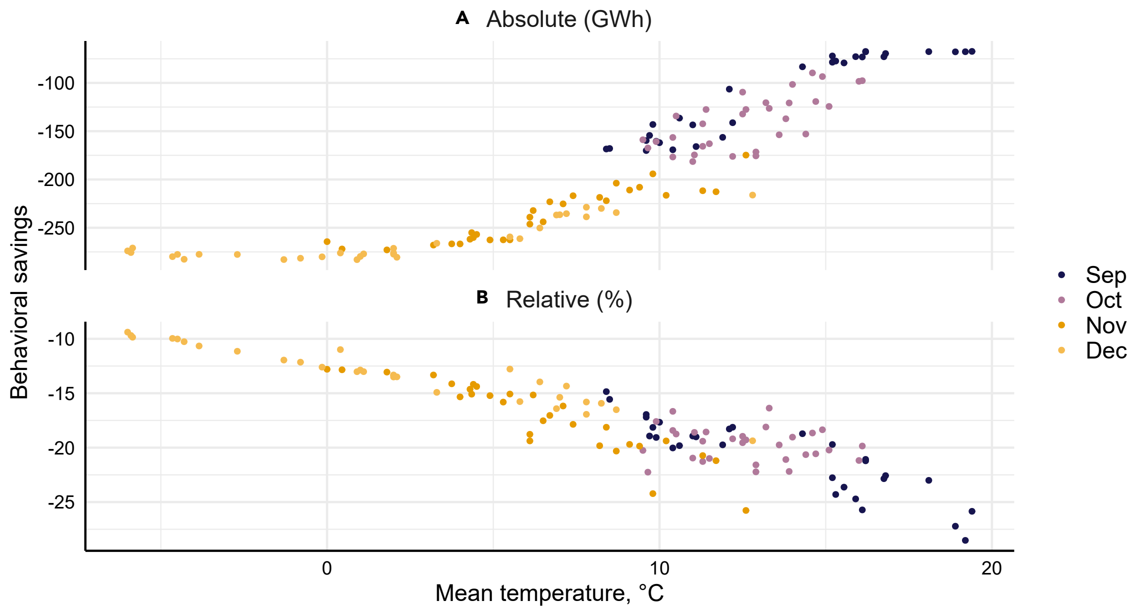

Figure 3. Relationship between behavioral savings and mean temperature
The relationship between estimated behavioral savings and the mean temperature.
(A) Absolute savings in GWh.
(B) Relative behavioral savings defined as absolute savings divided by estimated counterfactual consumption.

and commercial sectors have reduced their gas consumption. In contrast, the weather even had an increasing effect.

The reasons for these savings could be manifold, including but not limited to increased prices, clear communication by officials, changed expectations, and political conviction and solidarity.

As most of Germany's residential and commercial sectors face fixed price regimes, wholesale market price spikes usually do not affect consumers directly. Short-lived price hikes on the wholesale market typically do not translate into higher long-term retail tariffs. For the prolonged price increase in the wake of the Russian invasion of Ukraine, average retail prices only reacted sluggishly.[11] Furthermore, staggered contractual periods and the unavailability of individual-level consumption data make it challenging to compute precise price elasticities at the retail level. Notwithstanding, higher prices have certainly affected the estimated behavioral savings. Yet, the precise impact of prices on German residential and commercial sectors remains, for the moment, opaque.

As we observe savings despite incomplete price signals, we suggest they might have also been driven by a response to public communication. As September came to an end, Germany had experienced a colder start into autumn than usual, and the German Federal Network Agency, *Bundesnetzagentur*, and its president urged residential and commercial sectors to reduce consumption. Consequently, the agency released the aforementioned target of a 20% demand reduction. The president repeated this plea several times. In addition, consumers could have saved additionally in expectation of higher prices. Clear communication by the Federal Network Agency raised public awareness of the role of storage levels and their effect on wholesale prices and, eventually, contract prices. Consumers are likely to have understood that lower consumption levels today would keep storage levels sufficiently high in order to avoid costly additional imports. Other reasons might have played a role as well. Some consumers could have regarded saving gas as a part of responsible civil behavior. Political beliefs toward the support of Ukraine (or Russia) could also have (de-)motivated the savings behavior of some households.

Importantly, we want to highlight the essential role of continuous and timely data provision and analysis for public debate and policymaking. Transparency and publicly available data are crucial for consumers and policymakers, not only to better understand the topic but also to track whether measures and their efforts have any effect. In autumn 2022, little publicly available evidence existed on whether and how strong the residential and commercial sectors would help in savings gas to avoid a potential gas shortage in the winter months. Several platforms began to publish analyses on various aspects of the energy crunch, such as consumption data, storage levels, prices, etc. On the Open Energy Tracker,[3] we have been tracking behavioral gas savings of residential and commercial sectors since October 2022, providing the public with timely insights. The results and methods in this commentary are based on those published in a less elaborate form on the Open Energy Tracker.

Despite the impact that data and analyses might have already had on policy and consumer behavior in this gas crisis, improved data quality, e.g., by means of an accelerated smart meter roll-out, could yield further benefits. It could enhance the quality of the analysis by uncovering drivers of consumer behavior and thereby increase the policy relevance of real-time analyses. It could also allow for more direct pricing mechanisms that prompt an immediate consumer response to wholesale market developments.

Finally, all results in this piece can only be regarded as a snapshot in time, and a complete picture will only emerge in a continued analysis. The estimates presented in this commentary will be continuously updated online.[3] We believe that with a data-driven analysis of events, the public and policymakers have an important tool at hand to assess the success of saving efforts and their policies.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.joule.2023.05.001.

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Conceptualization, A.R. and F.S.; methodology, A.R. and F.S.; software, F.S.; formal analysis, F.S.; investigation, A.R. and F.S.; data curation, A.R. and F.S.; writing – original draft, A.R. and F.S.; visualization, A.R. and F.S.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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