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Gas consumption in Europe during the winter of 2022-23

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As supplies of Russian gas via pipelines dropped by more than 70 percent year-on-year and prices of energy rose sharply, consumption of gas in Europe fell by more than 20 percent during the winter of 2022-23. The impact on overall industrial production was nonetheless relatively mild. This paper decomposes adjustments to the energy shock across European economies. The largest contribution (7 percentage points, on average) came from changes in the structure of industrial production. We further show that the difference in contraction in industrial output between more and less carbon-intensive industries was greater in economies with larger increases in electricity prices for industrial consumers. Warm temperatures during the winter of 2022-23 are estimated to account for 4 pp of the average reduction in gas consumption, weak industrial activity accounts for another 2.7 pp, increased use of renewables (and coal) in electricity generation for 1.1 pp. The unexplained remainder, of around 6 pp, is equivalent to heating buildings by around 1.3 degrees less, on average.

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1 Introduction

After Russia's invasion of Ukraine on 24 February 2023, supplies of Russian gas to Europe via pipelines dropped by more than 70 percent year on year. Prices of gas rose sharply (see Figure 1), to a multiple of up to 11 times the US price, leading to a spike in wholesale electricity prices across the continent as well.

In response, consumption of gas in Europe fell sharply. In October 2022-March 2023 gas consumption in the European economies reporting to Eurostat (excluding Norway and Malta) fell by 21 percent, compared with the same period a year earlier (see Table 3, unweighted average across economies). This large drop in consumption enabled Europe to enter spring with more gas in storage than during the previous season and the price of gas subsequently fell sharply, although it remained 4 to 6 times higher than in the US (see Figure 1).

As a result, Europe came close to experiencing a technical recession (two consecutive quarters of negative growth in seasonally-adjusted quarter-on-quarter terms) in the last quarter of 2022 and the first quarter of 2023 (early estimates of economic growth published by Eurostat suggested a recession but were subsequently revised up). The period of weak growth coincided with the heating season. Nonetheless, the estimated drop in output was small (around 0.1 percentage point quarter on quarter). Economic activity has held up better than expected (see, for instance, Moll et al. (2023), McWilliams et al. (2023)). This paper looks into the sources of this resilience by decomposing the reduction in gas consumption into its various components.

The largest contribution (7 percentage points [pp], on average) came from changes in the structure of industrial production, such as a drop in output of construction materials and base metals, which involve highly energy-intensive processes, partially compensated by the expanding automotive industry, which is less reliant on heat.

In a difference-in-difference framework, we further show that the difference in contraction in industrial output between more and less carbon-intensive industries was greater in economies with larger increases in electricity prices for industrial consumers. In addition to being statistically significant, those differentials were large in terms of their magnitude. In other words, domestic price signals played an important role in guiding the overall adjustment to higher international energy prices.

Warm temperatures during the winter of 2022-23 are estimated to account for 4 pp of the average reduction in gas consumption. Weak industrial activity accounts for another 2.7 pp as slower growth in industrial production than could be otherwise expected (or an outright small contraction in the industry) was observed universally except in Denmark.

Another component of the adjustment is fuel switching in electricity generation. An increased use of renewables in electricity generation accounts for a further for 0.9 pp of savings in terms of gas consumption while 0.2 pp was contributed by switching electricity generation to other fossil fuels such as coal. The switch towards dirtier fossil fuels is consistent with the earlier findings of Martin et al. (2014) for the UK.

The remainder – an otherwise unexplained reduction in gas consumption of around 6 percentage points – is equivalent to heating buildings by around 1.3 degrees less, on average. In addition to less heating, this residual encompasses various other types of optimisation of gas consumption such as faster improvements in energy efficiency or electrification of the industry and heating.

We contribute to the growing literature on price sensitivity of output with respect to fossil-fuel prices (see, for instance, Fontagne et al. (2023), Marin and Vona (2021)) as well as to the literature on the economic costs of green transition (see, for instance, Metcalf and Stock (2023)). In particular, we review adjustments to a large and mostly exogenous shock to the gas supply and gas prices related to the invasion of Ukraine by Russia in February 2022, an event not anticipated by the markets or policymakers. Tracking adjustments across a large number of developed and emerging market economies facing similar circumstances enables us to document a variety of outcomes.

The estimated negative economic impact of a fossil-fuel price shock is larger than that derived from the history of carbon prices (for instance, Metcalf and Stock (2023), Metcalf and Stock (2020), Bernard and

Kichian (2021)) not least because carbon pricing tends to cover a relatively small part of greenhouse gas emissions. At the same time, structural shifts play an important role in the overall adjustment, resulting in a relatively modest contraction in economic activity. This modest reaction, however, implicitly relies on the ability of large economies not directly affected by the gas price shock to scale up exports to Europe, a scenario distinct from one involving a high price of fossil fuel emissions across the world.

The paper is structured as follows. Section 2 outlines the data and methodology. Section 3 presents the results and discusses their implications. Concluding remarks follow.

2 Data and estimation strategy

2.1 Data

Data on gas consumption, industrial production and the structure of the economy over the period January 2015-March 2023 are taken from Eurostat; data on average monthly temperatures by country come from the the International Energy Agency (IEA).

We look at the industrial structure of output in the base year distinguishing between 28 industries for which carbon intensities are available from Eurostat (at the 2-digit level of disaggregation of the ISIC classification). For the Slovak Republic where detailed data on monthly industrial production were not available we collect data from the national statistical offices. We also collect detailed data on consumption of energy by source (such as natural gas or electricity) in each industry in Germany, from the German Statistics Office. Descriptive statistics are presented in Table 1.

The most carbon-intensive industries include base metals and non-metal minerals – typically industries involving heating raw materials to temperatures in excess of 1,000 Celsius. On the other hand, manufacturing of electrical equipment and computers and electronics are among the least carbon-intensive per euro of output (see Table 4). The overall carbon intensity of industrial production in the base period is calculated as the sum product of industry shares and their carbon intensities.

We also collect data on the prevailing prices of gas and electricity for industrial consumers in each economy from Eurostat. These are available as averages for six-month periods. Approaches to gas and electricity pricing for industrial consumers varied considerably across economies reflecting differences in the fuel mix in electricity generation (with France, for instance, relying to a greater extent on nuclear power while Portugal and Finland having greater supply of hydro power). Differences in policy priorities also played a role. Indeed, Pieroni (2023) and Auclert et al. (2023) show that energy subsidies and other fiscal policy measures can be effective in shielding producers from the impact of higher energy prices at the cost of various externalities for taxpayers or foreign firms.

Averaging across all pricing bands (typically defined in terms of total electricity consumption of an industrial customer), changes in electricity prices (second half of 2022 compared with the same period of the previous year) ranged from 6 percent in Portugal to 75-90 percent in Croatia, Lithuania, Hungary and Romania. In levels, on the other hand, prices ranged from 14-17 euro cents in Finland, France and Portugal to 35-36 euro cents in Denmark and Italy. Similarly large differences are observed for the average gas prices across industrial consumer bands and for changes in gas prices (see Table 1).

2.2 Estimation strategy: Warm weather

We decompose the year-on-year change in gas consumption in October 2022-March 2023 in country i into its multiple components (see Equation 1). In particular, we estimate various components of changes in gas consumption in each economy, with the unexplained part being the residual $epsilon_i$.

$$\Delta Gas_i = \beta \Delta Temp_i + \gamma \Delta IndOutput_i + \Delta IndStr_i + \Delta Renewables_i + \Delta Fossil_i + \epsilon_i \quad (1)$$

The average monthly temperature clearly influences the demand for heating and this is reflected in the first component of the above decomposition. Within countries, the relationship between the average monthly temperature and the logarithm of gas consumption tends to be near-linear for average monthly temperatures below approximately 15 degrees (see Figure 2 for Poland as well as estimates in Ciais et al. (2021)). For higher average temperatures (typically in excess of 21C) demand for gas may pick up, to the extent that gas is used to produce electricity used for cooling. The cooling aspect, however, is not relevant for the winter heating season studied in this paper.

Hence we focus on downward deviations of the average monthly temperature from the threshold value of 15C. For instance, an average monthly temperature of 8C corresponds to a deviation of 7C in these specifications. Any average temperature of 15C or above (for example, 21C) yields a zero deviation.

With this in mind, we estimate the average elasticity of gas consumption with respect to the average temperature during the heating season (see Equation 2). In this exercise, the dependent variable is the logarithm of monthly consumption of gas (Gas) in each economy i in month t. Explanatory variables include the downward deviation of the monthly temperature from a threshold value (in degrees Celsius, $Tempdev$), the adjusted logarithm of industrial production in constant prices (physical terms, $IPadj$) as well as calendar-month-by-country fixed effects (δ_{mi}, to account for country-specific seasonality of demand) and month fixed effects (λ_t, to account for any trends in energy efficiency over time). Some specifications also include country-by-year fixed effects taking into account country-specific business cycles and longer-term trends in energy efficiency (ν_{it}).

$$ln(Gas)_{it} = \beta ln(IPadj)_{it} + \gamma Tempdev_{it} + \delta_{mi} + \lambda_t + \nu_{it} + \epsilon_{it} \tag{2}$$

Calendar-month-by-country fixed effects also account for country-specific fuel mix in generation of heat and electricity. On the other hand, they leave variation in terms of temperatures recorded in the same month in the same country in different years. In other words, differences in temperatures recorded across winters is an important source of identification in Equation 2.

Industrial production is adjusted for the long-term rate of improvements in energy efficiency of the industry in Europe. Such improvements have averaged around 1.8 percent per annum since the early 1990s, or 0.15 percent per month, based on the data from Eurostat. In other words, based on historical data, each month the industry could be expected to produce 0.15 percent more output with unchanged consumption of energy. This approach is similar to Gamtkitsulashvili and Plekhanov (2023) who analyse the relationship between economic growth and mobility during the Covid-19 crisis and assume that in each economy a potential level of economic growth is consistent with baseline (unchanged) mobility.

The estimates of elasticity of gas consumption obtained using Equation 2 are multiplied by the difference in average winter temperatures in 2021-22 and 2022-23 in each economy. This provides an estimate of the effect of warm weather on gas consumption, which is the first part of Equation 1.

2.3 Changes in industrial production

We also estimate the elasticity of gas consumption with respect to industrial production from Equation 2 and multiply it by the growth in adjusted industrial production between the winter of 2021-22 and the winter of 2022-23 in each economy. The resulting product is the second component of the right-hand side of Equation 1.

The next component of decomposition relates to the change in the structure of industrial production. Such structural shifts have been shown to play an important role in response to the introduction of carbon taxes (see, for instance, Azevedo et al. (2023) for the case of British Columbia and Andersson (2019) for the case of transportation industry in Sweden).

The calculation for country i is summarized in Equation 3. The denominator represents the average carbon intensity of production calculated as the sum-product of output shares and carbon intensities across industries indexed j (excluding energy supply). The numerator tracks the change in carbon intensity as the sum-product of output shares, carbon intensities and changes in industrial production in real terms. Output shares are calculated across the industries with available data. As carbon intensities are missing for many country-industry pairs, they are imputed using data for Germany and thus can be seen as values corresponding to Europe's technological frontier.

$$Contributiongas_i = \frac{\sum_j g_{ij} * s_{ij} * c_{ij}}{\sum_j s_{ij} * c_{ij}} \tag{3}$$

For each individual industry j, its contribution to the change in gas consumption in country i can similarly be calculated based on Equation 4.

$$Contributiongas_{ij} = \frac{g_{ij} * s_{ij} * c_{ij}}{\sum_j s_{ij} * c_{ij}} \tag{4}$$

The contribution of each industry to the change in gas consumption can be further contrasted with its contribution to the growth rate of industrial production calculated as the product of the growth rate and output share of an industry divided by the sum of output shares of all industries (see Equation 5).

$$Contributiongrowth_{ij} = \frac{g_{ij} * s_{ij}}{\sum_j s_{ij}} \tag{5}$$

2.4 Fuel switching in electricity generation

We also look at fuel switching in electricity generation. First, we multiply the share of total gas consumption in base period ($Gas_{i,t-1}$) accounted for by gas consumption in electricity generation ($Gasforelectro$) by the change in the share of gas in electricity generation ($GasShare$) from one winter season to another (measured in percent). For example, if the share of gas in electricity generation in Greece declined by 24 percent (from 43 to 32 percent of all energy sources in the fuel mix) and electricity generation used to account for 30 percent of gas consumption, this shift contributes 7.3 percentage points to the 33.6 percentage point drop in the consumption of gas in the Greek economy (see Equation 6).

$$ContrElectro_i = \frac{Gasforelectro_{i,t-1}}{Gas_{i,t-1}} * \frac{GasShare_{i,t} - GasShare_{i,t-1}}{GasShare_{i,t-1}} \tag{6}$$

If the share of electricity generated by gas declined, either the share of non-fossil-fuel sources ($REshare$) increased or that of fossil fuels (primarily coal and oil, $Fossilshare$), or both. Where reliance on fossil fuels and renewables (including hydro power and biomass as well as nuclear energy) moved in the opposing directions, we attribute all of the effect in Equation 6 to the part of electricity mix that moved in the opposite direction relative to gas. For example, in Spain the shift away from gas in electricity generation contributed 3 percentage points to lower gas consumption while the share of other fossil fuels in electricity generation also declined. In this case, all of the effect is attributed to the rise in the use of hydro power and other renewables in electricity generation.

In Greece, on the other hand, both the use of renewables and the use of other fossil fuels in electricity generation went up. In this case, the effect of reduced gas usage in electricity generation is attributed to renewables and other fossil fuels in proportion to the respective changes in their shares in the electricity fuel mix, as shown in Equations 7 and 8.

$$ContrFossil_i = ContrElectro_i \frac{Fossilshare_{i,t} - Fossilshare_{i,t-1}}{Gasshare_{i,t} - Gasshare_{i,t-1}} \tag{7}$$

$$ContrRE_i = ContrElectro_i \frac{REshare_{i,t} - REshare_{i,t-1}}{Gasshare_{i,t} - Gasshare_{i,t-1}} \tag{8}$$

By focusing on the base period, this calculation only takes into account changes in the fuel mix in electricity generation but not changes in overall electricity consumption as changes in the overall supply of electricity are to a large extent taken into account when looking at the total industrial output, its structure as well as average temperatures. In economies with no gas in the electricity fuel mix (such as Estonia or Norway), the effects of fuel switching are naturally set to be zero.

3 Results

3.1 Warm weather

We start by estimating temperature elasticities (Equation 2). The regression analysis suggests that a one degree colder weather, on average, increases demand for gas by around 5 percent (see Table 2). These estimates fall in the 4-6 percent range when looking at different sets of fixed effects and different time periods. They are broadly consistent with those in Ciais et al. (2021) who estimate country-specific gas-temperature curves using lagged daily values of gas consumption.

When we plug these estimates back into the decomposition of changes in gas consumption (see Table 3, Column 2) we find that, on average, warm weather during the winter of 2022-23 compared with the winter of 2021-22 accounts for 4 percentage points, or around a fifth of the total effect (the unweighted average across European economies of 21 percentage points).

The role of warm weather varies. For instance, the winter in Germany was not abnormally warm (see also Moll et al. (2023)). On the other hand, Bulgaria, Hungary, North Macedonia, Romania, Slovenia and Turkiye experienced a particularly warm winter, with estimated gas savings of 8 to 11 percentage points due to low demand for heating.

3.2 Changes in industrial production

The relationship between industrial production and gas consumption is substantially noisier than that between gas consumption and average temperatures during the winter months (for example, Figure 3 plots this relationship for Poland where every dot represents a month). As a result, the coefficient on industrial production is estimated less precisely, with a point estimate of around 0.6 when full sets of fixed effects are included (calendar-month-by-country fixed effects taking into account country-specific seasonality patterns; month fixed effects taking into account global conditions in a given month and country-by-year fixed effects taking into account country-specific business cycles).

In other words, a one percent reduction in industrial output is assumed to reduce demand for gas by 0.6 percent. As elasticities of up to 0.95 with respect to the adjusted industrial output cannot be rejected at conventional confidence levels, we provide conservative estimates of the impact of slowdown on gas consumption with an elasticity estimate close to one.

Based on these estimates, slower growth of industrial output in the last months of 2022 and the first months of 2023 accounts, on average, for up to 2.7 percentage points of the drop in gas consumption (or around 13 percent of the total effect, see Table 3, Column 3). Weak industrial performance made a relatively large contribution to gas savings in the Baltic States (5 to 12 pp) as well as Romania, the Slovak Republic and Slovenia (6-7 pp).

3.3 Changes in the structure of industrial production

Changes in the structure of industrial production are estimated to have accounted for approximately a 7 percentage point drop in consumption of gas, on average, or a third of the total savings). The largest gas consumption savings arose from lower output in non-metal minerals such as bricks or glass (2.3 pp), chemicals (2.1 pp) and base metals (1.6 pp, see Table 4).

At the same time, less carbon-intensive industries such as the automotive sector, manufacturing of other transport equipment, electronic equipment and pharmaceuticals expanded partially offsetting the impact of contracting gas-intensive industries on the overall output (see Table 4). For instance, chemicals production in Germany contracted by 21 percent, dragging industrial output down by 1.6 percent and yielding gas savings of 2.9 percent of baseline consumption. On the other hand, the expansion of output in the automotive sector, by 17 percent year on year, lifted industrial production by 2.8 percent while raising gas consumption by only 0.5 percent.

Shifts in industrial structure made a particularly pronounced contribution to gas savings in Estonia, Hungary, Lithuania, North Macedonia, Romania, the Slovak Republic, Slovenia and Turkiye (of 9 to 21 pp) while in Austria, Greece and Portugal the effects of changes in the structure of manufacturing output were negligible or had the opposite sign.

3.4 Shifts away from gas in electricity generation

Increased use of renewables in electricity generation, on average, afforded a 0.9 percentage point drop in gas consumption while an additional 0.2 percentage point reduction in gas consumption reflected an increased use of other fossil fuels such as coal in electricity generation.

Increased use of coal made a larger contribution to the change in gas consumption in North Macedonia, Turkiye, Greece and Austria (0.5 to 12 pp) while the use of renewables contributed 3 to 6 pp to the overall adjustment in Austria, Finland, Greece, North Macedonia, Portugal and Spain.

The estimates leave an unexplained residual, of around 6 percentage points, on average. It reflects other measures to optimise gas consumption by the industry, households and the public sector. This effect is equivalent to up to 1.3 degrees of difference in average winter temperature differences. Put differently, it corresponds to lowering the thermostat by 1.3 degrees Celsius across all residential, commercial and public buildings. As discussed above, the relative importance of various factors further varies from economy to economy (see Table 3).

3.5 Energy pricing and changes in industrial output

The decomposition reveals that changes in industrial production across manufacturing sectors made the largest contribution to gas savings. In the next subsection, we investigate the extent to which these savings could be attributed to differences in energy pricing across Europe. While European economies were exposed to a similar large shock to gas prices in the wholesale market, the extent to which these prices were passed on to industrial consumers varied significantly across economies.

We follow a difference-in-difference approach. In particular, we regress the change in the logarithm of industrial production IP in economy i and industry j (between the winter of 2021-22 and the winter of 2022-23) on an interaction term between the logarithm of energy intensity EI of each industry and a measure of energy price adjustment in each country (using indicators of gas and electricity prices, indexed k) as well as sets of industry and sector fixed effects (see Equation 9). Industry fixed effects subsume trends that affect an industry across all economies – changes in global demand or the fact that fertilizer production is much more energy intensive than furniture production. Country fixed effects take into account local economic conditions including government support measures afforded to all businesses or consumers. Country-industry varying controls X include the share of each industry in a country's industrial output.

$$\Delta ln(IP)_{ij} = \sum_k \beta_k ln(EI)_{kj} Pricing_{ik} + \gamma X_{ij} + \alpha_i + \delta_j + \epsilon_{ij} \tag{9}$$

When measuring energy intensity of various industries, we use estimates derived from data for Germany in 2021 obtained from the German statistics office. This measure effectively captures production at the European technological frontier in a large European economy. The approach here is similar to, for instance, Rajan and Zingales (1998) who measure an industry's dependence on external finance using data for the United States. We start by using the logarithm of gas intensity (the ratio of gas usage to output) interacted with gas pricing and the logarithm of electricity intensity interacted with electricity pricing.

The coefficients on the interaction terms in Equation 9 capture the extent to which the change in industrial production was greater in more energy-intensive industries in countries with higher energy price increases compared with economies with lower energy price hikes. The results are presented in Table 5.

More energy-intensive industries indeed grew relatively more slowly (contracted faster) during the winter of 2022-23 in those economies where electricity prices for industrial consumers increased to a greater extent (compared with the previous winter). This differential effect is statistically significant at the 5 percent level while controlling for industry and economy fixed effects as well as the share of each industry in the country's industrial output.

The level of electricity prices has a similar effect when only levels of prices are included (Column 1). However, it becomes smaller and loses its statistical significance when increases in prices and price levels are simultaneously interacted with the energy intensity of industrial production (Column 3). Interaction terms between energy intensity and gas prices are not statistically significant. This may reflect the fact that production in industries relying specifically on gas as a major input that cannot be replaced with other energy sources in the short term is more concentrated in a few large producers. In this case, various subsidy schemes may make differences in headline gas prices used in the analysis less reflective of the actual cost differentials experienced by producers.

Furthermore, different forms of energy may be substitutes to a certain degree even in the short term. To account for this possibility, we replace gas and electricity-specific measures of energy consumption per unit of output with a measure of overall energy intensity of an industry based on the logarithm of its carbon emissions per euro of output in Germany prior to the price hike. The carbon-based measure takes into account the overall energy intensity as well as the present reliance of prevailing technologies on fossil fuels such as gas and coal. The results presented in Table 6 (Columns 1-3) are similar. If anything, the effects are marginally greater and statistically significant at the 1 percent level.

The magnitudes involved are large. To see why, consider the difference between an industry at the 20^{th} percentile of the distribution of carbon intensity (such as manufacturing of other transport equipment) and that at the 80^{th} percentile (production of chemicals). The difference between the decline in industrial production observed in these industries was 12 percentage points greater in a country at the 80^{th} percentile of the distribution of increases in electricity prices, such as the Czech Republic, than in Germany or France, countries at around the 20^{th} percentile of that distribution.

3.6 Discussion

Across economies, the estimated negative economic impact of a fossil-fuel price shock tends to be larger than that derived from the history of carbon prices (Metcalf and Stock (2023)) not least because carbon pricing covers a relatively small part of emissions. At the same time, structural shifts play an important role in the overall adjustment, resulting in a relatively modest contraction in economic activity.

This modest reaction, however, implicitly relies on the ability of large economies elsewhere, which have not been directly affected by the gas price shock, to scale up exports to Europe. In fact, while changes in industrial structure in response to higher energy prices contribute to the lower carbon footprint of manufacturing in Europe, they do not necessarily reduce the global carbon footprint to the extent that carbon-intensive products are instead imported from other producers (as documented by Chiacchio et al. (2023)). In fact, those other producers may use relatively dirty technologies.

A global green transition, on the other hand, might involve a scenario with a high price of fossil fuel emissions across the world. That scenario may have a fairly different dynamics of prices and output in the energy-intensive industries.

In the short term, large changes in the structure of industrial production without corresponding changes in employment also contribute to tight labour markets. This translates into higher nominal wage growth and greater inflationary pressures, notwithstanding weak economic activity. In Germany, for instance, nominal wages were estimated to grow by close to 7 percent year-on-year in mid-2023 amidst recession.

3.7 Robustness checks

We conduct a number of robustness checks. When looking at the determinants of industrial production growth by industry-country, a placebo test randomly reassigns industries' carbon intensities. In particular, each industry is assigned the intensity of the next industry in the list presented in Table 4, while the last industry is given the intensity of the first one on the list. Estimations with placebo industry intensities do not yield a statistically significant coefficient on the interaction term between the industry carbon intensity and country energy pricing variables (see Table 6, Columns 4-6).

Next, we divide the sample into low-intensity and high-intensity industries, assigning sectors into each group depending on how they compare with the median. While the resulting exercise is based on very small samples, it confirms that the estimates effects are driven primarily by high-carbon-intensity industries.

Estimates based on specifications including changes in electricity prices only (and omitting the gas variables) are similar (see, for instance, Table 5 Column 4).

4 Conclusion

This paper provided a simple decomposition of a large drop in consumption of natural gas in Europe during the winter of 2022-23 in response to a sharp fall in gas imports from Russia and a significant increases in the price of gas. Overall, price signals were an effective tool and the European economies have proven agile in dealing with high gas prices. The contribution of warm weather to the overall adjustment has been non-negligible yet relatively modest, amounting to a fifth of total gas savings.

It should be noted that while changes in industrial structure contribute to the lower carbon footprint in Europe, they do not necessarily reduce the global carbon footprint to the extent that carbon-intensive products are instead imported from other producers. While alternative producers may have access to cheaper energy, they may not necessarily be more carbon-efficient than the European producers they displace.

The paper focuses on the adjustment in the short term and within Europe. It invites further research into longer-term shift in industrial structure (including relocation and re-skilling of workers) as well as changes in the global markets for the affected goods (such as base metals and construction materials).

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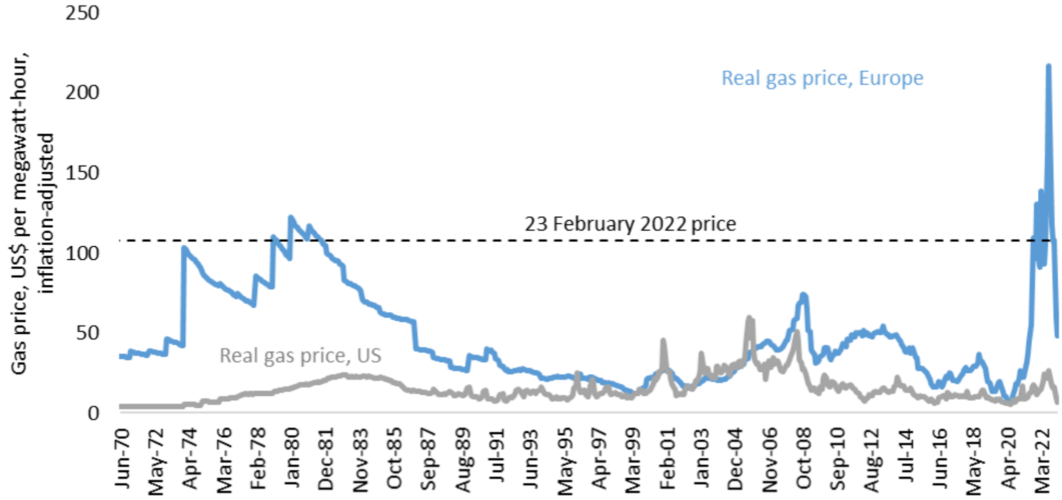
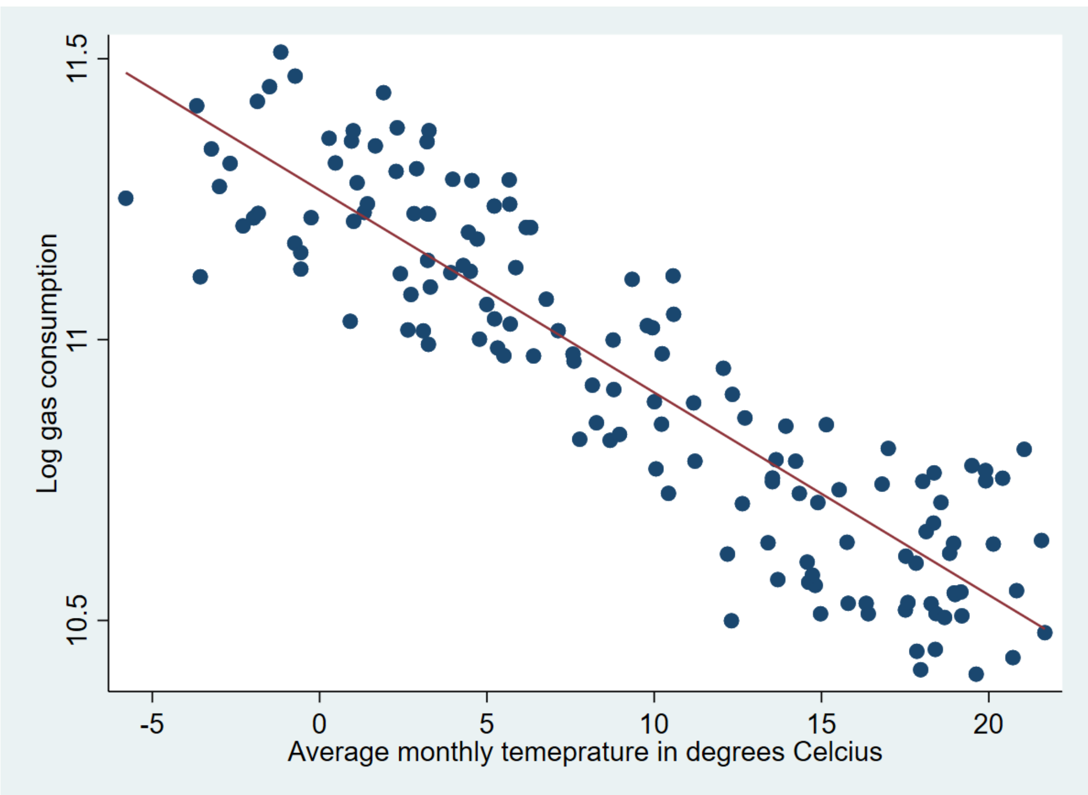
Figures and Tables

Figure 1: Price of natural gas in Europe and in the US



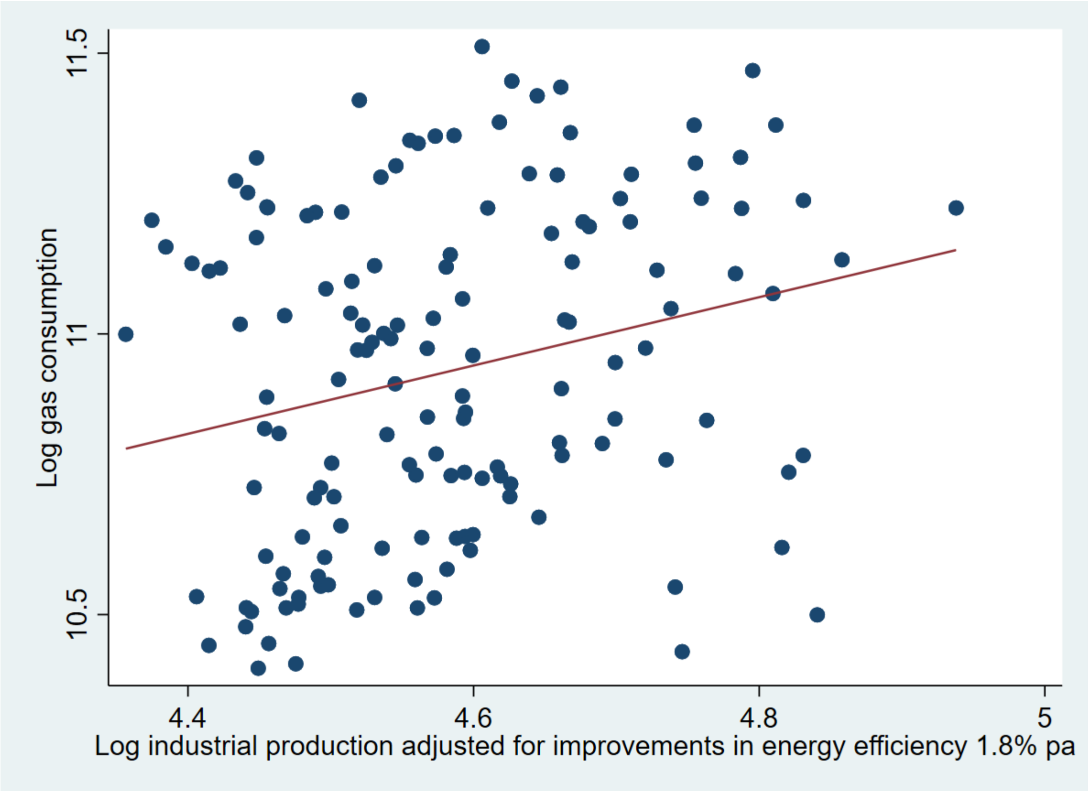
Source: Bloomberg, CEIC and authors' calculations.
Note: Prices are adjusted for US inflation.

Figure 2: Gas consumption and average monthly temperature in Poland, 2011-2023



Source: Eurostat, IEA and authors' calculations.
Note: Based on the period 2011 through March 2023.

Figure 3: Gas consumption and industrial production in Poland, 2011-2023



Source: Eurostat and authors' calculations.
Note: Based on the period 2011 through March 2023. Non-seasonally adjusted index of industrial production is adjusted for a constant rate of energy efficiency improvements.

Table 1: Descriptive statistics

Variables	Mean	Median	St. dev.	Min	Max
Industrial production, log change	-0.018	-0.014	0.169	-1.503	1.240
Carbon intensity, log	3.721	3.591	1.305	2.023	6.600
Gas intensity, log	5.731	5.318	1.189	4.309	8.033
Electricity intensity, log	5.678	5.779	0.979	4.069	7.445
Share of industry in industrial production	0.043	0.027	0.050	0.000	0.390
Average price, euro/kwh, gas	0.124	0.115	0.035	0.083	0.221
Average price, euro/kwh, electricity	0.247	0.246	0.060	0.142	0.360
Average price, gas, log change	0.702	0.701	0.227	0.326	1.331
Average price, electricity, log change	0.486	0.514	0.220	0.059	0.897

Source: National authorities, Eurostat and authors' calculations.
Note: Based on 499 industry-economy observations for the winter of 2022-23. Electricity and gas prices are averages across all price bands for the industry.

Table 2: Elasticity of gas consumption with respect to weather

Period	2015-23				2019-23
Dep. var: Log gas consumption	1	2	3	4	5
Industrial production, adjusted, log	0.240	0.241	0.174	0.540***	0.547**
	(0.142)	(0.178)	(0.165)	(0.195)	(0.208)
Temperature deviation from threshold	0.058***	0.044***	0.045***	0.041***	0.046***
	(0.005)	(0.011)	(0.004)	(0.005)	(0.008)
Country F	Yes	Yes			
Month FE		Yes			
Year FE		Yes	Yes		
Country*Month FE			Yes	Yes	Yes
Month*Year FE				Yes	Yes
Country * Year FE				Yes	Yes
R^2	0.970	0.973	0.984	0.991	0.994
Observations	2,553	2,553	2553	2,553	1,450

Source: Authors' calculations.

Note: Standard errors in parentheses are clustered at the country level. ***, ** denote statistical significance at the 1% and 5% levels, respectively. The dependent variable is logarithm of gas consumption in a given economy in a given month. Temperature deviation is calculated downward from 15C. Adjusted industrial production assumes a secular rate of energy efficiency improvements in the industry of 1.8 percent per annum.

Table 3: Decomposition of change in gas consumption during the winter of 2022-23, by economy, percentage points

Economy	(1) Gas consumption	(2) Warm weather	(3) Industrial output	(4) Industrial structure	(5) Fossil fuel electricity	(6) Renewable electricity	(7) Residual
Austria	-20.1	0.4	-6.1	-0.2	-0.5	-1.9	-11.8
Belgium	-9.5	-3.3	-2.1	-8.2	0.0	1.1	3.0
Bulgaria	-24.5	-2.2	-10.9	-2.5	0.0	-0.6	-8.3
Croatia	-19.5	-3.2	-5.2	-7.0	0.0	-0.3	-3.7
Czech R.	-14.7	0.3	-3.5	-7.9	0.0	-1.0	-2.6
Denmark	-13.5	10.1	-0.3	-2.0	0.8	0.0	-22.1
Estonia	-31.8	-11.7	-1.0	-12.8	0.0	0.0	-6.4
Finland	-39.4	-1.4	-3.2	-0.4	0.0	-4.1	-30.2
France	-15.9	-2.2	-3.3	-4.3	0.6	0.7	-7.4
Germany	-15.1	-2.1	-3.0	-7.6	-0.1	0.0	-2.4
Greece	-33.6	-1.2	-6.1	5.0	-1.4	-5.9	-24.0
Hungary	-24.6	-1.9	-7.7	-21.3	-0.1	-0.9	7.3
Italy	-23.0	-3.9	-4.3	-6.9	5.4	2.4	-15.6
Latvia	-15.9	-4.7	-0.4	-8.2	0.0	1.7	-4.4
Lithuania	-26.2	-8.3	-1.3	-‘17.4	0.0	1.3	-0.4
Netherlands	-15.3	-3.3	-0.3	-4.7	0.0	-0.4	-6.7
Poland	-9.3	-0.2	-2.9	-5.8	0.1	0.0	-0.5
Portugal	-16.5	-1.4	-0.2	-0.1	0.0	-6.0	-8.7
N. Macedonia	-35.7	-4.0	-8.5	-8.6	-11.8	-3.8	1.0
Romania	-16.6	-5.7	-8.7	-15.8	0.1	0.0	13.5
Slovak R.	-16.5	-6.8	-6.3	-11.2	0.0	-1.6	9.4
Slovenia	-16.0	-6.7	-8.2	-9.8	2.3	0.0	6.5
Spain	-19.7	-1.1	-3.5	-4.2	0.0	-3.0	-7.9
Sweden	-23.6	-0.3	-0.2	-1.6	0.1	0.7	-22.2
Turkiye	-20.4	-1.7	-7.8	-8.9	-1.4	0.0	-0.5
Average	-20.7	-2.7	-4.2	-6.9	-0.2	-0.9	-5.8
Norway	32.3	-1.0	-2.7	-1.4	0.0	0.0	37.3

Source: Authors' calculations based on Eurostat, IEA.

Note: The table presents decomposition of the reduction in gas consumption during Oct 2022 - March 2023 relative to October 2021 - March 2022, in percentage points.

Table 4: Industry characteristics

Industry	Carbon intensity	Average share of industrial output	Average growth rate	Contribution to growth	Contribution to change in gas consumption
Repair of equipment	8.4	2.1	8.3	0.1	0.0
Apparel	40.0	1.6	5.2	0.0	0.0
Basic metals	638.3	4.7	-2.4	-0.3	-1.6
Beverages	58.5	1.8	1.7	0.0	0.0
Chemicals	202.5	6.0	-16.4	-1.0	-2.1
Coke and petroleum	415.3	5.4	-3.5	0.0	-0.2
Computer electronics	9.7	4.6	17.8	0.3	0.0
Electrical equipment	8.2	4.9	8.1	0.4	0.0
Fabricated metals	22.0	7.1	-0.3	-0.1	0.0
Food products	58.5	13.6	-1.6	-0.2	-0.2
Furniture	42.5	2.1	-8.9	-0.2	-0.1
Leather	40.0	0.6	4.7	0.0	0.0
Machinery and equipment	10.6	7.7	4.9	0.3	0.0
Motor vehicles	20.2	8.3	13.4	1.2	0.2
Non-metalic minerals	803.8	3.4	-7.7	-0.2	-2.3
Other transport equipment	10.2	1.8	6.2	0.1	0.0
Paper	252.3	2.9	-9.2	-0.3	-0.7
Pharmaceuticals	24.6	4.2	12.8	0.6	0.2
Rubber and plastics	28.1	4.7	-6.4	-0.3	-0.1
Textiles	40.0	1.7	-8.0	-0.1	0.0
Tobacco	58.5	0.9	-3.9	-0.1	-0.1
Wood	20.2	4.0	-6.4	-0.3	-0.1
Mining of coal	508.3	0.6	-8.3	0.0	-0.1
Mining of metal ores	508.3	1.1	-7.1	0.0	0.0
Other mining and quarrying	508.3	0.8	8.4	0.0	0.0
Mining support services	508.3	0.3	2.5	0.0	0.0
Printing and recorded media	52.4	1.3	-6.5	-0.1	-0.1
Water supply	142.0	0.8	-2.6	0.0	0.0

Source: Authors' calculations based on Eurostat, IEA.

Note: Carbon intensities are based on data for Germany; industrial shares and contributions are simple averages across all economies in the sample. Excludes energy supply.

Table 5: Change in industrial output, energy prices and energy intensities

Dep. var.: Log-change in ind. output	(1)	(2)	(3)	(4)
Electricity intensity, log*Electricity price	-0.263*		-0.084	
	(0.135)		(0.130)	
Gas intensity, log*Gas price	0.045		0.011	
	(0.125)		(0.111)	
Electricity intensity*Δ electricity price		-0.102**	-0.089**	-0.091**
		(0.046)	(0.043)	(0.041)
Gas intensity*Δ gas price		0.028	0.031	
		(0.034)	(0.035)	
Share of industry in industrial production	0.342*	0.351*	0.345*	0.379*
	(0.197)	(0.202)	(0.200)	(0.197)
Industries	23	23	23	23
Economies	24	24	24	25
R^2	0.293	0.301	0.302	0.298
Observations	481	481	481	499

Source: Authors' calculations based on Eurostat, IEA.

Note: Robust standard errors in parentheses. ***, ** denote statistical significance at the 1% and 5% levels, respectively. The dependent variable is the change in the logarithm of industrial production in a given industry in a given economy, October 2022-March 2023 relative to the previous winter. All specifications include industry and economy fixed effects.

Table 6: Robustness tests

Dep. var.: Log-change in industrial output		Carbon intensity			Placebo carbon intensity	
	(1)	(2)	(3)	(4)	(5)	(6)
Carbon intensity, log*Electricity price	-0.183**		0.000	-0.014		-0.066
	(0.084)		(0.077)	(0.083)		(0.096)
Carbon intensity, log*Gas price	0.082		0.068	-0.141		-0.115
	(0.128)		(0.104)	(0.125)		(0.116)
Carbon intensity* Δ electr. price		-0.097***	-0.099***		0.018	0.030
		(0.033)	(0.031)		(0.031)	(0.029)
Carbon intensity, log* Δ gas price		0.040	0.037		-0.028	-0.019
		(0.040)	(0.040)		(0.037)	(0.040)
Share of industry in ind. prod.	0.350*	0.291	0.290	0.368*	0.380*	0.365*
	(0.201)	(0.204)	(0.205)	(0.199)	(0.206)	(0.202)
Industries	23	23	23	23	23	23
Economies	24	24	24	24	24	24
R^2	0.292	0.309	0.310	0.287	0.288	0.289
Observations	481	481	481	481	481	481

Source: Authors' calculations based on Eurostat, IEA.

Note: Robust standard errors in parentheses. ***, ** denote statistical significance at the 1% and 5% levels, respectively. The dependent variable is the change in the logarithm of industrial production in a given industry in a given economy, October 2022-March 2023 relative to the previous winter. All specifications include industry and economy fixed effects. Placebo carbon intensities are assigned by using carbon intensities of the next industry on the list presented in Table 4.