The Network Incidence of the 2022 European Energy Crisis

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Abstract

We trace the 2022 European energy price shock through the production network and decompose its incidence on industries, output, and workers. A partitioned Leontief price model on the World Input-Output Database (2,464 industry-by-country units) attributes about half of the total cost shock to the upstream supply-chain channel—48% among the 29 directly-shocked economies and 54% once downstream importer economies are included—so a screen on an industry's own energy use misses much of the incidence. Moreover, a substantial part of the upstream burden crosses borders, and natural gas is the largest single carrier. Split by destination—sold to final demand or used as an intermediate—more than half the cost-push falls on intermediate-bound goods. By contrast, a CES substitution scenario for the implied output and employment magnitude is sign-sensitive, so we read the aggregate magnitude as uncertain and validate the channels against realized 2019–2023 outcomes. In addition, instrumenting exposure with pre-crisis Russian-gas dependence, more-exposed industries contracted, and the decline loads on imported rather than own energy reliance. Because identification rests on a small, concentrated set of country shifters, we test the cross-border output effect with few-shocks randomization inference, and it survives; the realized employment loss is identified separately by its crisis timing and runs through the domestic upstream channel. The aggregate magnitude remains uncertain. Overall, exposure concentrates in the gas-dependent economies of Central and Eastern Europe (most exposed: Romania), and 41% of European workers are in industries where the shock is mostly indirect.

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1 Introduction

The 2022 European energy crisis, triggered by the disruption of Russian natural gas supplies following the invasion of Ukraine, was one of the largest input-cost shocks to hit advanced economies in decades, and one whose geopolitical origin makes it largely exogenous to any individual industry's conditions: industrial gas prices roughly tripled and electricity prices roughly doubled. Because industries are linked through input-output relations, the burden of such a shock does not stay where it lands: an industry's effective cost increase reflects its own energy purchases and, recursively, the energy embodied in everything it buys (Acemoglu et al., 2012; Carvalho et al., 2021). As a result, who ultimately bore the crisis—which industries, which countries, and which workers—depends on the structure of the production network, not just on who burns the gas. However, the policy response was overwhelmingly targeted at visible, direct energy use (Kremer et al., 2025).

This paper traces the shock through the European production network and decomposes its incidence at three levels: cost, output, and employment. In particular, we build on the input-output decomposition that de Ruijter and Dustmann (2025) develop for the China trade shock—which separates the total effect of a shock into *direct* and *upstream* (supply-chain) components, and each into domestic and international parts—and adapt it to an energy cost-push shock on the World Input-Output Database (Timmer et al., 2015), 2,464 industry-by-country units across 44 regions. In the case of the realized cost shock, the decomposition admits an exact identity over direct and upstream channels, crossed with domestic and international origin and with the energy carrier (gas, electricity, oil) that carries it. A final-versus-intermediate destination axis extends the cost decomposition, exact because the price model is linear. The implied output and employment effects, by contrast, are not pinned down by accounting alone: a CES substitution scenario brackets their magnitude and, consistent with the "power of substitution" critique (Moll et al., 2023), that magnitude is sign-sensitive. Consequently, we validate the channels and the sign of the effect against realized 2019–2023 industry outcomes—instrumenting the decomposed exposures with countries' pre-crisis Russian-gas dependence, with inference suited to the design's small number of shocks—while leaving the aggregate magnitude uncertain.

On the WIOD network as a whole the upstream channel accounts for 54% of the total cost shock; among the 29 directly-shocked economies, where the direct and upstream channels are comparable in scale, the upstream share is 48% against 52% direct. Overall, a screen based on an industry's own energy intensity misses about half of the incidence on either universe. Moreover, a substantial part of the upstream burden—roughly one-third to one-half across networks and weightings—crosses borders, and natural gas is the largest single carrier under the baseline weights. In particular, exposure is highly uneven: the energy-intensive, gas-dependent economies of Central and Eastern Europe are hit hardest, with Romania the most exposed at a total cost shock of 15.7% of gross output, several times the exposure of the least-affected Western economies. In the realized 2019–2023 data, more-exposed industries contracted, and the decline loads on imported rather than own energy reliance: instrumenting with foreign suppliers' Russian-gas dependence, a unit of imported-energy exposure maps to a -2.02 log-point fall in output while the own-energy coefficient is essentially zero. Because identification rests on a small, concentrated set of country shifters, we test the cross-border output effect with few-shocks randomization

inference and the recentering that non-random exposure requires; it survives ($p = 0.027$). That cross-border channel is identified for output, not jobs: the realized employment loss is identified instead by its crisis timing and runs through the domestic upstream channel (-2.42 instrumented, robust to detrending). Finally, 41% of European workers are employed in industries where the shock is mostly indirect, so for two in five workers an own-industry energy screen misclassifies their exposure.

We connect several literatures. Relative to the macro work on the crisis, which estimates the aggregate cost of a hypothetical embargo in structural models (Bachmann et al., 2024; Moll et al., 2023; Baqaee and Farhi, 2024; di Giovanni et al., 2023), we attribute the realized shock to named network channels and separate domestic from international propagation. Relative to the firm- and industry-level studies of the crisis's realized impact (Alpino et al., 2025; Bijnens et al., 2021; De Santis, 2024), which estimate energy-cost effects within a single country or in the aggregate, we trace the shock through the cross-border production network and ask where the incidence lands. Relative to the input-output propagation literature (Acemoglu et al., 2012; Carvalho et al., 2021; Baqaee and Farhi, 2019) and the nearest neighbor on the crisis (Ipsen et al., 2025)—a direct-versus-indirect EU inflation stress test that documents asymmetric core-to-periphery propagation but stops short of a per-industry domestic/international split—we add the cross-border, carrier, and destination dimensions and a worker-incidence validation. Relative to the energy cost pass-through literature (Fabra and Reguant, 2014; Ganapati et al., 2020; Adolfsen et al., 2024), which is typically single-sector or partial-equilibrium, we measure pass-through through the full network. Finally, we adapt the embodied-content-of-trade tradition (Johnson and Noguera, 2012; Koopman et al., 2014) and a global-value-chain output decomposition (Antràs and Chor, 2022; de Ruijter and Dustmann, 2025) from trade to energy, and validate it with a shift-share design (Borusyak et al., 2022; Adão et al., 2019b), with inference suited to its small number of concentrated shocks (Borusyak and Hull, 2023; Alvarez et al., 2022; Borusyak et al., 2025).

Section 2 sets out the cost decomposition (and distinguishes the two input-output models we use). Section 3 describes the data. Section 4 presents the cost-incidence results, including the carrier decomposition; Section 5 the sectoral heterogeneity. Section 6 completes the cost anatomy with a destination axis and brackets the implied output effect; Section 7 tests the exposures against realized outcomes. Section 8 maps incidence onto workers; Section 9 evaluates whether policy reached the upstream burden. Finally, Section 10 presents robustness checks, and Section 11 concludes.

2 The channel decomposition

The economy is an inter-country input-output system with 44 regions and 56 sectors, indexed by industry-by-country units $i = 1, \ldots, 2,464$. Let Z_{ij} be intermediate sales from i to j and x_j gross output. In addition, input coefficients are $a_{ij} = Z_{ij}/x_j$ (matrix $\boldsymbol{A}$), which we partition $\boldsymbol{A} = \boldsymbol{A}^{\text{dom}} + \boldsymbol{A}^{\text{int}}$ into within-country and cross-country blocks. Throughout, the units split into energy $E = \{\text{B, C19, D35 in every country}\}$ and non-energy M.

The crisis enters as a jump in the output prices of the energy-supplying sectors. For $e \in E$ the exogenous proportional price shock is $\widehat{p}_e$: for electricity/gas supply (D35), $\widehat{p} =$

$w\,\widehat{p}_n^{\text{elec}} + (1-w)\,\widehat{p}_n^{\text{gas}}$; for refined petroleum (C19), $\widehat{p} = \widehat{p}^{\text{oil}}$; for mining (B), $\widehat{p} = w\,\widehat{p}_n^{\text{gas}} + (1-w)\,\widehat{p}^{\text{oil}}$, with baseline $w = \frac{1}{2}$. The carrier changes are the 2019–2022 proportional changes in non-household industrial electricity and gas prices in country n and in Brent crude oil. Note that the shock reaches only the European countries with price data, which scopes the exercise to the European crisis.

An industry's direct cost shock is its energy purchases revalued,

$$\Delta c_j = \sum_{e \in E} a_{ej}\,\widehat{p}_e, \tag{1}$$

In words, this is $\sum_f \alpha_j^f\,\widehat{p}_j^f$ with energy-input cost shares $\alpha_j^f = \sum_{e(f)} a_{ej}$. As a result, using the energy sectors' own coefficients keeps the measure internally consistent with the table and free of any external industry mapping.

Energy-sector prices are exogenous, so non-energy prices solve the Leontief price model among themselves, $\Delta p_M = \boldsymbol{A}'_{MM}\Delta p_M + \Delta c_M$, i.e.

$$\underbrace{\Delta p_M}_{\text{total}} = (\boldsymbol{I} - \boldsymbol{A}'_{MM})^{-1}\Delta c_M = \underbrace{\Delta c_M}_{\text{direct}} + \underbrace{\left[(\boldsymbol{I} - \boldsymbol{A}'_{MM})^{-1} - \boldsymbol{I}\right]\Delta c_M}_{\text{upstream}}. \tag{2}$$

Because $\boldsymbol{A}_{MM}, \Delta c_M \geq 0$, upstream ≥ 0.[1] Next, we split upstream into the part running only through domestic suppliers and the remainder:

$$\begin{aligned} \text{upstream}^{\text{dom}} &= \left[(\boldsymbol{I} - \boldsymbol{A}^{\text{dom}\prime}_{MM})^{-1} - \boldsymbol{I}\right]\Delta c_M, \\ \text{upstream}^{\text{int}} &= \text{upstream} - \text{upstream}^{\text{dom}} \geq 0. \end{aligned} \tag{3}$$

The nested attribution loads the domestic×international interaction onto the international term; we report a symmetric (Shapley) variant as a robustness check (Dietzenbacher and Los, 1998).

The decomposition is an accounting identity, not an instrumental-variables design, and its credibility rests on three assumptions, each stated and tested rather than assumed away. First, shock exogeneity: 2022 energy prices were driven by the geopolitical supply disruption, with Europe a near price-taker on world gas and oil markets (Känzig, 2021). Second, a stable network, under which the 2014 coefficients approximate 2022; this holds up across vintages and against the OECD inter-country table. Third, fixed coefficients, ruling out short-run input substitution and making (2) an upper bound on propagation. This last assumption is the Moll et al. (2023) "power of substitution" point: substitution away from gas was larger than feared, so the Leontief magnitudes bound the true propagation from above, and the nonlinear general-equilibrium magnitude belongs to the structural literature (Baqaee and Farhi, 2019; Bachmann et al., 2024).

The paper uses two distinct and easily conflated Leontief objects. Consider first the *cost* (price) model above, which operates on the transpose, $\Delta p = (\boldsymbol{I} - \boldsymbol{A}')^{-1}\Delta c$: a unit's

[1] The inverse $(\boldsymbol{I} - \boldsymbol{A}'_{MM})^{-1}$ exists and is nonnegative because the WIOD coefficient matrix is productive: its spectral radius is below one (the Hawkins–Simon condition), which we verify directly, so the Neumann series $\sum_{k\geq 0}(\boldsymbol{A}'_{MM})^k$ converges to a nonnegative inverse.

cost rises with the prices of its inputs, recursively. Indeed, its natural axes are direct versus upstream, where the cost originates, and domestic versus international, where the embodied energy is sourced—the price-side analogue of the embodied factor content of trade (Johnson and Noguera, 2012; Koopman et al., 2014). In addition, a final-versus-intermediate axis follows from weighting each unit's price increase by where its output goes, to final demand or to intermediate use, which yields the cost anatomy of Section 6. By contrast, the *quantity* model, $\boldsymbol{Y} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{D}$, maps a change in final demand $\boldsymbol{D}$ and technology $\boldsymbol{A}$ into gross output, and it serves only the implied output effect, which is sign-sensitive (Section 6). Finally, the realized-data validation in Section 7 speaks to the channels and the sign, not to a precise level. In short, the two models answer different questions, and their levels are not directly comparable (Dietzenbacher, 1997).

3 Data

The analysis draws entirely on public sources. In particular, the production network comes from the WIOD 2016 release (Timmer et al., 2015), which spans 44 regions (43 countries plus a rest-of-world aggregate) and 56 sectors, for 2,464 industry-by-country units in total. We treat the 2014 table as the baseline network and read gross output directly from it. In addition, alternative WIOD vintages and the OECD ICIO 2018 tables enter the robustness analysis in Section 10.

In terms of carrier prices, proportional fuel price changes between 2019 and 2022 combine Eurostat industrial gas and electricity prices for industrial consumption bands, net of recoverable VAT, with the Brent crude oil price from FRED. Across the 29 European countries with price data, the median industrial electricity price rose by 102% and gas by 197% over this window, while Brent rose by 57%.

We measure each industry's *energy intensity* by its input coefficients from the three energy-supplying WIOD sectors—mining (B), coke and refined petroleum (C19), and electricity, gas, and steam supply (D35). As a result, this measure stays internally consistent with the input-output table and avoids mapping physical energy balances onto WIOD sectors.

Finally, national price caps and subsidies are characterized from the Bruegel fiscal-response tracker and feed the policy counterfactual of Section 9. Table 1 reports summary statistics of the decomposition across non-energy industries.

4 Cost incidence across the network

The energy-cost shock reaches most industries chiefly through the production network rather than through their own fuel purchases. Consider first the aggregate. Pooling all non-energy industries across the 44 regions of the network, the upstream channel accounts for 54% of the total cost shock, exceeding the direct channel; among the 29 directly-shocked economies, where exposure is interpretable and direct and upstream are comparable in scale, the two are closer (upstream 48%, direct 52%). In short, a measure built on an industry's own energy intensity alone understates the network incidence by roughly half.

This pattern holds for the bulk of European production, not just for small sectors that buy little energy directly. Indeed, weighting non-energy industries by gross output, 58% of output sits in industries where the majority of the energy-cost exposure is indirect, arriving through energy-intensive intermediates rather than through the industry's own fuel use (Figure 1). As a result, a screen based on direct intensity would miss precisely these units.

Of course, a direct-intensity screen does identify broadly the same set of industries: direct and total exposure are highly rank-correlated (Spearman 0.93). What such a screen gets wrong is the magnitude and the tail. Because the upstream channel is 54% of the total, a direct measure captures under half the true incidence; and a screen that flags the most energy-intensive quarter of output still misses 18% of the most-exposed quarter ranked by total exposure and 22% of the most-exposed quarter of employment—roughly 13 million European workers in industries exposed mainly through their suppliers (Table 2).

Countries differ markedly in their exposure, and the cross-border component is large. Figure 2 decomposes the output-weighted shock by country into direct, domestic-upstream, and international-upstream channels. In particular, the energy-intensive, gas-dependent economies of Central and Eastern Europe bear the largest total cost shocks: the most exposed is Romania, at 15.7% of gross output, several times the exposure of the least-affected Western economies. These extreme-exposure economies are hit mainly through their own energy intensity—57% of Romania's exposure is direct—so the upstream dominance in the aggregate is a property of the many moderately-exposed downstream industries rather than of the most-exposed few. Moreover, the international-upstream channel is large: 48% of all upstream exposure crosses borders on the WIOD network. Indeed, energy-intensive intermediates from the largest producers raise costs for downstream manufacturing elsewhere in the Union, and alternative networks and weightings place the cross-border share at roughly one-third to one-half (Section 10).

Turning now to the carriers, the shock also decomposes cleanly across them. Because each energy sector's price shock is a fixed linear combination of the three carrier price changes and the price inverse is linear, the total cost shock splits into gas, electricity, and oil components, each in turn divided into direct, domestic-upstream, and international-upstream parts (Figure 3). Note that natural gas is the largest carrier at the baseline weights, 48% of the total cost shock against 30% for oil and 22% for electricity, and the gas component is itself 54% upstream, with about half crossing borders. However, the split is sensitive to how the aggregate energy sectors' output prices are built from carrier prices: the gas share ranges from 32% to 62% across the carrier-mix weights, and at high electricity weights electricity rivals gas. The conclusion is therefore that gas is the dominant carrier rather than a sharp point estimate, and a precise attribution would require physical energy-balance weights. In addition, the carrier on which the network is most exposed bears directly on policy design, since a cap on wholesale gas prices reaches a different and larger slice of the network than a measure targeting electricity retail prices or fuel duties.

Importantly, all magnitudes here are computed under fixed input coefficients and are therefore an upper bound on cost propagation; the true figures, net of short-run substitution (Moll et al., 2023), are lower, and Section 6 examines that substitution explicitly. Finally, the aggregate split also masks sharp differences across broad sectors, the subject of the next section.

5 Heterogeneity across sectors

Incidence varies sharply across broad sectors. Consider first manufacturing, which bears the largest cost shock, 6.7% of output, more than double the 2.8% borne by services, and splits roughly evenly between the direct and upstream channels, with an upstream share of 51%. By contrast, services account for the majority of output and employment yet face a smaller shock that is 42% upstream. Their direct energy intensity is low, at 1.6% of output, but they remain exposed through the supply chain. Finally, construction is the most upstream-exposed group: almost two-thirds of its cost shock arrives through energy-intensive materials such as cement, steel, and glass rather than from a contractor's own fuel use.

Taken together, these patterns qualify a simple reading in which services are insulated. Indeed, services are less exposed in aggregate, but much of the exposure they carry is upstream and would be missed by an own-industry energy-intensity screen. Because employment is concentrated in services and construction, a large fraction of the labor incidence (Section 8) runs through the network rather than through workers' own industries. The next section completes the cost anatomy with a third axis—where the priced output lands—before turning to the implied effect on output and jobs.

6 The anatomy of the cost-push: origin, sourcing, and destination

Recall that Section 4 split the cost shock by where it originates (direct versus upstream) and how the embodied energy is sourced (domestic versus international). A third axis completes the anatomy: where the priced output lands. Note that each industry's cost increase is borne on output that is either sold to final demand or used as an intermediate by other firms, and the part embodied in intermediates keeps propagating down the chain. Because the cost-push price model is linear, the destination axis adds no approximation. In effect, it requires no behavioral counterfactual and, unlike the implied-output scenario below, no sign assumption.

In words, the construction weights each unit's cost-push price increase Δp_j by the share of its output going to final demand (D_j) versus intermediate use ($x_j - D_j$), and crosses this with the origin and sourcing axes. The result is an exact eight-cell decomposition of the total cost-push, $\{\text{direct, upstream}\} \times \{\text{domestic, international}\} \times \{\text{final, intermediate}\}$ (Appendix A). Together, Table 4 and Figure 5 report the cells as shares of the total. The origin and sourcing margins reproduce the Section 4 headline by construction—upstream 54%, of which 48% crosses borders—and the new information is the destination split: 56% of the cost-push is borne on output sold as intermediates, against 44% on final goods. This is a modest tilt rather than a sharp concentration: the output-weighted baseline intermediate share over the same universe is 50%, so the cost-push falls only somewhat more on intermediate-bound output than output does on average. This destination axis re-slices the same total cost-push by where the priced output lands; it does not add a further round of propagation. For example, the single largest cell, 20.2% of the total, is own-

energy cost embodied in intermediate-bound output. Indeed, splitting the direct channel by energy origin shows that 21% of it is imported energy, so even own-energy use carries a cross-border component; in all, 36% of the cost-push is foreign-sourced. Across European non-energy industries the cost-push averages 4.1% of gross output. Throughout, this is a gross-output cost-push accounting object—the first-round revaluation of production costs at fixed quantities—not a final-demand or welfare incidence, which requires the behavioral quantity model below.

On the other hand, the cost-push maps into output and jobs only through the quantity model $\boldsymbol{Y} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{D}$ together with a behavioral counterfactual: firms substitute away from energy (nested CES, $\sigma_E = 0.20$) and final demand falls with prices ($\widetilde{D}_i = D_i\, p_i^{-\eta}$, $\eta = 0.20$). From this, the de Ruijter and Dustmann (2025) eight-cell output decomposition (Appendix B) yields an implied European effect of -0.27% of gross output. This number is an illustrative scenario rather than an estimate, because its net magnitude is sign-sensitive (Table 5): -0.77% with no substitution, but mildly positive (0.40%) at high σ_E. That flip is an accounting artifact. To see this, decomposing the net effect, the demand-destruction term is robustly negative (-0.77% of output), while the technology cells are positive (0.50%): as firms re-source toward non-energy and domestic suppliers, those suppliers' gross output rises through additional intermediate transactions, without a real gain, and at high σ_E this reallocation term outweighs the demand loss. What is stable across the elasticity grid is the composition: the upstream share stays 40–55% and the international share near 20%, in line with the cost anatomy above. Overall, the aggregate magnitude stays bracketed: Section 7 validates the channels and the sign of the effect against realized data, while the level remains genuinely uncertain.

7 Validation against realized outcomes

The decomposition is an accounting identity, and on its own it carries no claim about behavior. If the channels it isolates are economically real, then industries more exposed through them should have fared worse as the crisis hit. To see this, we take the channels to realized national-accounts data and instrument exposure with a feature of the shock plausibly orthogonal to an industry's own demand: its own and its suppliers' dependence on Russian gas.

Consider first the data. The unit of observation is a country $\times$ industry cell. Outcomes are the log change in real gross output (chain-linked volumes), real value added, and employment (persons) from Eurostat national accounts, mapped to WIOD sectors one-to-one for 55 of 56 sectors. In particular, value added is the welfare-relevant measure: it nets out the intermediate-transaction churn that drives the sign-sensitivity of the gross-output scenario in Section 6. The regressors are the predetermined (2014-network) exposures of Section 2. We estimate

$$\Delta \log y_{cs} = \beta_1 \,\mathrm{Direct}_{cs} + \beta_2 \,\mathrm{Up}^{\mathrm{dom}}_{cs} + \beta_3 \,\mathrm{Up}^{\mathrm{int}}_{cs} + \boldsymbol{x}'_{cs}\boldsymbol{\gamma} + \alpha_c + \varepsilon_{cs}, \tag{4}$$

with country fixed effects α_c, so identification comes from within-country cross-industry variation; controls $\boldsymbol{x}$ are a 2017–2019 pre-trend and log baseline size. In addition, for the

key coefficients we report standard errors clustered by industry and two-way by country and industry, and the Adão et al. (2019b) exposure-robust standard error, which treats the country-level Russian-gas shifters as the source of identifying variation. Turning to the instrument, it re-runs the decomposition with each country's pre-crisis (2019–2021) Russian-gas import share in place of the realized carrier-price change—predetermined network shares times a geopolitical shifter (Borusyak et al., 2022; Adão et al., 2019b). The instrument applies the same network operator to a different shifter, so its first-stage F is mechanically large; relevance is therefore not the question. What identification rests on instead is the shifter—Russian-gas dependence—being as-good-as-random conditional on the country fixed effects and the predetermined shares. That variation is a small and concentrated set of shifters—an effective number of about 9, dominated by a handful of gas-dependent suppliers—so the exposure-robust error's many-shock asymptotic is itself demanding here, and for the cross-border result we test significance by randomization as well. Finally, Table 6 documents the sample, which runs from 2,332 non-energy units to 749 output and 1450 employment cells; the included cells are not an exposure-selected subset.

Two results come out of the realized data, and they are identified off different variation. A cross-border effect on *output* is identified by a leave-out instrument in foreign suppliers' Russian-gas dependence; an effect on *employment* is identified by its crisis timing and runs through the domestic upstream channel. We take them in turn.

The cleanest cross-sectional design splits exposure by the origin of the energy—domestically produced versus imported—and instruments each part with the corresponding country's Russian-gas dependence (the "IV: own/supp" columns of Tables 8–10). Note that the imported-energy instrument is a genuine leave-out shifter: it varies with foreign energy systems' Russian reliance, plausibly orthogonal to the home industry's own demand in a way that an industry's own energy intensity is not. Turning to the estimates, the contraction loads on the imported part: a unit of imported-energy exposure maps to a -1.83 log-point fall in output, while the own-energy coefficient is small and insignificant. Estimated as a single endogenous regressor (Table 11), the output effect is -2.02 log points.

Identification here rests on only an effective 9 country-level shifters, with exposure concentrated in a few large suppliers, so the exposure-robust standard error—which assumes many shocks—is not enough on its own. Therefore, we test significance by randomization, re-drawing the Russian-gas shifter across the shocked countries and rebuilding the instrument (Alvarez et al., 2022; Borusyak et al., 2025). Because the raw network instrument carries a mechanical component—a unit's total foreign-energy exposure, which is itself correlated with industry composition—valid inference recenters the instrument by its expected value under the reassignment (Borusyak and Hull, 2023). In particular, under the recentered randomization test the output effect is significant ($p = 0.027$), and stable across permutation, bootstrap, and parametric draws and across alternative test statistics; the unrecentered test does not separate it ($p = 0.27$), which is precisely the mechanical component the recentering removes. Moreover, the recentered point estimate, -2.71 log points, is if anything larger and rests on a strong first stage. The output effect persists even when taking these perturbations into account: it is stable as any single home country or any of the six largest supplier countries is dropped, and adding a control for each unit's direct input share from Russian *non-energy* sectors—a war-exposure control that WIOD's

Russia rows make possible—leaves it essentially unchanged. Cross-border energy reliance, not home energy use alone, is what shows up in realized output.

By contrast, the cross-border channel is identified for output and not for jobs. Value added moves the same way and larger, -7.54 log points, but it is imprecise and does not survive the recentered randomization test ($p = 0.58$). Similarly, the cross-border *employment* coefficient, -1.33 log points, is significant under two-way clustering but not under the exposure-robust standard error or the recentered randomization test ($p = 0.9$); an event study on the own/imported split (Figure 7) shows the imported channel diverging only weakly after the 2021 benchmark ($p = 0.148$). Consequently, we do not read a cross-border jobs effect from these estimates. The realized employment incidence is identified instead by timing, to which we turn.

A natural worry for any employment effect is that energy-intensive industries were already declining, so a 2019–2022 change confounds the crisis with a trend. Figure 6 traces the year-by-year effect of each exposure channel on log employment from 2015 to 2023. Indeed, both channels decline through the period—energy-intensive industry has been shrinking for a decade—but they differ where it matters. First, the direct channel shows no crisis-specific break: its post-2022 fall is fully explained by its linear pre-trend ($p = 0.18$). Second, the upstream-domestic channel does break: net of a linear pre-trend it falls a further -0.46 log points after 2021 ($p = 0.031$), and net of sector-specific trends the break is -1.29 ($p = 0.0001$), with jointly insignificant pre-2019 coefficients ($p = 0.21$; Table 7). In short, the secular decline runs through firms' own energy use, while the crisis-timed employment loss runs through the network, identified off the timing rather than off the cross-section. We do not show an output event study. In practice, real gross output is too cyclical at this annual industry frequency for a clean continuous-treatment event study—a linear detrend over a window that includes the crisis tilts the pre-period—so the output result rests on the cross-sectional leave-out instrument above.

In addition, the cross-sectional channel decomposition agrees and locates the margin. Instrumenting the channels jointly (the "IV: channels" columns), employment loads on the domestic upstream channel: a unit of upstream-domestic exposure maps to a -2.42 log-point fall in employment, robust to two-way country-and-industry clustering (SE 0.65) and to dropping any single country (leave-one-out range $[-2.65, -1.93]$), while output declines load on the direct channel. Put another way, workers lost jobs when their suppliers used energy, as well as when their own industry did.

Finally, Tables 12 and 13 re-estimate the country-fixed-effects specification over three windows for output and employment respectively. Overall, the effects strengthen as the crisis fully materializes: by 2019–2023 a unit of direct exposure maps to a -1.02 log-point output fall, and employment declines load significantly on both the upstream-domestic (-1.39) and upstream-international (-1.85) channels. However, the single-year 2021–2022 window is noisier, since 2021 was itself a strong, uneven rebound year, so the 2019-anchored windows are the cleaner comparison.

Taken together, these regressions validate the channels and the sign of the effect, not a precise aggregate. Indeed, the two natural ways to scale it disagree by an order of magnitude. The bracketed model of Section 6 implies a few hundred thousand to roughly two million jobs, whereas extrapolating these cross-sectional IV coefficients across the European workforce implies a fall several times larger, of order 7.8 million—too large to

take literally, and a sign that the coefficients still absorb part of the secular decline despite the pre-trend controls. That is, a gap of this kind is expected rather than anomalous: a reduced-form cross-sectional elasticity is a local sufficient statistic, not the general-equilibrium total, because the macroeconomic response to a network shock turns on the substitution and factor reallocation that a linear extrapolation omits and that the first-order accounting cannot see (Baqaee and Farhi, 2019; Adão et al., 2019a). The network channel therefore has real, crisis-timed content, while the aggregate magnitude remains genuinely uncertain.

Of course, two caveats keep these estimates short of a structural total. They are industry-level, and the identifying variation comes from a modest, concentrated number of country-level shifters, so the point estimates are suggestive rather than definitive—which is exactly why the randomization inference above is appropriately demanding. With those caveats, the realized data support the decomposition's core message along two distinct identifications: a cross-border supply-chain effect that shows up in output and survives few-shocks randomization inference, and a crisis-timed employment loss that runs through the domestic upstream channel and is robust to detrending. In sum, the network channel is not an accounting artifact.

8 From cost incidence to labor incidence

The decomposition so far weights industries by gross output. The policy-relevant question, though, is how many workers are exposed and through which channel. In particular, we re-weight the exposure measures by employment (persons engaged, WIOD Socio-Economic Accounts, 2014) across the 229 million-strong workforce of the 29 European countries that received the price shock.

As before, the upstream channel remains large under this re-weighting. Table 14 compares output- and employment-weighted incidence for the European workforce. The upstream share of the total cost shock is 45% on an employment basis, against 48% on an output basis, so shifting the weights toward workers leaves the supply-chain channel intact. Indeed, the misclassification implied for a direct-use screen is more acute for workers than for output: 41% of European workers are employed in industries where the shock is mostly indirect, with upstream exposure exceeding direct. Thus, for two in five workers, an energy-intensity screen built on their own industry's direct fuel use would place them in the wrong exposure category.

Moreover, these workers are not confined to lightly exposed industries. Figure 8 distributes European employment across bands of total cost-shock size, split by dominant channel. For example, 68 million workers are in industries facing a total cost shock above 5% of output, and 15 million above 10%, and a large fraction of these sit in industries where the exposure is predominantly upstream. The employment-weighted country ranking in Figure 9 tracks the output-weighted one—the energy-intensive, gas-dependent economies of Central and Eastern Europe lead on both measures—while the gap between the two weightings flags economies where exposure concentrates in labor-intensive activities.

Public European data do not resolve skill by sector—the WIOD accounts carry no skill split, and the labor force survey cross-tabulates education with occupation rather than

industry—but they do resolve gender. In particular, re-weighting exposure by female versus male employment (EU Labour Force Survey, 2019), the energy-cost shock falls more on male employment (4.9% of output) than female (3.7%): men are concentrated in energy-intensive manufacturing. Note that the upstream channel is large for both (45% versus 41% of the respective totals), so the network reaches workers of both genders even where direct energy use does not (Table 15). Resolving the skill and occupation incidence—and pushing exposure down to the firm and the job—requires matched employer-employee data; we sketch that design, on Danish registers, in Appendix E.

In sum, this labor-incidence mapping is the bridge to the broader agenda. That is, the machinery that attributes an aggregate cost shock to network channels can attribute it to workers, the object of ultimate interest, and—with matched employer-employee data—to particular jobs and earnings.

9 Reaching the upstream burden: a price-cap counterfactual

If much of the incidence runs upstream and reaches workers through their suppliers, the design of the policy response turns on where in the network an instrument acts. Indeed, European governments responded to the crisis on a vast scale, and whether the instruments they used reached the part of the cost burden this paper isolates—the large upstream channel that propagates through input linkages—depends on that point of incidence.

Consider first a wholesale price cap, which offers a clean benchmark within the model. The cap limits the proportional rise in energy-carrier prices to at most c. We cap the 2019–2022 electricity, gas, and oil changes at c, rebuild the energy-sector shock, and recompute the decomposition. Together, Table 16 and Figure 10 trace the result. In particular, a cap that holds energy-price growth to $+50\%$ cuts the European output-weighted cost shock by 50%, and the upstream component falls by 49%—almost in proportion. A price cap therefore reaches the upstream burden alongside the direct one, and this is where price-side and demand-side instruments diverge under the cost-incidence frame. By contrast, a transfer to a household's energy bill does not lower the input costs propagating to firms through the network, whereas a cap on the energy-sector price attenuates the entire column—mechanically, by the linearity of (2). Naturally, household support may still matter through demand, wages, or political feasibility, channels that lie outside this frame.

The policies governments actually adopted leaned the other way. For example, the Bruegel fiscal tracker catalogues 678 national measures adopted across Europe between September 2021 and January 2023. This analysis draws on the measure-category coding rather than the euro allocations: reconstructing spending requires Bruegel's curation to de-duplicate umbrella programs and guarantees, and a raw sum overstates the published totals several-fold. In particular, of the catalogued measures, 74% included support to households and 42% to firms, with overlap across categories, and 56% worked through income support against 44% through reducing energy prices. Thus, the policy mix tilted toward household income transfers; price-based measures—the instrument the counterfactual shows reaches the upstream, firm-side incidence—accounted for under half.

The more exposed economies did not redirect their policy toward firms. However, a

euro-level targeting test would require Bruegel's curated national totals, which cannot be reliably reconstructed from the public measure-level tracker: a rule-based sum overcounts the published figures by an inconsistent factor of roughly 1.4–4.2 across countries, from umbrella programs, guarantees, and liquidity support. Therefore, using instead the reliably coded orientation of measures, Figure 11 relates the share of each country's measures directed at firms to its total exposure across 28 countries. The association is weak and statistically insignificant, with a Spearman correlation of 0.19 against total exposure and 0.29 against manufacturing exposure. In short, the most-exposed economies did not systematically tilt their policy mix toward firms. The test counts measures rather than euros, so it is suggestive, but it is consistent with national responses tracking the visible, household-facing side of the shock rather than its larger, firm-side incidence.

10 Robustness

The channel split is a property of the European network, not of any particular modeling choice. Indeed, Table 17 re-estimates the decomposition under 8 alternative specifications, each changing one choice at a time, and the two headline statistics are stable throughout. In particular, the upstream share of the total cost shock stays at 52–54%, and the international share of upstream stays in a 38–49% band, with Romania the most-exposed economy in every specification.

First, the channel split does not depend on the vintage of the production network. Substituting the WIOD 2000 or 2007 tables for the 2014 table—reaching back up to two decades—barely moves either share, because the cross-industry structure of energy reliance is slow-moving and a pre-shock vintage is not doing the work.

Second, a different data source delivers the same picture. In particular, the OECD ICIO 2021 tables for 2018 use a finer 45-industry classification with a dedicated energy-mining sector, span 71 regions, and describe a more recent, post-2014 network. There the upstream channel accounts for 46% of the total cost shock, against 54% in WIOD; Romania is again the most-exposed economy; and 32% of the upstream burden crosses borders. However, the cross-border share is lower than the WIOD band of 38–49%, so the two sources together place it at roughly one-third to one-half, with the WIOD headline magnitudes sitting at the upper end of that range.

Third, the decomposition is likewise a feature of the network rather than of any single price-measurement choice. Varying the output-price weight on electricity relative to gas ($w \in \{0.3, 0.5, 0.7\}$), the tax basis of the Eurostat industrial prices (excluding recoverable VAT, excluding all taxes, or including all taxes), and the consumption-band definition (broad industrial bands versus a single mid band) all leave the channel split essentially unchanged.

Finally, allowing input substitution moves the cost magnitudes but not the qualitative ranking. The levels in Sections 4–5 hold input coefficients fixed and form an upper bound on cost propagation; the CES substitution scenario of Section 6, with firms substituting away from energy at the realized prices ($\sigma_E = 0.20$), lowers those cost magnitudes without disturbing the composition. Even under the maximal one-shot substitution consistent with the price increases, the economy-wide energy input share falls only 4%, so the

upstream channel survives. In short, whether input coefficients are held fixed or allowed to substitute, upstream exposure exceeds direct exposure and a sizeable share of it crosses borders. Moreover, the realized-outcome regressions of Section 7, which impose no coefficient-stability assumption, supply the complementary check from the data side.

11 Conclusion

We have traced the 2022 European energy price shock through the production network and decomposed its incidence at three levels: cost, anatomy, and evidence. In particular, the upstream supply-chain channel accounts for 54% of the total cost shock, more than the direct channel, with 48% crossing borders and natural gas the largest single carrier. Exposure concentrates in the gas-dependent economies of Central and Eastern Europe; Romania is the most exposed, at 15.7% of gross output. Moreover, adding a destination axis to the cost decomposition shows that 56% of the cost-push falls on intermediate-bound output—modestly more than the 50% baseline—so most of the shock re-enters production rather than reaching final demand. By contrast, a CES substitution scenario for the implied output and employment magnitude is sign-sensitive, so we validate the channels and the sign in realized data and leave the aggregate magnitude uncertain. Overall, the decomposed exposures predict realized contractions along two distinct identifications: a cross-border output effect that survives few-shocks randomization inference with the recentering that non-random exposure requires, and a crisis-timed employment loss that runs through the domestic upstream channel and is robust to detrending—even as the aggregate magnitude stays uncertain.

Two themes carry to the broader agenda. First, conventional, direct-energy-intensity screens—the basis of much of the crisis policy response—capture the broad ranking of exposure but understate its magnitude (a direct measure sees under half the cost-push) and miss a sizeable tail: 41% of European workers are in industries hit mostly indirectly, and a within-model price cap (Section 9) reaches the upstream burden that household transfers do not. Second, the natural next step is to push the worker mapping down to matched employer-employee data, attributing the shock to particular jobs, earnings, and skills—the design we sketch on Danish registers in Appendix E. In sum, the same machinery that attributes a cost shock to network channels can attribute it to workers, the object of ultimate interest.

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Tables and Figures

Table 1. Summary statistics: energy cost shock decomposition (non-energy industries)

Channel	Mean	SD	Min	Max
Direct	0.0223	0.0370	0.0000	0.4904
Upstream (total)	0.0171	0.0172	0.0000	0.0994
of which domestic	0.0098	0.0127	0.0000	0.0867
of which international	0.0073	0.0079	0.0000	0.0581
Total	0.0394	0.0494	0.0000	0.5248

$N = 2,196$ industry×country units, 44 countries, WIOD 2014.

Notes: Cost shocks as a share of gross output. Upstream = total − direct from the partitioned Leontief price model $(I - A'_{MM})^{-1} d_M$ with energy-sector prices exogenous. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 2. A direct energy-intensity screen misclassifies exposure

Statistic	Value
Spearman rank correlation, direct vs. total exposure	0.93
Most-exposed quarter of *output* a direct screen misses	18%
Most-exposed quarter of *employment* a direct screen misses	22%
European workers in that missed group	13 mn

Notes: European non-energy industries. The "most-exposed quarter" is the set of units making up the top 25% of output (or employment) when ranked by *total* cost-shock exposure; the "direct screen" is the analogous top-25% set ranked by *direct* energy intensity. The miss rate is the share of the former not captured by the latter. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 3. Channel decomposition by broad sector (European, output-weighted)

Sector group	Direct (%)	Upstream (%)	Total (%)	Upstream share (%)	Output share (%)
Manufacturing	3.29	3.41	6.70	51	27
Water/waste	3.46	2.38	5.84	41	1
Agriculture	2.88	2.43	5.31	46	2
Construction	1.63	2.87	4.50	64	7
Services	1.62	1.16	2.79	42	63

Notes: Non-energy industries, European countries, weighted by gross output. "Upstream share" = upstream/total; "Output share" = group share of (non-energy) gross output. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 4. The cost-push by origin, sourcing, and destination (share of total, %)

Channel	To final demand	To intermediate use	Total
Direct, own energy	15.8	20.2	36.1
Direct, imported energy	3.6	6.2	9.9
Upstream, domestic	12.7	15.2	27.9
Upstream, international	11.3	14.8	26.1
Total	43.5	56.5	100

Notes: Each cell is a share of the total energy cost-push borne by non-energy industries. Rows split the price increase by where it originates (own energy vs. suppliers') and how that energy is sourced (domestic vs. imported/international); columns split it by whether the priced output is sold to final demand or used as an intermediate. The origin/sourcing margins reproduce the Section 4 headline; the destination split is new. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 5. Output and employment effect across CES substitution (σ_E) and final-demand (η) elasticities

	Output (% output)	Employment (000s)	Upstream (% abs)	Intermediate (% abs)	Int'l (% abs)
Vary σ_E (at $\eta = 0.2$)					
$\sigma_E = 0.0$ (no subst.)	-0.77	-1912	55	0	22
$\sigma_E = 0.1$	-0.51	-1332	49	25	21
$\sigma_E = 0.2$ (baseline)	-0.27	-779	46	40	20
$\sigma_E = 0.3$	-0.03	-254	43	49	19
$\sigma_E = 0.5$	0.40	720	40	60	19
Vary η (at $\sigma_E = 0.2$)					
$\eta = 0.1$	0.12	181	41	57	19
$\eta = 0.2$ (baseline)	-0.27	-779	46	40	20
$\eta = 0.3$	-0.65	-1727	48	30	20

Notes: European non-energy industries. Output effect = net of demand-destruction and substitution cells, % of baseline output; employment in thousands of persons. Composition columns are shares of the summed absolute cell magnitudes. Higher σ_E lets input substitution offset more of the demand loss. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 6. Sample flow and exposure balance

Sample	Units	Countries	Mean exposure (%)
WIOD non-energy units (global)	2,332	44	3.71
in Eurostat-reporting countries	1,537	29	5.37
output regression sample	749	16	5.73
employment regression sample	1,453	29	5.53

Notes: Attrition from the full set of non-energy units to the regression samples is driven by Eurostat national-accounts coverage (non-European regions are unobserved) and a few missing or non-positive cells. Mean total cost-shock exposure is similar across the reporting universe and the regression samples, so the included cells are not a high- or low-exposure selection. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 7. Pre-trends and the crisis-specific break, employment

	Direct	Upstream (network)
Pre-trend joint test (p, 2015–18)	0.20	0.21
Crisis break, net of linear trend	-0.09	-0.46
(p-value)	0.18	0.031
Crisis break, sector-specific trends	—	-1.29
(p-value)	—	0.0001

Notes: Continuous-treatment event study, log employment 2015–2023 on each exposure channel × year (unit and year fixed effects, SEs clustered by industry). "Crisis break" is the additional post-2022 effect of the channel net of a linear (or sector-specific) pre-trend. The network-channel break survives; the direct channel shows no crisis-specific break beyond its secular decline. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 8. Realized output effect of energy-cost exposure

Dependent Variable:			Output		
Specification	OLS	Country FE	IV: own/supp	IV: channels	Two-way FE
Variables					
Constant	0.075				
	(0.054)				
Direct	-0.420*	-0.531*		-0.204	0.032
	(0.228)	(0.256)		(0.291)	(0.201)
Upstream (dom.)	0.447	-0.854		-1.50	0.724
	(0.312)	(1.12)		(1.31)	(0.999)
Upstream (int.)	0.006	0.257		0.102	2.25
	(1.12)	(1.17)		(1.22)	(2.12)
Pre-trend	0.467***	0.416***	0.423***	0.422***	0.291***
	(0.102)	(0.097)	(0.093)	(0.097)	(0.079)
Log size	-0.004				
	(0.005)				
Own energy			-0.066		
			(0.222)		
Imported energy			-1.83*		
			(0.908)		
Fixed-effects					
Country		Yes	Yes	Yes	Yes
Industry					Yes
Fit statistics					
Observations	749	749	749	749	749
R^2	0.09240	0.12944	0.15232	0.12464	0.36442
F-test (1st stage), Own energy			1,194.9		
F-test (1st stage), Imported energy			99.388		
F-test (1st stage), Direct				476.12	
F-test (1st stage), Upstream (dom.)				1,004.6	
F-test (1st stage), Upstream (int.)				6,625.3	

Clustered (Country & Industry) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Predetermined (2014-network) exposure on the realized log change, 2019–2022. The own/imported split divides exposure by whether the energy is produced at home or imported; instruments are the Russian-gas shift-share (own- and supplier-country dependence), the imported-energy instrument a foreign-reliance leave-out shifter. Standard errors are two-way clustered by country and industry; the first-stage statistic is the Sanderson–Windmeijer conditional F. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 9. Realized employment effect of energy-cost exposure

Dependent Variable:	Employment				
Specification	OLS	Country FE	IV: own/supp	IV: channels	Two-way FE
Variables					
Constant	0.078***				
	(0.024)				
Direct	-0.124	-0.165		0.014	-0.011
	(0.159)	(0.179)		(0.152)	(0.150)
Upstream (dom.)	-1.16***	-1.92**		-2.42***	-1.19*
	(0.354)	(0.734)		(0.655)	(0.675)
Upstream (int.)	-1.57*	-0.963		-0.725	-0.433
	(0.791)	(0.808)		(0.820)	(0.969)
Pre-trend	-0.105	-0.130	-0.129	-0.127	-0.180
	(0.164)	(0.166)	(0.166)	(0.165)	(0.172)
Log size	-0.005				
	(0.004)				
Own energy			-0.081		
			(0.167)		
Imported energy			-1.15		
			(0.851)		
Fixed-effects					
Country		Yes	Yes	Yes	Yes
Industry					Yes
Fit statistics					
Observations	1,450	1,450	1,450	1,450	1,450
R^2	0.03775	0.07737	0.07410	0.07536	0.21996
F-test (1st stage), Own energy			1,474.0		
F-test (1st stage), Imported energy			288.26		
F-test (1st stage), Direct				805.09	
F-test (1st stage), Upstream (dom.)				1,149.2	
F-test (1st stage), Upstream (int.)				7,942.5	

Clustered (Country & Industry) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Predetermined (2014-network) exposure on the realized log change, 2019–2022. The own/imported split divides exposure by whether the energy is produced at home or imported; instruments are the Russian-gas shift-share (own- and supplier-country dependence), the imported-energy instrument a foreign-reliance leave-out shifter. Standard errors are two-way clustered by country and industry; the first-stage statistic is the Sanderson–Windmeijer conditional F. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 10. Realized value-added effect of energy-cost exposure

Dependent Variable:	Value added				
Specification	OLS	Country FE	IV: own/supp	IV: channels	Two-way FE
Variables					
Constant	0.198**				
	(0.087)				
Direct	-1.22***	-1.34***		-1.32**	-0.275
	(0.411)	(0.427)		(0.500)	(0.570)
Upstream (dom.)	1.73***	1.14		0.572	2.82**
	(0.587)	(1.23)		(1.42)	(1.31)
Upstream (int.)	-4.22**	-3.56**		-2.86*	-1.04
	(1.66)	(1.58)		(1.66)	(2.56)
Pre-trend	-0.182*	-0.239**	-0.261**	-0.241**	-0.340**
	(0.104)	(0.114)	(0.114)	(0.115)	(0.127)
Log size	-0.013				
	(0.009)				
Own energy			-0.523		
			(0.592)		
Imported energy			-6.34*		
			(3.64)		
Fixed-effects					
Country		Yes	Yes	Yes	Yes
Industry					Yes
Fit statistics					
Observations	1,434	1,434	1,434	1,434	1,434
R^2	0.04788	0.08911	0.08854	0.08872	0.22773
F-test (1st stage), Own energy			808.12		
F-test (1st stage), Imported energy			319.99		
F-test (1st stage), Direct				476.78	
F-test (1st stage), Upstream (dom.)				1,153.9	
F-test (1st stage), Upstream (int.)				7,901.0	

Clustered (Country & Industry) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Predetermined (2014-network) exposure on the realized log change, 2019–2022. The own/imported split divides exposure by whether the energy is produced at home or imported; instruments are the Russian-gas shift-share (own- and supplier-country dependence), the imported-energy instrument a foreign-reliance leave-out shifter. Standard errors are two-way clustered by country and industry; the first-stage statistic is the Sanderson–Windmeijer conditional F. Value added (chain-linked) nets out the intermediate-transaction reallocation that inflates gross output. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 11. Imported-energy (cross-border) exposure and realized outcomes: robustness

	Output	Value added	Employment
Imported-energy IV	−2.02	−7.54	−1.33
two-way (country×industry) SE	(0.93)	(2.98)	(0.75)
country-clustered SE	[0.93]	[2.86]	[0.74]
exposure-robust (AKM) SE	{0.63}	{9.45}	{1.71}
Randomization-inference p (recentered)	0.027	0.58	0.9
unrecentered	0.27	0.16	0.27
recentered-instrument estimate	−2.71	2.32	0.24
Leave-one-country range	[−2.40, −1.45]	[−9.86, −6.29]	[−1.69, −0.74]
Leave-one-supplier-country range	[−3.30, −1.63]	[−13.00, −6.96]	[−2.70, −1.33]
With Russian non-energy input control	−2.19	−7.17	−1.08
First-stage F (Sanderson–Windmeijer)	191	593	524
Observations	749	1,434	1,450

Notes: Each column instruments imported-energy exposure with foreign supplier countries' pre-crisis Russian-gas dependence (a leave-out shifter), with country fixed effects and a 2017–2019 pre-trend control, on the 2019–2022 log change. The coefficient is reported with, in turn, the two-way (country and industry) clustered SE in parentheses, the country-clustered SE in brackets, and the Adao–Kolesar–Morales exposure-robust SE in braces. Because identification rests on a small, concentrated set of country shifters, the randomization-inference p re-draws the shifter across the shocked countries and rebuilds the instrument ($B = 1{,}000$ draws, studentized reduced form), valid without a many-shock asymptotic. The raw instrument's mechanical exposure component requires the Borusyak and Hull (2023) recentering, reported as primary with the unrecentered p and the recentered point estimate beneath it. The leave-one-country and leave-one-supplier-country rows give the range of the coefficient as each home country (respectively, each of the six largest supplier countries) is dropped from the estimate (respectively, the instrument). The penultimate row adds each unit's direct input share from Russian non-energy sectors as a control for broader (non-energy) war exposure. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 12. Output effect across outcome windows (country fixed effects)

Dependent Variable:	Output		
Outcome window	2019–22	2021–22	2019–23
Variables			
Direct	-0.531*	0.075	-1.02***
	(0.256)	(0.416)	(0.308)
Upstream (dom.)	-0.854	1.94	-1.82
	(1.12)	(1.12)	(1.23)
Upstream (int.)	0.257	-2.05*	-1.77
	(1.17)	(1.17)	(1.44)
Pre-trend	0.416***	0.196***	0.542***
	(0.097)	(0.056)	(0.096)
Fixed-effects			
Country	Yes	Yes	Yes
Fit statistics			
Observations	749	749	749
R^2	0.12944	0.08220	0.21327

Clustered (Country & Industry) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Country-fixed-effects estimates of the exposure channels on the log change in real gross output over three windows. Two-way (country and industry) clustered standard errors. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 13. Employment effect across outcome windows (country fixed effects)

Dependent Variable:	Employment		
Outcome window	2019–22	2021–22	2019–23
Variables			
Direct	-0.165	-0.012	-0.192
	(0.179)	(0.086)	(0.184)
Upstream (dom.)	-1.92**	-0.138	-1.39**
	(0.734)	(0.357)	(0.585)
Upstream (int.)	-0.963	-0.645	-1.85*
	(0.808)	(0.399)	(0.913)
Pre-trend	-0.130	-0.030	-0.021
	(0.166)	(0.088)	(0.109)
Fixed-effects			
Country	Yes	Yes	Yes
Fit statistics			
Observations	1,450	1,449	1,450
R^2	0.07737	0.02333	0.10521

Clustered (Country & Industry) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Country-fixed-effects estimates of the exposure channels on the log change in employment over three windows. Two-way (country and industry) clustered standard errors. Sources: realized outcomes from Eurostat national accounts; exposure measures from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

Table 14. Labor vs. output incidence of the energy cost shock (European workforce)

	Output-weighted	Employment-weighted
Direct (% of output)	2.1	2.4
Upstream (% of output)	1.9	1.9
Total (% of output)	4.1	4.3
Upstream share of total (%)	47.6	44.6

Notes: European workforce = 29 countries with Eurostat price data. Employment = persons engaged (WIOD SEA, 2014). Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 15. Energy-cost incidence by gender of employment (European, 2019 LFS weights)

	Female employment	Male employment
Total cost shock (% of output)	3.7	4.9
Upstream (% of output)	1.5	2.2
Upstream share of total (%)	40.8	44.8
International share of upstream (%)	26.6	30.6

Notes: Exposure measures (Section 2) weighted by female vs male employment (EU-LFS lfsa_egan22d, persons aged 15–64, 2019), mapped from 2-digit NACE to WIOD sectors. European countries only. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 16. Energy-price-cap counterfactual (European output-weighted incidence)

Cap on price growth	Total shock (% output)	Upstream shock (% output)	Reduction in total (%)
No cap (baseline)	4.1	1.9	—
Cap at +200%	3.9	1.9	2.7
Cap at +150%	3.6	1.7	10.7
Cap at +100%	3.1	1.5	23.8
Cap at +75%	2.6	1.3	34.8
Cap at +50%	2.0	1.0	49.7
Cap at +25%	1.0	0.5	74.7

Notes: Each row caps the proportional 2019–2022 rise in every energy carrier (electricity, gas, oil) at the stated level and recomputes the decomposition. Because the price model is linear in the energy shock, a cap lowers the upstream channel in proportion to the direct one. Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

Table 17. Robustness of the channel decomposition

Specification	Upstream share (%)	Intl. share of upstream (%)	Most exposed country (total %)
Baseline			
WIOD 2014 (baseline)	54.1	48.4	Romania (15.7)
IO vintage			
WIOD 2000 network	52.2	38.1	Romania (13.9)
WIOD 2007 network	53.6	41.7	Romania (13.6)
D35 weight			
$w = 0.3$ (more gas)	54.0	48.2	Romania (16.7)
$w = 0.7$ (more electricity)	54.2	48.5	Romania (14.8)
Price basis			
Prices excluding all taxes	54.0	48.3	Romania (17.1)
Prices including all taxes	54.1	48.4	Romania (15.7)
Price bands			
Single mid consumption band	54.0	48.3	Romania (16.3)
Different IO source			
OECD ICIO 2018	46.1	31.9	Romania (8.8)

Notes: Each row changes one choice relative to the baseline (WIOD 2014 network; Eurostat industrial prices excluding recoverable VAT; broad consumption bands; D35 output-price shock weighted w on electricity and $1 - w$ on gas). "Upstream share" is the output-weighted upstream share of the total cost shock; "Intl. share" is the international share of upstream. The final row re-runs the decomposition on a different source, the OECD ICIO 2018 network (45 sectors, 71 regions). Sources: World Input-Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

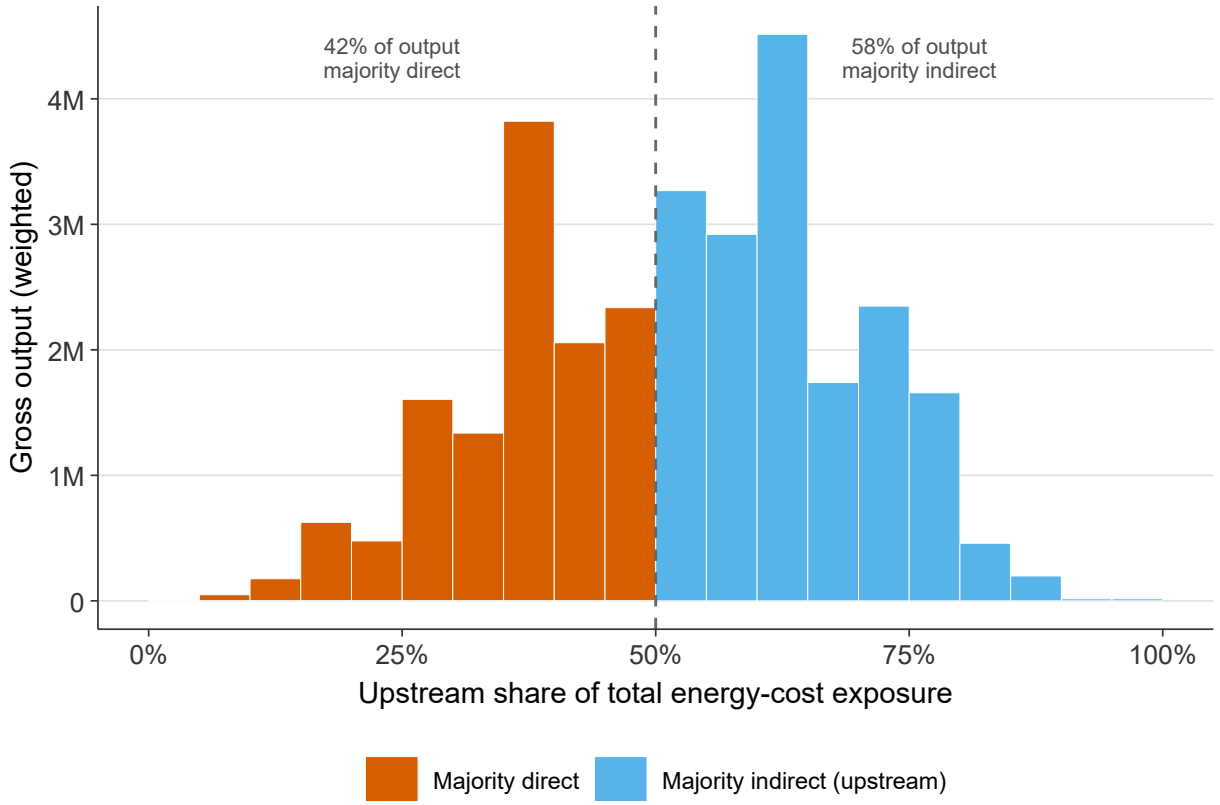


Figure 1. Output-weighted distribution of the upstream share of total energy-cost exposure across European non-energy industries.

Notes: The upstream share is the fraction of a unit's total cost shock that arrives through intermediates rather than through its own energy purchases; values above 50% indicate exposure that is predominantly indirect. Industries are weighted by gross output, so the distribution reflects the share of European production, not the count of sectors. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

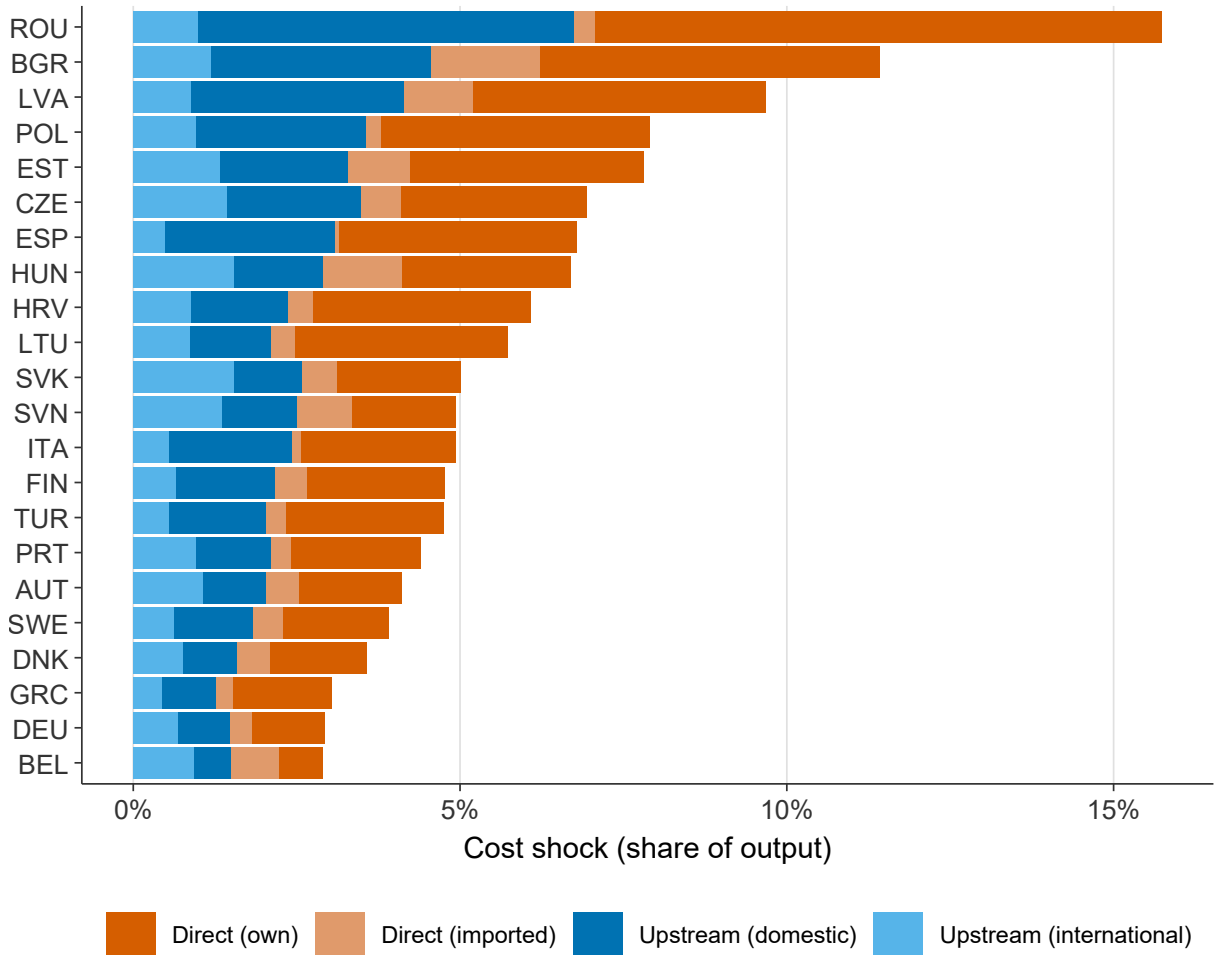


Figure 2. Energy-cost shock by transmission channel and country, output-weighted across non-energy industries.

Notes: For each country the total cost shock, in percent of gross output, is split into a direct component from the industry's own energy purchases, a domestic-upstream component transmitted through intermediates sourced within the country, and an international-upstream component transmitted through imported intermediates. Countries are ordered by total exposure. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

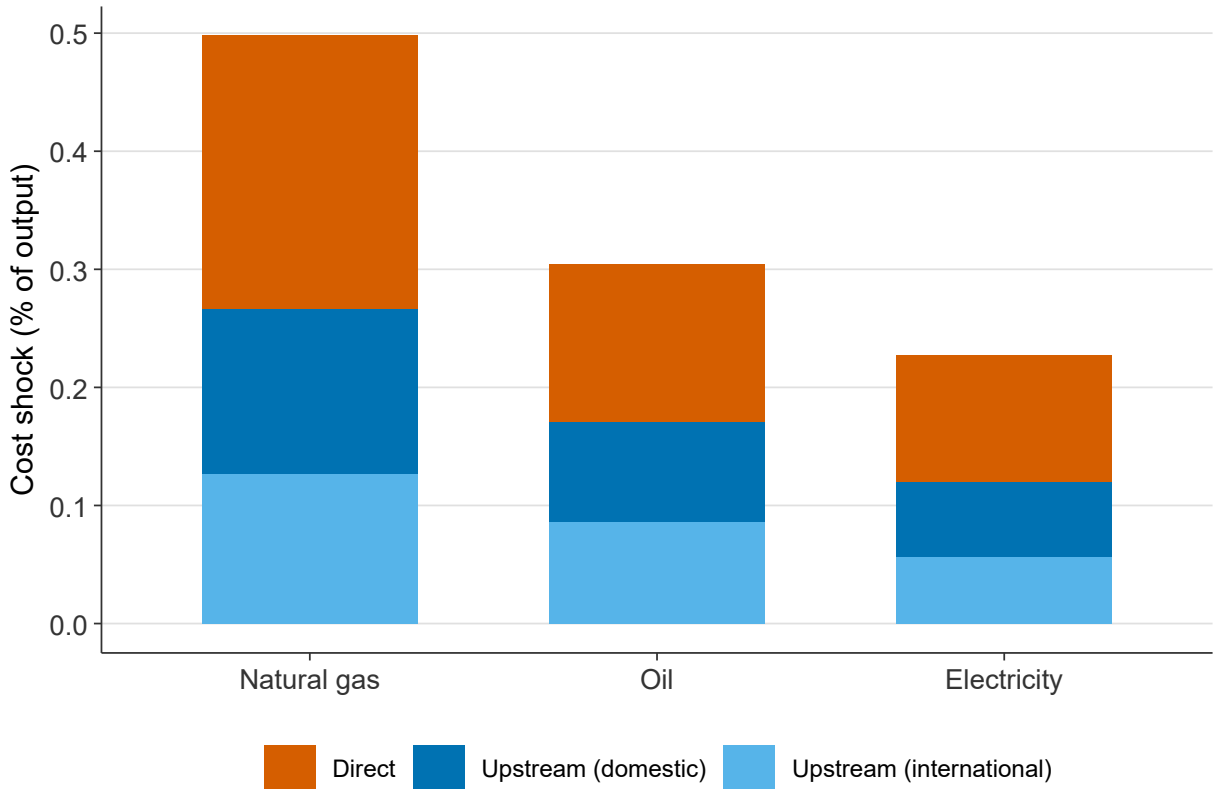


Figure 3. Energy-cost shock by carrier and transmission channel, output-weighted across non-energy industries.

Notes: The total cost shock, in percent of gross output, is attributed to natural gas, electricity, and oil, and each carrier is further split into direct, domestic-upstream, and international-upstream components. Shares are computed at the baseline carrier-mix weights. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

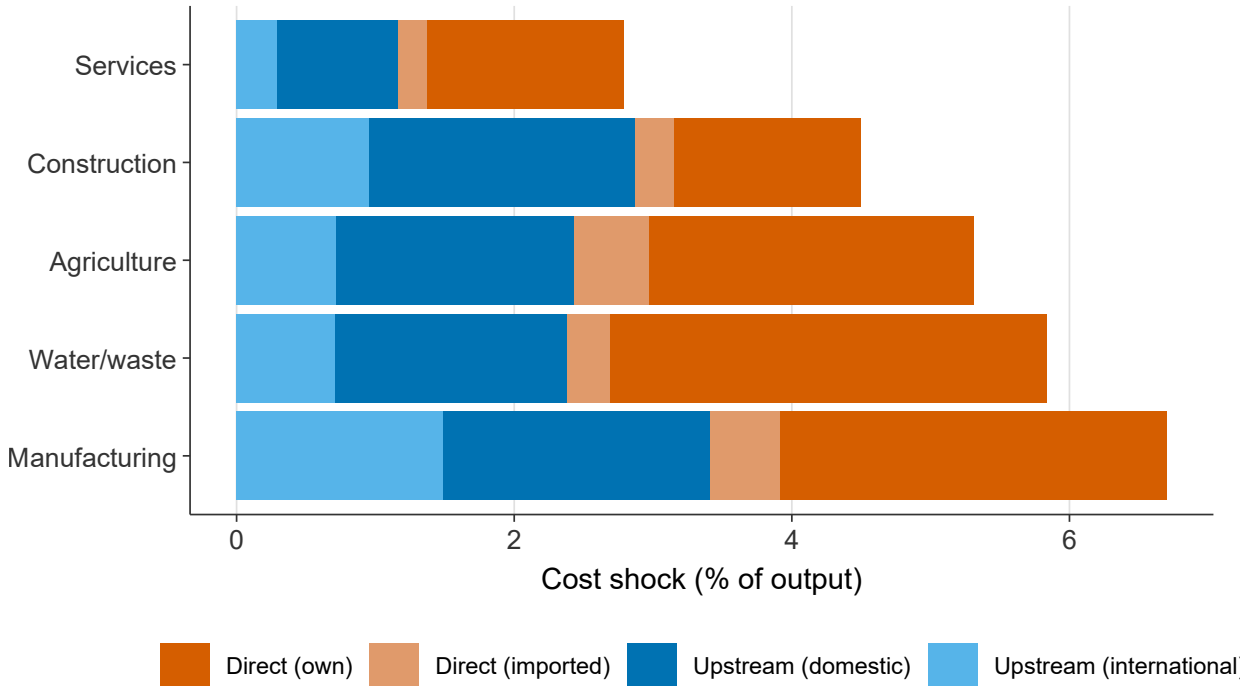


Figure 4. The 2022 energy-cost shock by broad sector, split into a direct component (the sector's own energy use) and an upstream component (energy embodied in purchased inputs).

Notes: Bars give the shock as a percent of gross output, across European countries and weighted by gross output, and stack to the sector total reported in Table 3. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

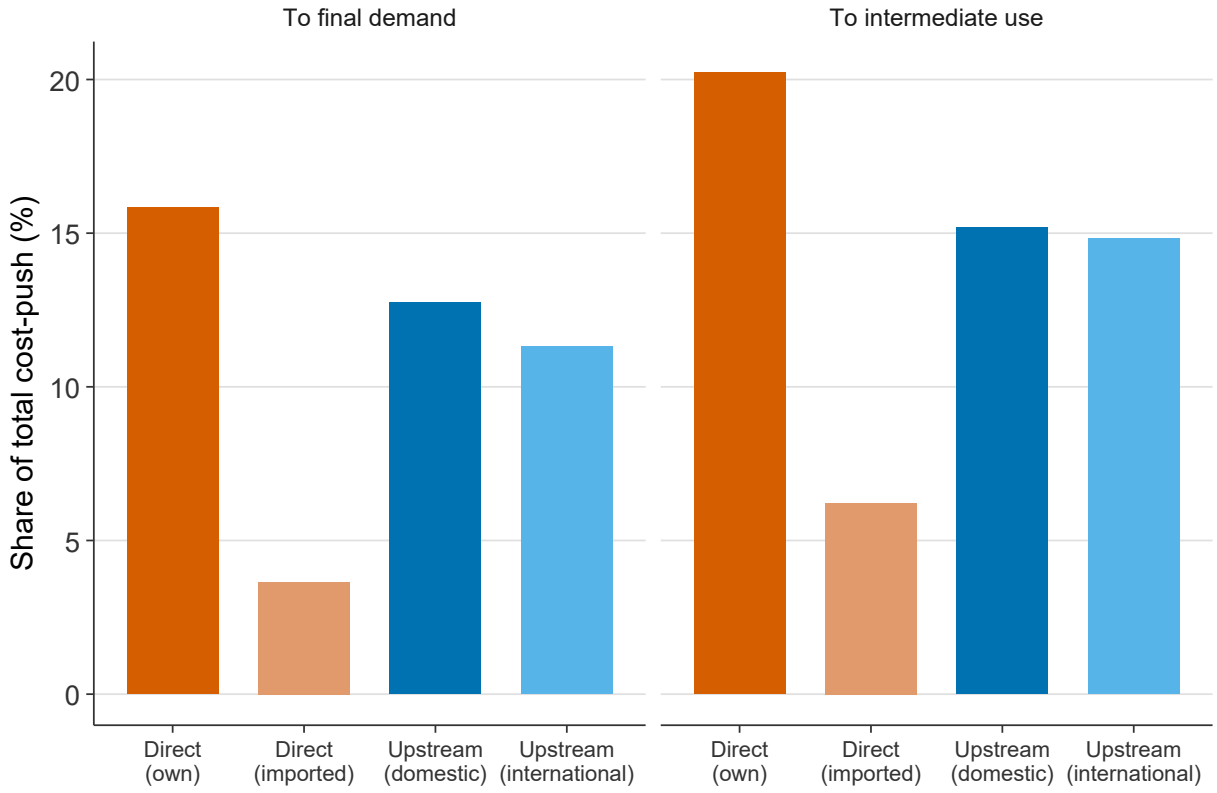


Figure 5. Decomposition of the 2022 energy cost-push by origin (direct versus upstream), sourcing (domestic versus international), and destination of the priced output (final demand versus intermediate use).

Notes: Bars give each cell as a share of the total cost-push, summing to 100%, across European non-energy industries; more than half the burden falls on output used as an intermediate, and the largest single cell is own-energy cost embodied in intermediate-bound output. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

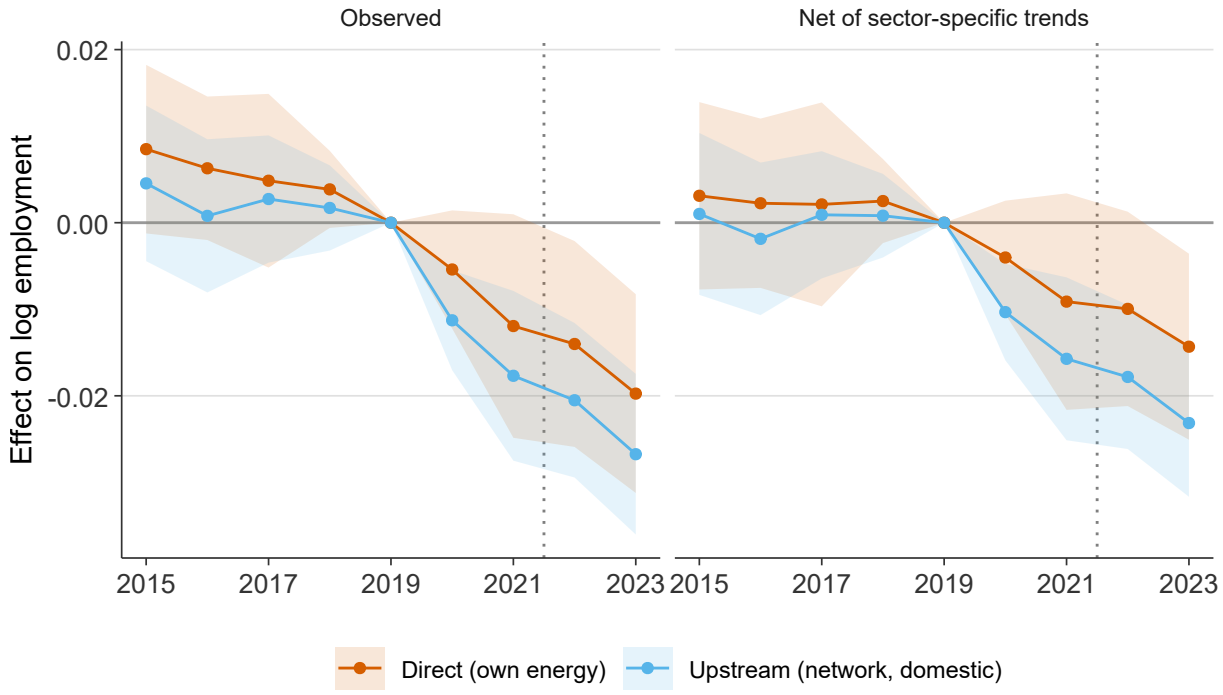


Figure 6. Employment relative to 2019 by exposure channel, observed and net of sector-specific linear trends.

Notes: Each line plots the per-standard-deviation effect of an exposure channel on log employment in each year, from a continuous-treatment event study with unit and year fixed effects; shaded bands are 95% confidence intervals with standard errors clustered by industry. The left panel is the raw event study; the right panel adds sector-specific linear time trends, which absorb the secular decline of energy-intensive industry. The direct channel's pre-existing downward trend then flattens, while the upstream (network) channel's post-2021 break survives and stands out more sharply (it remains significant net of sector-specific trends, $p = 0.0001$; Table 7). Sources: realized outcomes from Eurostat national accounts; exposure from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

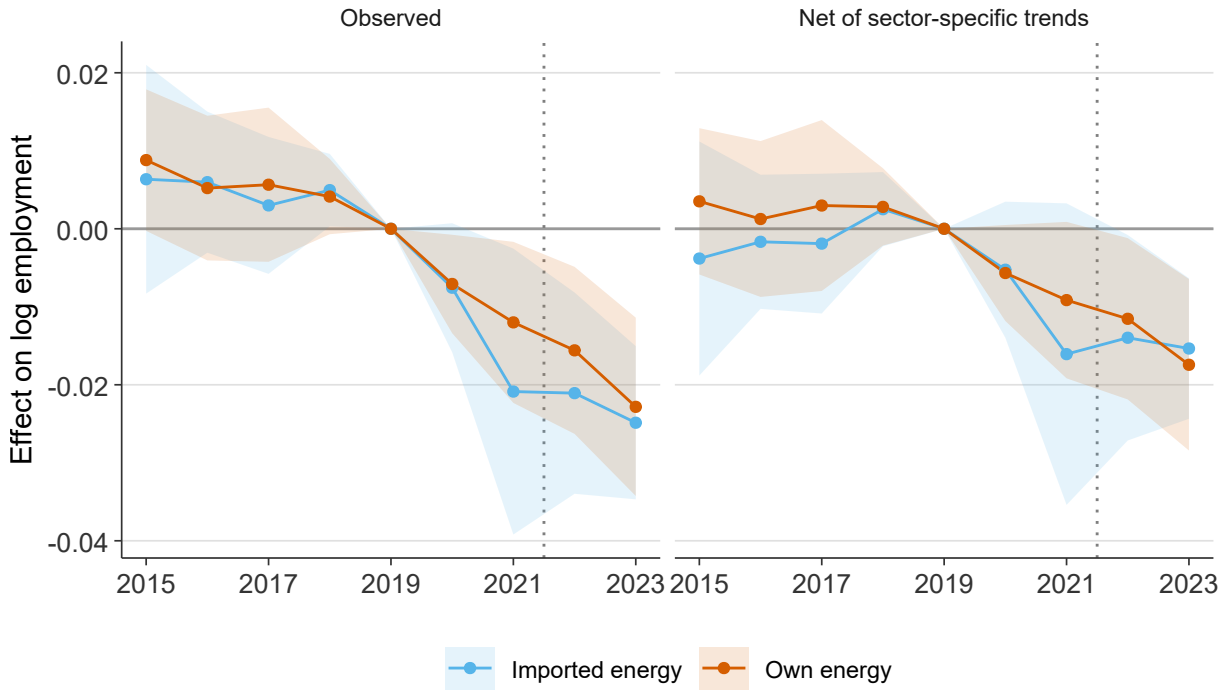


Figure 7. Employment relative to 2019 by energy origin (own versus imported energy), observed and net of sector-specific linear trends.

Notes: As in Figure 6, but splitting exposure by the origin of the energy rather than by direct versus upstream. The imported-energy channel diverges after the 2021 pre-crisis benchmark while the own-energy channel does not break beyond its trend; the imported-channel timing is estimated less sharply than the domestic upstream channel (break $p = 0.148$, against $p = 0.0001$ for the upstream channel). Shaded bands are 95% confidence intervals with standard errors clustered by industry. Sources: realized outcomes from Eurostat national accounts; exposure from the World Input–Output Database (2014 table), Eurostat industrial energy prices, and FRED Brent crude. Author's calculations.

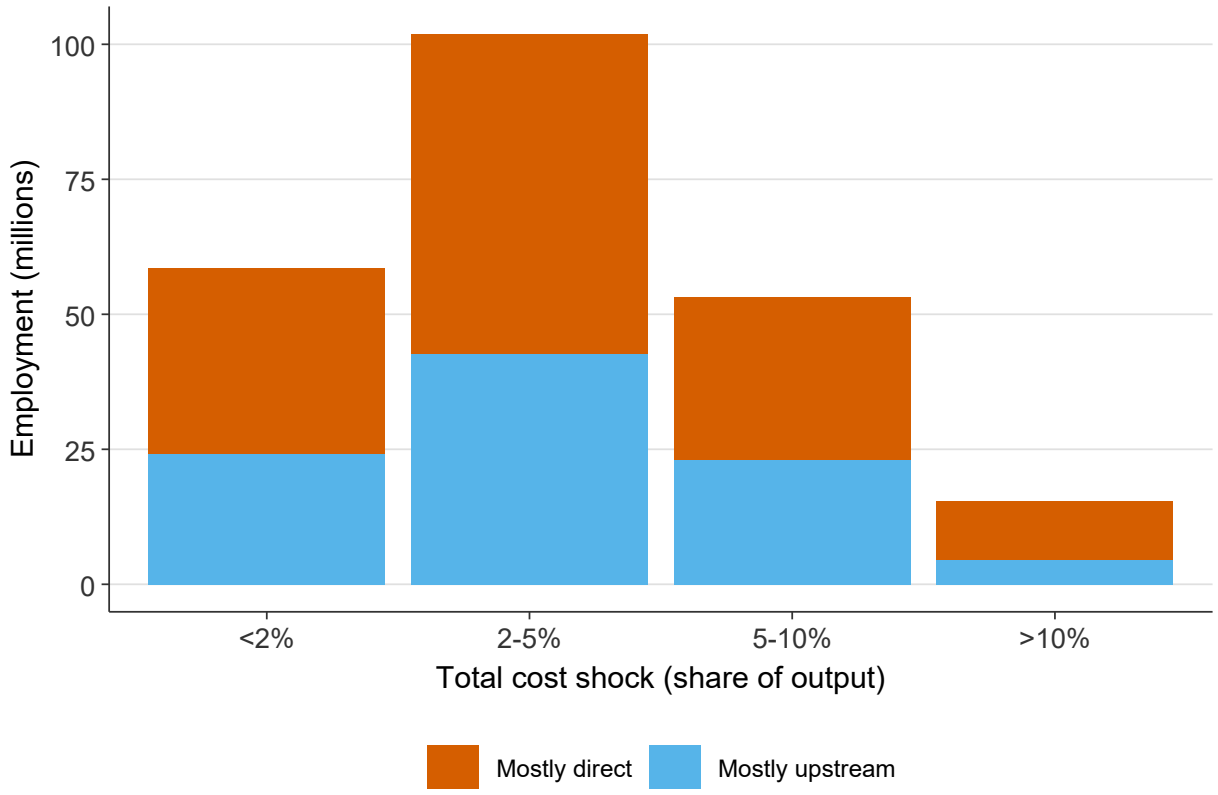


Figure 8. Distribution of European employment by size of the energy-cost shock and dominant channel.

Notes: Bars stack persons engaged (in millions) across bands of the total cost shock as a share of gross output (below 2%, 2–5%, 5–10%, above 10%); shading splits each band into industries where the shock is mostly upstream (upstream exceeds direct) and mostly direct. Workforce of the 29 European countries that received the price shock; employment from the WIOD Socio-Economic Accounts (2014). Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

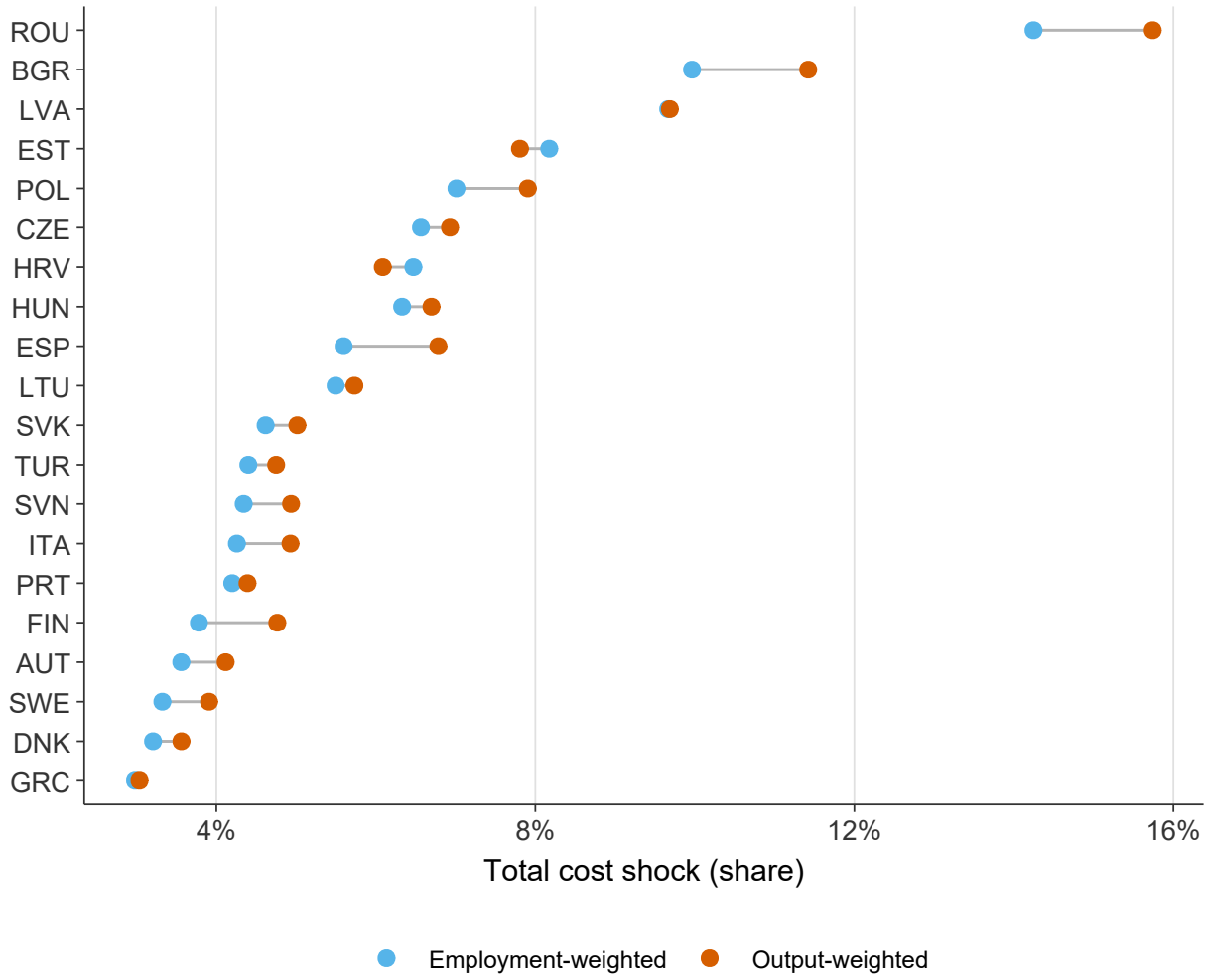


Figure 9. Employment-weighted versus output-weighted energy-cost exposure, by country.

Notes: Each row shows one country's total cost shock as a share of output under the two weightings, joined by a connecting segment; rows are the 20 most exposed countries on the employment-weighted measure, ordered by it. The horizontal distance between the two markers is the re-weighting gap, which widens where exposure concentrates in labor-intensive industries. European countries that received the price shock; employment from the WIOD Socio-Economic Accounts (2014). Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

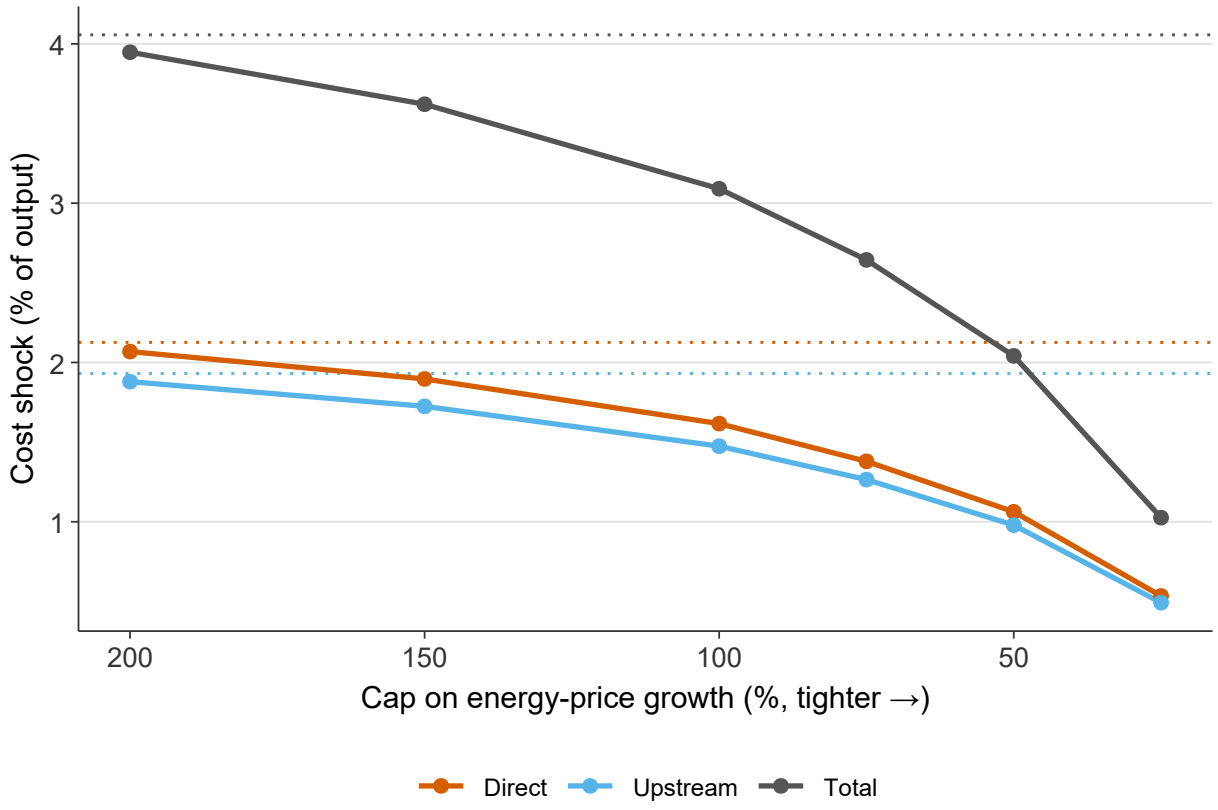


Figure 10. European output-weighted cost shock under caps on energy-price growth.

Notes: Each point holds the proportional 2019–2022 rise in every energy carrier (electricity, gas, oil) to the cap on the horizontal axis and recomputes the decomposition; the solid line is the total cost shock and the lower line is its upstream component, both in percent of gross output. Dotted lines mark the uncapped baseline. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

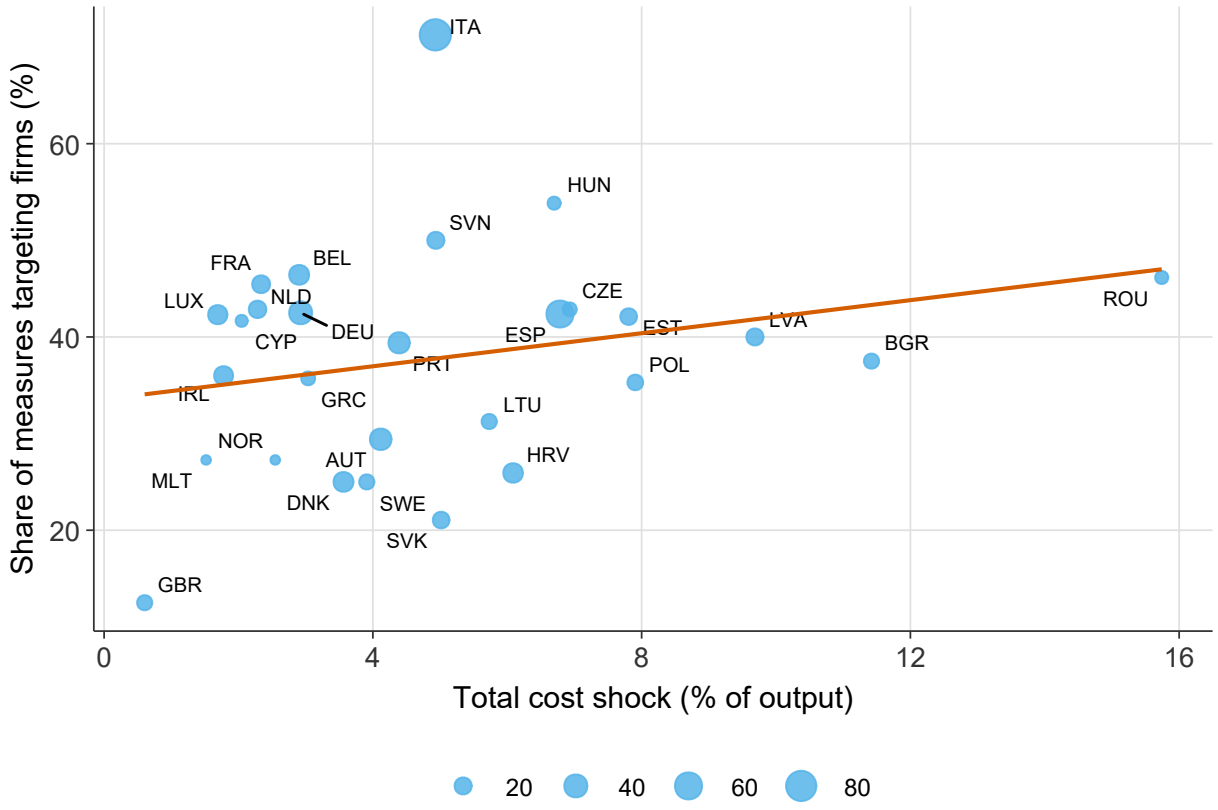


Figure 11. Firm-orientation of national fiscal measures against total cost-shock exposure, across 28 European countries.

Notes: The horizontal axis is a country's total output-weighted cost shock; the vertical axis is the share of its catalogued measures directed at firms. Each point is a country. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

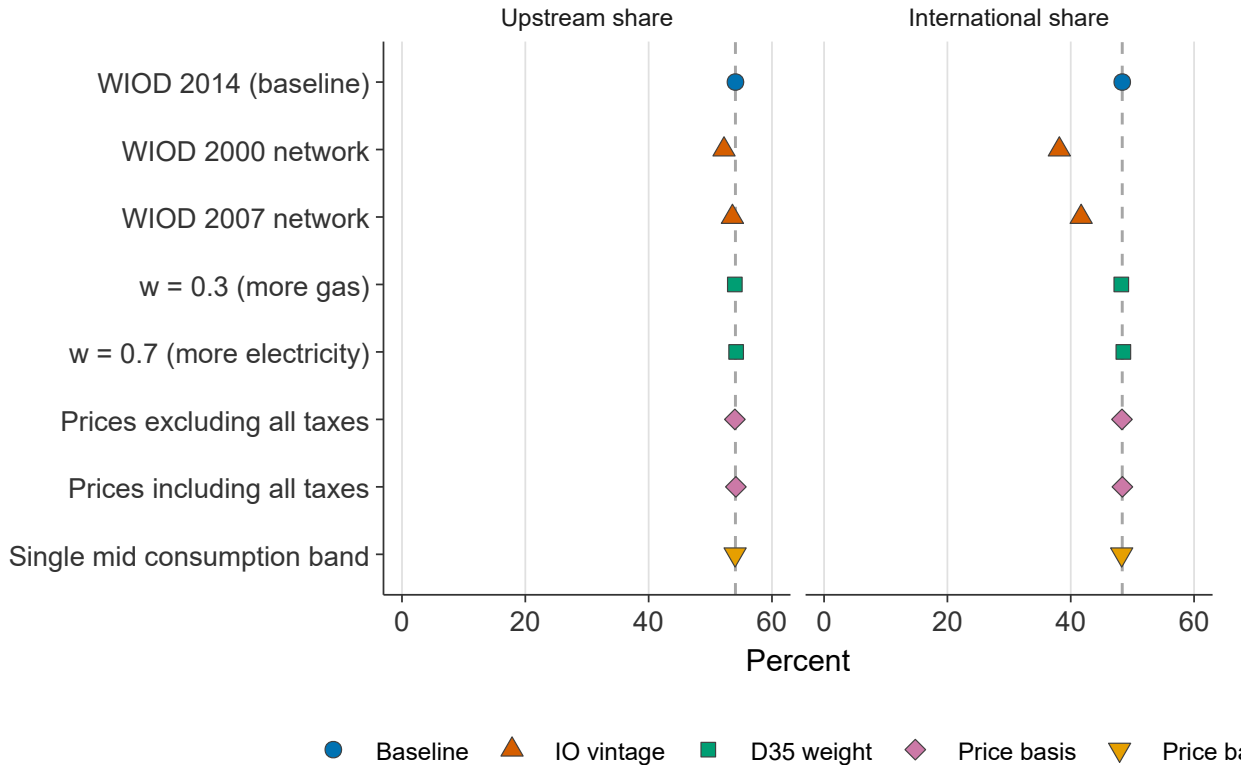


Figure 12. Upstream share of the total cost shock and the international share of the upstream burden, plotted for each robustness specification in Table 17.

Notes: Both shares are output-weighted and expressed in percent; the WIOD specifications cluster tightly, and the OECD ICIO 2018 source sits below them on both axes. Sources: World Input–Output Database (2014 table); Eurostat industrial energy prices; FRED Brent crude. Author's calculations.

A The cost-push eight-cell decomposition

Let Δp_j be the cost-push price increase of non-energy unit j from (2). It splits by origin and sourcing into four nonnegative components summing to Δp_j: direct domestic and direct imported (the own-energy term $\sum_{e \in E} a_{ej} \widehat{p}_e$ split by whether energy unit e is in j's own country), and upstream domestic and upstream international (from (3)). The price increase is borne on j's output, which by the accounting identity $\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{D}$ goes either to final demand (D_j) or to intermediate use ($x_j - D_j$). Allocating each origin×sourcing component by destination and aggregating with output weights gives the exact decomposition of the total cost-push,

$$\sum_j \Delta p_j \, x_j \;=\; \sum_o \sum_j o_j \big(\underbrace{D_j}_{\text{final}} + \underbrace{(x_j - D_j)}_{\text{intermediate}} \big), \qquad o \in \{\text{dir}^{\text{dom}}, \text{dir}^{\text{int}}, \text{up}^{\text{dom}}, \text{up}^{\text{int}}\},$$

the eight cells of Table 4 (reported as shares of $\sum_j \Delta p_j x_j$). Unlike the output decomposition below, this is exact and linear—no behavioral counterfactual enters—so every cell is a nonnegative cost increase.

B The CES output decomposition (implied-effect scenario)

Let the no-crisis baseline be $(\boldsymbol{A}, \boldsymbol{D})$ and the crisis world $(\widetilde{\boldsymbol{A}}, \widetilde{\boldsymbol{D}})$ from the CES counterfactual (Appendix C). Define the four Leontief output vectors

$$\boldsymbol{y}_1 = (\boldsymbol{I} - \widetilde{\boldsymbol{A}})^{-1}\widetilde{\boldsymbol{D}}, \quad \boldsymbol{y}_2 = (\boldsymbol{I} - \widetilde{\boldsymbol{A}})^{-1}\boldsymbol{D}, \quad \boldsymbol{y}_3 = (\boldsymbol{I} - \boldsymbol{A})^{-1}\widetilde{\boldsymbol{D}}, \quad \boldsymbol{y}_4 = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{D},$$

so $\boldsymbol{y}_1$ is crisis output and $\boldsymbol{y}_4$ no-crisis output. The total effect $\boldsymbol{y}_1 - \boldsymbol{y}_4$ decomposes, under the stage-mean ("$\bar{A}$") scheme of de Ruijter and Dustmann (2025), into

$$\begin{aligned}
\text{direct, final:} \quad & \widetilde{\boldsymbol{D}} - \boldsymbol{D}, \\
\text{upstream, final:} \quad & \tfrac{1}{2}\big[\widetilde{\boldsymbol{A}}(\boldsymbol{y}_1 - \boldsymbol{y}_2) + \boldsymbol{A}(\boldsymbol{y}_3 - \boldsymbol{y}_4)\big], \\
\text{direct, intermediate:} \quad & \tfrac{1}{4}(\widetilde{\boldsymbol{A}} - \boldsymbol{A})(\boldsymbol{y}_1 + \boldsymbol{y}_2 + \boldsymbol{y}_3 + \boldsymbol{y}_4), \\
\text{upstream, intermediate:} \quad & \tfrac{1}{4}(\widetilde{\boldsymbol{A}} + \boldsymbol{A})(\boldsymbol{y}_1 + \boldsymbol{y}_2 - \boldsymbol{y}_3 - \boldsymbol{y}_4),
\end{aligned}$$

the four terms summing to $\boldsymbol{y}_1 - \boldsymbol{y}_4$ identically, each split domestic/international by replacing its leading matrix (or $\boldsymbol{D}$) with the within-country block or its cross-border complement. The technology ("intermediate") cells are driven by $\widetilde{\boldsymbol{A}} - \boldsymbol{A}$ and the final cells by $\widetilde{\boldsymbol{D}} - \boldsymbol{D}$. The former are the gross-output reallocation that makes the net magnitude sign-sensitive (Section 6); the demand-destruction (final) cells are robustly negative.

C CES counterfactual

Substitution-adjusted coefficients are obtained from cost minimisation under a nested CES technology, evaluated at the Leontief cost-push prices $p_i = 1 + \Delta p_i$. For buyer j, with

baseline within-nest expenditure shares θ calibrated to the observed $\boldsymbol{A}$, the energy composite price is $P_{E,j} = \left(\sum_{e \in E} \theta_{ej}^{E} p_e^{1-\sigma_E}\right)^{1/(1-\sigma_E)}$, the materials composite $P_{N,j}$ analogously over non-energy inputs, and the intermediate composite $P_{I,j} = \left(\phi_{E,j} P_{E,j}^{1-\sigma_E} + \phi_{N,j} P_{N,j}^{1-\sigma_E}\right)^{1/(1-\sigma_E)}$. The updated coefficients are

$$\widetilde{a}_{ej} = a_{ej}\left(\tfrac{P_{E,j}}{P_{I,j}}\right)^{-\sigma_E}, \qquad \widetilde{a}_{ij} = a_{ij}\left(\tfrac{P_{N,j}}{P_{I,j}}\right)^{-\sigma_E} \quad (i \in N),$$

with the within-nest and value-added margins held Leontief in the baseline ($\sigma_W = \sigma_N = \sigma_M = 0$). Final demand responds as $\widetilde{D}_i = D_i\, p_i^{-\eta}$ on non-inventory categories. Setting $\sigma_E = \eta = 0$ reproduces $(\boldsymbol{A}, \boldsymbol{D})$ exactly, so the Leontief case is the $\sigma_E = \eta = 0$ corner of the same calculation. Calibration: $\sigma_E = 0.20$ (Atalay, 2017), $\eta = 0.20$; both are varied in robustness.

D Data and sources

The 56 WIOD industry codes coincide with Eurostat NACE Rev. 2 codes for 55 of 56 sectors; the one exception is the combined arts and other-services sector, which is the sum of NACE divisions R and S. Realized outcomes come from Eurostat national accounts: real gross output and value added in chain-linked volumes, together with employment in persons. The instrument uses Russian-gas import shares from Eurostat statistics on natural-gas imports by partner country (gas imports from Russia over total, averaged over 2019–2021). Gender weights come from the EU Labour Force Survey (employment by sex and industry). Replication files, including the source and access date for every series, are available from the author.

E A Danish matched employer-employee design

The industry-level analysis here points to a worker-level sequel. Public European data leave two gaps. Notably, sector-by-skill cells are not measured, and exposure is assigned at the industry rather than the firm level. Danish administrative registers close both. Here, they link worker, establishment, and firm panels carrying education, occupation, gender, and earnings to firm accounts that record energy spending and to the firm-level import register. From these one can build firm-specific direct, upstream-domestic, and upstream-international energy exposure—the last from each firm's imported intermediates interacted with partner-country energy shocks—and trace the response of worker earnings, separations, and reallocation across skill, occupation, and gender. Formally, identification generalizes the shift-share instrument of Section 7 to predetermined firm-level supplier networks weighted by each supplier's Russian-gas dependence.