

The impact of higher energy prices on Austrian GDP

Evidence from a partial-equilibrium short-run supply-side approach

This paper provides empirical estimates on the impact of a 50% rise in energy prices (relative to 2019) on Austrian GDP. We find that in such a scenario, Austrian GDP could decrease by up to 0.9% in the short run. Should energy prices stay higher permanently, additional output losses could occur via downward adjustments in capital stock. Our estimates highlight the relevance of energy prices for policymakers and can inform subsequent analyses on different economic policy options.

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Higher energy prices significantly dampen GDP

Our estimates show that following a 50% rise in energy prices (relative to 2019), Austrian GDP would drop by between 0.7% and 0.9% in the short run. This finding is well within the range of previous estimates from empirical studies.



Model extension considers monopolistic competition

For our estimations, we extend the partial-equilibrium short-run supply-side approach of Knetsch and Molzahn (2012) by introducing monopolistic competition and deriving exact GDP impact elasticity.



Model relies on firm-level data from Austria

We use Austrian firm-level data to inform the model results, given that these are sensitive to the elasticity of substitution between capital and energy and to the markup factors employed.

Opinions expressed by the authors of studies do not necessarily reflect the official viewpoint of the Oesterreichische Nationalbank or the Eurosystem.

Abstract¹

This study presents empirical estimates on the impact of the recent surge in energy costs on Austria's GDP. We employ a generalized version of the Knetsch and Molzahn (2012) partial-equilibrium short-run supply-side approach to simulate the impact of a permanent 50% energy price increase (relative to 2019) on Austria's manufacturing industries. Key parameters for our simulation are derived from Austrian firm-level data. Using our preferred parameter set, we find that the assumed energy price increases would have reduced value added in Austria's manufacturing industries by between 1.8% and 2.3%. With a share of manufacturing in total Austrian GDP of around 17% (2019), this amounts to an impact on national GDP of between -0.3% and -0.4%. Adding additional impacts via input-output interlinkages approximately doubles these figures to -0.7% and -0.9%. Should energy prices stay higher permanently, additional output losses would occur in the long run via downward adjustments in capital stock. Our estimates highlight the importance of energy prices for policymakers and provide a basis for assessing alternative economic policy choices.

1 Introduction

In the second half of 2021, around half a year before Russia invaded Ukraine, energy prices, especially prices for natural gas, started to increase sharply in Europe. At the height of the energy crisis, EU natural gas was nearly 7 times more expensive in the spot market than US natural gas. In 2024 and early 2025, energy prices were still 4 times higher in the EU than in the USA, while they had been roughly 2 to 3 times higher before 2020 (see left-hand panel of chart 1). In Austrian manufacturing, the price of 1 kWh of natural gas and electricity nearly tripled (+177%) between 2019 and 2023 (see right-hand panel of chart 1). The price of 1 kWh of diesel, by comparison, only increased by 38%. Weighting these three energy sources by their usage, the combined energy price for manufacturing in Austria rose by 166%. While it was expected that energy prices in Austrian manufacturing would fall significantly from their 2022 peak – natural gas prices fell slightly in 2023 already – they are also expected to remain above the pre-crisis levels of 2019 for the years to come.²

Higher energy prices in Europe relative to the USA and Asia raise production cost and thus output prices. This worsens Austria's competitive position vis-à-vis extra-EU countries, reducing export demand and decreasing output produced. A permanent increase in energy prices may lead to permanent decreases in output and may thus affect potential output. The Oesterreichische Nationalbank (OeNB) updates its potential output projections biannually as part of the Eurosystem staff macroeconomic projections. We use these projections to assess the cyclical position of the Austrian economy and to evaluate the resulting inflationary pressures. Apart from long-term trends such as aging, we can also include changes in cost competitiveness such as the recent energy price shock in our potential output projections for Austria.

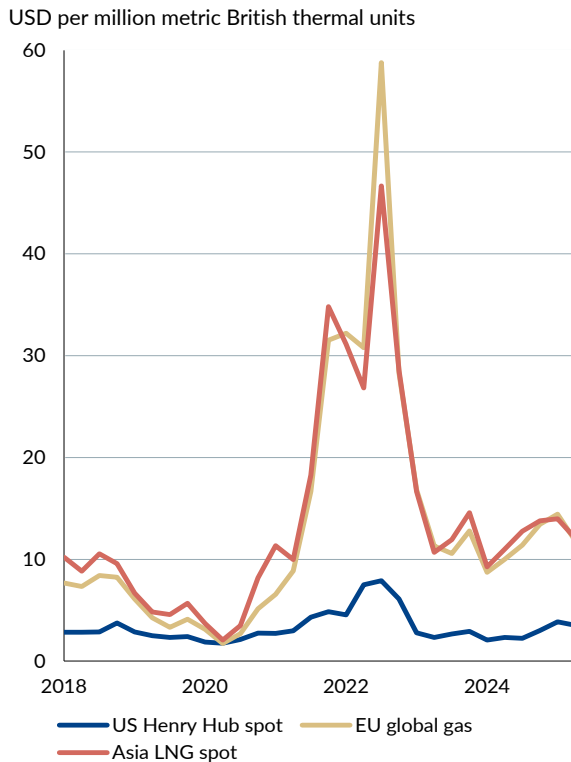
¹ The authors would like to thank an anonymous reviewer and Fabio Rumler (OeNB) for helpful comments, the staff of the Austrian Micro Data Center (AMDC) at Statistics Austria for the excellent cooperation, and Susanne Steinacher (OeNB) for valuable linguistic and technical support.

² In the June 2025 Eurosystem staff macroeconomic projections, the ECB assumed that in 2027, the wholesale electricity price for the euro area will still be 66% above its 2019 level. The wholesale price of gas is expected to be 116% higher in 2027 than it was in 2019.

Chart 1

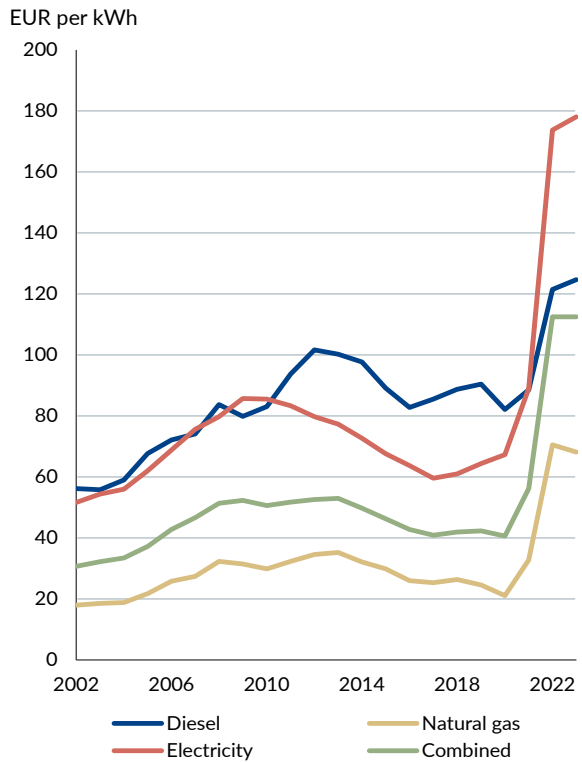
Developments in energy prices

Natural gas prices in the USA, EU and Asia



Source: FRED, Federal Reserve Bank St. Louis.

Energy prices in Austrian manufacturing



Source: Statistics Austria (materials input statistics).

The aim of this study is to quantify the supply-side impact of higher energy prices in manufacturing on Austrian GDP. We do this by extending the production function approach of Knetsch and Molzahn (2012) to include monopolistic competition and informing key parameters from Austrian firm-level data. The limited availability of data on energy consumption restricts our analysis to the Austrian manufacturing sector. We augment the direct impacts on manufacturing by adding impacts on all other Austrian industries via input-output interlinkages. The key advantage of our approach is that it can be easily updated as new macroeconomic data become available. A caveat of our approach is that we explicitly model only the manufacturing sector. This sector consumes roughly half of the energy consumed by all Austrian industries. Moreover, our approach also underestimates the long-run effects of the energy price shock since we assume that the capital stock does not adjust in the wake of an increase in energy prices. Furthermore, since we model the aggregate manufacturing sector, we abstract from heterogeneities within manufacturing, i.e. energy-intensive versus non-energy intensive industries.

Our results add to the empirical literature on the supply-side impacts of energy prices on output. Section 3.3 gives a thorough overview of studies covering Austria and other European countries and of how their results compare to our results. The method we employ is related to the literature on the effect of energy price changes on factor demand, see for instance Berndt and Wood (1975), Pindyck and Rotemberg (1983) or Atkeson and Kehoe (1999). Section 3.2 provides a short discussion on the relevance of the choice of modeling for the impact of energy price changes on output.

The rest of this article is structured as follows: Section 2 describes the methodology and data used. Section 3 presents our empirical results for Austria and shows how they relate to estimates from other studies. Section 4 concludes.

2 Methodology

Estrada and de Cos (2012) suggest that increases in energy prices can have impacts on potential output via all its sub-components: capital, trend productivity and trend employment. They show that if an increase in the price of energy leads to a more than proportional reduction in energy usage, a decrease in the share of energy in nominal gross production can push down the (measured) total factor productivity (TFP) contribution to potential output.³ A lower contribution of capital may manifest itself via increased user costs of capital (when viewing energy costs as part of these costs). The impact on trend labor will depend on how wages react to increasing energy prices. We expect a negative impact on labor demand if an energy price increase leads to a more than proportional decline in energy usage. On the labor supply side, increasing energy prices will have a positive effect on the wages demanded by workers. The structural unemployment rate that balances demand and supply will be driven up by an increase in energy costs.

For our empirical analysis, we will employ a generalized version of the model of Knetsch and Molzahn (2012) to estimate short-term supply-side impacts of energy price increases on manufacturing output in Austria. A decrease in manufacturing output will also reduce the demand of the manufacturing industries for intermediate services. To obtain the total impact on Austrian GDP, we add estimates of the effects of such a decline in demand derived from an input-output model to the direct impacts resulting from our model based on Knetsch and Molzahn (2012).

2.1 Basic model features

In the following, we outline the most important features and implications of the Knetsch and Molzahn (2012) partial-equilibrium model and generalize their setup to allow for monopolistic competition at the final good level and the capital-energy composite level.

Output $Y_t = \left[\int_0^1 (Y_t^i)^{\frac{\vartheta^Y - 1}{\vartheta^Y}} di \right]^{\frac{\vartheta^Y}{\vartheta^Y - 1}}$ in year t is competitively assembled from varieties produced on the unit interval, each subject to a constant returns-to-scale technology using a capital-energy composite X_t^i and labor L_t^i augmented by technological progress A_t as inputs

$$Y_t^i = F(X_t^i, A_t L_t^i) = A_t L_t^i f(x_t^i), \quad (1)$$

with $x_t^i = X(K_t^i, E_t^i) / A_t L_t^i$. In turn, the capital-energy composite $X_t = \left[\int_0^1 (X_t^i)^{\frac{\vartheta^X - 1}{\vartheta^X}} di \right]^{\frac{\vartheta^X}{\vartheta^X - 1}}$ is also competitively assembled from varieties produced on the unit interval using a linear homogenous constant elasticity of substitution (CES) function with capital K_t^i and energy E_t^i as inputs

$$X_t^i = X(K_t^i, E_t^i) = D[(1 - b)(K_t^i)^{-\rho} + b(E_t^i)^{-\rho}]^{-1/\rho}, \quad (2)$$

³ Furthermore, an increase in energy costs and thus in transportation costs may dampen regional specialization and thus productivity growth (see Le Roux et al., 2022).

with scaling factor D , share parameter $0 < b < 1$ and $\rho = \frac{1-\sigma}{\sigma}$, where $\sigma > 0$ is the elasticity of substitution between capital and energy.

In the long run, firms at both levels maximize their profits subject to downward-sloping inverse demand functions. The producers of the capital-energy composite adjust the inputs of capital and energy, taking the rental rate of capital R_t and the input price of energy P_t^E as given:

$$\max_{K_t^i, E_t^i} P^X(X_t^i)X_t^i - R_t K_t^i - P_t^E E_t^i. \quad (3a)$$

Aggregating the first-order conditions (FOCs) over i using the symmetry assumption gives

$$P_t^X \frac{\partial X_t}{\partial K_t} = \mu^X R_t, \quad (3b)$$

$$P_t^X \frac{\partial X_t}{\partial E_t} = \mu^X P_t^E \quad (3c)$$

where $\mu^X = (1 - 1/\vartheta^X)^{-1} > 1$ is the markup factor with the limiting case $\lim_{\vartheta^X \rightarrow \infty} \mu^X = 1$. Analogously, the final good producers adjust inputs of the capital-energy composite and of labor and energy, taking the factor prices P_t^X and W_t as given:

$$\max_{X_t^i, L_t^i} P^Y(Y_t^i)Y_t^i - P_t^X X_t^i - W_t L_t^i. \quad (4a)$$

The aggregated FOCs with markup factor $\mu^Y = (1 - 1/\vartheta^Y)^{-1} > 1$ are:

$$P_t^Y f'(x_t) = \mu^Y P_t^X, \quad (4b)$$

$$P_t^Y A[f(x_t) - x_t f'(x_t)] = \mu^Y W_t. \quad (4c)$$

In the long run, on a balanced growth path implied by this model, output, capital-energy composite and effective labor ($A_t L_t$) grow at the same rate. The steady state equilibrium of this model is characterized by a constant ratio of capital-energy to effective labor $x_t = \bar{x}$. This means that capital and energy are substitutes, but the capital-energy composite and effective labor are long-run complements. On the balanced growth path, real wages are proportional to labor productivity, implying a constant income share of labor. However, income shares of capital and energy may vary.

In the short run, the nominal wage and output price are fixed, while the remuneration of capital services may vary. Firms may be flexible in adjusting energy and labor, but the capital stock is fixed in the short run (i.e. $K_t = \bar{K}_t$). With real wages assumed to be fixed (\bar{W}_t/\bar{P}_t^Y), it follows from (4c) that the ratio of capital-energy to effective labor is also fixed. This also leaves the price of the capital-energy composite unchanged (i.e., $P_t^X = \bar{P}_t^X$), even as firms adjust their volume composition of the capital-energy composite.

Given a constant ratio of capital-energy to effective labor, firms will adjust their capital-energy composite at the same rate as effective labor following an energy price shock. An energy price shock will, thus, lead to the same percentage change in output as in the capital-energy composite. It therefore suffices to

inspect the impacts of energy price changes on the capital-energy composite. The capital-energy composite producers choose their energy input by maximizing their short-term profits

$$\max_{E_t^i} \bar{P}_t^X D[(1-b)(\bar{K}_t^i)^{-\rho} + b(E_t^i)^{-\rho}]^{-1/\rho} - R_t \bar{K}_t^i - P_t^E E_t^i, \quad (5)$$

where barred variables indicate initial steady-state values. We derive aggregate energy demand from aggregating the FOC of energy and solving for E_t :

$$E_t = (1-b)^{-1/\rho} \left[\left(\frac{\mu^X P_t^E}{\bar{P}_t^X D b} \right)^{-1/(1+\rho)} - b \right]^{1/\rho} \bar{K}_t. \quad (6)$$

Substituting (6) into aggregated (2), we derive the demand for the capital-energy composite good:

$$X_t = \bar{K}_t D (1-b)^{-1/\rho} \left[1 + \frac{b}{\left(\frac{\mu^X P_t^E}{\bar{P}_t^X D b} \right)^{-1/(1+\rho)} - b} \right]^{1/\rho}. \quad (7)$$

To analytically solve for the output elasticity with respect to changes in the energy price, let us define a shock as a multiplicative deviation from the short-run level such that $P_t^E = (1 + g_{pE}) \bar{P}_t^E$. The resulting relative deviation of the capital-energy composite is g_X in $X_t = (1 + g_X) \bar{X}_t$. As output and capital-energy are in fixed proportion, g_X is also equal to the relative change in output. Substituting these factors in (7) and reformulating yields the exact elasticity

$$\frac{g_X}{g_{pE}} = \frac{\left[\frac{(1+g_{pE})^s [m-b]}{m(1+g_{pE})^s - b} \right]^{-1/\rho} - 1}{g_{pE}}, \quad (8)$$

with $m = \left(\frac{\mu^X \bar{P}_t^E}{\bar{P}_t^X D b} \right)^s$ and $s = -\rho/(1+\rho)$. The short-term percentage effect on output of an increase in energy prices of $g_{pE} \times 100\%$ is given by $g_X \times 100\%$. This effect is a deviation from the baseline level and thus constitutes a level effect, which is either transitory or permanent, depending on the assumptions regarding the energy price increase. The reaction is non-linear as the elasticity itself is a function of the shock size.

Note that Knetsch and Molzahn (2012) used a local elasticity for marginal changes in energy prices, which can be recovered⁴ from (8) by letting g_{pE} approach 0:

$$\lim_{g_{pE} \rightarrow 0} \frac{g_X}{g_{pE}} = \frac{\partial X}{\partial P^E} \frac{P^E}{X} = -\frac{b}{1+\rho} \left[\left(\frac{\mu^X \bar{P}_t^E / \bar{P}_t^X}{D b} \right)^{-\frac{\rho}{1+\rho}} - b \right]^{-1}. \quad (9)$$

However, since we simulate the impact of a very large energy price shock, we apply (8) for simulation.

2.2 Accounting for indirect production network spillover effects

We calculate the impact of higher energy prices according to equation (9) only for Austria's manufacturing industries, for which detailed data on energy consumption are available. Our impact

⁴ To replicate the perfect competition setting from Knetsch and Molzahn (2012), we would have to set $\mu^X = 1$.

estimates will understate the full economic impact of higher energy prices for two main reasons. First, our approach does not capture the direct impact of higher energy prices on other industries of the economy, such as construction and services. According to energy account data provided by Statistics Austria for 2023, manufacturing accounts for 51% of the total energy demand of all industries in Austria (measured in terajoule (TJ)). Second, a lower production in manufacturing reduces the output of other industries via intermediate demand linkages. To capture the latter effects, we use an input-output model for Austria to simulate the effects of this negative demand shock.

In an input-output framework, the impact of a demand shock is computed using the Leontief model, where total gross output x satisfies $x = (I - A)^{-1}d$, with I as the identity matrix, A as the matrix of technical input coefficients a_{ij} (units of good i needed per unit output of industry j) and d as the final demand vector. For a demand shock Δd shifting final demand from d_o to $d_1 = d_o + \Delta d$, the induced change in output is $\Delta x = (I - A)^{-1}\Delta d$ where L denotes the Leontief inverse, capturing both direct and indirect effects. The element l_{ij} of L quantifies the total output increase in sector i required to support a unit rise in final demand for sector j 's output.

We calculated the indirect effects by assuming a demand shock of EUR 1 for manufacturing (NACE C). This shock translates into EUR 1 of total value added. Value added embedded in imports accounts for the largest share (51%) of total value added. One important factor behind this is the high degree of integration of Austrian manufacturing industries in international production networks. Domestic value added (49% of total value added) consists of three components: (1) Net taxes on goods, which cannot be attributed to specific industries, account for 14.4 % of domestic value added. (2) Value added in manufacturing accounts for 43.1 %. (3) Value added in other industries accounts for 42.5%. Half of the value added in other industries occurs in wholesale and retail trade, which accounts for 11.5 % (10.2 %) of domestic value added.

These results imply that we can roughly double (by a factor of 2.3) our impact on value added in manufacturing to obtain an estimate of the impact of an energy price shock on GDP. Note that this still underestimates the true shock, since we have no estimates of the direct impact of higher energy prices on the non-manufacturing industries.

2.3 Estimating key model parameters

To compute this effect under the assumption of monopolistic competition, we need estimates for the key parameters σ (i.e. ρ), μ^Y and μ^X as well as the unobserved series X_t and P_t^X . As our macroeconomic data sample on manufacturing only covers 22 observations⁵ from 2002 to 2023, we use our access to firm-level data⁶ to estimate μ^Y and σ .

To recover μ^Y we employ the approach of De Loecker and Warzynski (2012). They exploit the fact that under cost minimization, the optimal input demand of a variable production factor M (without adjustment costs) is satisfied if a firm i equalizes the expenditure share of that factor $s_{it}^M = \frac{p_{it}^M x_{it}^M}{p_{it}^Q Q_{it}}$ times the markup μ_{it}^Y with the variable input factor's output elasticity (β_{it}^M):

⁵ This is because data on energy usage from the materials input statistics (MIS) are available only from 2002 onward.

⁶ We had access to firm-level data via the Austrian Micro Data Centre (AMDC) of Statistics Austria.

$$\beta_{it}^M = \mu_{it}^Y s_{it}^M. \quad (10)$$

We estimate the output elasticity⁷ by running the regression

$$\ln(Q_{it}) = \alpha_i + \gamma_t + \beta_j^L \ln(L_{it}) + \beta_j^K \ln(K_{it}) + \beta_j^M \ln(M_{it}) + \varepsilon_{it}, \quad (11)$$

for each ÖNACE 2008 2-digit j . Note that Q is not value added but gross output volume and α_i and γ_t capture firm- and period-specific productivity components. As an adjustable input M , we choose purchases of goods and services (i.e. intermediate inputs). We recover the markups at the NACE 2-digit level as $\mu_j^Y = \max\left(\frac{\beta_j^M}{s_j^M}, 1\right)$, where s_j^M is the mean expenditure share of the input M in total sales of industry j . This avoids large fluctuations in markups that may arise when firm-level expenditure share data are volatile. As we outline in the annex, we use this estimate to retrieve X_t and P_t^X .

As Knetsch and Molzahn (2012) show, the elasticity of substitution between capital and energy σ can be estimated via the regression (see annex for derivation):

$$\ln\left(\frac{E_{it}}{X_{it}}\right) = \alpha_i + \gamma_t - \sigma \ln\left(\frac{P_{it}^E}{P_{it}^X}\right) + u_{it}. \quad (12)$$

Note that in (7) we controlled for firm and year fixed effects. We also ran alternative specifications with industry (NACE 2-digit) fixed effects or industry-time fixed effects. As shown in the annex, we need to control for constant terms and the markups in the capital-energy composite goods sector μ^X . If we assume that these vary only by industry, then this would correspond to including industry fixed effects.

Conditional on the estimate $\hat{\sigma}$, we can recover the parameters b and D (see annex). For these steps and also the simulation of the energy price impact, we return to the aggregated macro-level data, since these cover the total output of Austrian manufacturing.

2.4 Data

We restrict our core analysis to the manufacturing industries, since these industries account for the major share of industrial energy consumption and there are high-quality data on energy usage and costs available for Austria.⁸ After we obtain an estimate of the energy price increases for Austrian manufacturing, we augment the results via indirect production network effects on all other industries (transport, services, etc.) of the Austrian economy. We do this utilizing the 2021 input-output tables for Austria obtained from Statistics Austria.

2.4.1 Manufacturing industry data

To quantify the energy price impact for the Austrian manufacturing industries using the model described above, we need data on the volumes of labor, capital, energy and value added and on the prices for

⁷ In De Loecker and Warzynski (2012), the output elasticities that vary by year for each firm are estimated via a more flexible translog production function and by applying the Akerberg et al. (2015) correction. Since we are not interested in the markups per se but in their impacts on an energy price supply shock, we apply a simpler and more stable estimation approach. We account for the uncertainty in the size of markups in our energy price shock simulations by including a range of plausible markup values from the empirical literature.

⁸ But we leave out the transportation sector covered in Knetsch and Molzahn (2012) due to the limitations of energy costs data.

energy and value added. Data on hours worked by employees, real capital stocks and value added are available at a yearly frequency for 64 industries via Eurostat.⁹ We compute the total labor income share by adding the hours worked by the self-employed, assuming the average wage of those employed.

Data on energy consumed in both volume and value stem from the materials input statistics (MIS) of Statistics Austria. These contain data on total energy usage in the physical unit of the respective energy source and in thousands of euro per industry from 2002 onward.¹⁰ Since data on some energy types are unavailable due to data confidentiality issues, we approximated total energy usage with the sum of diesel, electricity and natural gas usage.¹¹ These three energy sources account for a major share of energy usage in manufacturing (see Reinstaller and Sellner, 2024). The energy price is derived by dividing energy costs by energy usage. Note that the MIS is based on a representative firm survey and constitutes one of the main inputs for the Austrian energy balances. It covers, essentially, all large firms (i.e. the heaviest energy users) in the industries of mining (NACE Rev. 2 B), manufacturing (C), energy and water supply (D and E) and construction (F), while transportation and storage (H) is not included.

According to Kilian (2008), one of the most common mistakes in this context has been to use a production function where the output is given by domestic value added, as value added is net of intermediate imports such as energy. We thus construct a new output measure by aggregating value added and energy expenditure. The respective chained volume series is constructed using the methodology suggested by Eurostat for compiling national accounts statistics (see annex for details).

2.4.2 Firm-level data

We access the firm-level data required for our model via the Austrian Micro Data Centre (AMDC). Our main firm-level data source is the structural business statistics (SBS). The SBS is based on an annual survey, covering around 38,000 economically active legal entities in Austria (6% of the total firm population as of 2021) in industries B to S (excluding O and S94) of the industry classification NACE 2008. For firms with 20 or more employees, the survey is mandatory, and firms with fewer employees may be added to reach at least 90% of total sales in each NACE header covered. The variables covered include production value, sales, employees, hours worked, investments, purchase of goods and services (intermediate inputs). Data are available for the years from 2008 to 2022. To deflate output, investments and intermediate inputs, we used the implicit price deflators of the national accounts statistics for output (P1), gross fixed capital formation (P51G) and intermediate consumption (P2) for 74 2-digit NACE 2008 industries available from Statistics Austria. We constructed a firm-level real capital stock using the perpetual inventory method as presented in Lutz (2016).

Our second main data source is the material input statistics (MIS) already described above. At the firm level, the MIS is based on firms' production plants and not on legal entities as is the SBS. It covers plants active in the NACE 2008 industries B to F (i.e. mining, manufacturing, utilities and construction) with at least 20 employees and a total production output of EUR 10 million (sales and deliveries to other plants

⁹ We used the databases nama_10_a64 (labor, value added) and nama_10_nfa_st (capital stocks).

¹⁰ This series was constructed using the MIS series from 2002 to 2007, 2008 to 2014 and from 2015 onward.

¹¹ The MIS records each energy type in its own unit. We aggregated the three energy types by converting them to TJ, using the conversion factors used by Statistics Austria (i.e. 0.0425 per ton of diesel, 0.0364 per 1,000 m³ of natural gas and 0.0036 per MWh of electricity). Note that confidentiality usually applies if the volumes or values used are very low. For this reason, we could not include coal coke, as its usage declined over time, eventually passing the threshold of confidentiality for later years.

within the same company), covering around 2,350 of the largest plants of the industry, which corresponds to around 5% of the plant population but to 70% of production value.

We restrict our sample to NACE divisions 10 to 33, which constitute the manufacturing industries. The output elasticity estimations of equation (6) are based on a total sample of around 20,500 firm-year observations. We drop the 0.5% smallest and largest observations of both variables prior to estimating equation (7). This mitigates the role of outliers and leaves between 11,000 and 13,000 firm-year observations, depending on the markup values¹² used.

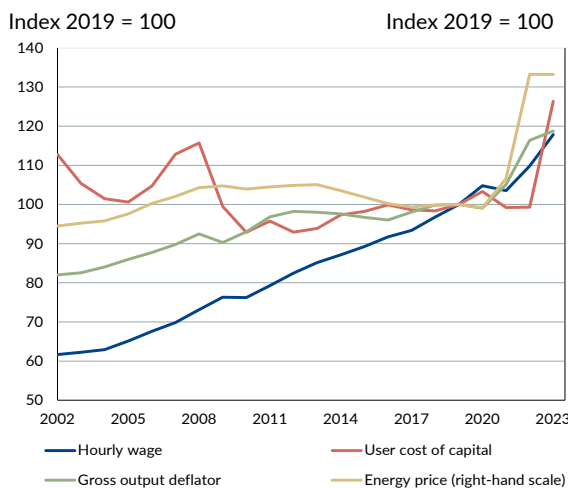
3 Results and discussion

Chart 2 shows the key data of our analysis. We see the sharp increase in average energy prices in manufacturing in 2022. Between 2019 and 2024, average energy prices in manufacturing soared by 166%.¹³ During the same period, energy usage fell by 8.6%. We also notice the sharp increase in user costs of capital in 2023.¹⁴ This increase was driven by a rise in the lending rate of loans for non-financial corporations from 1.8% to 4.6%.

Chart 2

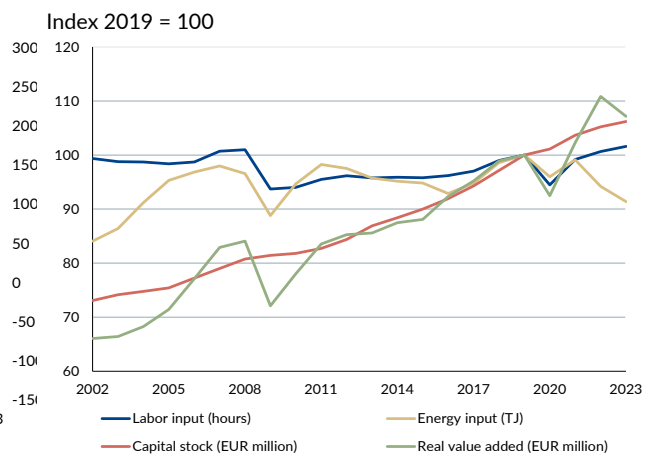
Factor prices and factor input usage in Austrian manufacturing

Factor prices



Source: Eurostat, Statistics Austria, authors' calculations.

Factor input usage



Source: Eurostat, Statistics Austria, authors' calculations.

3.1 Empirical results

We estimate the output elasticity with equation (6), using hours worked as L , the real capital stock as K and purchased goods and services (i.e. intermediate materials and services) as flexible input M . The results are shown in table A1 in the annex. The estimated output elasticities of M vary from 0.633 for repair and installation of machinery and equipment (NACE 33) to 0.856 for manufacture of chemicals

¹² From equation (A5) we see that P_t^X might turn negative for larger values of μ^Y .

¹³ Note that the right-hand scale in the left-hand panel of chart 2 is scaled to match 100 of the left-hand scale.

¹⁴ These are calculated as the ratio of investment to the output deflator times the sum of non-financial companies' lending rate and the depreciation rate (see Dahlqvist et al., 2021).

and chemical products (NACE 20). The average expenditure shares of intermediate inputs vary from 0.597 for printing and reproduction of recorded media (NACE 18) to 0.773 for food, beverages and tobacco (NACE 10–12).

In 5 out of 19 NACE 2-digit industries, markup factors are less than one. For those industries, we replace the markup factor with a value of one, de facto assuming no markups. The remaining industries' markups vary from 1.014 for manufacture of machinery and equipment n.e.c. (NACE 28) to 1.293 (NACE 18). In a recent study, Peneder and Unterlass (2024) estimated an average μ^Y of 1.187 for Austrian manufacturing for the period from 2008 to 2020. This is much larger than the output-weighted average μ^Y of 1.07 obtained from our sample. To reflect the uncertainty around this estimate, we varied μ^Y between 1 (no-markup case), our estimated industry-specific markups that average to 1.07 (low-markup case) and 1.187 (high-markup case) as sensitivity check. We retrieved P_t^X using these three markup cases and then estimated σ from equation (7) accordingly.

The estimation results for the coefficient $-\sigma$ are given in table 1. Knetsch and Molzahn (2012) estimated 0.85 for the German manufacturing sector. The size of the estimated coefficient compares to our estimates assuming no markups (first row) or controlling for only a constant term (column 1) or just year fixed effects (column 2). Note that the elasticity of substitution between capital and energy decreases the higher the markups we assume. The smallest elasticity is found when controlling for unobserved firm heterogeneity via firm fixed effects (column 6). The elasticity here ranges between 0.27 and 0.39, depending on the assumed markup. Note that estimating the regression assuming no markups and using our aggregated manufacturing data – as in Knetsch and Molzahn (2012) – results in an elasticity of 0.32, which is close to the microeconomic estimates controlling for firm heterogeneity (column 6) and the estimate of 0.34 calculated from aggregate German data by Haertel et al. (2022).

Table 1

Estimation summary for $-\sigma$

	(1)	(2)	(3)	(4)	(5)	(6)
$\mu^Y = 1$	-0.8376*** (0.0228)	-0.8427*** (0.0230)	-0.7397*** (0.0238)	-0.7437*** (0.0244)	-0.7462*** (0.0245)	-0.3903*** (0.0419)
$\mu^Y = 1.07$	-0.7731*** (0.0226)	-0.7768*** (0.0227)	-0.6902*** (0.0219)	-0.6931*** (0.0223)	-0.6955*** (0.0225)	-0.3363*** (0.0421)
$\mu^Y = 1.187$	-0.7042*** (0.0235)	-0.7063*** (0.0240)	-0.6172*** (0.0241)	-0.6189*** (0.0248)	-0.6214*** (0.0252)	-0.2697*** (0.0413)
Constant	Yes	No	No	No	No	No
Year fixed effects	No	Yes	No	Yes	No	Yes
Industry fixed effects	No	No	Yes	Yes	No	No
Year-industry fixed effects	No	No	No	No	Yes	No
Firm fixed effects	No	No	No	No	No	Yes
Standard errors, clustered	Firm and year	Firm and year	Firm and year	Firm and year	Firm and year	Firm and year

Source: AMDC (Statistics Austria), authors' calculations.

There are no empirical estimates available on markups in Austria's energy-capital composite market. So in our simulations of energy price shock impacts, we set μ^X – similar to μ^Y – either to 1, 1.07 or 1.187. Moreover, for each μ^Y in table 1, we vary σ between the lowest (column 6) and highest value (column 2).

The results of our simulation are summarized in table 2. The rows indicate the respective simulation setting with either no, low or high markups and a low or high elasticity of substitution between capital

and energy. Columns (1) and (2) show the respective values used in the simulations. The percentage impacts on manufacturing value added (VA) are given in column (3).

Table 2

Impact of a 50%¹ energy price shock on value added in manufacturing and GDP

	(1) Capital-energy elasticity of substitution (σ)	(2) Markups (μ^Y, μ^X)	(3) Impact on value added in manufacturing, without input-output effects (%)	(4) Impact on GDP, without input-output effects (%)	(5) Impact on GDP, including input-output effects (%)
(a) Low elasticity / no markups	0.39	1	-1.8	-0.3	-0.7
(b) Low elasticity / low markups	0.34	1.07	-1.9	-0.3	-0.7
(c) Low elasticity / high markups	0.27	1.187	-2.3	-0.4	-0.9
(d) High elasticity / no markups	0.84	1	-5.4	-0.9	-2.1
(e) High elasticity / low markups	0.78	1.07	-6.2	-1.1	-2.4
(f) High elasticity / high markups	0.71	1.187	-8.6	-1.5	-3.4

¹ Relative to 2019.

Source: Authors' calculations.

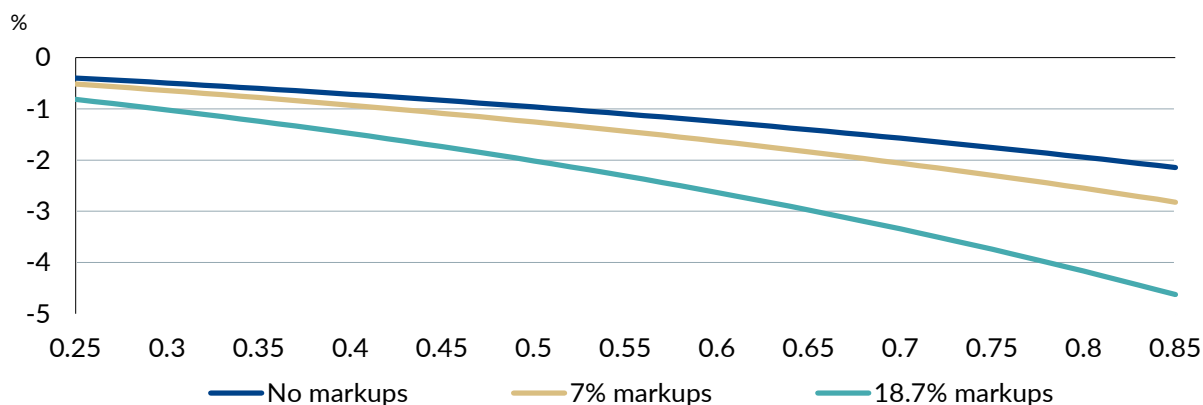
Using σ values that are similar to the estimates for Germany in Knetsch and Mohlzahn (2012), i.e. the higher ones in columns (1) and (2) of table 1, value added in Austrian manufacturing industries could decline by between 5.4% (assuming no markups) and 8.6% (assuming high markups) (see last three rows in table 2). With a GDP share of manufacturing of 17%, this would result in a decline of GDP between 0.9% and 1.5% (see column 4). Accounting for input-output interlinkages would increase the impacts to between -2.1% and -3.4%.

We, however, prefer the estimates of σ controlling for firm-specific heterogeneity and the business cycle, i.e. firm and year fixed effects (column 6 of table 1). These estimates are more in line with our regression results on aggregate manufacturing data and the values obtained in Haertel et al. (2022) for Germany. When using these elasticities in the estimation, the decline of manufacturing value added comes to between 1.8% and 2.3% (or 0.3% and 0.4% of GDP). The total impact on GDP, including industry interlinkages, increases to between -0.7% and -0.9% (see first three rows in table 2).

The results in table 2 show that the impacts are sensitive to the values of the elasticity of substitution between capital and energy σ and the assumed markups (μ^Y and μ^X). To further investigate this, we plot the total GDP impact (including input-output effects) of a 50% rise in energy prices as a function of σ for our three markup cases using equation (8) with data moments from our aggregate manufacturing data for Austria (see chart 3). The sensitivity of the results with respect to the markups slightly increases with increasing σ . Furthermore, for a given markup assumption, the sensitivity of results increases with respect to σ .

Chart 3

Impact of a 50% energy price increase on Austrian GDP¹



¹ Including input-output effects.

Source: Authors' calculations.

3.2 Short-run versus long-run impacts

Note that our estimated impacts presented above represent the short-term effects of energy price increases in the Knetsch and Molzahn (2012) model. In the long run, not only energy and labor but also capital is allowed to adjust. Should energy prices stay higher, firms would *ceteris paribus* lower their capital stock, leading to an even bigger drop in output. Note that this depends on assuming firms' production technology is fixed. In the long run, higher energy prices should promote research in energy-saving technologies, and firms can adopt a more energy-efficient capital stock. This should then dampen the long-run impact of permanently higher energy prices on output.

Knetsch and Molzahn (2012) note that the long-run implications will crucially hinge on the sharing of the extra cost burden, mentioning as an example the oil price shock in 2008 that drove up oil prices to USD 150 per barrel. As they noted, in 2008, German firms entered the high-energy price period with less strained cost structures, since they were coming from a period that was characterized by negative real wage developments. This contributed to the relatively mild increase in total costs compared to the oil price shocks of the 1970s. Given that Austrian manufacturing firms come from a period of major macroeconomic shocks, temporary demand distortions (COVID-19 pandemic) and strong rises in unit labor costs, the strain on the total costs of the energy price increases may be more pronounced.

Note that even when considering adjustments of the capital stock, long-run impacts will also be driven by the specific modeling assumptions. Atkeson and Kehoe (1999) compared their "putty-clay" to the "putty-putty" model of Pindyck and Rotemberg (1983). While capital faces adjustment costs in both models, once installed capital is fixed in the putty-clay model but remains adaptable in the putty-putty model. The simulations in Atkeson and Kehoe (1999) show that a doubling of energy prices in the long run leads to a fall in output of 33% in the putty-putty model but only to a 5.3% decline in the putty-clay model.

3.3 Comparing our findings to the impacts found in other studies

Table 3 provides a summary of the GDP impacts found in the empirical literature for Austria, Germany, the UK and the euro area. Our results of -0.7% to -0.9% for the lower elasticity of substitution between capital and energy are well in line with the empirical literature.

Hölzl et al. (2023) employed a multi-regional, multi-industry model to simulate the impact of a series of energy price scenarios on Austria’s medium-term output. Scaled to an energy price shock of 50% for manufacturing, their results would imply a GDP impact (including input-output effects) ranging from -0.4% to -0.6%.¹⁵ In another study, Reiter et al. (2024) employed a dynamic stochastic general equilibrium (DSGE) model with input-output linkages (including an energy satellite account) to model the impact of increasing energy prices on Austria’s manufacturing industries. They find that a persistent increase of the end user gas price of 47% results in medium-term GDP losses of between -0.6% and -0.9%.¹⁶

Based on a slightly different methodology than the one we employ in this study, the Deutsche Bundesbank (2022, p. 29) found an impact of a doubling of energy prices of -2.1% on Germany’s potential output (implying -1% for a 50% increase). Around half of this impact is accounted for by the manufacturing sector, one-quarter by the transport industry and the remainder by the rest of the economy.¹⁷ Chen et al. (2023) applied the directed technological change model of Acemoglu (2002) and found that energy prices that are 20% above the 2018–2019 average reduce Germany’s potential output by 1.2%. In their model, the technological change, i.e. energy efficiency improvements, mitigates the negative effects on output. Scenarios with less responsive energy efficiency or a 70% energy price shock show impacts of -2% and -2.9%, respectively. Scaling their impacts to 50%, we obtain a range of -2.1% to -3.4%. Compared to the results of other studies for Germany and Austria, which is structurally similar, these results are clearly on the upper bound of the available estimates.

Table 3
Summary of impacts of a 50% energy price shock on GDP

Study	Region	Impact estimates (range)
Hölzl et al. (2023)	Austria	-0.4% to -0.6%
Reiter et al. (2024)	Austria	-0.6% to -0.9%
Deutsche Bundesbank (2022)	Germany	-1%
Chen et al. (2023)	Germany	-2.1% to -3.4%
Office for Budget Responsibility (2022)	UK	-0.7% to -0.9%
Le Roux et al. (2022)	Euro area	-1%
Authors' (preferred) estimates	Austria	-0.7% to -0.9%

Note: We scaled the impact estimates of the studies listed to an energy price shock of 50%.

Source: Authors' compilation.

¹⁵ We used the difference of growth in the production value of manufacturing of their scenarios S1 (-2.7%) and S3 (-1.0%) to their reference scenario of 2.9% (see tables 3 and 27 in Hölzl et al., 2023). We multiplied this growth difference with the 2019 share of manufacturing value added in nominal GDP of 17% and doubled the results to account for input-output effects. To scale their results to a 50% energy price increase, we scaled their assumed gas price increase (180% in S1 and 100% in S2) down to 50% (i.e. by a factor of 3.6 and 2, respectively). So for S1, we get $(-2.7\% - 2.9\%) * 0.17 * 2.3 * (1/3.6) = -0.6$.

¹⁶ These ranges depict the scenarios given in Reiter et al. (2024, tables 2 to 5). Their scenarios include their worst-case scenario but exclude the scenarios that were included as illustrative cases (i.e. only green electricity is used, each country in the world faces the same energy price increases, etc.). Note that they increased the wholesale price of gas from EUR 25 per MWh to EUR 50 per MWh (i.e. by 100%). But since the end consumer price also includes country-specific fees such as gas network charges, this would result in an increase in the end consumer price of only 47%.

¹⁷ While the Deutsche Bundesbank (2022) also used the approach of Knetsch and Molzahn (2012), they simulated the impacts on the rest of the economy using the impulse-response functions of a vector autoregression (VAR) model containing the value added of industry, transport and the rest of the economy.

The Office for Budget Responsibility (2022, p. 80ff) used a three-factor production function approach for the UK and estimated short- and medium-run elasticities of potential output to energy prices of -0.013 and -0.018, respectively. An energy price increase of 50% would imply an impact on UK GDP of -0.7 (short term) to -0.9% (medium term). The ECB simulated the impact of oil prices that are 40% higher than before the pandemic (2017–2019) on euro area potential output (see Le Roux et al., 2022). Using elasticities from the macroeconomic models used in the Eurosystem staff macroeconomic projection exercise, they estimate GDP impacts to come to around 0.8% (i.e. 1% in case of an energy price shock of 50%).

4 Concluding remarks

We estimate the impact on Austrian GDP of a permanent 50% energy price increase for Austria's manufacturing industries. Results are derived using a generalized version of the Knetsch and Molzahn (2012) partial-equilibrium approach that accounts for monopolistic competition in final and capital-energy goods markets. As results are sensitive to the elasticity of substitution between capital and energy and to the markups employed, we estimate them using Austrian firm-level data. Using our preferred estimates that account for firm heterogeneity and the business cycle, we find that total impacts on Austrian GDP come to between -0.7% and -0.9%. Note that these effects are short-run supply effects of a permanent energy price increase. These short-run impacts likely represent a lower bound, as we modeled only the manufacturing industries, which consume about half of the energy consumed by all Austrian industries. In the medium to long run, if firms did not switch to more energy-saving technologies, the capital stock would also adjust downward, amplifying the impact further.

Stable energy supply and competitive energy prices are essential for the Austrian economy. Our estimated impacts on GDP are sizable enough to warrant policy action. In general, higher energy prices can serve the purpose of amplifying “directed technological change” (see Acemoglu, 2002) and efforts toward higher energy savings and efficiency increases. However, empirical evidence suggests that the transition to greener technologies via a substantial increase in investments is a difficult endeavor. Reinstaller and Sellner (2024) documented that the observed reduction of aggregate energy intensity post-2014 was driven more by structural economic changes than by within-sector improvements in energy intensity. Additional firm-level survey evidence in Hölzl et al. (2023) suggests that especially the energy-intensive manufacturing firms compensate part of the energy price increase with fewer investments. This would suggest that the introduction of energy-efficient production technologies has only limited potential to increase energy efficiency in the short to medium term.

An alternative would be to stabilize energy prices via economic policy interventions. In the short term, temporary external energy price shocks (e.g. a surge in energy prices in the wake of the war in Ukraine) could be offset through subsidies. In the long term, stable energy supply and competitive energy prices could be ensured through an appropriate grid infrastructure, adequate storage technologies, the expansion of renewable energy sources, higher energy autonomy in the EU and a functioning European energy market. However, these measures divert fiscal resources away from alternative uses in fields such as education, green transition or research and innovation policies. Our estimates can support further analyses of the costs and benefits of different energy policy options and provide a useful benchmark for comparing alternative growth strategies.

Our research has several limitations and caveats that future research could address. First, we do not account for general equilibrium effects between Austrian industries and those in other countries. Our results stem from a partial equilibrium analysis of the Austrian manufacturing sector that is augmented with production network effects. Second, we focus on short-run impacts and thus do not model adjustments in capital stocks in the medium to long run. And third, while we use firm-level data to inform some key parameters, we compute the impact of the energy price shock using aggregate manufacturing data moments. This aggregate perspective hides heterogeneities within manufacturing, i.e. energy-intensive versus non-intensive industries, but also between firms within particular industries.

5 Declaration

This research project was conducted with data from the Austrian Micro Data Center (AMDC). The AMDC is a research data infrastructure facility of Statistics Austria that enables research on micro data processed in compliance with data protection regulations (Fuchs et al., 2023).

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Annex

To compute the output measure Y_t consisting of value added and energy, we proceeded as follows: We obtain the series of current prices and previous year's prices by simply adding the value added (VA) and energy costs (CE) at current ($Y_t^{CP} = VA_t^{CP} + CE_t^{CP}$) and previous year's prices ($Y_t^{PYP} = VA_t^{PYP} + CE_t^{PYP}$), respectively. The chained volume index with base year 2020 is obtained according to the European System of National Accounts (see European Commission, 2010, chapter 10), by constructing the volume index

$$IVol_t = \frac{Y_t^{PYP}}{Y_{t-1}^{PYP}}, \quad (A1)$$

and chaining the base to it as follows:

$$Y_t^{CLV2020} = Y_{t=2020}^{CP} \prod_{k=2021}^t IVol_k \quad \forall t > 2020, \quad (A2a)$$

$$Y_t^{CLV2020} = \frac{Y_{t=2020}^{CP}}{\prod_{k=2020}^t IVol_k} \quad \forall t < 2020. \quad (A2b)$$

Following Knetsch and Molzahn (2012), we derive the unobserved capital-energy bundle X_t using the fact that in steady state, it grows at the same rate as effective labor $\bar{X}_t = \lambda A_t \bar{L}_t$. Labor-augmenting technical change A_t can be derived from a growth-accounting framework

$$A_t = A_0 \prod_{i=1}^t (1 + \theta_i), \quad (A3)$$

$$\theta_t = [\Delta \ln Y_t - \bar{\alpha}^L \Delta \ln L_t - \bar{\alpha}^E \Delta \ln E_t - (1 - \bar{\alpha}^L - \bar{\alpha}^E) \Delta \ln K_t] / \bar{\alpha}^L, \quad (A4)$$

with $\bar{\alpha}^L$ as sample average to approximate the long-run constant labor share implication and allowing the energy share to vary using the Törnqvist index $\bar{\alpha}_t^E = \frac{1}{2}(\alpha_t^E + \alpha_{t-1}^E)$. Having an estimate for X_t and assuming zero profits (i.e. markups $\mu = 0$), the price of the capital-energy composite is derived by

$$P_t^X = (P_t^Y Y_t / \mu^Y - W_t L_t) / X_t, \quad (A5)$$

with P_t^Y being the output deflator and W_t the money wage per hour worked.

To derive equation (12), we substitute the marginal product of energy given by

$$\frac{\partial X_t(\cdot)}{\partial E_t} = b D^{-\rho} \left(\frac{X_t}{E_t} \right)^{1+\rho}, \quad (A6)$$

into the FOC given in equation (3c). After taking logs and re-arranging, we get

$$\ln \left(\frac{E_t}{X_t} \right) = \sigma \ln b - \rho \sigma \ln D - \sigma \ln \mu^X - \sigma \ln \left(\frac{P_t^E}{P_t^X} \right), \quad (A7)$$

which can be estimated defining the constant term $\alpha = \sigma \ln b - \rho \sigma \ln D - \sigma \ln \mu^X$ and adding an independent and identically distributed error term u_t to get equation (12). Given an estimate for σ , we can retrieve ρ and further

$$b = \frac{\beta_t^E K_t^{-\rho}}{(1-\beta_t^E)E_t^{-\rho} + \beta_t^E K_t^{-\rho}}, \quad (\text{A7})$$

with $\beta_t^E = (\mu^X P_t^E E_t) / (P_t^X X_t)$ as well as

$$D = \frac{X_t}{K_t E_t} [(1 - \beta_t^E) E_t^{-\rho} + \beta_t^E K_t^{-\rho}]^{-1/\rho}. \quad (\text{A8})$$

Table A1

Estimated output elasticities and expenditure shares of purchased goods and services (M)

NACE (2008) 2-digit	Output share in NACE C	N	β^M	s^M	μ^Y
Food, beverages, tobacco (10-12)	14.4%	2750	0.84	0.77	1.08
Textiles, wearing apparel, leather products (13-15)	1.2%	569	0.84	0.72	1.16
Wood and wood products (16)	4.3%	1315	0.67	0.75	1
Paper and paper products (17)	2.9%	806	0.80	0.72	1.12
Printing and reproduction of recorded media (18)	0.8%	400	0.77	0.60	1.29
Coke and refined petroleum products (19)	3.1%	22	0.75	0.76	1
Chemicals and chemical products (20)	6.7%	809	0.86	0.74	1.16
Pharmaceutical products (21)	2.9%	273	0.72	0.67	1.08
Rubber and plastic products (22)	3.2%	1282	0.73	0.69	1.06
Non-metallic mineral products (23)	3.2%	1267	0.64	0.68	1
Basic metals (24)	9.3%	1022	0.86	0.74	1.16
Fabricated metal products (25)	8.1%	2427	0.68	0.66	1.04
Computer, electronic and optical products (26)	5.2%	794	0.62	0.63	1
Electrical equipment (27)	6.1%	1260	0.72	0.67	1.08
Machinery and equipment (28)	13.2%	3055	0.71	0.70	1.01
Motor vehicles, trailers and semi-trailers (29)	7.3%	804	0.79	0.75	1.06
Other transport equipment (30)	2.5%	186	0.80	0.74	1.09
Furniture and other manufacturing (31-32)	3.0%	856	0.71	0.66	1.07
Repair and installation of machinery (33)	2.6%	568	0.63	0.71	1
NACE C	100%	20465	0.75	0.71	1.07

Note: We set $\mu^Y < 1$ to 1, i.e. we exclude the case of negative markups.

Source: AMDC (Statistics Austria), authors' calculations.

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