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RISING ENERGY PRICES AND PRODUCTIVITY: SHORT-RUN PAIN, LONG-TERM GAIN?

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ABSTRACT/RÉSUMÉ

Rising energy prices and productivity: short-run pain, long-term gain?

Soaring energy prices have raised concerns about the risks energy price shocks pose for firms' performance and the green transition. This paper estimates the impacts of energy price changes on firms' productivity as well as their dynamics, distinguishing between the short and medium-to-long term, using historical data. The analysis shows that following an energy price shock, firms adjust down their capacity utilisation, and their productivity declines. The estimates suggest that a 5% increase in energy prices reduces productivity by approximately 0.4% one year later. However, firms may display positive productivity gains in the medium term. Specifically, a shock corresponding to a 10% increase in energy prices is associated with an increase in productivity growth of around 0.9 p.p four years after the shock. These gains are more likely in less energy-intensive sectors, but tend not to materialise for larger shocks. There is some evidence that investment may be the channel behind productivity gains, the latter being larger for firms that had made investments in capital just before the shock.

JEL codes: D22, D24, Q40, Q48, Q52.

Keywords: Energy prices, firm performance, productivity, environmental policy.

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Hausse des prix de l'énergie et de la productivité : coûts à court-terme et gains à long-terme ?

La flambée des prix de l'énergie suscite des inquiétudes quant aux risques que ce choc fait peser sur les performances des entreprises et la transition verte. Cet article utilise des données historiques pour estimer l'impact des variations des prix de l'énergie sur la productivité des entreprises ainsi que sur leur dynamique de productivité en distinguant l'impact de court et de moyen-long terme. L'analyse constate qu'à la suite d'un choc sur les prix de l'énergie, les entreprises ajustent à la baisse l'utilisation de leurs capacités de production et font face à une baisse de leur productivité. Les estimations suggèrent qu'à la suite d'une augmentation de 5 % des prix de l'énergie, la productivité est réduite d'environ 0,4 % un an après le choc. Cependant, les entreprises peuvent afficher des gains de productivité positifs à moyen terme. Plus précisément, un choc correspondant à une augmentation de 10 % des prix de l'énergie est associé à une augmentation de la croissance de la productivité d'environ 0,9 pp quatre ans après le choc. Ces gains sont plus probables dans les secteurs moins énergivores mais ont tendance à ne pas se matérialiser pour des chocs plus importants. L'analyse empirique suggère que l'investissement est un canal de transmission important derrière les gains de productivité, ces derniers apparaissant plus élevés pour les entreprises ayant procédé à des investissements en capital avant le choc.

Classification JEL: D22, D24, Q40, Q48, Q52.

Mots-clés: prix de l'énergie, performance de l'entreprise, productivité, politique environnementale.

Table of contents

Tables

Figures

Boxes

Rising energy prices and productivity: short-run pain, long-term gain?

By Christophe André, Hélia Costa, Lilas Demmou and Guido Franco[1]

1. Introduction

1. Soaring energy prices resulting from the strong post-COVID19 economic recovery and the war in Ukraine threatened to derail the post-pandemic recovery. In its latest Economic Outlook, the OECD revised down its global growth projections for 2023 to 2.2% from 3.2% a year earlier. Energy prices have recently declined thanks to a warmer winter than expected, improving the economic outlook. However, wholesale energy prices are still susceptible to renewed spikes and, though the diversification of energy sources is undergoing, not all the alternative energy sources have been fully secured.

2. The energy crisis has been a significant blow to many businesses, some of which were already weakened by the pandemic. Coal, natural gas and electricity are critical inputs to production in various sectors and an increase in their price puts strain on firms' profitability, forcing them to adjust down production levels in the short term. In the medium- to long-term, energy price increases pose a threat to firms' performance for the most energy-dependent sectors, especially in fuel-importing countries, and raise concerns about the risk of jobs shifting to low energy cost regions. High energy prices could also deter investment, undermining firms' productivity and competitiveness even further.

3. The optimal policy response to such a shock is complex. Policymakers may push towards temporarily shielding corporations from energy price shocks to preserve their economic performance and industrial jobs, at the expense of blurring the price signal needed for the green transition.[2] On the contrary, a long-term objective would be to reduce dependence on fossil fuels, both for energy security and climate mitigation reasons. This requires instead the price signal to operate, providing the right incentives for firms to invest in low-carbon technology to reduce fossil energy consumption. To design polices that reconcile the two, at times conflicting, goals of providing firm support on the face of energy price increases and promoting the green transition, it is key to understand the conditions under which the impacts of energy price increases on firms materialise.

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[2] Amid such a price shock, another critical challenge relates to the protection of the most vulnerable households, an issue not discussed in this paper (Causa et al., 2022[99]).

4. This paper contributes to the debate by estimating the impact of energy price shocks on productivity, a key driver of firms' performance. Beyond the impact of exogenous energy price shocks, the analysis also sheds light on the productivity effect of climate mitigation policies, which mostly result in increasing the price of fossil fuels (Sato et al., 2019[1]). Using historical data, the paper explores the potential impact of energy price shocks on within-firm productivity and resources reallocation, incorporating the heterogeneity across sectors and firms, and highlighting potential channels behind impacts. An important contribution of the paper is to highlight the distinction between the short- and the medium-long term impact, through the dynamics of gains and costs, on which the current literature is limited. Finally, performing a simulation exercise on a sample of European firms, we also provide some exploratory estimates on the impact of the current shock on firms' cost structure and profitability, documenting heterogeneities relevant for policy support design in the current context.

5. Our analysis relies on newly updated measures of sectoral energy prices estimated through country prices and sectoral energy mixes, based on Sato et al. (2019[1]). Compared to a simple measure of oil/gas world prices, this measure has the advantage of accounting for the considerable cross country-industry variation in energy mix and energy prices, which may be for instance related to differences in imported energy dependency, integration in world energy markets, supply bottlenecks due to transports costs or insufficiently developed infrastructures. A substantial share of cross-country variation comes from differences in taxes and levies charged on energy consumption, such as environmental taxes, as well as exemption rules or rebate schemes (Sato et al., 2019[1]). Our empirical approach exploits this country-industry-year variation (similarly to Dechezleprêtre, Nachtigall and Stadler (2020[2])) to contrast the impact of energy price changes across firms displaying different characteristics and operating in different settings.

6. The debate on the impact of carbon prices, and more generally of stringent environmental policy, on firm's performance is characterized by two opposing views. On the one hand, the pollution-haven hypothesis, derived from trade theory, predicts that environmental policy will increase compliance costs and crowd out efficiency investment, therefore reducing the productivity/competitiveness of firms (possibly shifting it to regions with lower abatement costs). On the other hand, the Porter hypothesis (Porter, 1991[3]; Porter and van der Linde, 1995[4]) predicts that higher carbon prices have positive effects on firms' outcomes by promoting efficiency improvements and encouraging innovation in new technologies, which in turn increases productivity. However, efficiency gains due to investment or innovation may take some time to materialize, highlighting the need to adopt a dynamic approach (Ambec et al., 2013[5]).

7. Despite the large literature on the short-term effects of energy prices, there is less evidence on their dynamic effects. By examining the yearly impact of the shock over five years, our study sheds light on the potential changes in impact of an energy price shock with time. Our findings suggest that energy price increases have initially an adverse impact on the average firm's productivity. This effect is stronger for energy-intensive sectors and firms facing tighter financial constraints. Under certain conditions, this is followed by a productivity improvement in the medium term as firms adjust to the shock, notably through investment. These findings are consistent with both the pollution haven and the Porter hypotheses and highlight the need to consider longer-term dynamics when analysing the impacts of energy prices.

8. These results provide insights into the policy responses to energy price shocks and implications for the green transition, which are particularly relevant at the current juncture. In the short term, sharp increases in energy prices may lead some firms to be less profitable and eventually exit the market. Smaller firms or those facing tighter financial constraints may be even further damaged. Supporting these firms against exogenous and severe energy shocks may therefore be warranted to avoid risks of scaring for workers and more broadly losses in human capital.

9. In the long term, mild energy price increases may induce firms to increase investment in energy efficiency, promoting environmental gains and possibly boosting productivity. Maintaining well-defined price signals may thus be desirable not only from an environmental perspective but also from a productivity perspective. The latter however is not guaranteed and depends on firms' ability to invest and the expected

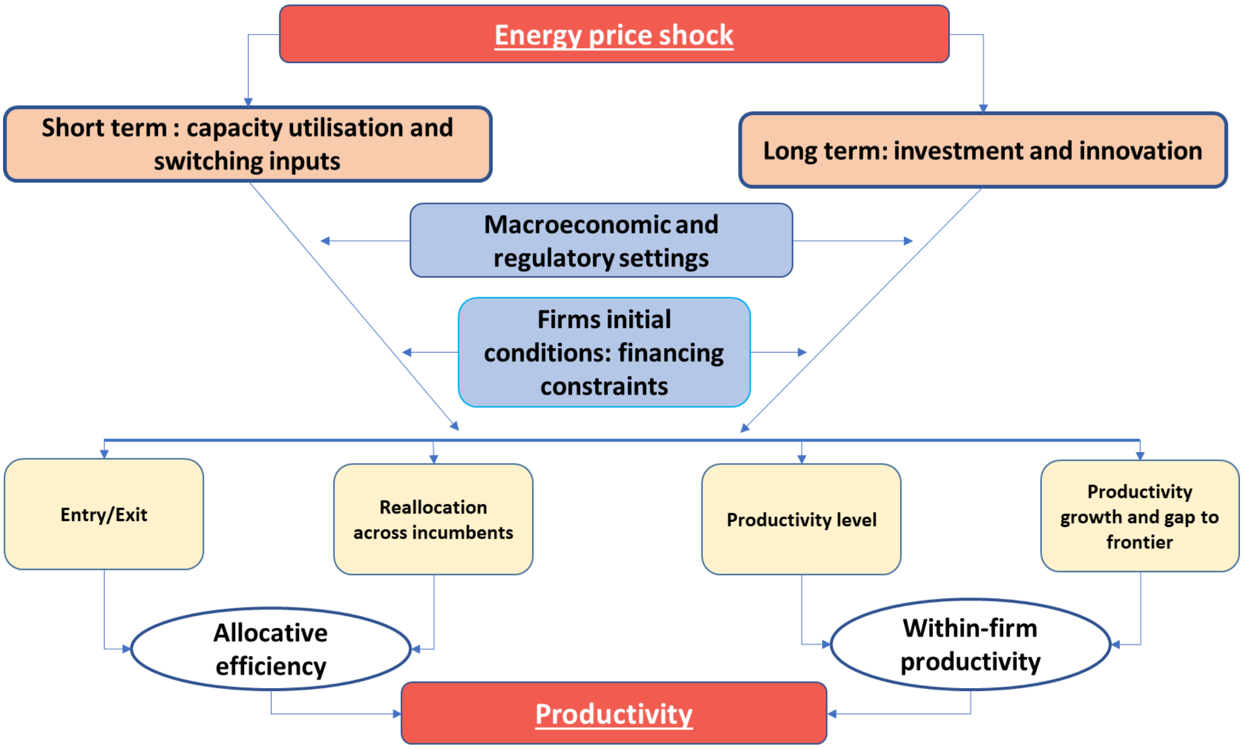
payoff of doing so. In order to promote productivity-enhancing investment in energy efficiency, governments should focus on lowering policy uncertainty, reducing financial constraints, and increasing awareness of environmentally related challenges. A particular focus on energy-intensive sectors might be necessary, combining additional decarbonisation incentives for firms remaining in the market with re-skilling of the workforce in sectors whose size will eventually be reduced.

2. Economic channels

10. Energy price changes may affect productivity through several channels, operating both through the allocative efficiency and the within-firm channels. Following a price shock, firms adjust their production process in a manner which may differ in the short and the long term, as well as depend on macroeconomic conditions, regulatory settings and firms' specific characteristics.

Figure 1. Economic channels: Energy price shocks and productivity

Short- and long-term channels and moderating conditions



2.1. Short-term adjustment

11. In the short term, to limit energy cost increases, firms may adjust their production process, reducing the use of capital overall, and therefore production, while switching to the most energy efficient capital available at the firm. This may lead to a decline in their energy-to-capital ratio and an under-utilisation of their capital stock (Gamtessa and Olani, 2018[6]). The impact on short-term productivity is not straightforward. On the one hand, productivity may decline as firms reduce capital utilisation and therefore production, with inputs remaining relatively fixed (Aldy and Pizer, 2015[7]; Marin and Vona, 2021[8]). On the other hand, productivity may increase for some firms due to selective utilisation of more efficient capital

vintages, which could offset the loss of productivity stemming from the under-utilisation of other vintages (Xepapadeas and Zeeuw, 1999[9]).

12. Firms may also switch energy sources if less costly alternatives exist (for instance switching from fossil fuel to biomass in some industries). Acemoglu et al. (2012[10]), show that if clean and dirty inputs are substitutable in production, emission-reduction targets can be achieved without sacrificing long-term economic growth. D'Arcangelo et al. (2022[11]), examining the impact of EU-ETS regulation on Italian firms, find that following an increase in emission prices, firms experience an increase in production and inputs, which could be consistent with a fuel-switching process. Several papers analyse firms' ability to switch between different fuels, but the extent of substitutability across fuels remains debated (Stern, 2012[12]; Hyland and Haller, 2018[13]).

13. Finally, a sharp increase in energy prices could favour productivity-enhancing reallocation if it helps push out of the market less productive companies or incentivise their downsizing (i.e., a cleansing effect). Yet the uncertainty arising from unstable price signals and financial strain hitting high-productivity but illiquid companies may impede their productive investments, hindering their growth and generating misallocation of labour into less productive firms. Symmetrically, a deep decrease in energy prices could ensure the survival or even expansion of low-productivity and zombie firms by lowering inputs costs, thus hampering the reallocation process; but it could also help relax the financing constraints faced by young and innovative SMEs, increasing the net present value of their investments and their growth opportunities, hence spurring productivity enhancing reallocation.

2.2. Medium- and long-term dynamics

14. In the aftermath of an energy price shock, firms' incentives to invest may change, affecting their medium- to long-term productivity. In particular, incentives to invest in energy-efficient technologies may be reduced due to a supply effect (i.e. an increase in marginal costs of production raises the threshold that determines whether an investment is profitable) as well as a demand effect (i.e. global demand declines with inflation) (see Hamilton (2008[14]); Bach Phan, (2019[15])).

15. On the contrary, higher energy costs may instead induce higher investments in new energy-efficient capital. Steinbuks and Neuhoff (2014[16]) show that the investment response to energy prices varies considerably across manufacturing industries in OECD countries, being more significant in energy-intensive industries and increasing over time. A similar result is found by Dlugosch and Kozluk (2017[17]), who estimate the energy price and total investment relationship based on a sample of listed firms in 30 OECD countries. Marin and Vona (2021[8]) find also, based on a sample of French firms, that an increase in energy price generates an increase in the capital stock in the long term.

16. Investment in more energy-efficient capital is expected to have positive impacts on productivity, by lowering maintenance and input costs (Pye and McKane, 2000[18]; Finman and Laitner, 2001[19]). It may also lead to improvements in operation and process reliability, with an impact on productivity (IEA, 2019[20]). Recent evidence seems to support this (Kalantzis and Niczyporuk, 2021[21]; Filippini et al., 2020[22]). As it tends to be more efficient, new capital is also predicted to enhance total factor productivity through capital-embodied technical progress (Solow, 1960[23]; Benhabib and Rustichini, 1991[24]).

17. However, switching resources away from traditionally "productive" uses to achieve energy saving objectives may also imply an additional burden for firms, meaning that gains do not systematically offset the costs, especially when the macroeconomic environment is not favourable.[3] Overall, the gains

[3] The abundant literature on the Porter Hypothesis has been mostly undertaken at the industry and macro level, suggesting overall a non-significant impact on productivity (Metcalf and Stock, 2020[91]; Bernard, Islam and Kichian, 2018[92]) or a small negative impact (Goulder and Hafstead, 2017[90]). Existing micro-level evidence on the effects of price increases, induced by environmental regulation, on firm productivity is inconclusive, with some evidence of

associated with energy efficiency investment may take time to materialize, while firms bear the short-term costs, warranting a dynamic approach to gains and costs (Ambec et al., 2013[5]). While this has been so far insufficiently explored, a few exceptions exist. Lanoie et al. (2008[25]) for example, analyse, over a four-year period, the productivity impact of stricter regulations in a sample of 17 Quebec manufacturing sectors, finding a decline in productivity in year one, a slightly positive effect in year two, and more positive outcomes in years three and four. Again for Canada, Gamtessa and Olani (2018[6]) study the short- and long- term impact of energy price shocks on capital productivity, finding that a shock promotes productivity in the long term, which could be the result of induced investment in efficient capital.

18. Energy prices and regulation may also promote energy-efficient innovation (Aghion et al. (2016[26]); Calel and Dechezleprêtre (2016[27]); Haščič et al. (2009[28]); Popp (2002[29])). The impact of innovation on firms' outcomes is still not well understood, with some evidence pointing to a positive impact (Rexhäuser and Rammer, 2014[30]; Van Leeuwen and Mohnen, 2017[31]; Agnelli, Costa and Dussaux, 2023[32]) while others suggest a non-significant or nuanced impact (Lanoie et al., 2011[33]; Leeuwen and Mohnen, 2017[34]; Dechezleprêtre and Kruse, 2022[35]). The impact of innovation often requires a longer-term view, often spanning decades, as commercialisation of new technologies is a lengthy procedure (Gross et al., 2018[36]), and is therefore beyond the scope of the current analysis.

2.3. Macroeconomic conditions, institutional settings and firms' specific characteristics

19. The short- and long-term adjustments mentioned above may be affected by various factors, such as pre-existing institutional settings as well as macroeconomic and financial conditions.

20. Financing constraints are often put forward to explain a lack of investment, especially energy efficiency investment (Haas and Popov, 2019[37]; Martin et al., 2022[38]; Gillingham, Newell and Palmer, 2009[39]; Levine et al., 2018[40]). Financing conditions may also mediate the relationship between energy price shocks and allocative efficiency, with a mixed effect on productivity. First, energy-dependent firms that are financially vulnerable to the shock but still productive, may be pushed out of the market due to of credit frictions (Eslava et al., 2010[41]; Barlevy, 2013[42]), implying a cleansing effect from an environmental point of view (which is desirable) but potentially a scarring effect from a productivity perspective (which is less so). At the same time, it is likely that the least energy-efficient firms are also the least productive within a sector, having less capacity to deploy new energy-saving technologies or to offshore their production (Albrizio, Kozluk and Zipperer, 2017[43]).

21. The costs and benefits of environmental regulation or energy price shocks, as well as their impact across firms and sectors, may vary over the course of business cycle and depend on the type of shock. First, there is substantial evidence that oil price increases are directly linked to economic recessions and productivity slowdowns (Hamilton, 2003[44]; Schwark, 2014[45]). Further, supply-driven oil-price shocks are expected to have very different effect (i.e., adverse) from those of an oil-demand shock driven by global economic activity (Cashin et al., 2014[46]). Similarly, negative oil price shocks may not always have a symmetric effect from positive shocks (Davis and Haltiwanger, 2001[47]; Kilian and Vigfusson, 2011[48]).

22. Uncertainty also influences the relationship between energy price increases, energy-efficiency investment and productivity. Expectations about energy price fluctuations may adversely affect output and productivity if firms delay irreversible investment when facing uncertainty about future production cost (Bach Phan, Tran and Nguyen, 2019[15]; Bernanke, 1983[49]; Punzi, 2019[50]). Bloom (2009[51]) suggests that a large temporary uncertainty shock (such as an oil shock) generates a sharp decline in productivity in the short-term due to a slowdown in the investment and reallocation process, possibly followed by a

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negative impacts in the short run. For instance, Gollop and Roberts (1983[93]) found that SO_2 regulation slowed productivity growth of US electric utilities by 43% in the seventies. See (Ambec et al., 2013[5]) and (Dechezleprêtre and Sato, 2017[89]) for a more comprehensive literature review.

productivity overshoot in the medium term. Similarly, Elder and Serletis (2010[52]) find a significant negative impact of oil price volatility on investment and durable consumption, exacerbating the negative effect of an energy price increase on economic performance. Finally, Berestycki et al. (2022[53]) find that across 12 OECD countries climate policy uncertainty is associated with decreases in capital investment.

3. Data

3.1. Productivity and financial variables

23. The firm-level data underpinning the empirical analyses in the paper are gathered from the latest vintage of the Orbis database. Orbis is currently the largest cross-country firm-level dataset available and accessible for economic and financial research. To ensure firms' comparability across countries and sectors, the data are prepared as in Gal (2013[54]), following a number of procedures, such as keeping accounts that refer to entire calendar year, using harmonised consolidation level of accounts, and dropping observations with missing information on key variables, as well as outliers identified as implausible changes or ratios.

24. The data used in the empirical analysis cover firms located in 21 countries and operating in the manufacturing and construction sectors over the 1995-2020 period.[4,5] Moreover, the data excludes very small firms – those having less than 3 employees – to avoid concerns related to the quality of financial statements. Given that some regression specifications exploit exclusively within-firm variation, the dataset is further restricted to firms reporting for at least three consecutive years for the short-term analysis and for at least six years for the medium-term analysis. Finally, the sample is restricted to firms with available information to calculate value-added based multi-factor productivity, which constitutes our main dependent variable of interest, and to control for the most relevant firm characteristics in the econometric analysis (e.g., size, age, leverage, profitability, assets). Overall, the cleaned dataset used in the short-term analysis has more than 6 million observations in total.

25. Firm-level multi-factor productivity (MFP) is estimated through the GMM Wooldridge (2009[55]) value added based procedure, with the deflated value of fixed assets used as a proxy for the capital input, the number of employees as a proxy for the labour input and intermediate inputs (e.g., material costs) as an instrument for unobserved firm-specific productivity shocks.[6] While our MFP estimates are net of energy expenditures, as we account for the totality of intermediate costs in the production function estimation, there could be a potential bias arising from the inability to disentangle the specific contribution of energy expenditures in the production process. Thus, all estimations are repeated using labour productivity, measured as value added over number of employees, which does not have the same issue.

[4] The two-digit codes included are within the 10-43 range according to NACE Rev.2 classification, excluding the 35-39 codes, referring to energy producing and utilities sectors.

[5] Countries included (both firm-level and energy price data available) are: BEL, BGR, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, HUN, IRL, ITA, JPN, KOR, POL, PRT, ROU, SVK, SVN, SWE. For the medium-term analysis, where data is required for each firm for a minimum of 6 years, two countries with very little remaining information were excluded, IRL and JPN.

[6] The advantage of applying this methodology is twofold. First, it overcomes the OLS simultaneity bias, that is, inputs' choices are not independent from unobserved shocks. Second, it internalises the Ackerberg, Caves and Frazer (2015[94]) critique on the identification of the labour coefficient in both Olley and Pakes (1996[95]) and Levinsohn and Petrin (2003[96]) approaches, while also being more efficient than Ackerberg, Caves and Frazer (2015[94]).

3.2. Energy prices

26. Industrial sector-level energy prices are obtained from Sato et al. (2019[1]) from 1995-2015 and have been updated by the authors for 2016-2020. The data cover manufacturing and construction sectors across all the 21 countries in the analysis. The price indices are constructed as averages of country- and fuel-specific prices weighted by country- and sector-level fuel consumption. Specifically, the main estimations use the following country-sector level price:

$$\ln\left(EnPrice_{s,c,t}\right) = \sum_{f} w_{f,s,c} \ln\left(Price_{f,c,t}\right) \quad (1)$$

where $w_{f,s,c}$ is the share of fuel *f* consumed by sector *s* in country *c*, and $Price_{f,c,t}$ is the real price of fuel *f* in country *c* in year *t* per toe in constant 2010 USD. The share of fuel consumption refers to year 2005 and is kept constant over time to avoid endogeneity issues, as firms may change their fuel mix in response to fuel-specific energy prices.[7] Technological change, fuel substitution or industry-specific shocks could affect the fuel mix in given sectors and thus the sector-level energy prices (Sato et al., 2019[1]).[8]

27. The indicator uses information on four fuel types: oil, coal, gas, and electricity. Each sector's use of fuel in each country and year is available from the IEA World Energy Balances. The prices of different fuels are retrieved from the IEA Energy End-Use Prices database. The final industrial energy prices include taxes but exclude VAT and recoverable taxes and levies and the indicator uses GDP deflators and exchange rate information to derive real prices in constant 2010 USD.

28. Energy prices present considerable variation across countries and years, and to a lesser extent across sectors. Figure 2 Panel A depicts the average energy price across sectors by country for years 1995, 2007, and 2020, and Panel B the average energy price across countries by sector for the same years.[9] The differences across sectors reflect the differences in energy mixes. The fact that energy prices vary markedly across countries increases the relevance of the "pollution haven" hypothesis, in which firms in countries with higher prices lose competitiveness and may choose to move their production to a different country. While the data shows overall increases for some countries, the opposite is true for others, where prices went up in the 2000 decade but back down in the most recent one. Cross-country variation is largely the result of different taxation, with Sato et al. (2019[1]) finding that the tax component is a major part of the variation in coal, electricity and oil prices across countries.

29. While yearly price variations in the period of analysis are often small and less likely to result in major economic changes, the current energy crisis as well as the likely path of energy prices in the context of the needed energy transition may imply larger movements in energy prices. To better offer insights relevant for the future, we therefore focus on the impact that energy price changes of a certain dimension may have on productivity and firm behaviour. Country-sector specific price shocks are defined by isolating a yearly change in energy prices that goes beyond a certain threshold for a given country-sector pair. In particular, a mild shock occurs when the price yearly growth is approximately larger (smaller) than 10% (-10%), corresponding to a one-standard deviation of the price growth series; a severe shock when the price yearly growth is approximately larger (smaller) than 15% (-15%), corresponding to a 1.5 standard deviation

[7] The robustness checks include a sectoral price indicator that uses annual-varying weights as well as alternative reference years. Further robustness analysis conditions the firm-level sample to start at the date of the energy mix reference year.

[8] Using the logarithm of the price also helps control for arbitrary cross-country measurement errors in the underlying prices, when combined with sector-country fixed effects.

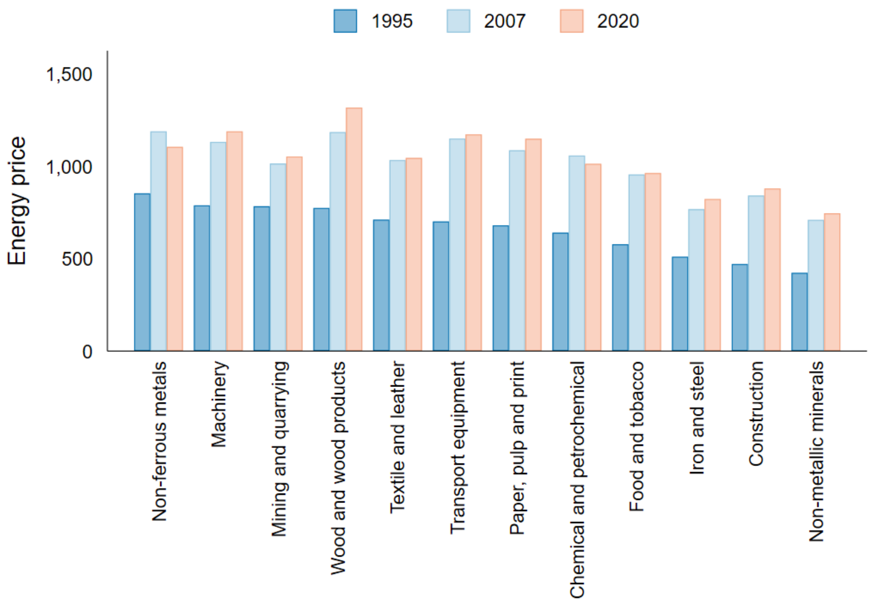
[9] The figures present the price indicator with a varying weight for the energy mix, not logaritmised, which is a better proxy for the prices actually observed in these countries and sectors.

in the price growth series. We define a categorical variable taking value 1 if we observe a positive shock (i.e., an increase in prices), value -1 for a negative shock (i.e., a decrease in prices) and 0 otherwise. We also use a dummy equal to 1 when the shock variable is equal to 1 and zero otherwise (measuring positive shocks) and a dummy equal to 1 when the shock variable is equal to -1 and zero otherwise (measuring negative shocks).

Figure 2. Energy prices vary across country, sector, and time

Energy price indexes across countries, in USD per toe

Energy price indexes across sectors, in USD per toe

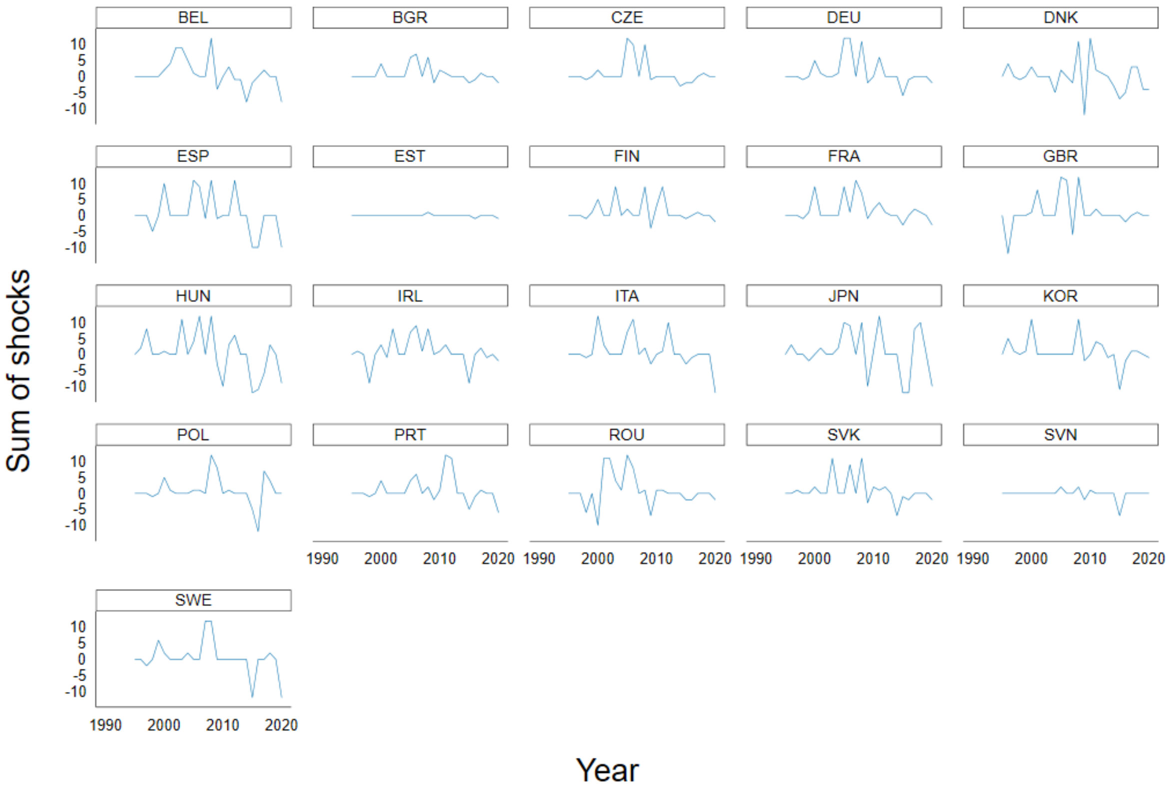


Note: The graphs present the average value for the energy price indicator computed as in Eq. (1) but using yearly energy mixes and non-logaritmised energy prices for each country and sector. It shows the price indicator in 2010 USD per toe (ton of oil equivalent). Bulgaria, Spain, Estonia and Slovenia are omitted from Panel A because information using varying energy mixes was not available but are included in the analysis.

30. In the remainder of the paper, we define a large increase (decrease) in prices as a positive (negative) price shock. Most of the shocks observed in the sample were positive price shocks. Out of 8 861 country-sector-year combinations, 1 269 observed a mild positive shock and 669 observed a mild negative shock. These numbers were respectively 643 and 212 for the severe shock. Figure 3 depicts the evolution of the sum of all mild shocks observed in each country in each year. There is considerable variation in the shocks, while less variation is observed for the severe shock (Annex Figure A.1).

Figure 3. Mild shocks over time for each country

Sum of shocks (positive and negative) in each country in each year



Note: Mild shocks are any energy price changes of more than one standard deviation relative to the median change.

3.3. Environmental policy, country-level economic variables and sectoral characteristics

31. Information on countries' environmental policy stringency is retrieved from the OECD's Environmental Policy Stringency indicators (Botta and Koźluk, 2014[56]; Kruse et al., 2022[57]). The indicator provides yearly information on 13 policy instruments with a focus on climate change and air pollution mitigation policies. The instruments are grouped in three equally weighted sub-indices, reflecting market based (e.g., taxes, permits and certificates), non-market based (e.g., performance standards) and technology support policies.

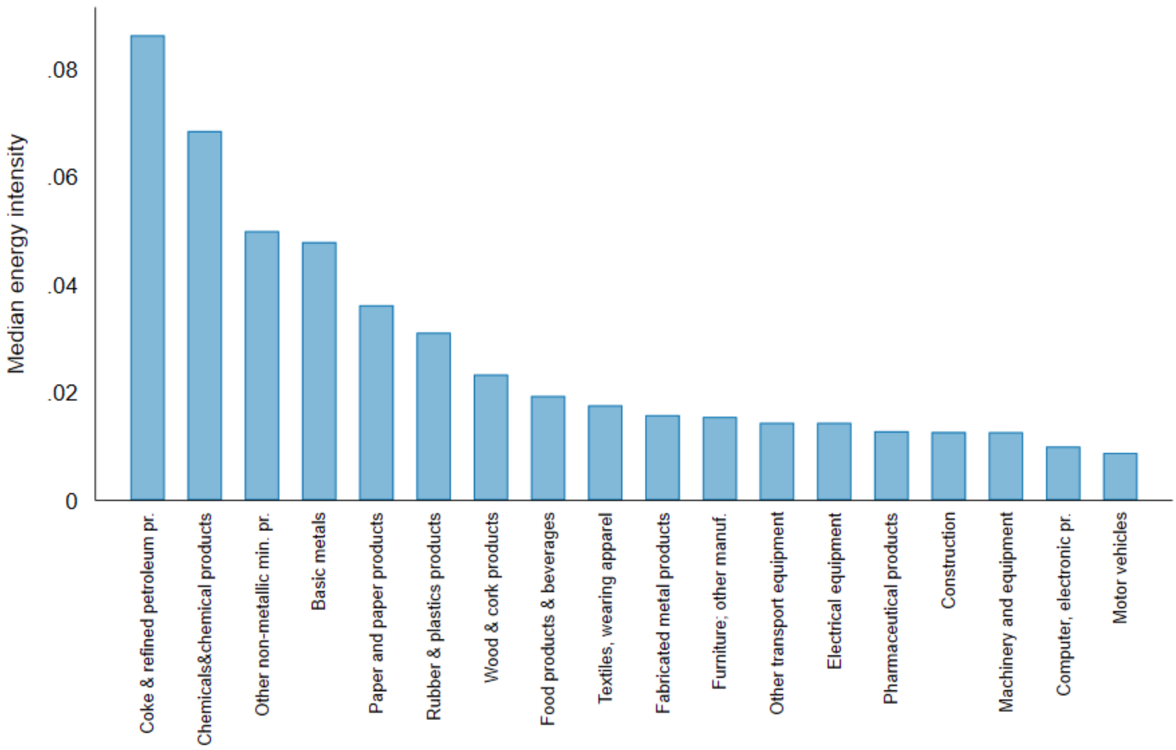
32. Data on country-level economic variables potentially affecting the relation between energy prices and productivity are gathered from a wide range of sources. Economic policy uncertainty is measured by averaging at the country-year level the well-known monthly indicator developed by Baker et al. (2015[58]). Financial development is proxied by a multidimensional index of financial development based on IMF data,

capturing the overall availability of finance in a country-year; the index measures the depth, access and efficiency of both financial institutions and financial markets (Svirydzenka, 2016[59]). The economic momentum is captured with the output gap (i.e., differences between actual GDP and potential GDP), gathered from OECD statistics.

33. Finally, we collect sector-level data relevant for the relationship between energy prices and productivity, namely on sectoral energy intensity and external finance dependence. Sectoral energy intensity is defined as the share of energy inputs relative to the total output of the sector. This is computed from the latest vintage of the OECD input-output tables and is country-specific: for each country-sector, we compute the total value of inputs bought from the energy sectors (namely, sectors 19 and 35 according to NACE Rev.2 classification) and normalise it by the given country-sector output. Consistently with the choice of 2005 as the reference year for the energy mix in the price indicator, energy intensity is also calculated based on 2005 data. The resulting measure is presented in Figure 4.

Figure 4. Energy intensity varies greatly across sectors

Median energy intensity, estimated as the share of energy inputs on total output, by sector



Note: Energy intensity is estimated through input and output tables as the share of energy inputs on each sector's total output. The figure represents each sector's median across countries.

34. External finance dependence is calculated as in Demmou et al. (2019[60]), following the methodology developed by Rajan and Zingales (1998[61]). More specifically, we use Compustat firm-level data on U.S. listed firms over the 1990-2006 period and calculate the median ratio across firms within each sector between cumulative capital expenditures minus cumulative cash flow from operations and cumulative capital expenditures.

4. The immediate effect of energy price (shocks) on productivity

4.1. Methodology

4.1.1. A static model of energy prices on productivity

35. To start, we investigate how energy prices affect firms' productivity in our sample, using a simple static panel fixed effects model. This approach is frequently used in the literature – for instance in Marin and Vona, (2021[8]) and Dechezlepretre et al., (2020[2]) - and provides a first simple picture of the energy price-productivity nexus under the assumption that firms fully adjust to the shock with a short delay. Analytically, we estimate the following equation:

$$Productivity_{i,c,s,t} = \beta_0 + \beta_1 EnPrices_{cs,t-1} + \beta_2 \boldsymbol{X}_{ics,t-1} + \delta_i + \delta_{ct} + \delta_{st} + \varepsilon_{icst} \quad (2)$$

where the subscripts *i*, *c*, *s*, *t* stand for firm, country, sector and time, respectively, *Productivity* for the logarithm of firm level multi-factor productivity (or labour productivity in robustness estimations),[10] while *EnPrices* is the lagged log-level of energy prices measured as described in the data section. The vector *X* includes a set of firm level controls – namely, detailed firm size classes based on the number of employees (3-10, 11-19, 20-49, 50-99, 100-249, 250+), age classes, the leverage ratio measured as total liabilities over total assets, and the profitability ratio, measured as the ratio of EBITDA over total assets. All control variables are lagged one period in order to reduce simultaneity bias concerns.

36. The model also includes a rich fixed-effects structure to control for unobservable confounding factors: country by time dummies (δ_{ct}) account for differences in macroeconomic developments across countries, while industry by time dummies (δ_{st}) account for sector specific shocks (e.g. technological developments) that are common across countries; the firm-fixed effects (δ_i) absorb the unobserved firm-specific heterogeneity and allow to focus exclusively on the impact of changes in prices on deviations of productivity from its mean.[11] The model is estimated by OLS, clustering standard errors at the firm (i.e., the unit of the panel) and at the country-sector-year (i.e., level of the treatment) level. The coefficient of interest, β_1, is expected to be negative if an increase in prices is detrimental to productivity. Endogeneity concerns are minimised given the aggregate nature of the regressor (at the sector-country level) and the use of time invariant energy mix information.[12]

37. Next, we check the consistency of our findings by expanding the previous model and adopting a strategy similar in spirit to Rajan and Zingales (1998[61]), whose rationale recalls a difference-in-differences methodology. More specifically, for this second strategy we rely on the assumption that small firms and firms with low mark-ups are more affected by an increase in energy prices: the former are more likely to be full price-takers, because they tend to not negotiate energy costs with their suppliers, unlike larger companies (Business Growth Hub, 2016[62]), and thus, combined with the lack of economies of scale, energy expenditures account for a larger share of their intermediate costs (Office for National Statistics

[10] All regressions are repeated using labour productivity, as defined in Section 3.1. as a dependent variable.

[11] Notice that country by sector fixed effects are subsumed by the firm fixed effects.

[12] However, the model implicitly assumes that all firms in the same sector face the same price. This is not necessarily true as, for example, large firms are able to negotiate energy contracts with suppliers. At the same, the overwhelming majority of firms in our sample are SMEs and thus should prevalently face similar prices within a given country-sector.

UK, 2022[63]). Similarly, firms able to set higher mark-ups are more likely to be able to pass-through energy price increases onto consumers.[13] Analytically, expanding Equation (2):

$$Productivity_{i,c,s,t} = \beta_0 + \beta_1(EnPrices_{cs,t-1} * Exposure_{ics}) + \beta_2 \boldsymbol{X}_{ics,t-1} + \delta_i + \delta_{cst} + \varepsilon_{icst} \quad (3)$$

where notation is again consistent with previous equation and *Exposure* is a dummy variable that takes value 1 if firms' average size (mark-up) over the sample period is smaller than 50 employees (the 25th percentile of the markup distribution).[14] The advantages of the model consists in that it allows: i) for full saturation, including country by sector by year fixed effects and hence controlling for all shocks at the country-sector level; ii) to exploit the richness of firm-level variation on the right hand side of the equations. However, it comes at the cost of computing a purely differential effect of changes in energy prices across firms with different characteristics and its interpretation fully rests on the validity of the assumption that small or low mark-ups firms are more affected.[15]

4.1.2. A short-term dynamic model of energy prices on productivity

38. Next, we introduce some dynamics in our econometric modelling in order to start disentangling the short- and the long-term effects of changes in energy prices. While the previous approach is useful to get a sense of the general relationship between energy prices and productivity, it implicitly assumes that firms' adjustment fully occurs with a short delay and is persistent, conflating short-term and long-term effects. Further, a static model is less suited to analyse the impact of (large) price shocks, which are of particular interest in the current circumstances. We begin by analysing the short-term productivity consequences of changes in energy prices, focusing both on within-firm and between-firm adjustments.

Within-firm productivity

39. We estimate a model of firm productivity growth, based on the Neo-Schumpeterian growth approach to technology diffusion and innovation by Aghion and Howitt (1997[64]) and Acemoglu et al. (2006[65]), and already implemented in several firm-level empirical studies (e.g. Adalet McGowan et al. (2017[66]); Gal et al. (2019[67])):

$$\begin{aligned}\Delta Productivity_{i,c,s,t} &= \beta_0 + \beta_1 EnPriceShocks_{cs,t-1} + \beta_2 GapToFrontier_{ics,t-1} \\ &+ [\beta_3 EnPrices_{cs,t-2}] + \beta_4 \boldsymbol{X}_{ics,t-1} + \delta_{cs} + \delta_{ct} + \delta_{st} + \varepsilon_{icst}\end{aligned} \quad (4)$$

40. where notation is consistent with the one in Equation (2), the dependent variable is *Productivity growth*, measured as the yearly difference in log MFP levels (or LP levels in robustness estimations) and the main variable of interest the lagged country-sector-time varying energy price shocks, as defined in Section 3.2. The *GapToFrontier* term measures the distance of each firm in year *t-1* from the worldwide sector-time specific productivity frontier – measured as the average productivity performance of the top

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[13] As the extent of pass-through critically depends on the interaction between firms' margins and the elasticity of demand, it is not necessarily the case that high mark-up firms are less affected. However, given that the estimation of Equation 3 using mark-ups as an exposure variable is used as a robustness check and always paired with estimations using size as an alternative exposure, we deemed this simplifying assumption reasonable.

[14] Mark-ups are estimated similarly to Andrews et al. (2016[98]), using labour as the flexible input and following the methodology pioneered by De Loecker and Warzynski (2012[97]).

[15] The effect is purely differential as the main effects of both the energy prices and exposure regressors are absorbed by the country-sector-time and firm fixed effects respectively.

5% of the productivity distribution – and captures potential catch-up effects, controlling for reversion to the mean characterising the growth process.[16] Again, we control for country specific (δ_{ct}) and sector specific (δ_{ct}) shocks, as well as for country-sector time invariant characteristics (δ_{cs}) – replaced by firm fixed effects in some specifications – and energy price levels before the shock.

Between-firm effects: allocative efficiency

41. We apply standard models of dynamic allocative efficiency (Foster et al., (2016[68]); Decker et al., (2017[69])) to study the potential role of energy price shocks in driving productivity-enhancing labour reallocation. These models predict that firms with higher productivity should attract more labour and grow faster, if there are no frictions obstructing optimal resource allocation. Analytically, following Adalet McGowan et al. (2017[66]), we estimate the following equation, augmenting the canonical models with an interaction term:

$$\begin{aligned}\Delta Empl_{icst} = \beta_0 + \beta_1 Productivity_{ics,(t-1)} \\ + \beta_2\ \left(Productivity_{ics,(t-1)} * EnPriceShocks_{cs,(t-1)}\right) \\ + \left[\beta_3\left(Productivity_{ics,(t-1)} * EnPrices_{cs,(t-2)}\right)\right] + \beta_4\, \boldsymbol{X}_{ics,(t-1)} + \delta_{cst} \\ + \epsilon_{icst}\end{aligned} \qquad (5)$$

where notation is again consistent with previous equations and $\Delta Empl$ stands for employment growth, computed as the yearly difference in log employment.[17] As before, the equation is estimated by OLS and standard errors clustered at the firm and country by sector by year level. The main parameter of interest is β_2, measuring the relative employment growth associated with energy shocks for firms of different productivity levels.[18] We expect it to be positive (negative) if energy price shocks are beneficial (detrimental) to productivity-enhancing labour reallocation. By controlling for any country-sector specific shock, the triple interacted country by sector by year dummies, δ_{cst}, allows us to compare the reallocation process within each country-sector-year cell.

4.2. Main findings

4.2.1. Static model: baseline results

42. Results reported in Table 1 show that higher energy prices have a negative and significant impact on productivity in the short term (Column 1), consistent with previous empirical work (e.g., (Marin and Vona, 2021[8])). Our estimates would imply that a 5% increase in energy prices is associated to a decrease in productivity of approximately 0.4%. Supportively, and in line with (Steinbuks and Neuhoff, 2014[16]), this negative effect appears to be stronger for firms operating in energy-intensive sectors (Column 2). Further investigating potential heterogeneity across firms shows that old companies also seem to be the most affected, followed by young firms, while mature firms face a lower impact (Column 3). A potential explanation is that older firms' capital stock displays a larger proportion of old capital vintages, which tend to be less energy efficient and thus more exposed to an increase in energy prices. Similarly, the strength of the negative productivity effect of higher energy prices tends to be inversely proportional to firms' size,

[16] To avoid endogeneity concerns, the frontier firms are excluded from the estimating sample. Moreover, notice that the sector-time varying frontier is not included as an explanatory variable because it is absorbed by the sector by time fixed effects.

[17] Results are robust to whether we include or not a control interacting lagged productivity with lagged energy price levels.

[18] In the baseline specification, productivity levels are measured in t-1, as standard in these models. To overcome potential concerns related to feedback effects of energy prices on productivity, we also check the consistency of our findings when lagging productivity twice or using the average productivity level of the firm during the sample period.

with larger firms being more equipped to weather a price increase (Column 4). This is consistent with the observation that large firms are better able to negotiate energy price contracts with providers than small firms (Business Growth Hub, 2016[62]).

43. Columns (5) and (6) of Table 1 report the findings when expanding the baseline specification and estimating a model similar in spirit to Rajan and Zingales (1998[61]), thus considering firms whose average size (mark-up) during the sample period is lower than 50 employees (is in the bottom quarter of the mark-up distribution) as the treatment group (i.e. Equation 4). In line with our theoretical predictions, results show that small and low-mark-up firms are relatively more exposed to the shock, further corroborating the negative impact of higher energy prices on productivity.

Table 1. Higher (lower) energy prices could undermine (spur) productivity

Dependent Variable: Multifactor productivity (MFP) levels						
	(1)	(2)	(3)	(4)	(5)	(6)
Lag Energy Prices	**-0.075*** **	**-0.054***	-0.061**	-0.096***		
	(-2.6)	**(-1.7)**	(-2.1)	(-3.3)		
Lag Energy Prices * Energy Intensity		**-0.812** **				
		(-2.0)				
Lag Energy Prices * Firm with L < 50					**-0.043*** **	
					(-7.9)	
Lag Energy Prices * Low Mark-up Firm						**-0.161*** **
						(-17.7)
Mature Firm * Lag Energy Prices			0.005*			
			(1.9)			
Old Firm * Lag Energy Prices			-0.017***			
			(-3.7)			
Small Firm * Lag Energy Prices				0.024***		
				(8.9)		
Medium Small Firm * Lag Energy Prices				0.038***		
				(9.2)		
Medium Firm * Lag Energy Prices				0.054***		
				(9.1)		
Medium Large Firm * Lag Energy Prices				0.059***		
				(7.4)		
Large Firm * Lag Energy Prices				0.032***		
				(2.9)		
Observations	6,606,830	6,606,830	6,606,830	6,606,830	6,606,382	6,606,382
R-squared	0.829	0.829	0.829	0.829	0.835	0.835
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Country by Sector FE	Subsumed	Subsumed	Subsumed	Subsumed	Subsumed	Subsumed
Country by Year FE	Yes	Yes	Yes	Yes	Subsumed	Subsumed
Sector by Year FE	Yes	Yes	Yes	Yes	Subsumed	Subsumed
Country by Sector by Year FE	No	No	No	No	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting of estimating Equation 2 in specifications (1) and (2). The coefficients in specifications (3) and (4) are those resulting of estimating Equation 2, with the addition of an interacted term between energy prices and age class (specification 3) or size class (specification 4). The coefficients are those resulting from estimating Equation 3 in specifications (5) and (6). In these estimations the lag of energy prices is dropped as they include country by sector by year fixed effects. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

44. These findings are qualitatively and quantitatively unchanged when using labour productivity rather than multi-factor productivity as the dependent variable (Table B.2). Additionally, while Table 1 relies on the baseline sectoral price indicators (using 2005 as a reference year), the results are robust to alternative choices, such as using annual-varying weights or alternative reference years, as well as to restricting the sample to the post-global financial crisis period (Table B.1, columns 1 to 4).

4.2.2. Dynamic model -- within firms results

45. Table 2 explores the short-term impact of major price shocks as opposed to continuous price changes. Results show that a severe (circa 15%) shock to energy prices is inversely related to firms productivity growth. Our findings suggest a symmetric impact of positive and negative severe price shocks (column 4): a positive price shock is detrimental to firms' productivity performance, while a negative price shock appears to spur productivity. The magnitude of estimated positive and negative coefficients is similar, which is in line with Davis and Haltiwanger (2001[47]). A mild shock, on the contrary, seems to affect firm productivity only through the effect of a positive shock (column 3): a positive shock appears to significantly hamper firm productivity, but there are no benefits from mild negative shocks.

46. The remaining specifications in Table 2 show that, also in this dynamic setting, our results hold when using price levels rather than shocks: the short-term productivity effect of higher energy prices is negative and significant (column 5), also when further including firm fixed effects in this model (column 6).[19] Noticeably, the estimated coefficient on the gap with respect to the productivity frontier is found to be positive and statistically significant in all specifications, consistent with the endogenous growth literature suggesting that laggard firms tend to benefit from technological diffusion and with the mean reverting nature of the growth process. Next, as highlighted by the interaction term between the gap to frontier and energy prices in column (7), an increase in energy prices appears to reduce the ability of laggard firms to benefit from technological diffusion, resulting in a weaker catch-up process. This illustrates the risk that the current crisis may widen the gap between frontier and laggard firms and hence damage overall productivity. Finally, the findings are once again unchanged and even stronger when using labour productivity rather than multi-factor productivity as dependent variable (Table B.4).

47. A major channel through which energy prices could affect productivity in the short term is by reducing their capital utilisation – i.e., firms do not fully use their productive capacity to save on energy costs or because lower demand prevents them to pass through costs to consumers. Panel A of Table 3 tests this hypothesis and the findings show that a shock to energy prices (either mild or severe) is negatively correlated with firms' capacity utilisation – proxied by the ratio of revenues over lagged fixed assets (columns 1 and 2). Moreover, the adjustment appears to operate mainly following a shock increasing energy prices, while strong price decreases do not seem to significantly affect capacity utilisation. If firms are already operating at full capacity or close before the shock, they can adjust downward their capacity utilisation, while the reverse is not true.

[19] Results are once again consistent when i) using annual-varying weights or alternative reference years for building the energy prices series (Table B.1, columns 5 to 7); ii) restricting the sample to the post-GFC period (Table B.1, column 8); iii) expanding the catch-up model by applying a Rajan and Zingales (1998[61]) type of approach (Table B.3).

Table 2. Positive and negative price shocks have a symmetric impact on productivity in the short-term

Mild (one standard deviation changes) and severe (1.5 standard deviation changes) price shocks

Dependent Variable: Multifactor productivity (MFP) growth							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Size of the price shock	Mild	Severe	Mild	Severe	\	\	\
Energy Price Shock	**-0.003**	**-0.011*** **					
	(-0.9)	**(-3.0)**					
Price Increase Shock			**-0.008***	**-0.010****			
			(-1.8)	**(-2.0)**			
Price Decrease Shock			**-0.004**	**0.014****			
			(-0.5)	**(2.0)**			
Lag Energy Price Levels					**-0.025****	**-0.057*****	
					(-2.1)	**(-2.6)**	
Lag MFP Gap To Frontier * Lag Energy Price Lev.							**-0.036*****
							(-6.0)
Lag MFP Gap To Frontier	0.306***	0.306***	0.306***	0.306***	0.305***	0.677***	0.542***
	(89.8)	(89.8)	(89.8)	(89.8)	(90.3)	(137.1)	(13.6)
Observations	6,250,876	6,240,272	6,250,498	6,188,824	6,188,824	6,188,824	6,188,824
R-squared	0.239	0.487	0.250	0.239	0.239	0.239	0.239
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Energy Price Levels Before Shock	Yes	Yes	Yes	Yes	No	No	No
Country by Sector FE	Yes	Yes	Yes	Yes	Yes	Subsumed	Subsumed
Country by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Subsumed
Sector by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Subsumed
Country by Sector by Year FE	No	No	No	No	No	No	Yes
Firm FE	No	No	No	No	No	Yes	No

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting from the estimation of Equation 4 in models 1 to 4, while in columns 5 to 7 lagged price levels are included in place of price shocks. In column 7 the lag of energy prices is dropped as it includes country by sector by year fixed effects. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

48. Both financing and macroeconomic conditions could play a relevant role in shaping firms' ability to weather a shock such as a sudden and sharp increase or decrease in energy prices (Panel B of Table 3, Figure 5). Accordingly, our results show that firms holding larger cash buffers before the energy price shock (columns 1 and 2) experience a significantly milder decline in productivity, as the availability of liquid funds allows them to better sustain an increase in input costs. Symmetrically, the impact of price shocks is more binding in sectors which tend to rely relatively more on external financing (columns 3 and 4), most likely because of difficulties to access enough liquidity to countervail the shock. Along similar lines, the negative impact of the shock on productivity is cushioned and seems to disappear in more financially developed countries and in economies performing above potential, particularly when the price shock is severe (columns 5 to 8). The latter suggests that when energy price increases are driven by sustained demand, the damaging impact on productivity is much more limited.

Table 3. Capacity utilisation and finance are driving the productivity impact of energy price shocks

PANEL A

Dependent Variable: Capacity Utilisation				
	(1)	(2)	(3)	(4)
Size of the price shock	Mild	Severe	Mild	Severe
Energy Price Shock	**-0.359****	**-0.580*****		
	(-2.5)	**(-2.9)**		
Price Increase Shock			**-0.585*****	**-0.637****
			(-3.0)	**(-2.2)**
Price Decrease Shock			**0.007**	**0.486***
			(0.0)	**(1.8)**
Observations	6,536,522	6,536,522	6,536,522	6,536,522
R-squared	0.629	0.629	0.629	0.629
Firm Level Controls	Yes	Yes	Yes	Yes
Energy Price Levels Before Shock	Yes	Yes	Yes	Yes
Country by Sector FE	Subsumed	Subsumed	Subsumed	Subsumed
Country by Year FE	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

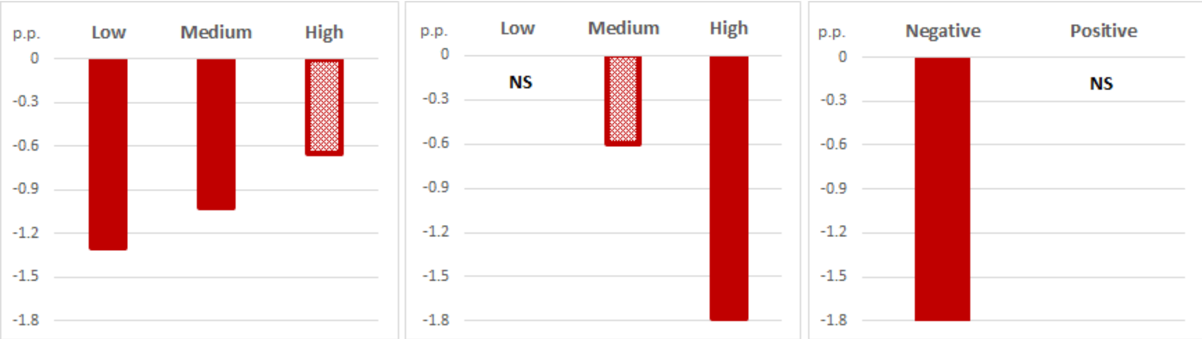
PANEL B

Dependent Variable: Multifactor productivity (MFP) growth								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Interaction variable	Cash		ExtFinDep		FinDev		Output Gap	
Size of the price shock	Mild	Severe	Mild	Severe	Mild	Severe	Mild	Severe
Energy Price Shock	**-0.006**	**-0.014*****	**-0.005**	**-0.012*****	**-0.053***	**-0.081****	**-0.007**	**-0.019*****
	(-1.5)	**(-3.5)**	**(-1.3)**	**(-3.2)**	**(-1.7)**	**(-2.2)**	**(-1.2)**	**(-3.5)**
Energy Price Shock * Interaction var.	**0.018*****	**0.019****	**-0.021*****	**-0.020*****	**0.070***	**0.094****	**0.008**	**0.016****
	(2.9)	**(2.3)**	**(-4.2)**	**(-3.3)**	**(1.7)**	**(2.0)**	**(1.0)**	**(2.3)**
Interaction var.	0.028**	0.028**						
	(2.2)	(2.2)						
Lag MFP Gap To Frontier	0.306***	0.306***	0.309***	0.309***	0.314***	0.314***	0.306***	0.306***
	(90.2)	(90.1)	(89.5)	(89.5)	(87.9)	(87.9)	(88.9)	(88.8)
Observations	6,006,285	6,006,285	6,055,639	6,055,639	5,473,178	5,473,178	6,157,021	6,157,021
R-squared	0.240	0.240	0.241	0.241	0.247	0.247	0.218	0.219
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Energy Price Levels Before Shock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country by Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	No	No	No	No

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance level for which the null hypothesis is rejected: + 15%, *10%, **5%, ***1%. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period. Panel A: The coefficients are those resulting of estimating Equation (2), but a) with capacity utilisation, defined as the ratio of revenues over lagged capital, as the dependent variable and b) with the addition of the energy price shock (models 1 and 2) or positive and negative price shocks (models 3 and 4) as the main explanatory variable of interest. Panel B: The coefficients are those resulting of estimating Equation (4), but a) with the addition of the energy price shock as the main explanatory variable of interest and b) the addition of an interacted term (and related main effects when not absorbed by the fixed effects) between the shock and the interaction variable of interest (Cash, External Finance Dependence, Financial Development and Output Gap).
Source: OECD calculations based on Orbis®, OECD, IMF and Compustat data.

Figure 5. Zooming in on the role of financial and economic conditions

Panel A: By firm cash holdings levels | Panel B: By sectoral external finance dependence | Panel C: By country's output gap



Note: The figure shows the size of the effect estimated in specifications 2, 4 and 8 of Panel B of Table 3 at different levels of the interacted variable. A bar with a solid fill indicates results that are statistically significant at the 1% level, while a pattern fill indicates results significant at the 10% level and "NS" results that are not statistically significant. Low, medium and high stand respectively for 10th, 50th and 90th percentile of the distribution of the interaction variable of interest; the only exception is the output gap, as in the estimation we use a binary variable taking value 1 for output above potential (i.e. positive gap) or and 0 for output below potential (i.e. negative gap)
Source: OECD calculations based on Orbis®, OECD, IMF and Compustat data.

4.2.3. Dynamic model -- between firm results

49. Finally, we explore whether episodes of mild and severe price shocks alter the extent to which labour reallocation is productivity enhancing. Consistent with priors, the estimated coefficient on lagged MFP is positive and statistically significant, suggesting that higher productivity is generally associated with stronger firm-level employment growth (Table 4). The strength of the relationship is positively related to our price shock variable, suggesting that most productive firms have a relatively higher (lower) capacity to attract resources and grow larger when facing a positive (negative) shock to energy prices.

Table 4. A deep reduction in prices could spur misallocation

Dependent Variable: Employment Growth				
	(1)	(2)	(3)	(4)
Size of the price shock	Mild	Severe	Mild	Severe
Lag MFP Levels	0.075***	0.072***	0.078***	0.073***
	(10.2)	(9.9)	(10.5)	(9.9)
Lag MFP Levels * Energy Price Shock	**0.003****	**0.007*****		
	(2.1)	**(3.0)**		
Lag MFP Levels * Price Increase Shock			**0.000**	**0.006***
			(0.2)	**(1.8)**
Lag MFP Levels * Price Decrease Shock			**-0.009*****	**-0.010*****
			(-4.9)	**(-3.5)**
Observations	6,540,777	6,540,777	6,540,777	6,540,777
R-squared	0.068	0.068	0.068	0.068
Firm Level Controls	Yes	Yes	Yes	Yes
Lag MFP Levels * Pre-Shock Energy Prices	Yes	Yes	Yes	Yes
Country by Sector by Year FE	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting of estimating Equation 5. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

50. When explicitly distinguishing positive and negative shocks, the effect appears to operate prevalently through negative shocks favouring the survival and growth of relatively less productive companies. Back-of-the envelope calculations hint that a shock implying a 15% reduction in energy prices is associated to a reduction in the productivity enhancing nature of labour reallocation of approximately 10%. On the contrary, evidence on a potentially cleansing effect of a sharp increase in energy prices is significant at the margin and only for severe shocks.[20] [21]

5. Digging into the dynamic: productivity response to energy price shocks over time

51. In this last empirical exercise, we dig further into the dynamic of the energy price-productivity relationship, with the aim to assess whether the negative effect unveiled in the previous exercises is persistent and under which conditions it could be mitigated over the medium-term.

5.1. Methodology

5.1.1. Baseline

52. While the previous models are useful for analysing short-term effects, understanding the firm's medium-term behaviour requires a more complex dynamic specification. The methodology for assessing the medium-term impact of energy price shocks on productivity is based on the local projection estimator developed by (Jordà, 2005[70]). The method allows for the robust estimation of impulse response functions by estimating its coefficients directly for each time horizon (Teulings and Zubanov, 2014[71]). It has been widely used as a flexible alternative to dynamic models such as autoregressive distributed lag specifications, which have been criticised for being sensitive to small specification errors.

53. We use a cumulative local projection method, where we compare the behaviour of firms' productivity in the years 0-4 after the price shock with their productivity in the year before the price shock. The baseline estimate is therefore as follows:

$$\begin{aligned} Productivity_{i,t+k} - Productivity_{i,t-1} &= \beta_1 GapToFrontier_{ics,t-1} + \beta_2 Priceshock_{c,s,t} + \beta_3 EnPrices_{c,s,t-1} \\ &+ \beta_4 \boldsymbol{X}_{ics,t-1} + \sum_{h=1}^{k} \varphi_h Priceshock_{c,s,t+h} + \delta_{cs} + \delta_{ct} + \delta_{st} + \varepsilon_{icst} \end{aligned} \quad (6)$$

$$k = \{0, \dots, 4\}$$

where the dependent variable is the growth in *Productivity* (MFP or LP in robustness specifications) in firm *i* in sector *s* in country *c* between year $t-1$ and year $t+k$, where $k = \{0, \dots, 4\}$. As before $GapToFrontier_{ics,t-1}$ is the gap in terms of productivity between firm *i* and the 5% most productive firms in each sector-year pair, $Priceshock_{c,s,t-1}$ is the price shock as defined in Section 3, $\boldsymbol{X}_{ics,t-1}$ the firm-level control variables specified in Section 4, and δ_{cs}, δ_{ct}, and δ_{st} the same fixed effects as in equation (2). The model also controls for energy price shocks happening within the projection period through the series of leads of the shock $\sum_{h=1}^{k} \varphi_h Priceshock_{c,s,t+h}$. This control is found to be necessary to avoid a downward

[20] Table B.5 shows that our findings are qualitatively unchanged when using twice lagged MFP or average MFP in the sample in place of lagged MFP, reducing potential concerns that feedback effects between productivity and energy prices are driving our findings.

[21] Energy price shocks could affect business dynamism also through the extensive margin. However, due to data limitations, the direct investigation of these effects is beyond the scope of this paper.

estimation bias of the model (Teulings and Zubanov, 2014[71]). Standard errors are robust to heteroskedasticity and clustered at the firm level.

54. Because of the need to look at medium-term dynamics, the sample for the analysis is constrained to firms that are in the sample for a period of at least six years.[22] Further, we impose that our panel is "locally" balanced. That is, we restrict the sample in each horizon's estimation to be the same as the one used for the longest horizon (*k=4*) to ensure there are no changes in the composition of the sample.

5.1.2. The investment channel

55. When facing an energy price shock, firms may invest in energy efficient technology, which could have an impact in its medium-term productivity. Given the lack of firm-level data on energy efficiency investment, we proceed in two ways to investigate the channels through which energy price shocks may affect productivity growth. First, we expand the model to account for the impact of variables that could affect the firm's ability to invest when hit by the shock. This is done by augmenting the model with an interaction between the shock and these variables (such as environmental policy stringency or policy uncertainty) lagged one period.

56. Second, we focus on firm investment in capital, measured as the difference between its capital stock in year *t* and in year *t-1*. Although not specifically a measure of energy efficiency, it is likely that new capital vintages are more efficient than previous ones, including in terms of energy efficiency. When affected by a positive energy price shock, firms may choose to bring forward their investment in new capital to decrease the impact of price increases.

57. We therefore estimate the following equation:

$$\begin{aligned} InvestRatio_{i,s,c,t+k} - InvestRatio_{i,s,c,t-1} &= \beta_1 InvestRatio_{ics,t-2} + \beta_2 Priceshock_{c,s,t} + \beta_3 EnPrices_{c,s,t-1} \\ &+ \beta_4 \boldsymbol{X}_{ics,t-1} + \sum_{h=1}^{k} \varphi_h Priceshock_{c,s,t+h} + \delta_{cs} + \delta_{ct} + \delta_{st} + \varepsilon_{icst} \\ & k = \{0, \dots, 4\} \end{aligned} \quad (7)$$

where $InvestRatio_{i,t}$ is firm I's ratio between investment and accumulated capital stock in year t, sector s and country c, and where we control for the level of past investment by including the twice lagged investment ratio as an independent variable. It is twice lagged given the once lagged variable on the left-hand side. All the other variables are similar to those in Eq. (6).

5.2. Main findings

5.2.1. Baseline

58. Our main baseline results are shown in Figure 6 Panel A and columns (1)-(5) of the first panel of Annex Table B.6. They show that, in line with the results of the previous section, when firms are subject to a relatively mild energy price shock, they experience a decrease in their productivity that starts in the same period as the shock and lasts up to two years after the shock. However, this impact starts to reverse in the third period after the shock, and there is a positive impact in the fourth period after the shock. The results are robust to not including price shocks occurring between t and the time horizon of each estimation (columns (6)-(9) of Annex Table B.6), to restricting the sample to only include firms for which data is available for a minimum of ten years (Annex Table B.7) and to the exclusion of lagged energy prices as a control variable.

[22] As a robustness test, we re-estimate the baseline equation while restricting the sample to include firms available in the sample for periods of at least seven, eight, nine and ten years as well.

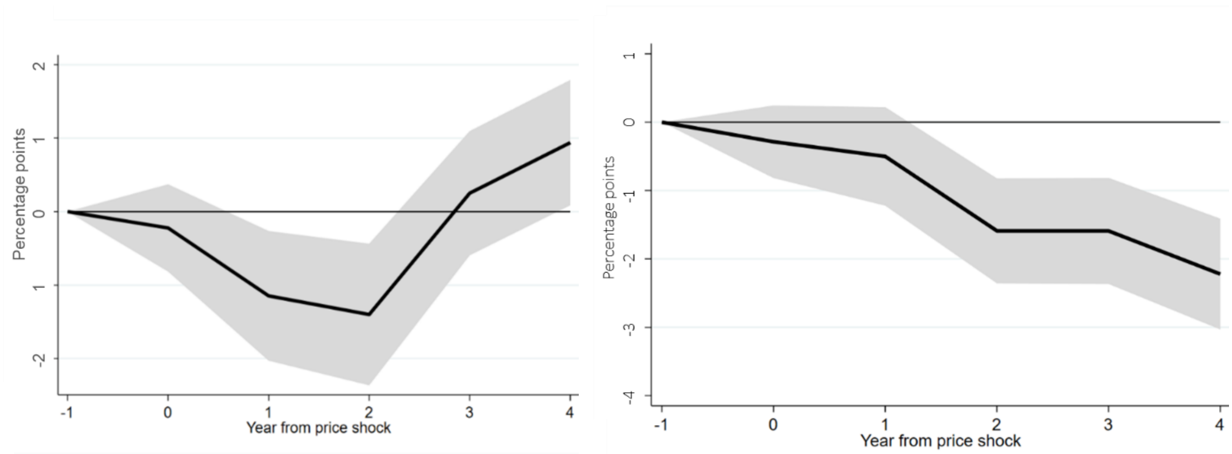
59. These results lend support to the strong version of the Porter Hypothesis, albeit with a lag relative to energy price shocks, as predicted in previous work (Ambec et al., 2013[5]). Our results suggest that while firms may reduce capacity in the short-run when energy prices increase, they may invest in low-carbon technologies or in more efficient production processes, eventually leading to a positive impact on productivity. This is in line with previous empirical work (e.g., Gamtessa and Olani (2018[6]) for Canada), and indicates that a longer term perspective should be adopted when evaluating the impacts of energy price changes on the firms.

60. Results focusing on the impact of a severe energy shock portray a different dynamic. While short run effects are similar, an improvement is not observed in the medium term, with negative effects being felt continuously (Figure 6 Panel B and second panel of Annex Table B.6). One explanation is that, given a large shock, firms' marginal costs go up so much in the short term that they are not able to make investments that eventually lead to productivity improvements. Another possibility is that when faced with a large energy price shock, demand decreases reducing the profitability of investment (Kilian, 2008[72]). This result suggests that to avoid severe scarring effects in face of a shock of the magnitude observed in 2022, policy intervention might be warranted.

Figure 6. The medium-term response of productivity to energy price shocks

Panel A: Response of MFP growth to a one standard deviation shock to energy prices

Panel B: Response of MFP growth to a 1.5 standard deviation shock to energy prices



Note: The thick black line represents the coefficients of the variable measuring energy price shocks resulting of estimating Equation (6) multiplied by 100 to be interpreted as percentage point changes. The shaded area represents the 90% confidence interval around the estimates. Full table available in Annex Table B.6.

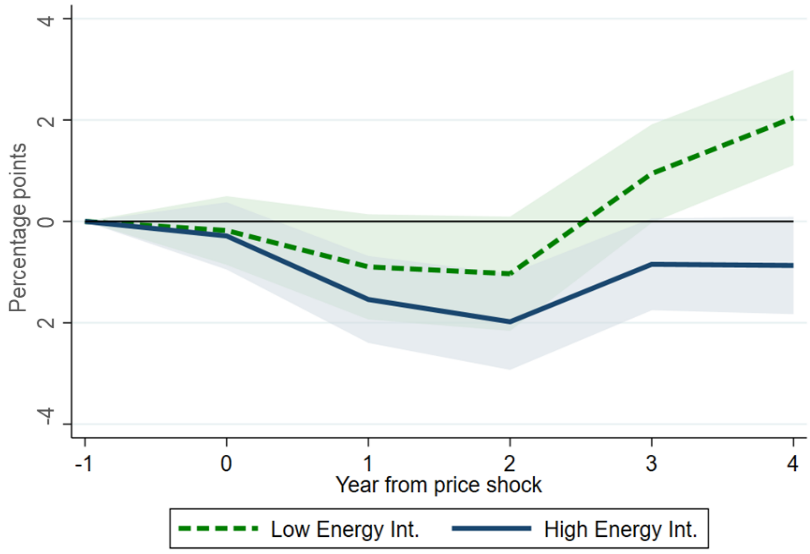
61. These results hide significant heterogeneity across sectors with different energy intensity, that is, the share of energy costs in the total costs of inputs. Figure 7 depicts the marginal effects of a mild shock (one standard deviation change of energy prices) on cumulative productivity growth for firms in more energy intensive (blue line) and firms in less energy intensive sectors (green line) relative to the median energy intensity of sectors in the sample[23]. It shows that only firms in sectors with high energy intensity have statistically significant negative impacts from energy price shocks in the very short run (period 1). In the medium term, the differences between firms in less and more energy intensive sectors are even starker,

[23] Noteworthy that the analysis focuses on sectors that are relatively energy intensive such that even low energy intensity sectors relative to the median in the data may be more energy intensive than the overall average sector in the economy.

with only those in less energy intensive sectors presenting positive effects of energy price shocks in the medium term (periods 3 and 4).

Figure 7. The effects of shocks differ for firms of different energy intensities

Response of MFP growth to a one standard deviation shock to energy prices by energy intensity



Note: The lines represent the coefficients of the variable measuring energy price shocks resulting of estimating Equation (6) augmented of an interaction between the energy price shock and a dummy variable equal to 1 for sectors that are more energy intensive than the median, multiplied by 100 to be interpreted as percentage point changes. The blue line is the effect for energy intensive sectors and the green line for non-energy intensive sectors. The shaded areas represent the 90% confidence interval around the estimates. Full table available in Annex Table B.8.

62. In what follows, we focus on understanding the channels behind the medium-term impact of mild (one standard deviation) energy price shocks on productivity. The focus on mild shocks instead of severe shocks is justified by both practical reasons, in that mild price shocks offer more variation in the sample, and by policy concerns. As countries move towards decarbonisation, it is important to understand the conditions under which energy price increases might not have negative impacts on the economy, to shape policies accordingly.

5.2.2. The investment channel

63. The strong version of the PH states that more stringent environmental policy or higher energy prices affect firms' economic outcomes through incentives for energy efficiency investment or innovation.[24] Unfortunately, data on energy efficiency investment is not easily available at the firm level in cross-country settings and including small, unlisted firms. As such, in order to understand whether investment in energy efficiency could be a channel behind the medium-term results, we proceed in two ways. First, we explore the mediating impact of variables that could affect firms' ability to start investing when affected by the shock on the relationship between the shock and productivity. Second, we investigate the impact of energy price shocks on firms' investment in capital stock. As new capital vintages tend to be more energy efficient, investment in the renewal of capital stocks can be seen as a proxy for energy efficiency investment.

64. We first study the mediating impact of environmental policy stringency levels in the country, as a proxy for the preparedness of firms with respect to environmental and energy efficiency considerations. Indeed, awareness of green issues by firms' management, or "green management", has been found to

[24] Requiring the observation of long timespans, innovation is out of the scope of the current paper.

positively affect firm investment in energy efficient technologies (Martin et al., 2022[38]; Kalantzis, Schweiger and Dominguez, 2022[73]). In countries where environmental policy stringency is higher, managers are more likely to be aware of energy efficiency issues and available technologies and production methods to improve it.

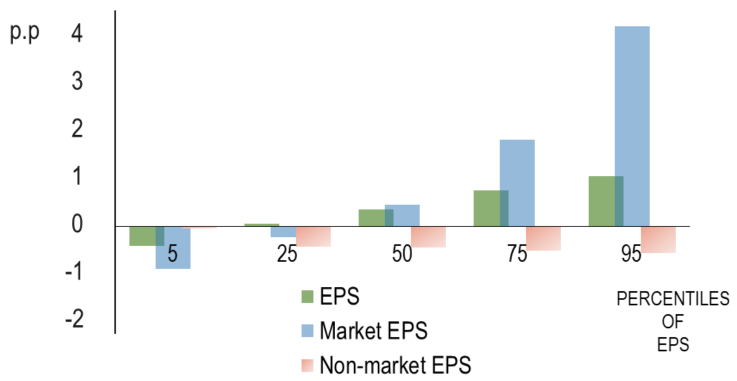
65. The impacts are estimated for the three environmental policy stringency (EPS) indicators described in Section 3.3, namely the overall indicator, the market-based indicator (including market-based policies like taxes and permits), and the non-market-based indicator (including non-market-based policies like performance standards or labelling). The results are presented in Annex Table B.9 for the five horizon years of analysis. We are particularly interested in the effect of market-based EPS, which includes policies that incorporate explicit price signals and are normally more flexible (de Serres, Murtin and Nicoletti, 2010[74]).

66. The results show that, in countries with more stringent market-based environmental policy, the marginal effect of shocks on productivity growth were similar in the short term but more positive from year 2 onward. Non-market-based EPS does not have the same effect. The effect is visible in the overall indicator, which shows a positive impact in the medium term, although only marginally statistically significant. This signals that while in the short term, higher energy prices may force firms to decrease production even in the presence of policy stringency, in the medium term, firms operating in environments where they have to be aware of energy efficiency issues are more likely to make the necessary investments to adjust to higher energy prices.

67. Figure 8 further zooms in on the estimated impacts four years after an energy shock takes place for firms in countries with different levels of environmental policy stringency. The estimated effects indicate that EPS levels in the year before the shock affect firms' outcomes four years after. Specifically, for countries in the 50th percentile of EPS, the impact of a one standard deviation shock in energy prices is to increase MFP by 0.3pp, while for countries in the 95th percentile of EPS this effect is triple. The effects are even larger when considering market-based EPS.

Figure 8. Preparedness helps firms' ability to deal with energy price shocks

Effect of energy price shocks on productivity growth for different levels of existing EPS (horizon=4)



Note: The bars show the coefficients of energy price shocks for different percentiles of existing levels of Environmental Policy Stringency before the shock. Coefficients result from the estimation of Equation (6) augmented of an interaction between the energy price shock and EPS, market EPS, and non-market EPS levels for horizon 4, that is, 4 years after the energy price shock. Coefficients are multiplied by 100 to be interpreted as percentage point changes. Full table available in Annex Table B.9.

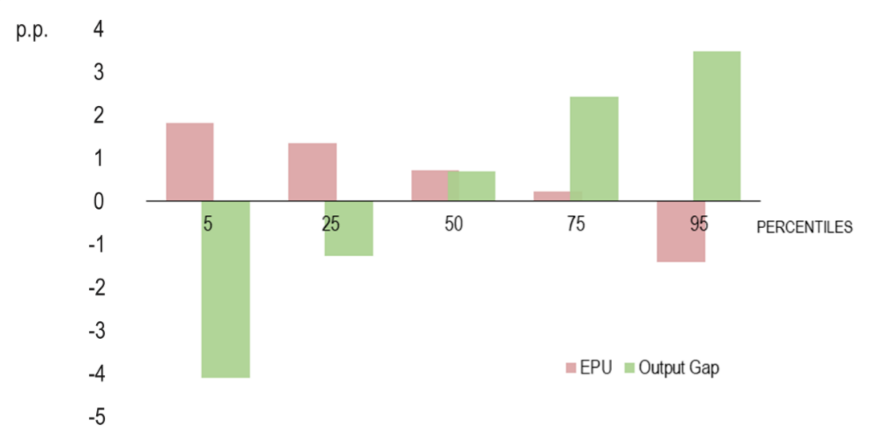
68. Further, we estimate how the relationship between shocks and productivity growth varies depending on the macroeconomic conditions of a country. Focusing on the country's position in the business cycle, we find that when a country's output gap is positive, energy price increases not only have a less negative impact in the short term (as seen in Section 4) but they also have a more positive impact in the long term (columns (3)-(5) of Annex Table B.10). Price increases are in that case likely to be driven

by increases in demand, which imply that firms are not deterred from making investments when hit by a positive price shock, leading to productivity gains. To illustrate this, Figure 9 focuses on the fourth period after the shock, and represents the impact of energy price shocks on productivity growth for different percentiles of the output gap, showing that when the economy operates below full capacity, energy price shocks have negative impacts on productivity growth even in the medium term.

69. When facing uncertainty over future production costs and streams of revenues, firms are likely to delay irreversible investment, such as that in energy efficiency. If energy price shocks cause increases in productivity growth in the medium term through investment, elevated economic uncertainty may dampen this positive effect. Results show that indeed the higher policy uncertainty, the lower the positive effects of energy price shocks observed in the medium term (Annex Table B.10). In fact, when looking at the fourth period after the shock (Figure 10) we see that the effect of energy price shocks on productivity in the medium term is smaller the higher uncertainty is, and when economic policy uncertainty is very high (95^{th} percentile) a positive effect is no longer observed.

Figure 9. Macroeconomic conditions matter for firms' capacity to adapt to shocks

Effect of energy price shocks on productivity growth for different levels of EPU and output gap (horizon=4)

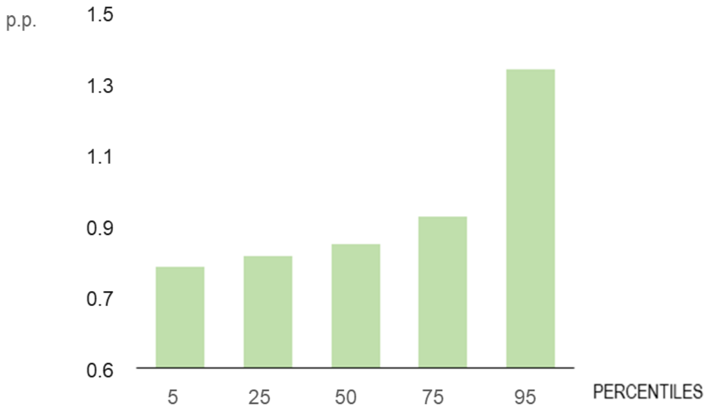


Note: The bars show the marginal effect of energy price shocks for different percentiles of existing levels of Economic Policy Uncertainty (EPU) and country output gap before the shock. Coefficients result from the estimation of Equation (6) augmented of an interaction between the energy price shock and EPU and output gap levels for horizon 4, that is, 4 years after the energy price shock. Coefficients are multiplied by 100 to be interpreted as percentage point changes. Full table available in Annex Table B.10.

70. Financing constraints have been found to decrease investment in energy efficiency (Martin et al., 2022[38]), so firms' financial capacity also matters for the relationship between energy price shocks and productivity growth in the medium term if investment is a channel behind it. Results show that firms that had made investments in capital just before the shock, and therefore were more likely to already have access to finance, have better results when faced with an energy price shock, both in the short and long term (columns (1)-(5) of top panel of Annex Table B.11). Figure 10 depicts the estimated coefficients of the impact of shocks on productivity for different percentiles of the past capital investment, four years after the shock.

Figure 10. Investment capacity affects the ability of the firm to adapt to price shocks

Effect of energy price shocks on productivity growth for different levels of past investment (horizon=4)



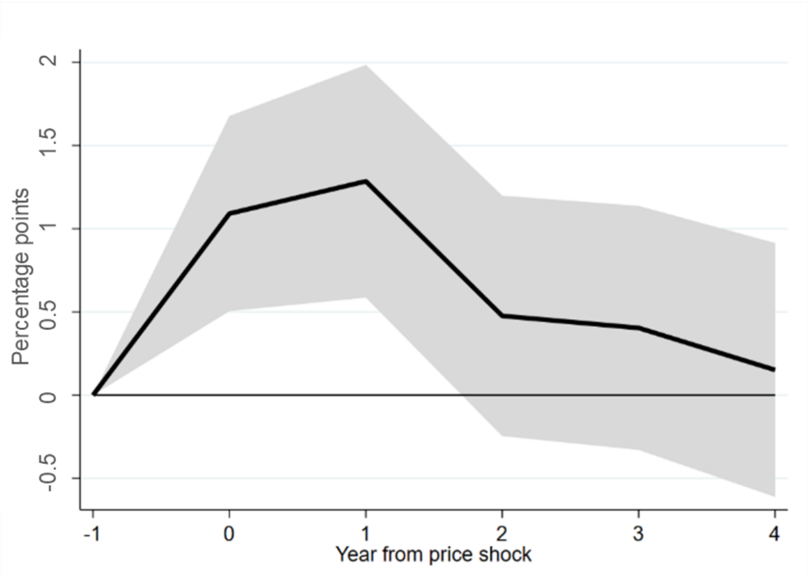
Note: The bars show the marginal effect of energy price shocks for different percentiles of existing levels of capital investment before the shock. Coefficients result from the estimation of Equation (6) augmented of an interaction between the energy price shock and investment ratio for horizon 4, that is, 4 years after the energy price shock. Coefficients are multiplied by 100 to be interpreted as percentage point changes. Full table available in Annex Table B.11.

71. We also focus on the role of worker skills on mediating the medium-term impact of energy price shocks on productivity, because of the larger skilled-labour bias of technological change generating higher capital-skill complementarity for more efficient technologies (Lindquist, 2005[75]; Correa, Lorca and Parro, 2019[76]). If investment is indeed the channel through which productivity improves in the medium term, then higher skills should enhance this effect. Specifically, we interact the energy price shock with a proxy for the level of worker skills in the year before productivity growth is evaluated. We proxy worker skills with the average wage the firm pays its workers, in tens of thousands of U.S. dollars. The results are presented in the bottom panel of Annex Table B.9, and show that, while not present in the first year, in the medium term a small positive effect is present.

72. Finally, Figure 11 and Annex Table B.12 present the results of estimating the capital investment growth equation (Eq. 7). They indicate that, in the immediate aftermath of a positive energy price shock, firms invest more in capital, a finding that is consistent with previous research for French firms (Marin and Vona, 2021[8]). In particular, in the two first periods after a one standard deviation shock, firms increase their investment ratio (investment over capital stock) by respectively 1.1% and 1.3%. The investment subsides from the following period. These results suggest that the spur in capital investment following energy price shocks could be an explanation for the improving productivity outcomes in following years.

Figure 11. Capital renewal occurs more rapidly after a shock

Growth of investment, as a share of total capital stock, in response to an energy price shock



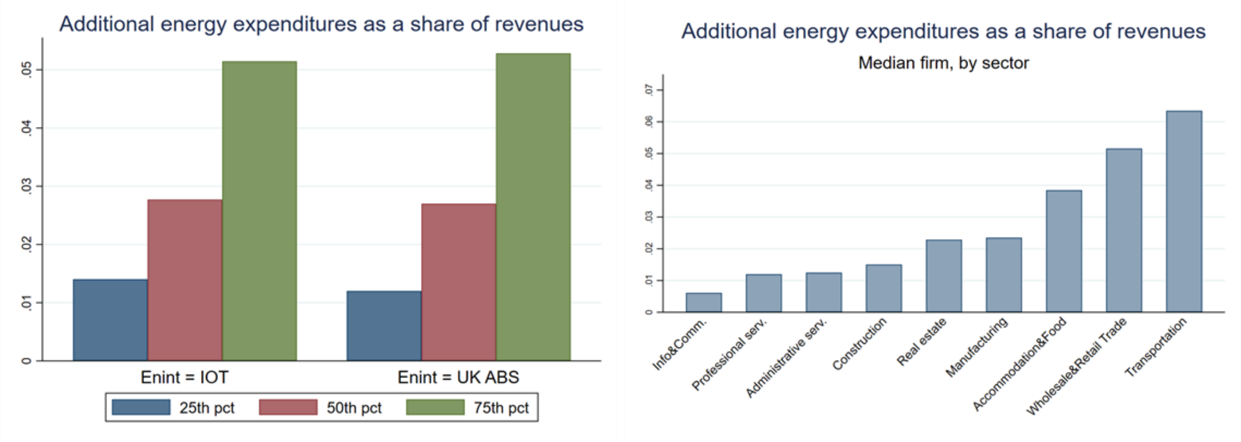
Note: The thick black line represents the coefficients of the variable measuring energy price shocks resulting of estimating Equation (7) multiplied by 100 to be interpreted as percentage point changes. The shaded area represents the 90% confidence interval around the estimates. Full table available in Annex Table B.12

6. Policy discussion

73. The exceptional rise in energy prices following the strong post-COVID-19 recovery and the Ukraine war represents a severe shock for many firms, with a price increase much larger than those covered by the empirical analysis. In an environment of rising costs, pressure on customers' purchasing power and higher interest rates, some companies are bound to face tighter liquidity constraints, especially where support during the pandemic was in the form of loans or deferred payments. Difficulties are particularly acute in Europe and Asia, which saw the largest increases in energy prices.

74. A simple accounting exercise (see Annex C for the methodological details) allows us to get a sense of the potential effects of 2022 energy prices on the European corporate sector. Firms' expenditures on energy increased substantially in the aftermath of the onset of war in Ukraine (1st semester of 2022) for a wide range of firms and across sectors (Figure 12). The median firm in the economy is expected to face an increase equivalent to approximately 3% of its revenues, while for firms at the 75th percentile of the distribution of costs to revenues the rise could reach the equivalent to 5% of revenues. Firms in the transport sector are expected to face the highest increase, with the median firm facing an increase larger than 6% of its revenues. Companies in the professional services and the information and communication sectors are the least affected.

Figure 12. Firms' expenditures on energy as a share of revenues could have increased substantially in 2022



Note: In the left panel, "Enint = IOT" indicates that energy intensity is estimated on the basis of OECD Input-Output Tables, while "Enint = UK ABS" that it is estimated from the UK Annual Business Survey. The abbreviation "pct" in the legend stands for percentiles of the expenditure to revenues distribution. See Annex C for the details on the methodology used to predict firms additional expenditures on energy following the 2022 energy price shock.
Source: OECD calculations based on Orbis®, OECD, Eurostat, World Bank and UK Annual Business Survey data.

75. Higher expenditures on energy may have rendered the core activity of many firms unprofitable in 2022: the overall share of European firms displaying a negative EBITDA in 2022 may have risen up to 16-22%, depending on the assumptions made on the ability of firms to pass-through the price increase without reducing output sold, from a 12% characterising a no shock scenario. Micro firms are predicted to have suffered disproportionately more as well as firms in the bottom quartile of the productivity distribution, with the more pessimistic estimates reaching 25% and almost 40% for these two groups respectively.[25]

[25] On the one hand, the estimates obtained through the accounting exercise could be viewed as a pessimistic scenario, given that they are based on the price increase observed during the 1st semester of 2022, but the price hike was temporary. On the other hand, the simulation model may deliver an optimistic picture as it does not take into account second-order effects via supply chains: the increase in energy prices does not only increase energy costs, but also the price of other inputs, further reducing firms' profitability.

Figure 13. A higher share of firms is predicted to face losses, especially among micro and low productivity enterprises

Note: See Annex C for the details on the methodology used to predict firm profitability following the 2022 energy price shock.
Source: OECD calculations based on Orbis®, OECD, Eurostat, World Bank and UK Annual Business Survey data.

76. These results are in line with those of the empirical study, showing that the impact of an energy price shock varies according to firms' characteristics and thus may require a targeted policy answer. Further, it also shows that a non-negligible share of productive firms may become at risk of facing disruptions, justifying potential support towards most vulnerable but viable firms. Policy makers have gained a large experience into emergency support during the COVID-19 crisis (Demmou et al., 2022[77]). However, despite similarities, there are also significant differences compared to the COVID-19 crisis, which exclude a blanket approach to support (Box 1). In particular, short-term policies should not undermine the adjustment needed to reach long term objectives, i.e., the green transition.

Box 1. Similarities and differences with the pandemic-related crisis

Being massive, unexpected and to some extent temporary, the current shock bears some resemblance with the COVID-19 crisis. However, there are important differences between the two episodes, which have implications for policy responses.

The pandemic brought many activities to a halt, threatening to bankrupt many otherwise viable businesses. To support households and firms and to preserve economic potential, the authorities in OECD and many other countries provided ample liquidity and fiscal support. A concern was that very broad support could also prop up non-viable firms and slow economic restructuring. However, there is little evidence that the COVID-19 crisis caused resource misallocation and zombification (André and Demmou, 2022[78]; Demmou and Franco, 2021[79]). Even though the pandemic provided a durable boost to some companies, notably those relying heavily on digital tools (Andrews et al., 2021), it mainly looks like a hibernation period in which government support shielded businesses and workers, preparing the ground for a strong bounce back.

The energy shock looks more complex. Rather than halting activity in a great part of the economy, the energy crisis raises costs, especially for energy-intensive companies. At the same time, it lowers demand through the erosion of customers' purchasing power (which was largely preserved in OECD countries by public transfers during the pandemic). This affects cashflows, even of viable companies. While big firms generally have financial buffers and access to liquidity, which allows them to absorb a temporary shock, SMEs tend to be more credit-constrained, potentially justifying more liquidity support, especially as the financial position of many SMEs has already been weakened by the COVID-19 crisis and interest rates are going up.

Also, policy goals are more complex. In addition to the fiscal cost of extending government support, climate policy targets make it necessary to preserve some price signals to incentivise energy savings and the move towards decarbonised energy sources. Further, the potentially permanent asymmetric effects across continents (i.e., the increase in natural gas and electricity prices was much higher in Europe) has raised concerns that energy-intensive industries may relocate to places with cheaper and more secure energy supply: this could threaten the supply of strategic products, especially in times when global supply chains are prone to disruptions, justifying targeted policy interventions.

77. In the context of the 2022 energy price increase, many governments have provided support aimed at helping companies cope with higher energy costs. Box 2 provides detailed insights on the approaches adopted in selected European countries, but more generally two broad types of measures have been taken to prevent viable firms from going bankrupt due to the energy price shock.

78. First, some countries have capped retail energy prices or provided subsidies for energy use, sometimes targeted at specific kinds of businesses, like small enterprises (e.g., France, Japan) or specific industries (e.g., France, Italy, Spain). Some countries have reduced energy-related taxes (e.g., Austria, France, Germany) or network fees (e.g., Estonia, Italy).

79. While these measures directly lower retail energy costs and are relatively easy to implement, they have drawbacks. They weaken the price signal, which is essential to incentivise energy savings and efficiency gains. However, this can be mitigated by applying the cap or subsidies to levels corresponding to a limited share of past consumption (e.g., Germany), or by making the support conditional on plans to improve energy efficiency, as in Ireland. Another drawback of energy price caps or subsidies is their fiscal cost. Many European countries have financed at least part of their energy support through taxes on windfall profits of energy suppliers. The European windfall tax on oil, gas and coal companies has proved controversial, raising concerns that the taxation of infra-marginal electricity producers could deter incentives for investment in clean electricity generation, especially when measures are inappropriately designed, for instance applying to revenue instead of excess profit. Although well-designed taxes on economic rents do not necessarily deter investment, permanent taxes on windfall profits would be preferable to temporary taxes, as they would increase predictability, which is essential to support investment (Baunsgaard and Vernon, 2022[80]).

80. Second, liquidity constraints have been in some cases alleviated through measures to smooth firms' financial burden, especially for SMEs. Some countries have allowed the deferral of tax or social contribution payments (e.g., Austria, Belgium, Sweden). Firms can also be given more time to repay guaranteed loans granted during the pandemic (e.g., France).

81. However, the risk of keeping non-viable firms afloat and slowing economic renewal increases as support is extended in time. Debt levels may increase excessively, heightening risk and lowering investment (Demmou et al., 2021[81]; Kalemli-Özcan, Laeven and Moreno, 2022[82]). Some firms may need to restructure their debt, especially as interest rates rise. Restructuring can be achieved in a variety of ways, ranging from purely private agreements to formal insolvency procedures (Financial Stability Board, 2022[83]; World Bank, 2017[84]). Many countries have strengthened their insolvency frameworks during the pandemic (Gurrea-Martínez, 2022[85]). Enhanced early warning systems and pre-insolvency procedures should help corporate restructuring. However, many countries would benefit from introducing simplified restructuring procedures for small businesses (André and Demmou, 2022[78]).

Box 2. Short-term policy measures: selected cases

France

A wide range of measures have been introduced to shield businesses, particularly SMEs, from energy price increases. Companies with less than 10 employees and turnover below EUR 2 million (TPEs) with power installations below 36 kVA benefit from a cap on electricity price increases of 4% in 2022 and 15% in 2023. Companies with less than 250 employees with unit electricity cost above EUR 350/MWh are eligible to a 20% rebate on their electricity bill until end-2023. Companies with more than 250 employees are eligible to support for electricity and natural gas payments if their energy price has increased by at least 50% relative to 2021 and if their energy cost represents more than 3% of their 2021 turnover. The support level is increased for energy-intensive companies and to sectors exposed to a risk of carbon leakage.

Germany

The government has introduced a brake on natural gas and electricity prices de facto from the start of 2023 to April 2024. Natural gas (electricity) prices for small businesses, as for households, are capped at EUR 120/MWh (EUR 400/MWh) for 80% of their previous year's consumption. For around 25 000 large industrial consumers, natural gas (electricity) prices are capped at EUR 70/MWh (EUR 130/MWh) for 70% of their previous year's consumption. Consumption beyond the thresholds on previous consumption is subject to market prices. A windfall tax on energy companies will contribute to financing. However, the fiscal cost will remain substantial, the price brake may distort international competition and the windfall tax may discourage investment, notably in renewables.

Ireland

Several measures were introduced in the 2023 government budget to help Irish business overcome the energy crisis, while taking into account the need to improve energy efficiency and lower carbon emissions. The Temporary Business Energy Support Scheme (TBESS) compensates qualifying businesses for up to 40% of the increase in electricity or gas bills up to EUR 10 000 per month, until at least February 2023. The Ukraine Enterprise Crisis Scheme aims at assisting viable but vulnerable businesses in the manufacturing and internationally traded services sectors which are suffering the broader effects of the war in Ukraine and increasing energy costs. One strand of the scheme will provide up to EUR 2 million in grants for energy intensive companies impacted by the exceptionally severe increases in gas and electricity costs. Eligible businesses must produce an energy efficiency plan which shows how they will get their energy costs down. Guaranteed loans are also offered to SMEs to provide liquidity and encourage investment in energy efficiency and microenterprises can benefit from new grants to increase energy efficiency.

Spain and Portugal

In Mid-June 2022, Spain and Portugal introduced a cap on the price of natural gas for electricity generation to contain the rise in wholesale electricity prices. The mechanism combines a subsidy for fossil fuel generation with a tax on electricity aimed at capturing the rents of inframarginal electricity producers using renewable and nuclear energy. It is scheduled to last until end-May 2023. The scheme benefits all electricity users without requiring any action from them. The scheme was designed with specific features of the Iberian Peninsula in mind: interconnections to neighbouring countries are limited, preventing large leakages due to price differentials; access to natural gas is relatively easy due to a large LNG import capacity; and forward hedging is limited, which allows an intervention focussed on the spot market to work (Schlecht et al., 2022)*.

*Schlecht, I., J. Mühlenpfordt, L. Hirth, C. Maurer and A. Eicke (2022), "The Iberian electricity market intervention does not work for Europe", 29 August.

82. Beyond preventing the bankruptcy of viable firms, the response to an energy price shock should be consistent with long-run policy goals, namely maintaining firm performance and promoting decarbonisation.

83. Our empirical exercise highlights that concerns with respect to firms' performance in fuel importing countries may be warranted by showing that severe shocks may have persistent adverse effects on productivity (i.e., lasting at least 4 years). Other studies based on historical data suggest only small effects of energy prices on different dimensions of competitiveness (Sato and Dechezleprêtre, 2015[86]; Ellis, Nachtigall and Venmans, 2019[87]).However, further research would be needed to assess the potential impact on competitiveness and location of activity of shocks of larger magnitudes such as the one of 2022.

84. Finally, policy support should not hinder the reallocation of resources towards less energy-intensive activities, which may be inevitable if energy prices remain high (Ari et al., 2022[88]) or if industries are unable to move to cleaner energy sources. As suggested by our empirical analysis, it may be possible to promote the green transition while maintaining or increasing productivity and economic resilience in the long run. This hinges on the capacity of firms to make investment in energy efficiency, which could be promoted by for example decreasing financial barriers and facilitating the diffusion of knowledge regarding energy efficient technologies. Major initiatives to support the green transition have been taken for example in the United States (US Inflation Reduction Act) and the European Union (EU Fit for 55 and REpowerEU) (Box 3). These plans need to be implemented in a way that minimises distortions to competition and carbon leakage. More research on the conditions under which green investment materialises may be warranted.

Box 3. Major initiatives to support the green transition in the United States and the European Union?

The US Inflation Reduction Act (IRA)

The IRA contains a set of provisions to accelerate the energy transition, amounting to close to USD 400 billion over 10 years. It could allow a reduction in US greenhouse gas emissions by between 32% and 42% by 2030 relative to 2005 levels, compared to 24% to 35% without it (Larsen et al., 2022)*. In particular, the legislation encourages investment in clean energy generation and storage, biofuels, clean hydrogen, carbon capture and buildings' energy efficiency, primarily through tax credits. It also provides tax credits and subsidies to decarbonise industry and transportation, notably by supporting the manufacturing of clean vehicles, batteries and charging devices in the United States.**

REPowerEU

The scheme aims at ensuring independence from Russian fossil fuels well before 2030 and will mobilise more than EUR 200 billion by 2027, mainly through the Recovery and Resilience Facility. The scheme promotes energy savings, clean energy production and energy supply diversification***. Beside short-term measures, REPowerEU aims to speed up the green transition and spur massive investment in renewable energy (the EU's 2030 target for renewables is raised to 45% from 40%), as well as to enable industry and transport to substitute fossil fuels faster than previously planned, to bring down carbon emissions and energy dependence. Measures to achieve these objectives include new legislation and recommendations for faster permitting of renewables, investments in an integrated gas and electricity infrastructure network, measures to ensure industry has access to critical raw materials, regulations to enhance energy efficiency in the transport sector, funding for innovation leading to industrial decarbonisation and investments in clean hydrogen.

EU Fit for 55

The plan sets out the ways in which the Commission will reach its updated 2030 climate targets, through action in different policy areas, including climate, energy, transport and taxation. It includes various improvements to the European Union Emissions Trading System (EU ETS), including a broadening of its coverage, increases in Member State emission reduction targets in a fair and cost-effective way, more ambitious EU CO_2-emission targets for new cars and vans from 2030 and reforms to land-use and forestry regulations****.

* Larsen, J., B. King, H. Kolus, N. Dasari, G. Hiltbrand and W. Herndon (2022), "A Turning Point for US Climate Progress: Assessing the Climate and Clean Energy Provisions in the Inflation Reduction Act", Rhodium Group, New York.
** For a summary, see Bipartisan Policy Center (2022), "Inflation Reduction Act Summary, Energy and climate provisions", Washington, DC.
*** For a more comprehensive description, see REPowerEU: affordable, secure and sustainable energy for Europe.
**** For a more comprehensive description, see Delivering the European Green Deal.

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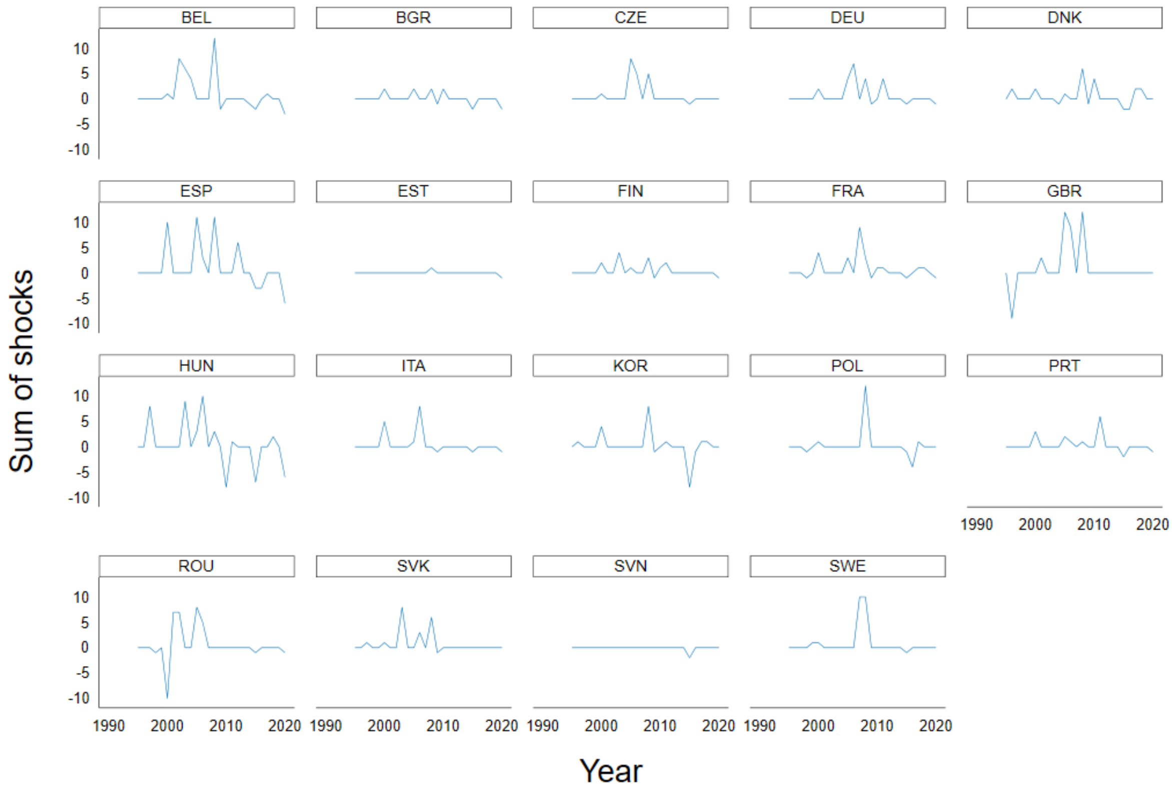
Annex A. Further data description

Figure A.1. Severe energy shocks across years

Sum of severe energy shocks for each country



Annex B. Results: Full Tables

Table B.1. Alternative definitions of the energy price variable

Dependent Variable: MFP levels or MFP growth								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Model	Static	Static	Static	Static	Dynamic	Dynamic	Dynamic	Dynamic
Dependent Variable: MFP	Levels	Levels	Levels	Levels	Growth	Growth	Growth	Growth
Prices baseline year	1995	2015	No base	2010	1995	2015	No base	2010
Sample	Full	Full	Full	Post-GFC	Full	Full	Full	Post-GFC
Lag Energy Prices	**-0.062****	**-0.143*****	**-0.000***	**-0.210*****	**-0.024+**	**-0.054*****	**-0.000*****	**-0.039****
	(-2.3)	**(-4.8)**	**(-1.8)**	**(-5.6)**	**(-1.6)**	**(-4.0)**	**(-5.4)**	**(-2.4)**
Lag MFP Gap To Frontier					0.302***	0.303***	0.367***	0.302***
					(86.1)	(90.3)	(32.5)	(76.0)
Observations	5,812,929	6,832,857	4,811,004	3,836,331	5,487,231	6,473,933	4,506,023	3,667,655
R-squared	0.843	0.827	0.844	0.858	0.243	0.238	0.271	0.210
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country by Sector FE	Subsumed	Subsumed	Subsumed	Subsumed	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	No	No	No	No

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting of estimating Equation 2 in specifications (1) to (4) and of Equation (4) for specifications (5) and (8). Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

Table B.2. Static model with labour productivity as dependent variable

Dependent Variable: Labour productivity (LP) levels				
	(1)	(2)	(3)	(4)
Lag Energy Prices	**-0.104*** **	**-0.077** **		
	(-3.5)	**(-2.4)**		
Lag Energy Prices * Energy Intensity		**-1.031** **		
		(-2.4)		
Lag Energy Prices * Small Firm			**-0.053*** **	
			(-9.4)	
Lag Energy Prices * Low Mark-up Firm				**-0.144*** **
				(-19.4)
Observations	6,606,830	6,606,830	6,606,382	6,606,382
R-squared	0.802	0.802	0.809	0.809
Firm Level Controls (including lagged capital)	Yes	Yes	Yes	Yes
Country by Sector FE	Subsumed	Subsumed	Subsumed	Subsumed
Country by Year FE	Yes	Yes	Subsumed	Subsumed
Sector by Year FE	Yes	Yes	Subsumed	Subsumed
Country by Sector by Year FE	No	No	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting of estimating Equation 2 in specifications (1) and (2) and Equation 3 in specifications (3) and (4), using LP rather than MFP as dependent variable. Firm-level controls include size and age dummies, ROA, leverage and the ratio of fixed assets to total assets, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

Table B.3. Exposure variable setting in the catch-up growth model

Dependent Variable: Multifactor Productivity growth		
	(1)	(2)
Lag Energy Prices * Small Firm	**-0.012*** **	
	(-2.8)	
Lag Energy Prices * Low Mark-up Firm		**-0.124*** **
		(-17.7)
Lag MFP Gap To Frontier	0.696***	0.696***
	(146.2)	(146.6)
Observations	6,239,807	6,239,807
R-squared	0.499	0.500
Firm Level Controls	Yes	Yes
Country by Sector by Year FE	Yes	Yes
Firm FE	Yes	Yes

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting of estimating Equation 4 expanded to pursue the exposure variable approach. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

Table B.4. Short-term dynamic model with labour productivity growth as dependent variable

Mild (one standard deviation changes) and severe (1.5 standard deviation changes) price shocks

Dependent Variable: Labour productivity (LP) growth							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Size of the price shock	\	\	\	Mild	Severe	Mild	Severe
Lag Energy Price Levels	**-0.041*** **	**-0.086*** **					
	(-3.4)	**(-3.7)**					
Lag LP Gap To Frontier * Lag Energy Price Lev.			**-0.034*** **				
			(-5.1)				
Energy Price Shock				**-0.006+**	**-0.015*** **		
				(-1.5)	**(-4.0)**		
Price Increase Shock						**-0.011** **	**-0.015*** **
						(-2.6)	**(-3.0)**
Price Decrease Shock						**-0.003**	**0.015** **
						(-0.4)	**(2.3)**
Lag LP Gap To Frontier	0.332***	0.713***	0.554***	0.333***	0.333***	0.333***	0.333***
	(100.4)	(157.3)	(12.8)	(99.9)	(99.9)	(99.8)	(99.9)
Observations	6,261,423	6,248,141	6,261,049	6,198,620	6,198,620	6,198,620	6,198,620
R-squared	0.262	0.506	0.272	0.262	0.262	0.262	0.262
Firm Level Controls (including lagged capital)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Energy Price Levels Before Shock	No	No	No	Yes	Yes	Yes	Yes
Country by Sector FE	Yes	Subsumed	Subsumed	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Subsumed	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Subsumed	Yes	Yes	Yes	Yes
Country by Sector by Year FE	No	No	Subsumed	No	No	No	No
Firm FE	No	Yes	No	No	No	No	No

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting from the estimation of Equation 4 in models 4 to 7, while in columns 1 to 3 lagged price levels are included in place of price shocks, with labour productivity growth rather than MFP as dependent variable. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

Table B.5. Between-firm effects: robustness check

Dependent Variable: Employment Growth								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MFP variable	Twice Lagged MFP Levels				Average MFP over time			
Size of the price shock	Mild	Severe	Mild	Severe	Mild	Severe	Mild	Severe
MFP Levels	0.015***	0.013***	0.015***	0.014***	0.047***	0.046***	0.049***	0.047***
	(3.6)	(3.3)	(3.7)	(3.3)	(11.0)	(10.8)	(11.0)	(10.9)
MFP Levels * Energy Price Shock	**0.001***	**0.003****			**0.002***	**0.004****		
	(1.7)	**(2.2)**			**(1.9)**	**(2.3)**		
MFP Levels * Price Increase Shock			**0.001**	**0.003+**			**0.001**	**0.002**
			(0.7)	**(1.5)**			**(0.6)**	**(1.2)**
MFP Levels * Price Decrease Shock			**-0.002****	**-0.003****			**-0.005*****	**-0.007****
			(-2.2)	**(-2.0)**			**(-2.6)**	**(-2.4)**
Observations	5,471,334	5,471,334	5,471,334	5,471,334	6,540,777	6,540,777	6,540,777	6,540,777
R-squared	0.050	0.050	0.050	0.050	0.060	0.060	0.060	0.060
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MFP Levels * Energy Price Levels Before Shock	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country by Sector by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	No	No	No	No

Note: T-statistics in parentheses; standard errors clustered at the firm and country by sector by year level. Significance Level: + 15%, *10%, **5%, ***1%. The coefficients are those resulting of estimating Equation 5, using twice lagged MFP in specifications 1-4 and average MFP levels in specifications 5-8. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period.
Source: OECD calculations based on Orbis® and OECD data.

Table B.6. Medium-term analysis: Baseline results

The effect of severe energy price shocks on compounded MFP growth

Dependent Variable: Multifactor productivity growth $(MFP_{i,t+k} - MFP_{i,t-1})$									
Moderate shock									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	t + 0	t + 1	t + 2	t + 3	t + 4	t + 1	t + 2	t + 3	t + 4
Energy Price Shock	-0.002	-0.011**	-0.014**	0.003	0.009*	-0.010*	-0.008	0.009*	0.014***
	(-0.6)	(-2.1)	(-2.4)	(0.5)	(1.8)	(-1.9)	(-1.4)	(1.9)	(2.9)
Lag Gap To Frontier	0.291***	0.341***	0.376***	0.403***	0.423***	0.341***	0.376***	0.404***	0.423***
	(110.0)	(122.6)	(129.4)	(137.6)	(139.7)	(122.6)	(129.0)	(137.1)	(139.3)
Lag Energy Price	-0.036***	-0.070***	-0.048***	-0.033*	-0.012	-0.062***	-0.016	0.014	0.024
	(-3.6)	(-4.9)	(-3.0)	(-2.0)	(-0.7)	(-4.3)	(-1.0)	(0.8)	(1.2)
Observations	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883
R-squared	0.212	0.239	0.258	0.284	0.268	0.239	0.258	0.283	0.268
Severe shock									
Energy Price Shock	-0.003	-0.005	-0.016***	-0.016***	-0.022***	-0.003	-0.010**	-0.008*	-0.012**
	(-0.9)	(-1.1)	(-3.4)	(-3.4)	(-4.5)	(-0.8)	(-2.3)	(-1.7)	(-2.5)
Lag Gap To Frontier	0.291***	0.341***	0.376***	0.404***	0.423***	0.341***	0.376***	0.404***	0.423***
	(110.0)	(122.6)	(129.0)	(137.3)	(139.5)	(122.6)	(129.0)	(137.2)	(139.3)
Lag Energy Price	-0.036***	-0.062***	-0.030*	-0.023	-0.023	-0.057***	-0.016	0.004	0.010
	(-3.5)	(-4.3)	(-1.8)	(-1.2)	(-1.2)	(-4.0)	(-1.0)	(0.2)	(0.5)
Observations	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883
R-squared	0.212	0.239	0.258	0.284	0.268	0.239	0.258	0.283	0.268
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Leads of price shock	No	Yes	Yes	Yes	Yes	No	No	No	No
Country by Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The coefficients are those resulting of estimating Equation (6), considering a moderate and a severe price shock (a shock of at least 1.5 standard deviation change in energy prices). The sample is restricted to firms having at least six years of available information. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%.

Table B.7. Medium-term analysis: Restricted sample

Baseline results restricting the sample for firms with at least ten years of available data

Dependent Variable: Multifactor productivity growth $(MFP_{i,t+k} - MFP_{i,t-1})$									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	t + 0	t + 1	t + 1	t + 2	t + 2	t + 3	t + 3	t + 4	t + 4
Mild shock									
Energy Price Shock	-0.002	-0.015***	-0.014**	-0.018***	-0.013**	0.001	0.006	0.009+	0.012**
	(-0.5)	(-2.6)	(-2.5)	(-2.8)	(-2.1)	(0.2)	(1.2)	(1.6)	(2.2)
Lag Gap To Frontier	0.286***	0.337***	0.337***	0.371***	0.371***	0.397***	0.397***	0.418***	0.418***
	(101.1)	(109.7)	(109.7)	(116.5)	(116.2)	(122.9)	(122.6)	(124.5)	(124.4)
Lag Energy Price	-0.051***	-0.084***	-0.080***	-0.061***	-0.038**	-0.037**	-0.002	-0.021	-0.000
	(-4.6)	(-5.5)	(-5.2)	(-3.6)	(-2.1)	(-2.1)	(-0.1)	(-1.1)	(-0.0)
Observations	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284
R-squared	0.210	0.238	0.238	0.257	0.256	0.270	0.270	0.270	0.270
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Severe shock									
Energy Price Shock	-0.003	-0.006	-0.004	-0.017***	-0.013***	-0.015***	-0.010**	-0.021***	-0.014***
	(-1.0)	(-1.2)	(-0.9)	(-3.4)	(-2.7)	(-3.0)	(-2.0)	(-4.0)	(-2.8)
Lag Gap To Frontier	0.286***	0.337***	0.337***	0.371***	0.371***	0.397***	0.397***	0.418***	0.418***
	(101.1)	(109.7)	(109.7)	(116.2)	(116.2)	(122.7)	(122.7)	(124.5)	(124.4)
Lag Energy Price	-0.051***	-0.076***	-0.071***	-0.045**	-0.035*	-0.032*	-0.011	-0.036*	-0.015
	(-4.5)	(-4.9)	(-4.6)	(-2.5)	(-1.9)	(-1.7)	(-0.6)	(-1.8)	(-0.7)
Observations	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284	1,517,284
R-squared	0.210	0.238	0.238	0.257	0.256	0.270	0.270	0.270	0.270
Firm Level Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Leads of price shock	No	Yes	No	Yes	No	Yes	No	Yes	No
Country by Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The coefficients are those resulting of estimating Equation (6), considering in turn a mild (one standard deviation) and severe (1.5 standard deviation) shock. The sample is restricted to firms having at least ten years of available information. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%.

Table B.8. Medium-term analysis: Effects by energy intensity

The effect of energy price shocks on productivity for non-energy-intensive and energy-intensive sectors

Dependent Variable: Multifactor productivity growth $(MFP_{i,t+k} - MFP_{i,t-1})$					
	(1)	(2)	(3)	(4)	(5)
	t + 0	t + 1	t + 2	t + 3	t + 4
Energy Price Shock	-0.002	-0.009	-0.010+	0.009+	0.020***
	(-0.4)	(-1.4)	(-1.5)	(1.6)	(3.6)
Energy Price Shock x	-0.001	-0.006	-0.010*	-0.018***	-0.029***
Energy Intensive	(-0.3)	(-1.3)	(-1.7)	(-3.3)	(-5.4)
Lag Gap To Frontier	0.291***	0.341***	0.376***	0.403***	0.423***
	(110.0)	(122.6)	(129.4)	(137.6)	(139.7)
Lag Energy Price	-0.036***	-0.071***	-0.049***	-0.035**	-0.016
	(-3.6)	(-5.0)	(-3.1)	(-2.1)	(-0.9)
Observations	2,111,883	2,111,883	2,111,883	2,111,883	2,111,883
R-squared	0.212	0.239	0.258	0.284	0.268
Effect for Energy Int	-0.00286	-0.0154	-0.0198	-0.00845	-0.00869
P-value	0.477	0.00305	0.000574	0.125	0.136
Firm Level Controls	Yes	Yes	Yes	Yes	Yes
Leads of price shock	No	Yes	Yes	Yes	Yes
Country by Sector FE	Yes	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes	Yes

Note: The coefficients are those resulting of estimating Equation (6) augmented with the interaction between the price shock and a dummy equal to 1 if a sector is above the median energy intensity of the sample. All equations include firm-level controls (size and age dummies, ROA, and leverage, all lagged one period) and country-sector, sector-year, and country-year fixed effects. The sample is restricted to firms having at least ten years of available information. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%. Effect of energy price shocks estimated for most energy intensive sectors as the sum of the coefficient of the energy price shock (effect for least energy intensive sectors) and the interaction term.

Table B.9. The effect of EPS on the relationship between shocks and productivity

The effect of energy price shocks on productivity for different levels of experienced environmental policy stringency

Dependent Variable: Multifactor productivity growth $(MFP_{i,t+k} - MFP_{i,t-1})$					
	(1)	(2)	(3)	(4)	(5)
	t + 0	t + 1	t + 2	t + 3	t + 4
	$EPS_{c,t-1}$				
Energy Price Shock x	-0.001	-0.004	0.006+	0.003	0.005
Interaction variable	(-0.4)	(-1.1)	(1.5)	(0.7)	(1.0)
Energy Price Shock	0.012	0.013	-0.019	-0.002	-0.011
	(1.6)	(1.3)	(-1.6)	(-0.2)	(-0.8)
Observations	1,978,444	1,978,444	1,978,444	1,978,444	1,978,444
R-squared	0.206	0.223	0.237	0.246	0.231
	$MarketEPS_{c,t-1}$				
Energy Price Shock x	0.002	0.005	0.014**	0.002	0.018**
Interaction variable	(0.4)	(0.7)	(2.0)	(0.3)	(2.3)
Energy Price Shock	0.006	-0.005	-0.022**	0.003	-0.023*
	(0.8)	(-0.5)	(-2.1)	(0.3)	(-1.9)
Observations	1,978,444	1,978,444	1,978,444	1,978,444	1,978,444
R-squared	0.206	0.223	0.237	0.246	0.231
	$NonMarketEPS_{c,t-1}$				
Energy Price Shock x	0.001	-0.003	0.001	0.003	0.001
Interaction variable	(0.7)	(-1.4)	(0.3)	(1.0)	(0.3)
Energy Price Shock	0.004	0.014	-0.005	-0.005	-0.001
	(0.6)	(1.6)	(-0.5)	(-0.4)	(-0.1)
Observations	1,978,444	1,978,444	1,978,444	1,978,444	1,978,444
R-squared	0.206	0.223	0.237	0.246	0.231

Note: The coefficients are those resulting of estimating Equation (6) augmented with the interaction between the price shock and each mediator. All equations include firm-level controls (size and age dummies, ROA, and leverage, all lagged one period) and country-sector, sector-year, and country-year fixed effects. The sample is restricted to firms having at least ten years of available information. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%.

Table B.10. The effect of macroeconomic conditions on the relationship between shocks and productivity

The effect of energy price shocks on productivity for different levels of economic policy uncertainty and output gap

Dependent Variable: Multifactor productivity growth $(MFP_{i,t+k} - MFP_{i,t-1})$					
	(1)	(2)	(3)	(4)	(5)
	t + 0	t + 1	t + 2	t + 3	t + 4
	EPU (t-1)				
Energy Price Shock x	-0.000**	-0.000**	-0.000	-0.000	-0.000**
Interaction variable	(-2.6)	(-2.3)	(-0.5)	(-1.3)	(-2.2)
Energy Price Shock	0.017***	0.019**	-0.001	0.017	0.031**
	(2.7)	(2.1)	(-0.1)	(1.3)	(2.4)
Observations	1,643,002	1,643,002	1,643,002	1,643,002	1,643,002
R-squared	0.211	0.226	0.238	0.246	0.230
	Output Gap (t-1)				
Energy Price Shock x	0.001	0.007***	0.009***	0.009***	0.007***
Interaction variable	(1.1)	(3.3)	(3.5)	(4.3)	(3.5)
Energy Price Shock	-0.002	-0.007	-0.009	0.008	0.014**
	(-0.4)	(-1.1)	(-1.3)	(1.4)	(2.5)
Observations	2,109,788	2,109,788	2,109,788	2,109,788	2,109,788
R-squared	0.212	0.238	0.258	0.270	0.258

Note: The coefficients are those resulting of estimating Equation (6) augmented with the interaction between the price shock and each interaction variable (EPU and output gap). All equations include firm-level controls (size and age dummies, ROA, and leverage, all lagged one period) and country-sector, sector-year, and country-year fixed effects. The sample is restricted to firms having at least ten years of available information. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%.

Table B.11. The effect of firm conditions on the relationship between shocks and productivity

The effect of energy price shocks on productivity for different leverage ratio, capital investment, and skills

Dependent Variable: MFP growth $(MFP_{i,t+k} - MFP_{i,t-1})$					
	(1)	(2)	(3)	(4)	(5)
	t + 0	t + 1	t + 2	t + 3	t + 4
	Capital investment ratio (t-1)				
Energy Price Shock x	0.001	0.003**	0.002	0.003*	0.003*
Interaction variable	(1.0)	(2.2)	(1.4)	(1.7)	(1.8)
Energy Price Shock	-0.002	-0.019***	-0.028***	-0.005	0.009
	(-0.5)	(-3.6)	(-4.5)	(-0.8)	(1.6)
Interaction variable	0.016***	0.020***	0.024***	0.027***	0.029***
	(27.2)	(29.7)	(34.0)	(33.3)	(32.6)
Observations	1,692,960	1,692,960	1,692,960	1,692,960	1,692,960
R-squared	0.208	0.233	0.254	0.265	0.253
	Skills (t+h-1)				
Energy Price Shock x	-0.005***	0.0004	0.008***	0.005**	-0.005
Interaction variable	(-5.6)	(0.3)	(5.9)	(2.2)	(-1.2)
Energy Price Shock	0.014***	-0.013*	-0.040***	-0.005	0.034**
	(2.8)	(-1.7)	(-4.8)	(-0.5)	(2.2)
Interaction variable	0.004***	0.065***	0.033***	0.037***	0.045***
	(4.4)	(75.7)	(16.5)	(14.3)	(14.7)
Observations	2,568,618	2,568,618	2,568,618	2,568,618	2,568,618
R-squared	0.254	0.319	0.324	0.349	0.332

Note: The coefficients are those resulting of estimating Equation (6) augmented with the interaction between the price shock and each interaction variable (leverage ratio, capital investment, and skills). All equations include firm-level controls (size and age dummies, ROA, and leverage, all lagged one period) and country-sector, sector-year, and country-year fixed effects. The sample is restricted to firms having at least ten years of available information. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%.

Table B.12. Capital investment and energy price shocks

The effect of energy price shocks on compounded capital investment growth

Dependent Variable: Capital investment ratio growth $(Investment_{i,t+k} - Investment_{i,t-1})$					
	(1)	(2)	(3)	(4)	(5)
	t + 0	t + 1	t + 2	t + 3	t + 4
$Priceshock_{c,s,t-1}$	0.011***	0.013***	0.005	0.004	0.002
	(3.1)	(3.0)	(1.1)	(0.9)	(0.3)
$Investment_{i,cs,t-2}$	-0.029***	-0.035***	-0.029***	-0.026***	-0.026***
	(-15.9)	(-17.9)	(-14.4)	(-12.6)	(-11.3)
$EnPrices_{c,s,t-1}$	0.024**	0.031**	0.062***	0.069***	0.031**
	(2.6)	(2.4)	(4.7)	(5.1)	(2.2)
Observations	1,356,796	1,355,195	1,353,074	1,350,074	1,344,946
R-squared	0.011	0.014	0.016	0.019	0.023
Firm Level Controls	Yes	Yes	Yes	Yes	Yes
Leads of price shock	Yes	Yes	Yes	Yes	Yes
Country by Sector FE	Yes	Yes	Yes	Yes	Yes
Country by Year FE	Yes	Yes	Yes	Yes	Yes
Sector by Year FE	Yes	Yes	Yes	Yes	Yes

Note: The coefficients are those resulting of estimating Equation (7). The sample is restricted to firms having at least six years of available information. Firm-level controls include size and age dummies, ROA, and leverage, all lagged one period. T-statistics in parentheses; standard errors clustered at the firm level. Significance level for which the null hypothesis is rejected: +15%, *10%, **5%, *** 1%.

Annex C. Simulating the impact of the 2022 energy price shock: methodological overview

1. We develop a stylized accounting model to gauge the potential impact of the 2022 energy price shock on firms' performance. Building on the framework developed by the Finance, Investment and Growth workstream to analyse the impact of COVID-19 on the corporate sector, it relies on three main inputs:

- Balance sheet data describing firms performance in "normal" time.
- Detailed data on energy expenditures, sectors energy mix and on price developments during 2022.
- Stylized accounting exercise linking energy expenditures to firms' profitability

2. *Balance sheet data*. Firm level data are once again collected from the latest vintage of the Orbis database. We retain 2019 balance sheet data, as this is the latest year available potentially representing represent firms' financial situation in normal times with respect to their average revenue and operating expenses. After applying a basic data cleaning process, the final sample consists of more than 1 million firms, located in 15 European countries and operating in manufacturing, construction and non-financial business services industries. [26]

3. *Detailed on energy expenditures*. Data on energy costs at the firm level would constitute the ideal setting for analysis. However, these data are not available on a cross-country basis and thus we rely on sector-level information instead, hence assuming that the share of energy expenditures over total intermediate costs is similar across firms within sectors. We rely on two main data sources:

- OECD Input-Output tables. For each country-sector, we compute the amount of inputs bought from the energy sectors (namely, sectors 19 and 35 according to Nace Rev.2 classification) and normalise it by the given country-sector total expenditures on intermediate consumption.
- Estimates from the UK Annual Business Survey (ABS). The survey provides the share of energy costs over intermediates at a very detailed sectoral level, also distinguishing firms by size class and computing average shares rather than a total share. However, the use of this source would imply the additional assumption that the share of energy costs over intermediates does not vary substantially across countries and thus is mainly used as a robustness check.

4. *Energy price shock*. In order to proxy the energy price shock faced by firms, we combine two ingredients:

- Real-time data on price developments of the main four the 4 main fuels: electricity, gas, oil and coal.
  - Electricity and gas price data are gathered from Eurostat. Eurostat provides country specific prices (either including or excluding taxation) for non-household consumers. The data cover both semester 1 and semester 2 of 2019, while only semester 1 in 2022. In the absence of 2022 second semester, the growth rate of prices is computed only on the basis of 2019 and 2022 first semesters. Moreover, prices are provided by consumption bands and we average across bands to obtain a unique value for prices growth.

[26] Countries included are: BEL, BGR, CZE, DEU, ESP, EST, FRA, HUN, ITA, POL, PRT, ROU, SVK, SVN, SWE. Italy, Spain, Portugal and Romania are the countries accounting for the largest share of observations.

  - For oil and coal, we use monthly data at the world level on commodity prices published by the World Bank. We average over months in 2019 and all available months in 2022 and then take the growth rate. By definition, the price does not include any tax or mark-up over the fuel distribution chain.
- Detailed data on fuel consumption at the sector level, to identify the exposure of each sector (and thus firm) to a specific fuel price fluctuations and compute a weighted average of the prices changes. The sectoral energy mix is obtained from Sato et al. (2019[1]), and the details are presented in Section 3.2.

5. *Accounting exercise*. As a first step, we exploit (country-) sector information on the share of energy expenditures (*enint* from now on) over total intermediate expenditures (*totint* from now on) to proxy firms spending on energy in normal times:

$$EnexpNormalTime_{ics} = Totint_{ics} * Enint_{(c)s} \tag{8}$$

6. Second, the increase in energy expenditures is obtained by multiplying normal time energy expenditures by the change in prices observed from 2019 and 2022:

$$EnexpIncrease_{ics} = EnexpNormalTime_{ics} * PriceChange_{cs} \tag{9}$$

7. Next, a key parameter relates to the capacity of firms to pass-through the price shock to their customers. In order to make an informed assumption on the extent of pass through, we use STAN country-sector level data to estimate the elasticity of the price level of output to the price level of intermediate inputs, controlling for country, sector and year fixed effects. Our estimates suggest that, on average, 79% of the increase in inputs prices is passed through on output.[27] Hence, assuming further that the output produced and sold remains the same (i.e., inelastic demand), the increase in revenues from higher prices is computed as follows:

$$RevenuesIncrease_{ics} = EnexpIncrease_{ics} * PassThrough \tag{10}$$

8. Finally, having computed both the increase in costs and the related increase in revenues, firm's profits in shock times are computed as:[28]

$$ShockedEbitda_{ics} = Ebitda2019_{ics} - EnexpIncrease_{ics} + RevenuesIncrease_{ics} \tag{11}$$

[27] We performed sensitivity analyses to check how results vary when modifying this elasticity within a reasonable interval.

[28] Among the various profitability measures available, we focus on ebitda as it allows to disentangle the profitability of firms' core business, net of extraordinary revenues or costs as well as net of taxes, which may impair cross-country comparability.