Energy Prices and Competitiveness in the Manufacturing Sector

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1.1 Abstract

We investigate the relationship between energy prices and manufacturing competitiveness at the industry level. Drawing on panel data spanning the mid-1990s to the 2010s from an extensive multi-sector dataset, we shed light on the nonlinear dynamics between energy prices and the sector-level performance of manufacturing industries. Our findings link to ongoing work on the effect of energy prices on firm-level performance by highlighting considerable sector-specific heterogeneity, indicating the complex and intricate relationship between economic performance and the cost of energy.

Keywords: Energy prices; competitiveness; manufacturing.

1.2 Introduction

In light of the current and ongoing global climate crisis and efforts to achieve net zero, research on the effect of energy prices on socio-economic indicators has developed into a highly active field. For example, empirical research has investigated the benefits of energy price changes at the macroeconomic level, e.g., Heine and Black (2019), Schoder (2022), and Hille and Möbius (2019) or drawn from firm-level microdata to gain insights into this phenomenon, e.g., Cali et al. (2022).

While numerous empirical papers shed light on heterogeneities in the economic effect depending on the type of energy that will experiences price increases and highlight sector-specific effects,[4] fewer papers focus on the question of the extent to which these economic effects of energy price increases vary conditionally on energy intensity or energy prices.[5] We argue that the latter merits further investigation: Suppose that energy prices are so low that the return on investment in more energy-efficient machinery may be minuscule. In such a scenario, firms may be less likely to make investment decisions to improve the energy efficiency of their productive processes. In turn, with rising energy prices, the marginal returns may increase and drive the innovation cycle in firms. Yet, once firms have reached the technological frontier and energy prices continue to rise, the innovation channel may not remain open to generate any positive economic windfall, and firms may use different transmission channels to cope with any additional energy price increases. As such, the energy price level may affect firms' investment decisions during price hikes and, therefore, also the way in which they navigate energy price changes more broadly.

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[2] This is an advanced draft of a chapter for the book Food-Energy-Water Nexus – Integrated Challenges and Global Perspectives that will be published in 2026 by Springer Nature in the book series Contribution to Economics and edited by Holger Schloer, Sandra Venghaus and Sascha Stark.

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[4] Amongst others, these are Rentschler, Kornejew, and Bazilian (2017), Amann et al. (2021) and Cali et al. (2022).

[5] Some recent exceptions are Cali et al. (2023) and Amann and Grover (2023).

This paper seeks to provide some initial insights into this question. We combine sector-level energy price data (Sato et al., 2019) with manufacturing (INDSTAT, 2022) and mining (MINSTAT, 2022) production data, respectively, yielding a panel dataset from 1995–2015 for ten sectors and 44 countries. We examine the potentially non-linear relationship between energy prices and four sector-level socioeconomic indicators, i.e., productivity (output per worker), employment, wages, and investment (gross fixed capital formation). In addition to conducting an exploratory data analysis, we compare the estimated elasticities obtained from a canonical fixed-effects panel model with those derived from a quantile fixed-effects one.

Our results align with existing work analysing the firm-level effects of energy prices and economic performance. Furthermore, we find evidence for the presence of significant non-linear dynamics and sector-level heterogeneity. Our work supports the existing literature, which suggests that changes in energy prices do not necessarily have detrimental effects on firm performance or employment. Instead, we observe prevalent sector-specific heterogeneities at the sub-sectoral level of manufacturing industries that may be linked to sectoral patterns, firm-level characteristics, differences in substitution patterns across energy types, and energy price levels.

1.3 Literature review

The literature has highlighted potential negative side-effects associated with artificially lowered energy prices, e.g., through subsidies. Such interventions have the potential to distort market processes, thereby negatively impacting a firm's decision-making process (Amann et al., 2024). For example, artificially lowered energy prices may reduce a firm's incentive to adopt energy-efficient technologies. Moreover, extensive energy subsidies can incentivise the utilisation and exploration of technologies that would not be pursued in a more cost-transparent environment, thereby hindering the development of innovative and sustainable solutions (Ley et al., 2016).

In turn, selective interventions in energy prices could potentially be employed to enhance the economic competitiveness of specific sectors within the economy. This idea was first formulated by Porter and van der Linde (Porter, 1991; Porter and Van der Linde, 1995), who proposed that appropriately designed regulations have the potential to generate a double dividend by reducing emissions and improving production processes and overall efficiency, which offsets the initial costs associated with policy interventions. The underlying response mechanism, whereby firms *innovate* by adopting new and more efficient technologies in response to a policy-induced energy price increase, is often referred to as the *Porter Hypothesis*.[6] Such regulations may increase price transparency and foster innovation while reducing path dependence (Ley et al., 2016; Meng, 2021).

It is crucial to consider the full extent of the fiscal and social costs of such interventions (Coady et al., 2006; Iraldo et al., 2011), as firms may have additional response mechanisms at their disposal to navigate energy price increases (Rentschler et al., 2017; Coste et al., 2018): In addition to *innovation*, they may *pass costs on* to customers; *absorb* the cost increases, e.g., by reducing their profit margins; or *substitute* between input factors.

A growing body of research has utilised firm-level microdata to investigate the extent to which firms leverage different response mechanisms to navigate energy price changes.[7] The literature finds robust evidence of capital upgrading in response to energy price increases, the potential of

[6] See Ambec et al. (2013) and Cohen and Tubb (2018) for a meta-analysis of the literature and Jaffe and Palmer (1997) for a discussion of the different variants of the *Porter Hypothesis* in the literature.

[7] For a more comprehensive review of the literature, consider, amongst others, Ambec et al. (2013), Arlinghaus (2015), Cohen and Tubb (2018), Dechezleprêtre and Sato (2020), or Amann et al. (2024).

substantial cost pass-on and limited aggregate employment impacts. Further evidence highlights the importance of intra-fuel substitution effects, examining how firms switch between different energy sources to mitigate the impact of price changes, e.g. Rentschler and Kornejew (2018), or explore the relevance of firm-specific characteristics and potential non-linearities in the relationship between energy prices and firm behaviour (Amann and Grover, 2023; Cali et al., 2023).

1.4 Data

Sector composition. We combine sector-level energy price data from Sato et al. (2019) with sectoral manufacturing data taken from UNIDO's Industrial Statistics Database *INDSTAT 2 – 2021, Revision 3* (INDSTAT, 2022) and Mining & Utilities statistics from *MINSTAT 2 – 2022, Revision 3* (MINSTAT, 2022). This yields a panel dataset for the period 1995–2015 for ten sectors and 44 countries.[8] We aggregate the INDSTAT and MINSTAT sectors to match the aggregation in Sato et al. (2019); see Table 1.

Table 1. Sector aggregation.

Sectors	INDSTAT/*MINSTAT*
Manufacturing	15–37
Food and tobacco	15, 16
Textile and leather	17, 18, 19
Wood and wood products	20
Paper, pulp and print	21, 22
Chemical and petrochemical	23, 24, 25
Non-metallic minerals	26
Machinery	29, 30, 31, 32, 33
Transport equipment	34, 35
Mining and quarrying	*1C*

Note: Sector aggregates following Sato et al. (2019). The construction and metals sectors are not included. Manufacturing encompasses manufacturing sectors 15–37.

Data transformations. To recover sector-level deflators for the respective INDSTAT data, we resort to the experimental deflators proposed by Haraguchi and Amann (2023). For the mining and quarrying sector, we resort to GDP deflators from the World Bank's national accounts data, and the OECD National Account's data files. We trim the top/bottom 0.5% of each data sequence to minimise the effects of extreme outliers on our results.

Endogeneity. We acknowledge that reverse causality in measuring the relationship between energy prices and socioeconomic outcomes may arise. For example, energy prices may drive investment, and, at the same time, investment drives prices. Despite the exploratory nature of our work, we attempt to reduce this effect by resorting to the energy price index *EP* proposed by Sato et al. (2019), which is derived from the time-invariant (at the 1995-level) energy mix for each sector-level and national time-varying shifts in the different prices of respective energy sources:[9]

[8] These are: Bulgaria, Canada, Chile, China, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Kazakhstan, Korea, Republic of, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Taiwan, Republic of China, Thailand, Turkey, United Kingdom, the USA, and Venezuela.

[9] This price measure has also been employed by others, e.g., by Marin and Vona (2021) or Cali et al. (2023).

$$EP_{cst} = \log\left(\sum_j \theta_{jcs,t=1995} \times p_{jct}\right) \quad (1)$$

where $\theta_{jcs,t=1995}$ is the share of energy source *j* = *{crude oil, LPG, electricity}* across the total energy use of sector *s* in country *c* in year *t* = 1995, and p_{jct} is the real price of energy source *j* in country *c* and year *t*.

1.5 Stylised findings

Fig. 1 provides an exploratory data analysis of the relationship between the socio-economic indicators and energy price levels by sector. Our initial visualisation exercise indicates the existence of a non-linear and positive relationship between productivity and energy prices. This implies that changes in energy prices have a varying impact on productivity, depending on their level. Specifically, the effects exhibit a hump-shaped pattern for certain sectors, namely non-metallic minerals, wood products, and in the textile and leather industries.

The analysis of the relationship between investment and energy prices reveals interesting findings. Firstly, there is no strong correlation between the two variables. Secondly, we observe a slightly downward-sloping pattern when comparing GFCF levels at increasing energy price levels. This suggests that investment is more strongly correlated with lower energy prices. Productivity increases from higher energy process could be the outcome of a change in the firms' strategies aimed at replacing the production of capital-intensive goods with less capital-intensive ones or at replacing the use of capital with other inputs (Ma et al., 2014; Casagrande et al., 2024). Moreover, when considering specific sectors, certain industries exhibit a hump-shaped relationship between investment and energy prices. Notably, the chemicals, food, and mining sectors display this distinctive pattern, indicating that their investment levels are influenced by the interplay of energy prices in a non-linear manner.

Concerning the non-linear relationship between wages with energy prices, the results presented in Fig. 1 provide evidence for an inverse relationship, meaning that wages tend to increase with increasing energy prices. This finding is apparently surprising, as a common understanding could be that firms tend to decrease production costs and wages when energy prices increase, but it is in line with previous evidence indicating increasing productivity at higher energy prices. Higher energy prices could trigger Porter-type competitiveness improvement effects, leading to wage increases. Moreover, these trends may be partly explained by technological progress and globalisation, which have been particularly pronounced during the periods studied (Vu et al., 2021) and which can explain a decreasing level of employment beyond a certain energy price threshold. The positive wage effects identified in the analysis are particularly significant within the chemical, food, and machinery sectors, which are characterised by a relatively high level of capital-intensity.

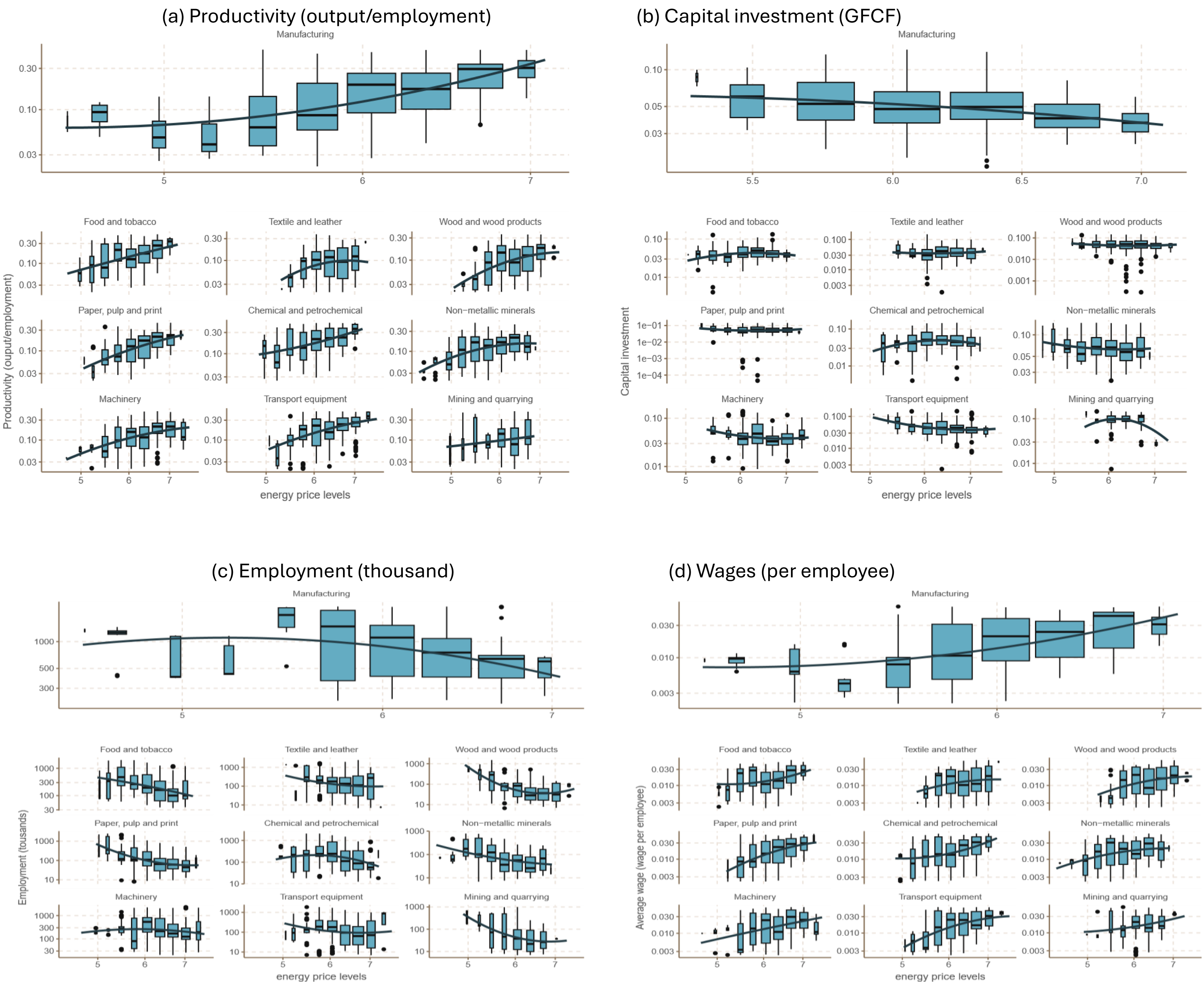

Fig. 1. *Exploratory data analysis* – the relationship between socio-economic indicators and energy price levels by sector. *Note:* Axes in logs. The width of the boxplots corresponds to the within-bin sample size by sector. The regression line is based on a quadratic model. *Source:* Authors' calculations. Energy price levels are based on Sato (2019) manufacturing and mining production data based on INDSTAT (2022) and MINSTAT (2022), respectively.

1.6 Econometric analysis

1.7 Empirical Model

Canonical Fixed-Effects. We analyse the effect of energy prices, as specified in Equation 1, on a set of socio-economic outcomes. These are: (i) productivity (output per worker); (ii) investment (gross fixed capital formation); (iii) employment (total number of workers per sector); and (iv) wages (average wages per sector) and are taken from INDSTAT (2022) and MINSTAT (2022). We address potential endogeneity issues by employing a fixed-effects (FE) setup to capture endogeneity from time-invariant attributes. We add time effects to capture the long-run development patterns of governments, infrastructure, and/or technology innovation. More specifically, we estimate the canonical fixed-effects model as follows:

$$y_{it} = \beta\, ep_{it}\, \boldsymbol{X}'\gamma + \varepsilon_{it} \quad (2)$$

$$\varepsilon_{it} = \alpha_i + \varphi_t + e_{it} \quad (3)$$

where the lower-case letters denote log transformations of the energy price index (ep) and the set of socio-economic outcome variables (y) for country *i* and period *t*, respectively. Furthermore, α denotes the country-specific intercepts, φ captures time-effects, and e denotes the idiosyncratic error term. Finally, $\boldsymbol{X}$ corresponds to a vector of control variables and includes control variables for (real) GDP, population, a common market dummy, and a financial crisis dummy. Throughout all of the model's estimations, we also employ clustered standard errors to address the endogeneity arising from autocorrelation or heteroscedasticity.

Quantile Fixed-Effects. In addition to the canonical FE model described in Equation 2, we investigate potential non-linear patterns by estimating a panel quantile regression model (Machado and Silva 2019). More precisely, the linear specification for the conditional quantile of dependent variable *y* and generic explanatory variables $\boldsymbol{x}_{it}$ is given by:

$$Q\left(\tau|\boldsymbol{x}_{it}, \beta(\tau)\right) = \beta(\tau)\boldsymbol{x}_{it} \quad (4)$$

where $\beta(\tau)$ is a vector of the coefficients related to the τ^{th} quantile. We estimate Equation 4 for τ = *{*10*,* 25*,* 50*,* 75*,* 90*}* and present the estimated coefficients alongside those of the canonical FE model obtained from Equation 2 in the next section.

1.8 Results

Fig. 2 compares the canonical FE coefficient estimates (horizontal grey line for the coefficient estimates, area for the confidence interval) with the quantile estimates (blue scatters for quantile coefficients, blue area for confidence intervals). The black horizontal line highlights an estimated effect of zero. The analysis reveals important findings regarding the relationship between energy prices and firm-level productivity in manufacturing.

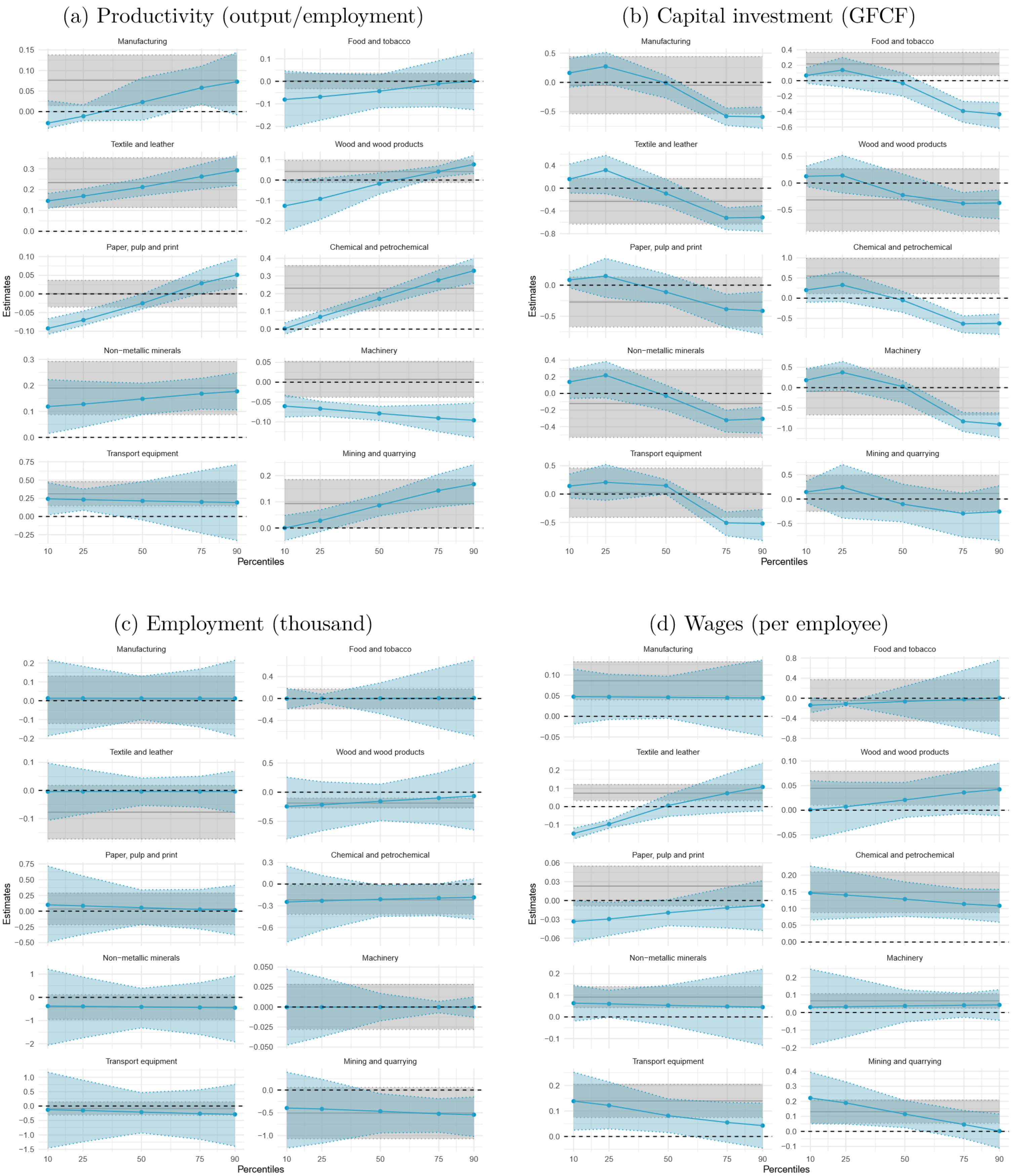

Fig. 2. *Econometric analysis* – the relationship between socio-economic indicators and energy price levels by sector. *Note:* Separate sector estimates and standard errors are clustered at the country level. Scatters (error bars): Quantile fixed-effects estimates (confidence interval). Horizontal solid line (area): Fixed-effects coefficient (confidence interval). *Source:* Authors' calculations. Energy price levels: Fixed, real, weighted Energy Price Index (Sato, 2019) of manufacturing and mining production data based on INDSTAT (2022) and MINSTAT (2022), respectively.

First, the results indicate a positive and upward-sloping pattern, suggesting that the effect of energy price increases on productivity becomes more pronounced as energy prices rise. This finding aligns with the theoretical expectation that higher energy prices incentivise firms to improve their energy efficiency and adopt more efficient production technologies. However, it is important to note that the fixed effects (FE) estimator used in the analysis tends to overestimate the productivity effect at lower energy prices and underestimate it at higher levels. Yet, the quantile estimates obtained from the analysis fall within the confidence interval of the linear model. These results align with the field's findings, which typically observe positive productivity effects, especially at the more aggregated level, which does not consider changes in the firm makeup of the respective sectors. Furthermore, heterogeneous effects can be observed at the sub-sectoral level. The analysis demonstrates significant variation in the productivity effects across different manufacturing sectors. For instance, chemicals and petrochemicals exhibit distinct patterns compared to industries like paper, pulp, and printing. This heterogeneity underscores the need for a nuanced understanding of the sector-specific dynamics and the importance of considering industry-level characteristics in policy design and decision-making. Our results are again in line with the literature, confirming considerable sector-level heterogeneities.

Second, one of the key findings of this study pertains to the formation of capital, as illustrated in Figure 2b. The canonical fixed effects estimates largely demonstrate a positive and significant relationship between energy prices and capital formation across various sectors. This suggests that higher energy prices stimulate capital investment. However, quantile estimates reveal a more nuanced relationship between energy prices and investment. At lower levels, increases in energy prices have a pronounced positive impact on investment. However, as energy prices rise, the investment effects diminish and eventually become negative at higher levels. This indicates a non-linear relationship between energy prices and investment, highlighting the diminishing returns associated with price increases. These results hint at a more complex relationship between energy prices and investment. They suggest that while moderate energy price increases can incentivise capital formation, excessively high energy prices can have detrimental effects on investment.[10]

Third, the literature finds limited evidence of energy price variations in employment figures. Our analysis finds similar results. For most sectors and manufacturing in aggregate, the marginal effect of energy price increases on employment is insignificant and small, and sector-level differences appear minuscule.

Fourth, and finally, the results on employee wages are again consistent with the literature, pointing at, by and large, stable wage progression, even at higher energy price levels. This means that higher energy prices trigger an increase of wages, as highlighted when discussing the descriptive statistics. Compared to the fixed effect model, the non-linear estimates highlight a greater estimates uncertainty at higher levels of energy prices. The result of higher energy prices associated with higher wages, together with the results on employment, indicates a rotation in the labour force towards higher-paid employment aligning with firm-level evidence pointing at the potential within- and across-sector reallocation of labour. Investigating sub-level development

[10] We wish to caveat these findings by pointing out that more research, preferably at the firm level, is needed to shed more light on these dynamics. Our aggregate analysis cannot account for differences in the energy mix across countries and types and could be further driven by the deflator of our choice. We also posit that our empirical set-up does not necessarily eliminate any endogeneity concerns and that our aggregated data may furthermore be subject to aggregation bias.

patterns suggests that this effect is more detrimental in some sectors than others (e.g., machinery vs wood and wood products).

1.9 Conclusions

This study contributes to understanding the relationship between energy prices and manufacturing competitiveness at the industry level. By analysing panel data spanning a significant period from the mid-1990s to the 2010s and utilising a comprehensive multi-sector dataset, we provide insights into the non-linear dynamics between energy prices and performance across manufacturing industries. We find that increasing energy prices intuitively generate an increasing path of productivity, a decreasing path of investments, a non-significant impact on employment, and a stable or mildly increasing impact on wages. The findings presented in this paper complement existing research on the energy price and economic performance nexus, as they further strengthen evidence that higher energy prices may not necessarily lead to a worsening of economic indicators but can increase productivity and wages. The results also highlight the presence of significant sector-specific heterogeneities that could be useful to consider when crafting vertical industrial and energy policies. Moreover, this study underscores notable non-linear relationships across various manufacturing industries, indicating the intricate and complex link between economic performance and energy costs. These findings emphasise the importance of considering sector-level dynamics and non-linearities when examining the impact of energy prices on manufacturing competitiveness.

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