TECHNICAL REPORT

ENERGY SUBSIDY REFORM IN ACTION

FIRM-LEVEL EFFECTS OF ENERGY PRICE INCREASES

Evidence and Insights from Recent Research

THE WORLD BANK
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ESMAP
Energy Sector Management Assistance Program

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Juergen Amann, Defne Gencer, and Dirk Heine

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ABOUT ESMAP

The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and over 20 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the WB, ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7), which ensures access to affordable, reliable, sustainable, and modern energy for all. It helps shape WB strategies and programs to achieve the WB Climate Change Action Plan targets. Learn more at: https://www.esmap.org.

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ABOUT THIS SERIES

This report is part of the "Energy Subsidy Reform in Action" series produced by the ESMAP Energy Subsidy Reform Facility, with the objective of drawing insights from recent experiences and emerging approaches related to reform of energy subsidies in developing countries. The series includes issue-specific reports from various relevant domains such as energy sector reform, macroeconomic and fiscal policy, carbon pricing, poverty and distributional analysis, social protection, political economy, and communications.

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Executive Summary

Energy is a critical factor of production for firms, and energy subsidies encourage excessive and inefficient energy use. When the government subsidizes any specific input, firms' decisions regarding the optimal mix of input factors to produce output are distorted, which can reduce economic efficiency: reducing the price of one particular input encourages firms to use more of it per unit of output, distorting both the amount and the way a good is produced.[1] Reforming energy subsidies can help address distortions and misplaced incentives for firms to overuse energy and can encourage firms to allocate production inputs more efficiently.

The complex topic of how firms are affected by and respond to policy-induced energy price increases had not been extensively explored in research and the academic literature until recently. In the past few years, more evidence and studies exploring this subject have become available. To better understand emerging knowledge and evidence in this field, this report reviews a selection of the academic and empirical literature on the firm-level impacts of energy price increases published from 2010 onward.

The recent empirical literature shows that the impact of energy price increases and firms' responses to them depend on multiple factors. These factors include the firm's energy dependence, the magnitude of the changes in price levels, and the availability of options the firm can use to adapt and reduce energy consumption in response to price signals. Firms have several response mechanisms at their disposal when confronted with policy-driven energy price increases. Firms typically navigate policy-induced energy price changes by (1) passing the price increase on to customers; (2) absorbing the price increase; (3) replacing one energy carrier[2] with others, or changing the relative shares of energy and other inputs; or (4) using firm-level capacity that drives innovation and productivity.

The empirical literature identifies substantial cost pass-through by firms in response to energy price increases. Research consistently demonstrates that increased costs stemming from energy price reforms are often passed on to consumers. This dynamic interplay underscores the potential ramifications for overall consumer welfare. Cost pass-through is identified across various levels of analysis, including sectoral, firm-specific, and commodity-based assessments, revealing intricate links within production networks.

1. Energy subsidies are input subsidies and tend to be more distortionary than output subsidies, which encourage firms to produce more of their outputs by using any combination of inputs that the firm chooses and will only distort the amount produced. Sometimes, the two categories can be combined; output subsidies for upstream producers in the supply chain for a specific good can become input subsidies for downstream producers.
2. An energy carrier can be defined as a "substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes" (ISO13600:1997). In the energy value chain, the carriers are the intermediate step between primary energy sources, such as crude oil and coal, and end-use applications, such as lighting, refrigeration, or heating. Examples include electricity; solid, liquid, or gaseous fuels; and heat.

Furthermore, data constraints at the firm level complicate the understanding of capacity-related response patterns, particularly within the context of developing economies.

Firms' tendency to *absorb* policy-induced energy price increases varies depending on their characteristics and sectoral attributes. Not surprisingly, businesses in sectors that use substantial amounts of energy tend to react the most when prices go up. Although there is no conclusive evidence for firm exit or significant aggregate employment loss in response to energy price increases, the evidence does suggest potential shifts in the workforce within specific sectors, highlighting the need for careful policy responses.

The literature presents compelling evidence of substantial substitution among various production inputs, notably between energy and labor inputs and among different energy sources. The necessary data for analyzing interfuel substitution requires comprehensive information on diverse energy inputs used by firms, which is not commonly available in standard firm-level data sets. Consequently, empirical insights into interfuel substitution mechanisms remain relatively scarce. Nevertheless, the overall picture emerging from the literature highlights widespread substitution. Particularly noteworthy are discernible disparities in the ability of firms to substitute between different fossil fuels, in particular between coal and gas, but also between fuels and electricity.

Finally, recent research offers insights into the relationship between government intervention—energy price intervention in particular—and innovation. The empirical field finds broad support for the weak form of the Porter hypothesis, in which policy interventions trigger innovation. In turn, the research does not appear to offer conclusive support for the strong Porter hypothesis, according to which environmental policy innovations spur firm competitiveness, productivity growth, and profitability.

Overall, research does offer evidence that firms' responses to rising energy prices vary depending on their characteristics, with firm size being a particularly important factor. Another highly relevant aspect is managerial quality, given that well-managed and environmentally conscious firms are typically more responsive and adjust to changes in energy prices more successfully. Finally, firm-level responses to energy price increases vary by energy source or carrier: although firms have been observed to use Porter-type adjustment mechanisms in response to fossil fuel price increases, electricity price increases are typically found to have much more significant firm-level impacts, with relatively limited options for adjustment.

On aggregate, evidence and analyses from recent research indicate that energy price increases are not necessarily detrimental to firms as they have multiple response mechanisms at their disposal with which to navigate them. First, not all firms may be similarly affected by policy-induced price changes; for example, smaller firms and those in

more energy-intensive sectors tend to be more substantially affected by such policy changes. Second, from a policy perspective, some of the responses by firms may be more desirable than others. For example, if firms can pass through all energy price increases to households, the welfare, socioeconomic, and environmental outcomes from such changes may require further consideration than when firms instead resort to cleaner and more modern production processes. A third and related point is that policy and regulatory choices by governments can mitigate impacts on firms and influence the responses deployed by firms. Indeed, a few studies show that the impact of energy price increases on firms can be reduced if these increases are accompanied by policy measures and government spending that support innovation and productivity or that are favorable to the private sector and business environment. Such measures may include those aimed at reducing corporate taxes, issuing vouchers to consumers, or investing in public goods crucial for innovation, productivity, and efficiency. Successfully addressing these challenges requires a nuanced understanding of market conditions and tailored policy approaches, underscored by further investigation into firm-level data.

Future work on the firm-level impacts of energy price increases and responses to them could focus on gathering additional evidence and documenting novel approaches. The review of recent research pointed to several topics that may be of interest, including (1) conducting more granular analyses of firm responses, (2) leveraging novel data and methodologies to develop a more comprehensive understanding of the response mechanisms (3) ensuring the sustainability and inclusiveness of policies that focus on the unique challenges and opportunities faced by firms in developing countries, (4) exploring the effectiveness of various policy incentives and targeted mitigation, and (5) focusing on the use of fiscal savings from energy subsidy reforms for improving firm and sector level outcomes and broadening the scope of the impact to green policies over time.

ONE
Introduction

Energy is an essential production input for firms. In market-based economies, a firm's objective is to maximize profits by combining energy with other inputs, such as labor, capital, and natural resources, to produce goods and services. The prices of these different production inputs determine how much of each resource firms use.[1] Government subsidies to any specific input distort firms' calculus in determining the optimal mix of input factors and encourage them to use more of the subsidized input per unit of output. This alters both the amount and the way a good is produced and leads to overall economic inefficiency.

Governments around the world have been subsidizing the production and consumption of energy for decades.[2] The main arguments in favor of energy subsidies tend to include a combination of shielding domestic producers from global fuel price volatility and making cheap energy available to lower-income households, thereby serving as a redistributive measure. Although there may be benefits conferred by energy subsidies to certain segments of the economy, they also come with significant ramifications for public resources (Kojima, Bacon, and Trimble 2014), firms, households, and the environment (Couharde and Mouhoud 2020; Clements et al. 2013; Inchauste and Victor 2017; Kojima, Bacon, and Trimble 2014). Artificially low energy prices can lead to inefficient and excessive energy consumption (Coady et al. 2017) and slow down innovation (Aghion et al. 2016; Ley, Stucki, and Woerte 2016).

By reforming energy subsidies, governments can reduce some of the distortions affecting how firms mix production inputs to generate output. Energy price increases—not only those resulting from subsidy reforms but also those that are the result of other price and nonprice policies—can provide incentives to firms to allocate production factors more efficiently. Energy price increases may affect firms to varying degrees, and the magnitude and channel of impact depend on various factors, including the firm's energy dependence, the extent of the changes in price levels, and the availability of options for the firm to adapt and reduce energy consumption in response to price signals.

Although there is extensive academic literature and policy debate about the impacts of energy subsidies and their reform focusing on households, much more limited research and evidence had been available on firm-level effects. From 2010 onward, there has been a growing amount of research examining the various ways in which firms are affected by energy price changes. These recent papers explore how and the extent to which energy price changes affect firms of different sizes, capacities, and setups across various sectors.

This paper reviews recent research on the firm-level impacts of energy price increases, documents emerging themes and insights, and offers recommendations for dimensions that can be considered in future work. The objective of the review is to

1. A key idea in economics is that of the *marginal rate of technical substitution*, which expresses the idea that firms can produce their goods and services using different methods and combinations of production inputs. A firm decides how to combine the various inputs based on their respective prices, with the objective of maximizing profits.
2. For a summary of fossil fuel subsidy reforms in developing countries, see Couharde and Mouhoud (2020).

strengthen the understanding of the impact of policy-induced energy subsidy changes on firms by reviewing recent advances in the empirical literature. The review focused on empirical, firm-level studies in developing and developed countries. Relevant articles were identified through targeted keyword searches on Scopus, Web of Science, and Google Scholar, focusing on peer-reviewed work and well-established working paper series published after 2010 with an empirical, typically firm-level, foundation. The reviewed papers were categorized following a framework of firm-level response mechanisms that was developed based on different conceptualizations in the field. In addition to providing an empirical synthesis of firm-level response mechanisms, the review focuses on heterogeneities in firm-level response patterns to energy price hikes. The review concludes with recommendations for future empirical work, dealing with both country setting and types of analyses.

1.1. Background and First Principles

Energy price subsidies, which artificially lower the energy costs faced by consumers, constitute input subsidies for firms that rely on energy as an input for their production.[3] Such subsidies reduce the price of a specific input factor and decrease their costs relative to those of other inputs, which encourages firms to use more of the subsidized production factor. Furthermore, given the lower postsubsidy costs of inputs, firms can now generate more output given the same production costs. In other words, input subsidies distort both the amount of goods produced and the way they are produced.[4] Artificially lower energy prices may not only lead to excessive consumption and inhibit energy efficiency, they may also create suboptimal path-dependence: low energy prices may discourage investment in more energy-efficient capital and new technology, which ultimately may affect a firm's competitiveness and also undermine the utilization of and research into technologies that could have taken place in a more cost-transparent environment (Ley, Stucki, and Woerter 2016).

Reforming energy subsidies can address the distortions, misplaced incentives, and cost misalignment between production inputs caused by those subsidies, and restore transparency. Under the basic assumption of market-based economies, reforming energy subsidies would improve firm efficiency. However, there are several potential impacts and

3. For a comprehensive discussion of energy subsidies, see Kojima (2017).
4. In general, subsidies can be broadly categorized as input subsidies and output subsidies (Schwartz and Clements 1999). Different from input subsidies, output subsidies provide a financial reward for outputs, thereby encouraging a firm to produce more, using any combination of inputs that the firm manager chooses. For example, a subsidy per unit of coal consumed by power plants is an input subsidy, whereas a subsidy per unit of electricity produced is an output subsidy. While input subsidies distort both the amount and the way goods are produced, output subsidies only distort the amount produced. Sometimes, the two categories of subsidies can overlap—output subsidies for upstream producers in a good's supply chain can become input subsidies for downstream producers (OECD 2019a), for example, when a subsidy per megawatt hour of electricity provided to the power sector reduces the price of electricity, a key input for industrial consumers. Similarly, supporting upstream industry development, for example, by developing manufacturing capacities, can increase demand for the downstream segment of the value chain (OECD 2019b).

constraints that need to be considered. First, even though energy subsidies create large distortions in the economy, removing them can involve transition risks that need to be managed carefully. Simply put, if a subsidy regime has been in place for a long time, firms will have adapted to these distortions, and a rapid move to higher energy prices can cause disruptions, overwhelm firms with managerial or liquidity constraints, or lead to stranding of energy-intensive assets. Moreover, if multiple countries whose firms are competing in the same goods markets provide energy subsidies, increasing energy input costs can risk putting some of the firms at a disadvantage. An increase in energy input costs could also contribute to a contraction in output in that sector, even when there are some efficiency gains due to operational responses to higher energy prices. The aggregate effect of subsidies depends on the type of firm directly affected by the subsidy and those indirectly affected by the subsidy through product market competition (Rotemberg 2019).

Firms vary in their ability to respond to increasing energy prices, and their ability to do so may be tied to firm characteristics such as size, age, or sector. Even though energy subsidies may be an inefficient way to support firms, their elimination can be detrimental for firms that are not in a position to respond quickly and efficiently to such policy changes. Consequently, energy subsidy reforms need to be based on an understanding of the variation in the potential firm-level impacts and responses and an assessment of the impact of specific policy options on the economy, markets, and firms.

An important consideration is how the government uses the fiscal resources that would be freed up from reforming energy subsidies. Government spending decisions that are beneficial for the private sector and market development, and fiscal resources directed toward these objectives instead of being used to finance energy subsidies, can contribute to positive effects for firms. Examples of the types of "revenue recycling" actions that can be beneficial to firms include lowering taxes on the output of the firms' production (corporate and personal income taxes), substituting output-based support (including vouchers to consumers for the firms' output) for input subsidies, and providing cash transfers or other social assistance to consumers with resulting positive income effects for demand or improving the provision of the public good (Beck et al. 2015; Beiser-McGrath and Bernauer 2019; Liu and Lu 2015). Subsidies that are financed through direct taxes on nonenergy inputs of production such as labor distort firm decisions twice: the energy subsidy encourages production processes to be more energy-intensive than what would have been the free market outcome, and labor taxes to finance the subsidy make production less labor-intensive. Labor can also be substituted for indirectly: in many industries, higher energy intensity correlates with greater use of machinery (see, for example, Sahu and Narayanan 2009), which can mean that increased energy subsidies raise incentives for firms to mechanize, further reducing employment. In these situations, firms and workers can benefit if the government replaces energy subsidies with lower taxes, especially on labor. However, this potential benefit from lower taxes on employment and firms is mostly shown at the macroeconomic level; examples of relevant papers include Heine and Black (2019) and Schoder (2021).

While there are examples of the impacts of fiscal policy tools on the private sector in the aggregate, much less information is available on what happens at the firm level in response to these policies. Even though governments have allocated more than 70 percent of revenues generated through various emissions trading systems (ETS) and carbon taxes to either green spending, private revenues, and government general budgets (Carl and Fedor 2016), studies isolating the firm-level effects of energy subsidies are scarce. Such evidence is crucial to understanding how firms navigate the changes introduced by fiscal policy tools and how governments can support firms' adaptation to policy by using freed-up revenues as part of policy implementation. Given the complexity of firm-level response dynamics, the effects of energy price increases on firms are subject to considerable uncertainty, especially in the short run. Thus, the focus of this review is to survey the empirical literature on the question of how policy-induced energy price increases affect firms. This review explores the literature for evidence on how firm-level outcomes may differ based on firm-level characteristics to minimize the negative impacts arising from energy subsidy reform on firms.

1.2. What Do Microdata Say about Firm-Level Impacts of Energy Price Changes?

Firm-level microdata provide the necessary resolution to capture the more granular effects or dynamics of energy price increases. Using these data, analysts can investigate important distributional aspects of energy subsidy reforms. Furthermore, firm-level analysis can address the issue of aggregation bias[5] and unveil additional response mechanisms, such as firm exit, that can rarely be observed at more aggregated levels.

Even though econometric research on the effects of energy price changes on firm performance has largely been limited to a small set of advanced countries, it has already revealed complex relationships. In a foundational piece of research, Kossoy et al. (2015) explore the various carbon pricing instruments that have emerged at the global level and analyzes competitiveness as well as carbon leakage concerns in relation to the globally fragmented carbon pricing instrument environment. The author highlights that carbon leakage is concentrated in emissions- and trade-intensive sectors, and international corporations can help reduce the global costs of emissions reduction. Other studies explore, for example, the type of energy inputs that are subject to price increases (Rentschler and Kornejew 2018) and the substitutability between different production inputs based on firm characteristics (Brucal and Dechezleprêtre 2021). Such granular

5. Aggregation bias occurs when effects observed in the aggregate, for example, at the sector level, are assumed to also hold at the level of the individual, for example, the individual firm (Clark and Avery 1976). In the context of linear empirical models more specifically, the issue describes the deviation of estimated macro parameters from the average of the corresponding micro parameters (Pesaran et al. 1989).

insights are likely to be highly useful to policy makers when designing energy subsidy reforms as well as support mechanisms during their transition and implementation phases.

A key challenge for assessing the effects of policy-induced energy price changes on firm-level outcomes is the extensive data required. Much of the research consists of individual country-level studies, typically focusing on larger and more developed economies (Burke et al. 2016). To provide a broader context, this review emphasizes potential heterogeneities between findings for advanced economies and developing countries as well as heterogeneity aspects of the individual studies based on firm characteristics.

The review considers a wider range of energy price adjustment mechanisms, not just those resulting from energy subsidy reforms. It also discusses price effects stemming from environmental and fiscal policies, such as carbon pricing or energy taxes, to highlight potential differences in firm-level response strategies conditional on the type of energy price change. The review focuses on policy-induced energy price changes and does not include unexpected energy price shocks, such as the ones prompted by unexpected geopolitical events (Kilian 2008; Zhang et al. 2023), but considers firm-level responses to price increases brought about by subsidy removal or general market movements. Planned interventions also differ from energy price changes brought about by exogenous price shocks in that planned price changes resulting from energy subsidy reforms are announced well in advance and are expected to be long-lasting. In contrast, exogenous energy price shocks are unexpected and uncertain and are either the result of shocks, for example, geopolitical, technological, or climate-related shocks, or result from supply- or demand-driven market dynamics.

1.3. Firm-Level Response Mechanisms to Policy-Induced Energy Price Changes

Research on the firm-level impacts of energy price increases identifies four main response mechanisms. Firms typically respond to policy-induced energy price changes by (1) passing the price on to customers, (2) absorbing the price increases, (3) substituting inputs, or (4) using firm-level capacities that drive innovation and possibly productivity (figure 1.1).

The choice of firm-level adjustment mechanisms is also affected by firm-specific, sectoral, institutional, financial, or macroeconomic considerations (André et al.

FIGURE 1.1

Firm-Level Response Framework

	Expected		Unexpected

	• Planned and certain
	• Policy based
	  • Price interventions and nonprice interventions
			• Unplanned and uncertain
			• Shocks with market-based effects (on supply or demand)
			  • For example, geopolitical, technological, climate-related

Conditions	Responses	Description	Metrics	
Firm and sector specific • Financial constraints • Available technology • Market power Government • Government support • Regulatory framework • Revenue recycling Global • Uncertainty • Supply chain disruptions • Global market conditions	**Pass-through**	Energy cost increases passed on to customer (household or firms), constrained by market structure, rigidities, price elasticities, and market adjustment mechanisms	• Responsiveness of firms' output prices to energy price changes • Firm-level metrics: Unit sales price, pass-through rates, other firm-level metrics (for example, exports, trade intensity, operational revenue)	Short run: No or limited adjustment to production
	Absorption	Energy cost increases absorbed by the firm if pass-through is not available; constrained by profitability	• Responsiveness of firms' financial metrics to energy price changes • Firm-level metrics: Profits, costs, employment and wages, firm exit, other firm-level metrics (for example, capital, production, export reduction, delayed investment, and others)	
	Substitution	Energy type substitution constrained by access to alternatives, supply, and technology	• Elasticities between input factors in response to energy price changes • Firm-level metrics: Substitution between input factors (capital, labor, energy) and interfuel substitution (substitution between fuel types)	Medium to long run: Adjustment to production
	Innovation and productivity	Weak Porter hypothesis: Process and product innovation.	• Innovation-related firm activity in response to energy price changes • Firm-level metrics: Investment (capital formation, information and communication technology, vehicles, buildings, and so on), research (foreign direct investment, research and development, patents, and others)	

		Strong Porter hypothesis:
		Impact on productivity and profitability
			• Productivity-related firm outcome in response to energy price changes and investment activity
			• Firm-level metrics:
			  • Direct: Value-added or output per worker, total factor productivity, and others
			  • Indirect: Return on investment, profit, revenue, market and export share, production volume, employment, turnover, and others	

Source: Authors' elaboration.
Note: The framework presented in figure 1.1 draws from previous concepts by Ambec et al. (2013), André et al. (2023), Coste et al. (2018), Dechezleprêtre and Sato (2020), and Rentschler, Kornejew, and Bazilian (2017) and describes the various transmission channels of energy price changes stemming from planned price interventions, which may or may not be accompanied by nonprice interventions.

2023). For example, the regulatory framework and government support play a strong role in how firms navigate policy-induced energy price changes. In fact, energy subsidy reforms are often accompanied by nonprice interventions, for example, government support schemes to modernize infrastructure. For instance, in Oman, assistance programs were implemented to help small and medium industrial enterprises improve their energy efficiency and sustainability and adopt information and communications technology activities, offering investment support for the digital economy (Amann et al. 2021). Furthermore, firms' investment strategies are strongly dependent on the global macroeconomic outlook (Cashin et al. 2014), uncertainty (Phan, Tran, and Nguyen 2019), or financing constraints (Levine et al. 2018).

It is important to highlight that a firm can deploy multiple actions simultaneously. For example, a firm's gross profit increases may be driven by pass-through (if the firm under consideration has sufficient market power) or could be the positive and significant impact on productivity resulting from the firm's process and production innovation. Furthermore, a firm's response strategy may evolve and be continuously affected by further changes in price and nonprice policies and structural and macroeconomic factors.

At the same time, some potential response mechanisms may be more immediate than others. For example, changing the mix of inputs or energy carriers used in a production process may require some upfront investment, such as the purchase and installation of more efficient machinery, whereas increasing sales prices proportional to the increase in energy costs is an action that can be taken more immediately.

Identifying which specific response is deployed by a firm as a result of energy price increases and assessing its impact can be challenging because of the absence of "perfect" metrics that can be directly attributable to each response, as well as by measurement issues with existing indicators. For example, when seeking to understand energy price increase impacts on productivity and innovation, Hille and Möbius (2019b) emphasize the importance of controlling for the potential endogeneity of environment- and energy-related policy reforms. Countries experiencing changes in productivity trends may react by changing policy rather than policy change driving productivity. Moreover, firms at the forefront of technology may support stricter regulations for strategic reasons. Similarly, recent firm-level studies address concerns regarding endogeneity stemming from omitted-variable bias or simultaneity. Although the concern over time-invariant unobservable characteristics is typically addressed via panel fixed effects estimation, time-varying unobservables and simultaneity remain, and researchers have resorted to different types of spatial (for example, Calì et al. 2022), shift-share (Marin and Vona 2021), or eligibility (Martin, de Preux, and Wagner 2014) instrumental variable designs. In other instances, difference-in-differences (Wagner et al. 2014), synthetic control analysis (Arcila and Baker 2022), or different types of regression discontinuity designs and semiparametric matching (Liu and Pan 2024; Wagner and Petrick 2014) have been used for causal identification.

A comprehensive analysis and identification of the individual mechanisms requires careful consideration of all of the different channels. Otherwise, ambiguity in the understanding of the various firm-level responses may arise as a consequence of selective analysis. A comprehensive analysis can only be achieved with rich firm-level microdata and may warrant exploiting novel data sources and methodologies to capture these nuances and provide valuable insights into how firms navigate energy price fluctuations and uncover previously hidden vulnerabilities.

1.3.1. Pass-Through

One of the most expedient ways for firms to respond to energy input price surges is by increasing the sales price of their output proportionally to the energy price increase, thus passing the cost increases on to their customers. Depending on the position of the firm in the production chain, these cost increases can either be passed on to households or to other firms. The degree to which firms can pass energy price increases on to their customers depends on market structure, domestic and foreign competition, and the price elasticity of the sold product (Joltreau and Sommerfeld 2019). Firms may also be in a position to generate profits on top of abating emissions, depending on the market structure (Sijm, Chen, and Hobbs 2012), competition (Alexeeva-Talebi 2010), and the existence of price rigidity as well as demand, supply, and markup adjustments (Fabra and Reguant 2014). Depending on these variables, the energy cost increases may be entirely passed on to households, either directly or through production chains, potentially resulting in notable welfare impacts either domestically or abroad, depending on the type of production network. In the most extreme case, complete pass-through can result in welfare loss with no positive environmental impact at all. Consequently, the pass-through mechanism requires careful consideration and needs to account for specific market conditions, which should be evaluated on a case-by-case basis. It is important to note that the cost pass-through mechanism may bring with it potential welfare implications. Furthermore, the effect may also be exported to other countries via supply chain links, thereby potentially affecting nondomestic households.

Although cost pass-through is typically measured as the change in the unit sales price following an energy price increase, such detailed information may not be readily available in firm-level data sets. This lack of data, in turn, would make it difficult to identify this transmission channel clearly. Moreover, supply chains and production networks are typically identified at the more aggregated sector level, for example, by means of multiregional input-output tables or computable general equilibrium models. Although these are powerful tools, particularly for policy analysis of aggregate effects, they may suffer from aggregation bias, and the underlying modeling assumptions may not lend themselves to a granular analysis of heterogeneity aspects of response dynamics. Consequently, although the pass-through mechanism is of socioeconomic concern and can carry important welfare implications, its quantification may be plagued by measurement and identification challenges.

1.3.2. Absorption

Another response mechanism immediately available to the firm is the absorption of the higher costs resulting from the energy price increase. Similar to cost pass-through, absorption does not require any changes in a firm's production process. If firms decide to absorb the costs of the energy price increases, like pass-through, firms can

practically maintain production with no changes in the utilization rate of (now more expensive) energy. As such, this channel may also be counterproductive to the intention of the policy maker if the goal of the price change is to encourage energy conservation.

Financial cost absorption may be a viable response for firms, but only for solvent firms and in the shorter run. Firms may also respond to cost increases by downsizing (Datta et al. 2010). More extensive or prolonged spells of low firm-level solvency may also yield notable changes in sector composition and can drive firm exit, for example, given that smaller and less profitable firms or firms in particularly energy-intensive sectors may be more likely to exit the market. Furthermore, household welfare loss may be possible because of potential job loss. Such socioeconomic impacts may be particularly pronounced at the regional level, especially if regional economic activity is concentrated in a few energy-intensive industries (Vona 2019). Thus, the result of absorption-related firm responses is closely linked to firm-level employment.

An additional impact channel on employment is through substitution between input factors, for example, replacing energy with labor or capital. Such substitution requires some degree of flexibility and the technical feasibility to switch and may not necessarily be possible in the short run. Consequently, substitutability between broader input factors, that is, energy, labor, and capital, also informs the discussion on the effects of substitution and innovation and productivity. To avoid ambiguity in the understanding of the various firm-level responses that may arise as a consequence of selective analysis, a comprehensive analysis and identification of the individual mechanisms requires careful consideration of all of the different channels.

Absorption is typically measured by considering marginal costs as well as profit losses and related indicators. For example, return on sales measures a firm's profitability by dividing net income by total sales and can be used as an alternative dependent variable (Lo, Yeung, and Cheng 2012). Conceptually, absorption may also be reflected as a reduction in capital, lower production, or delayed investment decisions and may be difficult to measure with annual data, particularly if the changes in investment strategies change within one financial year.

Changes in employment is the typical variable capturing a firm's capacity to absorb absolute and relative (compared with other production inputs) labor cost increases (Evangelista and Vezzani 2012) and indicates the potential substitution of capital for labor through technical progress (Rowthorn 1999). Furthermore, employment loss is tied to firm exit, and higher job replacement is associated with higher earnings losses (Alba-Ramírez. Arranz, and Muñoz-Bullón 2007; Jacobson, LaLonde, and Sullivan 1993). Finally, the potential employment effects of environmental policies have been found to affect countries differently (Markandya et al. 2016).

1.3.3. Substitution

When a production input becomes more expensive, a straightforward solution is to replace it with the most similar, and cheaper, input. If inputs are perfectly substitutable, the firm's adjustment cost is minimal. In the context of substituting energy sources, some energy resources may be more easily replaced by others, such as petroleum-based diesel with biodiesel. Other types of substitution are more complex and expensive, for example, the replacement of coal turbines with gas-powered ones (Carapellucci and Giordano, 2015) or switching boilers and fuel for supplying process heat. Interfuel substitution, in which one fossil fuel is replaced by another fuel, is rather hard to quantify and determine through firm-level data, and as such, empirical evidence is relatively scarce in the existing literature (Stern 2012). In turn, a broader substitution mechanism, in which energy is replaced by other production inputs, such as labor or capital, is explored and identified in the field.

The main preconditions for the different substitution mechanisms are the availability of alternatives, some degree of flexibility in the production process, and financial resources to enable the change. For successful substitution of energy inputs, alternative energy sources and the necessary technology and supply are required. However, most energy substitution requires some adaptation of the production process and may, therefore, require firm-level capacity utilization in the form of investment. Substitution may only be a salient response mechanism if firms have the financial space for investing and are more likely to be implementing medium- to long-term strategies. Similarly, replacing energy with labor or capital may be a more long-term strategy of the firm compared with short-term fuel switching, particularly between largely interchangeable inputs (Haller and Hyland 2014; Rentschler and Kornejew 2018). Interfuel substitution can be measured by considering the combined effect of changes in energy consumed in response to different energy price changes, various forms of cross-price elasticities, and changes in production functions. The latter two approaches are also commonly used in the literature to quantify the substitution of broader production inputs, such as labor, for energy (Acemoglu et al. 2012).

1.3.4. Innovation and Productivity

A response mechanism that requires notable investment is the case in which firms respond to energy price increases by innovation and productivity improvement resulting from capital upgrades. Under this response mechanism, policy-induced energy price increases result in cost increases that lead to investment in production and process technology so that firms become more efficient in the utilization of the more expensive energy input. A well-established framework related to this mechanism is the Porter hypothesis (Porter 1991; Porter and Van der Linde 1995).[6] The "weak" Porter hypothesis suggests

6. See Ambec et al. (2013) and Cohen and Tubb (2018) on a meta-analysis of the literature as well as Jaffe and Palmer (1997) for a discussion of the different variants of the Porter hypothesis in the literature.

that government intervention, particularly taxes and market-based incentives, may spur innovation. Under the ”strong” version of the Porter hypothesis, environmental regulations would be expected to lead to further increases in firm competitiveness, which translates into higher productivity outcomes and profitability. Accordingly, increases in firms’ productivity are the result of reaping the economic benefits underpinning the adoption of modern and more efficient technologies.

Multiple firm-level metrics are used to identify innovation and productivity responses by firms triggered by policy-induced energy price increases. The weak form of the Porter hypothesis is generally identified and assessed by looking at direct or indirect investment-related economic activity, such as capital upgrading, research and development (R&D) expenditures, foreign direct investment engagement, investment in technology-related fields such as information and communications technology, as well as the number of research staff or potential patent claims. Innovation and productivity responses can also be identified via corporate strategies, such as joint ventures; technology licensing, particularly of more advanced and foreign firms; or training-related activity for employees. On the other hand, the literature assesses the strong version of the Porter hypothesis through direct, productivity-related metrics such as value-added per worker or total factor productivity, or induced outcomes, such as production volume, market or export shares, employment, or profit in response to firm-level investment.

TWO

A Summary of the Literature

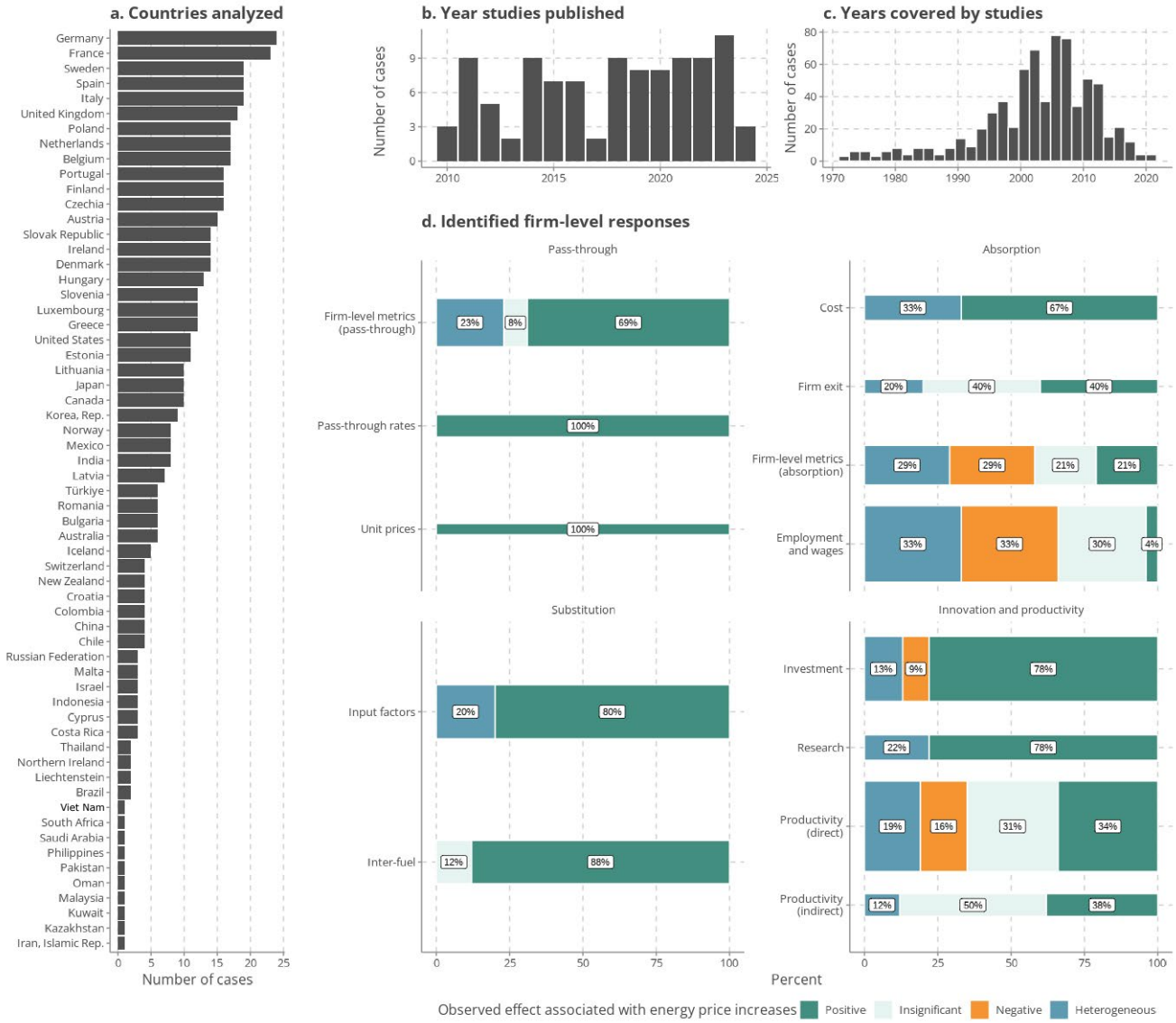
Empirical identification of the magnitude and causal direction of firm-level dynamics, impacts of price increases, and response mechanisms remains an open question in ongoing research. This review follows the framework introduced in figure 1.1 and organizes the literature along the four response strategies.

To deepen the understanding of available research and evidence about the effect of energy price changes on firms, this review explores recent literature analyzing input prices using firm-level microdata in different contexts. The review aims to identify and distill emerging evidence about how energy price increases affect firms. The review focuses on empirical, firm-level studies in developing and developed countries published after 2010. Relevant articles were identified through targeted keyword searches on Scopus, Web of Science, and Google Scholar, focusing on peer-reviewed work and well-established working paper series published after 2010 with an empirical, typically firm-level, foundation. This review surveys about 100 papers covering more than 60 countries, with the majority of papers written after 2018 covering the period between 2000 and 2021 (figure 2.1).

Summarizing the observed metrics by response patterns, the absorption and innovation and productivity response mechanisms have been studied extensively, with most studies finding a positive association with investment and research metrics or either positive or insignificant effects on productivity. The results on absorption metrics remain more ambiguous, particularly with regard to employment and wage effects. Although the substitution response channel remains less frequently studied, overwhelming evidence hints at the general substitutability of broader input factors. Pass-through, in turn, is mainly observed through different firm-level metrics because of the generally limited availability of unit price information regarding firm output.

FIGURE 2.1

Scope and Coverage of Review



Source: Authors' elaboration.
Note: Bar segment width: Frequency of observed metrics in surveyed articles across all response mechanisms. Labels: Share of observed effect (positive and significant; insignificant; negative and significant; heterogeneous and significant) in surveyed articles by metric. Observed effects based on reported and discussed significant effects in surveyed articles. Heterogeneous effects identify subsample effects that go in opposite directions or impacts that vary over time.

2.1. Pass-Through

Summary of the pass-through response. Numerous studies find significant cost pass-through from firms to the consumer, which suggests that under certain circumstances, firms only bear part of the cost increases from energy price reforms. The literature identifies cost pass-through in sector-, firm-, and commodity-level analysis and also finds evidence of sectoral and production chain linkages. Identifying cost pass-through requires information that is often not contained in typical official firm-level microdata, thereby introducing notable ambiguity in linking to capacity-related response patterns, particularly in the context of developing economies.

Cost pass-through can generally be identified by analyzing unit sales prices of firms in response to an energy price hike; however, such information may not readily be available in firm-level surveys. This complication may result in notable ambiguity, blurring the link to capacity-related response patterns. For example, while Wagner and Petrick (2014) find that German firms that were subject to the European Union (EU) Emissions Trading System (ETS) vastly reduced their carbon emissions by switching from high-carbon fuels to low-carbon fuels, their findings also suggest that ETS regulations caused an overall increase in total exports of between 6 and 18 percent between phases I and II of the ETS. As the authors state, given the data availability, it is unclear whether the increase in exports reflects an increase in the volume of shipments, a price increase, or both. In the absence of unit sales price information, other performance-related indicators, such as revenue increases, may be driven by pass-through, may be linked to innovation and efficiency improvements, or may be the result of shifting market dynamics, where firm exits increase the market power of surveyed firms, which then increase their profit margins. For example, Martin et al. (2014) use trade intensity as a proxy measure to quantify the extent to which UK manufacturing firms can pass on the cost of the Climate Change Levy to their customers, for which they find little evidence.[7] Conversely, Marin, Marino, and Pellegrin (2018) find significant increases in markups of firms under the EU ETS scheme. These findings align with Demailly and Quirion (2008), who predict a notable pass-through of EU ETS costs for the iron and steel manufacturing sectors through a theoretical model.

Recent research identifies substantial cost pass-through at the firm level. Ganapati et al. (2016) illustrate that US firms in selected manufacturing industries passed on much of the energy price increases resulting from climate policies to final customers. Using data from the US Census of Manufacturers, they analyze the effects on about 5,000 single-product plants across six industries between 1972 and 1997. The authors emphasize that the

7. Trade intensity is calculated as the value of imports and exports to non-EU countries over the total market size within the EU27 and taken from the Impact Assessment accompanying the "Commission Decision determining a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage pursuant to Article 10a (13) of Directive 2003/87/EC," of September 4, 2009. NACE is the statistical classification system of economic activities in the European Union. As Martin et al. (2014) argue, firm-level trade intensity measures the degree of competition from nonregulated countries and picks up the inability of firms to pass on the cost of the Climate Change Levy to their customers, and this measure has also been used by the EU Commission to measure the impact the EU ETS has on firms in manufacturing.

magnitude of cost pass-through in the event of an energy price shock largely depends on the market's competitiveness. Similarly, Dechezleprêtre, Nachtigall, and Venmans (2018) analyze the effects of the EU ETS for a sample of European economies and illustrate that their findings are compatible with the notion that firms in the electricity and heat sector can pass at least part of the energy price increases on to their customers. Furthermore, the authors report that the impact on profit depends on firm size across countries covered by the EU ETS. They illustrate that smaller firms did not experience statistically significant changes in their profits but did experience statistically significant decreases in their return on assets. The authors argue that this finding is compatible with the ability of larger firms to pass through the costs of carbon emissions on to their customers and lower carbon abatement costs. In the same vein, Chan, Li, and Zhang (2013) analyze a panel of more than 5,800 firms in the power, cement, and iron and steel sectors across 10 European economies between 2001 and 2009. The authors find that only the power sector experienced a significant increase in material costs and revenues, which may be indicative of at least a partial cost pass-through.

Sector- and commodity-level data also offer solid empirical evidence on pass-through. Focusing the analysis on specific manufacturing sectors and energy price impacts associated with specific climate policies, numerous studies have found evidence supporting the pass-through mechanism, for example, in a national multisector setting for Germany (Alexeeva-Talebi 2010). The author finds that when local German companies dominate diverse product markets, they have more power to pass on the input price increases. Alexeeva-Talebi (2011) analyzes cost pass-through by European refineries and illustrates that oil price and exchange rate increases are found to increase euro-95 gasoline prices, and that gasoline prices are inelastic with respect to carbon prices in the long run. Similarly, Kirat and Ahamada (2011) investigate pass-through rates of power producers in France and Germany and find that a substantial part of electricity price volatility in both countries before 2007 can be explained by ETS emissions allowance price changes. In the same vein, Fabra and Reguant (2014) analyze pass-through of emissions costs to wholesale electricity prices in Spain between 2004 and 2006, thereby covering the first phase of the EU ETS. The authors find that emissions costs are almost completely passed through to electricity prices.

Other studies look at isolated commodity cases. Oberndorfer, Alexeeva-Talebi, and Löschel (2010) quantify the cost pass-through of certain refinery, glass, chemicals, and ceramics commodities in the UK using weekly price data. The authors find that upstream producers and retailers have at least partly passed carbon costs on to diesel and gasoline consumers. De Bruyn et al. (2010) confirm the existence of this transmission channel at the commodity level within the aluminum, iron and steel, cement, refineries, and petrochemicals sectors for a broad set of advanced economies and illustrate that in particular cases, such as the refineries in Europe, pass-through rates as high as 100 percent can be observed (Arlinghaus 2015).

There is evidence of intersectoral linkages and notable dispersion of energy price increases along the value chain. Cost increases may also result in notable knock-on effects across industries and transmittable spillovers through firm-level linkages. Using a

computable general equilibrium model for China, Lin and Jiang (2011) demonstrate that energy price increases can lead to a contraction in energy-intensive industries while simultaneously raising input prices for other industries, thereby affecting downstream sectors. Naturally, intersectoral linkages may be country and sector specific, and successful adaptation strategies depend on cross-national technology transfers: Chan, Manderson, and Zhang (2017) analyze the effect of aggregate energy costs on export performance while including indirect energy costs. Using panel data for 10 manufacturing sectors in 43 countries from 1991 to 2012, the authors find that intermediate factor intensities and trade relationships significantly influence how energy shocks affect export prices as indirect energy costs are passed through the upstream supply chain. The results show that energy price increases could extensively reduce net manufacturing exports across developing and developed economies. Kumar and Prabhakar (2020) study the impact of energy price increases and find that a 10 percent increase in energy prices is associated with a 1 percent drop in aggregate exports, with sector-level variation from 0.9 percent for chemicals to 1.4 percent for nonferrous metals.

Empirical evidence for developing countries remains scarce and results are diverse. In the context of Indonesia, Rentschler and Kornejew (2018) confirm that higher prices for all energy types are associated with higher long-run sales prices; that is, the firms pass on the energy costs to the consumer. However, this study analyzes a 2013 cross-section of small and micro firms (with 19 or fewer employees) for the mining and manufacturing sector, and therefore no conclusion on the general existence or magnitude of cost pass-through can be made. Analyzing the effects of electricity and fuel price increases on profits and unit output prices of micro and small firms in Mexico, Greve, Lay, and Negrete (2023) use cross-sectional data on both formal and informal firms and present evidence of cost pass-through.

2.2. Absorption

Summary of the absorption response. Recent research finds that energy price increases trigger different absorption channels and that firms' ability to absorb and likelihood of absorbing price increases vary depending on their characteristics and sectoral attributes. Unsurprisingly, firms in energy-intensive sectors in particular respond most notably to price increases. A firm's choice to absorb some or all of the impact of energy price increases can be reflected in key indicators of profitability and employment. Overall, recent research does not offer conclusive evidence of firm exit or significant aggregate employment loss as a result of the absorption response to energy price increases. However, the evidence does point to potential impacts on profitability and within-sector labor reallocation, underscoring the importance of implementing sensitive policy measures.

Firms' tendency to absorb policy-induced energy price increases varies depending on their characteristics and sectoral attributes and can be identified through different metrics. The extent to which a firm has absorbed an energy input price increase can be measured by looking into financial loss and cost-related metrics. Moreover, changes in marginal costs, where data are available, can offer insights into how the firm responds.

Financial cost absorption can serve as a feasible strategy for companies, but it is crucial to note its applicability primarily to financially stable firms, and usually in the short term. However, sustained periods of low solvency among firms could bring about significant shifts in sector dynamics, leading to the departure of smaller, less lucrative businesses or those operating in highly energy-intensive sectors. Furthermore, firms may respond to cost increases by means of downsizing (Datta et al. 2010). Consequently, absorption-related responses by firms are closely intertwined with firm-level employment.[8] Changes in employment and wages also carry socioeconomic weight and indicate potential within-firm and within-sector reallocation and job replacement.

Cross-country studies highlight potential heterogeneities in absorption metrics. For example, with regard to employment impacts, Dechezleprêtre, Nachtigall, and Venmans (2018) report no adverse effect on employment from energy price increases when comparing the metrics of regulated (that is, subject to the ETS) and unregulated firms in the EU ETS. They find the employment effects across all sectors to be positive and insignificant, except for the basic metals and electricity and heat sectors, which both report positive and significant employment effects. In a cross-country European study, Abrell, Ndoye Faye, and Zachmann (2011) find that the EU ETS did not result in any significant aggregate employment effect but do find negative employment effects in the nonmetallic minerals sector. Further evidence of the effect of energy price increases on employment can be found in Hille and Möbius (2019a). Using a macro-level panel on 33 primary, secondary, and tertiary sectors in 27 Organisation for Economic Co-operation and Development (OECD) countries from 1996 to 2009, the authors find that rising energy prices have no significant effect on net employment across manufacturing sectors. Finally, the research indicates that the employment effect becomes positive and significant once all economic sectors are considered. Furthermore, the authors point out potential heterogeneities across countries and that regulations are likely to result in job reallocation with positive macroeconomic effects but require support for certain firms or members of the workforce.

- Using panel data for 10 European countries during 2001–09, Chan, Li, and Zhang (2013) analyze the impacts of the ETS on the three most polluting industries covered under the program, that is, power, cement, and iron and steel. The authors report no significant effect on material costs, employment, or revenue in the cement and iron and steel industries, yet a significant impact on both material costs and revenue but not employment in the power sector. Conversely, Ganapati et al. (2016) records a significant impact

8. Moreover, another factor affecting employment is the substitution between input factors, such as substituting labor for energy. However, this substitution relies on having a certain level of flexibility and technical feasibility, which may not be readily available in the short term. Thus, the interchangeability among broader input factors—energy, labor, and capital—plays a crucial role in discussions surrounding substitution as well as innovation and productivity effects.

of energy price increases on marginal costs for US manufacturing firms. Covering 19 EU countries over the period 2006 to 2014 and the three phases of the EU ETS, Makridou, Doumpos, and Galariotis (2019) find little evidence that the scheme affected firm-level profitability.

- Similar evidence has also been found in single-country studies: Dussaux (2020) explores the effect of energy price changes on output, investment, and employment in the French manufacturing sector and further focuses on identifying heterogeneous response patterns based on firm size. The author finds a direct causal link between energy price variations and energy use, as well as evidence of a shift in market shares and workers from energy-intensive to energy-efficient firms. However, the overall effect of energy price variations on output and investment was not statistically significant. The study also finds notable differences in the impact of energy prices depending on firm size. In response to the same price change, large firms reduced their output while medium-sized firms did not. Surprisingly, small firms actually increased their output. One possible takeaway is that different optimal responses to energy price changes apply to firms depending on their market power.

Research does offer some evidence of challenges for workers with respect to within-sector (labor) reallocation. Looking at the French manufacturing sector, Dussaux (2020) observes that an increase in energy prices leads to a shift of production and employment to more energy-efficient firms, with no aggregate employment effect at the industry level overall. Increased energy costs do not appear to affect employment in small firms but reduces it marginally in medium-sized firms and more in large firms. The authors find that, in aggregate, employment gains for small firms and new entrants compensated for the employment loss recorded for larger and energy-intensive firms. Similarly, Marin and Vona (2021) find a modest impact of higher energy prices on employment but no effect on wages in the French manufacturing sector. The authors report evidence of capital deepening, skill-biased job replacements, and heterogeneous labor adjustment processes. Large establishments reported larger employment losses, whereas small firms experienced greater losses in wage rates. Dechezleprêtre, Nachtigall, and Stadler (2020) analyze the impact of energy prices and environmental stringency on manufacturing employment using manufacturing sector-level data across OECD countries between 2000 and 2014. The authors find a significant and negative effect of energy price increases on manufacturing employment, particularly for energy-intensive sectors. Additionally, in this analysis, energy price increases are found to be associated with an increase in firm exits.[9] The authors also report substantial evidence pointing at worker reallocation within manufacturing as firms that remain operational experience a slight increase in overall employment. However, this hiring among the surviving businesses does not offset the overall negative effect on employment.

9. These results are at odds with the findings in Hille and Möbius (2019a) and are at least partially explained by the different empirical modeling choices; see footnote 8 in Dechezleprêtre, Nachtigall, and Stadler (2020) for a more extensive discussion. Furthermore, only Dechezleprêtre, Nachtigall, and Stadler (2020) employ additional firm-level data to analyze firm exit. Hille and Möbius (2019a) do not conduct a similar firm-level analysis.

- Drawing on administrative labor market data from Germany and focusing on instances of mass layoffs, Barreto, Grundke, and Krill (2023) analyze the financial impact of involuntary job displacement on workers in high-carbon-intensity sectors, contrasting it with the effects on those in low-carbon-intensity sectors. They find that individuals displaced from high-carbon-intensity sectors typically experience more substantial earnings declines and encounter greater difficulty in securing new employment and regaining their previous earnings levels. These outcomes are primarily attributed to the specificity of workers' human capital, the concentration of carbon-intensive activities in certain regions, and the premium wages offered by firms in such sectors. Displaced workers from high-carbon-intensity sectors tend to be older, face heightened local labor market saturation, and have fewer alternative employment opportunities that match their skill sets. Notably, according to the paper, women, older workers, individuals with vocational qualifications, and those residing in eastern Germany tended to bear particularly high costs when displaced from high-carbon-intensity sectors. Comparable impacts have also been identified by Haywood, Janser, and Koch (2024) and have been similarly discussed in the context of the UK coal industry (Rud et al. 2022) and the US (Hanson 2023; Walker 2013). The research indicates that the economic effects of job losses may warrant particular political consideration given their potential regional and sector-specific concentration (Vona 2019).

Overall, research does not offer conclusive evidence that policy-induced changes and energy price increases lead to negative impacts on employment. For example, using German firm-level manufacturing data, Wagner and Petrick (2014) find that while German firms covered by the EU ETS vastly reduced their carbon emissions by switching from high-carbon fuels to low-carbon fuels, they did not do so at the expense of employment, which is confirmed in Flues and Lutz (2015). Similarly, Martin, de Preux, and Wagner (2014) illustrate that the UK carbon tax did not affect either employment or plant exit for the UK. Furthermore, Wagner et al. (2014) do not find notable effects on employment during phase I of the ETS but significant employment losses during phase II in French manufacturing firms, whereas the evidence of other emissions-reallocation strategies, such as within-firm or between-market carbon leakage, remains inconclusive. Using a synthetic control analysis between 1998 and 2017 and province-sector-level data, Arcila and Baker (2022) show that the carbon tax policy in the Canadian province of British Columbia is associated with more stagnant employment growth compared with the synthetic control group. Meta studies lend further support to these findings. For example, Arlinghaus (2015), summarizing work on the effectiveness of the EU ETS, finds little evidence of profit reduction but does find some employment effects, likely driven by the nonmetallic minerals sector. Similarly, Ellis, Nachtigall, and Venmans (2019) find little evidence of a negative employment effect in response to carbon prices:[10] out of the nine reviewed studies, only Marin, Marino, and Pellegrin (2018) provide evidence of a negative and significant employment effect during phase I of the EU ETS scheme.

Although most of the research focuses on OECD countries, research on developing countries points to similar dynamics and pronounced sector-level differences. The

10. The studies are either pan-European or focus on high-income economies such as Canada, France, Germany, Italy, or the UK.

work by Rentschler and Kornejew (2018) is among the few studies that consider the impact of a variety of energy sources on firm-level outcomes in developing country contexts. In a cross-section study on Indonesian micro and small manufacturing firms, their analysis indicates that higher energy prices are associated with higher long-run unit costs for all types of energy carriers and sectors. Furthermore, the analysis also finds that firm-level responses differ substantially between sectors. Increasing prices of certain energy carriers is likely to have disproportionately large effects on specific sectors. This outcome may be due to their production processes' inherent technological characteristics, which determine their ability to implement response measures. Looking at the economic performance of Indonesian manufacturing plants in response to an increase in energy prices, Brucal and Dechezleprêtre (2021) report that energy price increases are causally linked to upticks in plant exit and employment contraction, but only for energy-intensive and large firms.[11] The authors also report job reallocation from energy-intensive to energy-efficient firms and sectors. Although the employment bases in most sectors were not found to contract in response to an energy price increase, significant effects were reported for the Indonesian food and basic metal sectors.

- As an example of the variation in responses across energy carriers, in the case of Mexican micro and small enterprises, Greve, Lay, and Negrete (2023) find sizable potential effects in the short term, during which fuel price changes have a more pronounced impact than electricity price changes. The impact varies across sectors and also depends on the firm's status—formal firms are generally more vulnerable to energy price changes because they have a higher share of energy costs in their production. These results indicate immediate transitional risks for abrupt price changes, especially for energy-using low-profit firms. In contrast to the previously mentioned studies, in a firm-level analysis of the Chilean[12] manufacturing sector between 1995 and 2015, Amann and Grover (2023) find that fossil fuel price increases are not associated with decreases in employment or wages. The paper finds other response mechanisms at play, given that the data show that firms do respond to fuel price increases by absorbing part of the costs, as suggested by a reduction in profit margins and cost increases. On the other hand, electricity price increases are found to negatively affect employment and drive down profit margins. Singer (2024) analyzes the firm-level impact of electricity and coal price changes on manufacturing firms in India between 1998 and 2013 and finds that lower electricity prices reduce marginal costs and improve both labor and electricity productivity.

- Using sector-level data between 2009 and 2013 to analyze the 2010 energy subsidy reforms in the Islamic Republic of Iran, Zarepour and Wagner (2023) find a notable decrease in posted profits and an increase in direct energy costs. The authors also report a significant increase in pass-through of costs following cost increases in upstream firms. Finally, using World Bank Enterprise Survey data, Calì et al. (2023) analyze firms' economic performance in response to energy price increases for

11. See Brucal and Dechezleprêtre (2021, table 2). The impact is not significant for less energy-intensive plants and is positive for small plants.
12. Following the historic World Bank Country and Lending Groups classification, Chile was an upper-middle-income country at the beginning of the sample period in 1995 and became a high-income country in 2012.

11 developing countries from 2002 to 2013. The authors do not find statistical evidence that price increases lead to employment loss. Furthermore, they find that energy-intensive firms are more responsive in how they navigate energy price changes—in particular, large and export-oriented firms navigate energy price hikes better, whereas domestically owned firms remain more vulnerable. Finally, firms with experience in dealing with electricity outages are less sensitive to price increases.

In summary, there is mixed evidence on the firm-level impacts of energy price increases on employment outcomes in developing countries. Apparent heterogeneity across countries, sectors, and firm characteristics, along with policy design and accompanying policies, may affect the ultimate position. This is an area that merits further data collection and analysis.

2.3. Substitution

Summary of the substitution response. The literature finds strong evidence of input substitution between broader input types, particularly between energy and labor, and between energy types. Data on different types of energy inputs of firms are needed to analyze interfuel substitution, but these data are not a common feature of firm-level data sets. Consequently, empirical evidence on this response mechanism remains relatively scarce. However, the overall picture emerging from the literature suggests that substitution across production inputs occurs widely, although the extent of substitution varies depending on the country and policy context, hinting at the role of heterogeneous production technology. In particular, the literature identifies notable differences in the substitutability of different fossil fuels (especially between coal and gas), as well as between fuels and electricity.

Empirical evidence demonstrates substitutability between energy and other production factors as well as interfuel substitution, notwithstanding sector and country differences. In a meta-analysis of 47 studies on interfuel substitution, Stern (2012) confirms the existence of substitution possibilities between fossil fuels and electricity, and posits that such replacements appear more constrained at the macro level than they are when zooming into lower levels of data aggregation. The author finds strong evidence for the possibility of substitution between electricity and fossil fuels for the manufacturing sector, which features the most extensive elasticities compared with either macro- or industry-level elasticities.

In particular, strong interfuel substitution by firms can be observed in response to the EU ETS, with an unambiguous decrease in the use of coal. Bretschger and Jo (2021) evaluate the elasticity of substitution between labor and energy using French

manufacturing sector firm-level data for 11,000 firms between 1994 and 2015. Overall, the authors find strong complementarity between labor and energy. At the firm level, this relationship depends on the ability of a firm to alternate between the two input sources. Firms with limited substitution capacity propagate the negative employment effect of energy price increases. In turn, no such contractions are found in firms with a higher capability to alternate between the input factors. Dussaux (2020) confirms that higher energy costs lead to energy substitution for French firms. The results suggest that firms reduce their energy intensity by decreasing energy use relative to other inputs and reduce their carbon dioxide (CO_2) intensity by increasing electricity use instead of fossil fuel use. The author also finds that larger firms typically improve their environmental performance in response to higher energy costs (electricity and fossil fuels). In line with other work, Bardazzi, Oropallo, and Pazienza (2015) investigate how Italian manufacturing firms react to energy price changes and find extensive energy substitution capacity between different carriers such as gasoil, electricity, fuel oil, and natural gas. Furthermore, they identify an asymmetric relationship in the energy-labor substitution channel: it is easier for Italian manufacturing firms to substitute labor for energy in response to an increase in energy prices than to substitute energy for labor when labor costs increase. The authors argue that this is a reasonable result given labor regulations in Italy that restrict labor mobility, which is in line with results from earlier studies.[13] Wagner and Petrick (2014) show that the price incentives from the EU ETS caused German firms to vastly reduce their carbon emissions by switching from high-carbon to low-carbon fuels. Changes in the policy framework encouraged affected firms to abate one-fifth of their CO_2 emissions between 2007 and 2010. This reduction was achieved predominantly by improving energy efficiency and curbing the consumption of natural gas and petroleum products, but not electricity use. Similarly, Wagner et al. (2014) illustrate that the EU ETS emissions certificates led French manufacturing firms to substitute gas for coal and oil. As the authors show, this effect accounts for nearly 50 percent of the observed emissions reductions. In the same vein, Martin, de Preux, and Wagner (2014) find evidence of firms substituting labor for energy, but no statistical support for interfuel substitution.

In the context of developing countries, the degree to which different energy carriers can replace each other is still relatively unexplored. Rentschler and Kornejew (2018) show that Indonesian firms in the manufacturing and mining sectors respond to energy price increases by adjusting their energy mix, using less of the more expensive energy. Although a blend of other energy sources can be replaced by electricity, the degree to which different fossil fuels can serve as replacements for other fuels is a complex subject, indicating that varying fuels may be used at different stages of the production process—although liquefied petroleum gas and gasoline can be complementary, and diesel and kerosene can be used instead of other energy carriers for select end uses, gasoline can to be difficult to replace in certain contexts. Recent research indicates that increases in diesel

13. While overall estimates align, Haller and Hyland (2014) find that Irish manufacturing firms in energy-intensive sectors have lower technical substitution potential compared with Italian firms (Bardazzi, Oropallo, and Pazienza 2015). These differences may partly be explained by the different definitions of energy-intensive sectors (Bardazzi, Oropallo, and Pazienza 2015, footnote 32). Furthermore, Haller and Hyland (2014) find less asymmetric Morishima elasticities between capital and energy than Bardazzi, Oropallo, and Pazienza (2015). The authors argue that this result may be explained by the traditionally higher energy prices in Italy compared with other European economies, which has led Italian manufacturing firms to have already adjusted their capital stock to incorporate more energy-saving technologies.

and liquefied petroleum gas prices tend to have the most significant impacts on firm competitiveness, and sector-level differences are notable.[14] Amann et al. (2021) test for substitutability between electricity and fossil fuels for Omani manufacturing firms. However, the authors do not differentiate between various fossil fuels and only evaluate the substitutability of electricity and fossil fuels. They find a high degree of substitutability between the quantities of electricity and fossil fuels consumed by firms in response to increasing fuel prices. Regardless, a similar effect cannot be observed for electricity price increases for which no significant substitution can be reported. Looking at a 2012 cross-section of Mexican micro and small enterprises, Greve et al. (2023) find that firms react to energy price shocks by substituting labor for energy and self-employed firms increase their own labor input. In the context of Chilean manufacturing firms, Amann and Grover (2023) find strong evidence of replacement of fossil fuels with electricity in response to a fossil fuel price hike. Conversely, firms also respond very strongly to electricity or fossil fuel price increases by reducing consumption of the energy source experiencing a relative price increase.

To summarize, the extent of substitution remains a relatively unexplored topic. These topics can be further explored in the context of developing countries.

2.4. Innovation and Productivity

Summary of the innovation and productivity response. Recent literature finds robust evidence that policy-led energy price increases can lead to innovation and business upgrading, resulting in significant efficiency improvements. These findings align with the "weak" form of the Porter hypothesis, which suggests that policy spurs innovation. Support for the "strong" version, which suggests that policy will lead to increases in firm performance, is more ambiguous—the empirical literature finds that policy-induced price interventions do not always directly translate into productivity gains. Conversely, little evidence suggests that policy-induced energy price increases would have a negative effect on innovation and productivity. The literature also identifies managerial quality as a main driver of firm-level innovation dynamics and emphasizes sector-level heterogeneities in firm responses. Finally, firm-level responses to energy price increases are consistently found to vary by energy carrier—fossil fuel price increases are more often associated with pronounced innovation and productivity outcomes, whereas electricity price increases can be more detrimental to firms.

14. For example, kerosene is found to be relatively important for mining coal, lignite, and peat as well as in producing technical products (manufacturing of chemicals and chemical products; manufacturing of rubber and plastics products; manufacturing of other nonmetallic mineral products; manufacturing of basic metals; manufacturing of fabricated metal products; manufacturing of machinery and equipment; manufacturing of office, accounting, and computing machinery; manufacturing of medical, precision and optical instruments, and watches and clocks; manufacturing of radio and television and communication devices; manufacturing of other electrical machinery) and tobacco, but less relevant for other sectors.

The reviewed literature strongly supports the weak Porter hypothesis, wherein policy reforms spur innovation. However, the evidence for its strong version, in which policy reforms lead to increases in firm competitiveness, is more ambiguous.[15] The majority of ETS-related studies cover the first three phases of the EU ETS and consistently find that the largely identified reduction in fuel-related emissions is linked to innovation, while not necessarily being detrimental to the average economic performance of firms. A comprehensive review of the first 10 years of the EU ETS is provided in Martin, Muûls, and Wagner (2016).[16] The majority of the relevant studies, including Dechezleprêtre, Nachtigall, and Venmans (2018), Joltreau and Sommerfeld (2019), and Verde (2020) are aligned in their findings that the EU ETS contributed to a significant and positive impact on innovation. For example, Dechezleprêtre, Nachtigall, and Venmans (2018) analyze the effects of the EU ETS across all countries covered by the EU scheme and find support for the weak Porter hypothesis. Marin, Marino, and Pellegrin (2018) show that the EU ETS positively affects investment and labor productivity. Although the more recent phases of the ETS are less studied, analysis indicates that the further tightening has had no significant negative effect on firm performance (Bordignon and Gamannossi degl'Innocenti 2023), and firms' responses align with the Porter hypothesis (Boungou and Dufau 2024). In particular, Boungou and Dufau (2024) find consistently positive and significant R&D investment following the EU ETS phase IV announcement in 2016, with positive effects on productivity and output in 2019 and no significant effects in the previous years. However, the authors also find a borderline negative impact on employment for 2019—and no significant effect in the previous years.

Such findings are consistent with earlier studies[17] and ample empirical evidence from single- and cross-country cases. Wagner and Petrick (2014) find that German firms responded to the EU ETS regulation by reducing their carbon intensity through production and process innovation and not by reducing the scale of their production (as suggested by the absorption mechanism).[18] Furthermore, Flues and Lutz (2015) find that granting exemptions from electricity taxes to energy-intensive factories does not translate into improved performance outcomes based on a micro-level analysis of German manufacturing firms. Companies receiving the energy tax expenditures did not benefit from improved turnover, exports, value-added, investment, and employment results. Analyzing the German Community Innovation Survey 2008, Rexhäuser and Rammer (2014) posit that the strong version of the Porter hypothesis depends on the type of environmental innovation. More explicitly, only innovations that increase firms' input efficiency produce positive profitability outcomes.

15. For an extensive review of the links between environmental policy and innovation, see Popp (2019) and Popp, Newell, and Jaffe (2010, chapter 21).
16. The EU ETS was officially put in place in 2005 and has undergone four phases: During phase I (2005–07), almost all allowances were allocated free of costs, with phase 2 (2008–12) introducing a tighter allowance cap and noncompliance penalty. In phase 3 (2013–20), the allowance allocation moved to an auction scheme, while phase 4 (2021–28) sees a stronger reduction in annual allowances compared with previous years and phases.
17. Evidence from earlier work shows that energy price increases are a strong driver in explaining firms' proclivity to innovate (Popp 2002) and thus they are more likely to integrate technologies to improve energy efficiency (De Groot, Verhoef, and Nijkamp 2001).
18. Similar results of no significant negative effect of the EU ETS on output and productivity were found in related work. In particular, while Löschel, Lutz, and Managi (2019) report a significant increase in economic performance in regulated firms, particularly in the paper industry, Lutz (2016) reports a positive and significant productivity effect.

- Similar positive results for emissions reduction can be observed in China (Filippini et al. 2020; Zhang and Kong 2022), France (Wagner et al. 2014), Lithuania (Jaraite-Kažukauske and Maria 2016), Norway (Klemetsen, Rosendahl, and Jakobsen 2020), Sweden (Lundgren et al. 2015), the United Kingdom (Martin, de Preux, and Wagner 2014), and the Canadian province of British Columbia (Ahmadi, Yamazaki, and Kabore 2022; Yamazaki 2022). Although data limitations prevented Wagner et al. (2014) from evaluating the impact on carbon intensity (emissions divided by output), Klemetsen, Rosendahl, and Jakobsen (2020) report a significant and positive effect on value-added and productivity. Conversely, Jaraite-Kažukauske and Maria (2016) find evidence of modest capital upgrading and improved CO_2 intensity but fail to report positive impacts on firm-level profitability. Martin, de Preux, and Wagner (2014) analyze the impact of the Climate Change Levy in the UK on domestic manufacturing plants using production census data. While the authors report that the price reform significantly reduced energy intensity and use, it did not negatively affect firm performance, including gross output or productivity. Lundgren et al. (2015) analyze the impact of the Swedish CO_2 tax and the EU ETS on Swedish firms in the pulp and paper sector. The authors find that fossil fuel price hikes encourage firm-level technology development. Yamazaki (2022) examines the effect of a revenue-neutral carbon tax in British Columbia using confidential microdata. The author reports a significant reduction of productivity as a result of taxing energy purchases, which is partially offset by a significant positive revenue-recycling effect on firm-level productivity; however, the overall net effect remains negative. In a closely related study on the same tax policy, Ahmadi, Yamazaki, and Kabore (2022) extend the analysis to output and emissions intensity responses.

- Broadening the scope to a more heterogeneous group of countries, Ellis, Nachtigall, and Venmans (2019) review empirical work on the impact of carbon pricing on competitiveness in the OECD and Group of 20 countries for the electricity and industrial sectors. The authors find positive and significant innovation responses across the vast majority of surveyed papers. Similarly, positive or insignificant effects are observed for other firm fundamentals, including turnover, employment, productivity, or profit. Analyzing data from 14 manufacturing sectors across 28 OECD countries between 1995 and 2009, Hille and Möbius (2019b) find that policies do lead to innovation but not necessarily to increases in productivity, supporting the weak version of the Porter hypothesis.

Contrary evidence highlights alternative response mechanisms and the role of country- and time-specific effects. Yoon and Ratti (2011) quantify the effect of energy price rises on the investment decisions of firms in the US manufacturing industry, indicating that energy price stability helps consolidate firm-level investment. Drawing from more than 1 million plant observations between 1972 and 1993, Greenstone, List, and Syverson (2012) find that although stricter air quality regulations are typically associated with a drop in productivity, carbon regulations positively affect firm-level productivity.

- Sadath and Acharya (2015) evaluate how price variation affected the investment decisions of a sample of more than 6,000 manufacturing firms in India between 1993 and 2003. Their findings suggest that higher energy prices caused a decline in the firms'

investment expenditure because of an income effect (that is, the pass-through of increased costs to consumers generates a decrease in final output demand) and the inability to respond adequately to the increased marginal cost of production. Market structure, demand elasticity, and the evolution of market willingness to pay are essential factors concerning energy price increases.

- Abeberese (2017) provides further evidence on Indian manufacturing firms and presents evidence of how electricity prices affect firm-level productivity. Based on data from the Indian Annual Survey of Industries between 2001 and 2008, the author finds that price increases cause firms to switch to less electricity-intensive production processes, become less machine-intensive, and reduce output and productivity rates. These findings align with other work isolating the economic impacts of electricity hikes, which, compared with fossil fuel increases, are much more disadvantageous to firms' performance patterns. In the case of the Iranian subsidy reform, Zarepour and Wagner (2023) report a significant drop in output and value-added of between 3 and 7 percent, with a greater impact on more energy-intensive industries.

There is no evidence that environmental innovations by regulated firms induce significant effects in other parts of the value chain. Dechezleprêtre and Kruse (2022) analyze the direct and supply-chain-induced effect of climate policy stringency on economic performance and innovation for 19 countries for the period 1990 to 2015. Although climate policies are positively and significantly related to an increase in low-carbon technologies in the directly regulated sector, these regulations are not found to significantly induce innovation in the rest of the supply chain. Furthermore, their results show that climate-related policies neither improve nor worsen the economic performance of firms in the regulated sectors, thereby supporting the weak form of the Porter hypothesis. The discussion on the propagation of environmental innovation spillovers along production lines runs adjacent to concerns about policy-induced carbon leakage (Babiker 2005; Branger and Quirion 2014).

Evidence suggests that increases in energy input costs change the type of innovation firms undertake, including the overall quantity of innovation. Dechezleprêtre, Martin, and Mohnen (2014) argue that the higher innovation potential of energy-efficient and clean technologies creates more significant positive spillovers and that redirecting public funds from dirty to clean technologies induces greater innovation. Calel and Dechezleprêtre (2016) discovered that the EU ETS has boosted low-carbon innovation within regulated companies by up to 10 percent without suppressing patenting activities in other technological domains. The authors also determine that the EU ETS has not influenced patenting activities outside the realm of regulated firms. They observe greater innovation potential among chemical producers, energy corporations, and automotive manufacturers.

- Focusing on the automotive sector, Aghion et al. (2016) investigate the relationship between innovation for fuel-intensive cars (internal combustion engines) and their alternatives (such as electric, hybrid, and hydrogen vehicles). The authors find that increases in fuel prices hamper the generation of combustion-engine-type patents while

positively affecting the generation of "clean" patents. Furthermore, they illustrate that both innovation history and aggregate spillovers explain and create path dependence in the type of innovation firms pursue. Similarly, Agnelli, Costa, and Dussaux (2023) show that passenger car market shares increase significantly in response to fuel price increases for firms that have previously filed patents for either electric or hybrid vehicles or technology increasing fuel efficiency in combustion engine cars. Bretschger and Jo (2021) find that energy price increases do not affect the number of employees related to R&D activities; however, firms with lower input substitution capacity see a reduction in R&D–devoted personnel in response to energy price hikes.

The impact of energy price changes on firm performance varies by firm characteristics. Albrizio, Koźluk, and Zipperer (2014) posit that the policy impact of environmental regulation depends on firm types. The authors analyze the environmental stringency–productivity nexus using a cross-country panel data set of 17 OECD countries and 10 manufacturing sectors over the period 1990–2009, as well as a firm-level data set composed of 11 OECD countries with 22 manufacturing sectors between 2000 and 2009. The authors find that environmental regulations induce a temporary productivity boost for the most productive country-industry combinations, whereas a slowdown in productivity growth is found for less productive pairs. One possible explanation for this result is that policy reforms shake up market settings, which productive firms can exploit for a one-off gain before settling into a new equilibrium.

- Analyzing data from about 450 US manufacturing industries between 1972 and 2005, Aldy and Pizer (2015) find that energy-intensive manufacturing industries are significantly more likely to decrease production than their less energy-intensive counterparts. The estimated effects are most pronounced for the most energy-intensive sectors, namely, aluminum, cement, and bulk glass. Furthermore, more energy-intensive sectors face higher net imports than less intensive ones in response to energy price hikes, indicating that a significant part of the reduction in domestic production is offset by drawing from outside markets.

- In the context of French manufacturing firms, Marin and Vona (2021) report a strong correlation between higher energy prices and lower emissions, but also a small negative effect on productivity. The study suggests a significant trade-off between environmental goals and maintaining the competitiveness of energy-intensive sectors that are exposed to global competition, particularly for larger firms.
- Similar findings can be observed in developing countries. Goldar (2011) finds that the decline in energy intensity of Indian manufacturing after 1992 can be attributed to improved energy efficiency of energy-intensive industries, which can, in turn, be traced in part to increases in the price of energy paid by manufacturing firms. At the same time, the author asserts the high potential for further energy improvements given the considerable variation of energy prices across firms. In particular, older and larger firms appear to be less energy efficient while there are significant energy efficiency spillovers from foreign to local firms.

Structural and managerial features are linked to green innovations of firms, but evidence for developing countries is scarce. Blass et al. (2014) argue that management practices play a pivotal role in how firms respond to energy price changes. The authors emphasize the importance of managerial quality in adopting energy efficiency. Based on a sample of about 750 small and medium-sized manufacturing firms in the US, the authors find that top operations managers, who typically possess knowledge of raw materials, production processes, costs, quality control approaches, and techniques for maximizing manufacturing efficiency, are more likely to implement changes that result in higher energy efficiency gains and more disruptive technologies than their general-management counterparts (owners, CEOs). Although empirical evidence on the dissemination of energy-efficient technology remains scarce, De Haas et al. (2022) identify managerial and financial barriers as a bottleneck to energy efficiency in emerging economies. The authors use firm-level data in a cross-country study of 22 emerging economies to show that firms that are subject to constraints in terms of environmentally minded management capacity[19] and credit availability are causally linked to lower investment in efficient and less-polluting industries.

- Using firm-level data on management practices and energy expenditures from 40 countries and about 2,000 manufacturing firms in central and eastern Europe, Central Asia, and the Middle East and North Africa, Schweiger and Stepanov (2018) examine the relationship between generic management practices and energy intensity. In no- or low-fuel subsidy environments, the authors record a reduction in fuel intensity of more than 20 percent, subject to improvements in management quality. In turn, in high fuel-subsidy settings, improvements in managerial quality are associated with a modest decline in energy intensity of about 2 percent. This finding may imply that improving management quality by itself is not effective in reducing energy intensity but needs to be accompanied by price incentives.

19. De Haas et al. (2022) analyze information taken from the EBRD-EIB-WB Enterprise Surveys on firms' credit constraints, green management and green investments, and the Green Economy module therein, enquiring about green management practice in four key areas, covering (1) climate change and environmental-related strategic objectives, (2) environmental managerial practices, (3) environmental targets, and (4) monitoring of energy, water, emissions, and pollutants.

- By analyzing data following two of China's regional pilot emissions trading schemes, Yong et al. (2021) provide empirical evidence of how management quality affects firms' responses to higher energy prices. Using data on about 200 firms, the authors illustrate that well-managed firms are, on average, more productive and positively associated with "green" patenting. Well-managed firms are also found to become significantly more energy efficient in response to a carbon-pricing regime. Similar results cannot be observed for their less well-managed counterparts.

Porter-type innovation mechanics can also be established in the most recent micro-level literature focusing on developing economies. Most of the empirical evidence in the literature has so far been collected for advanced economies (Burke et al. 2016). More recently, a substrand of the literature has emerged focusing on developing economies.

- Brucal and Dechezleprêtre (2021) demonstrate that within Indonesian manufacturing, larger and energy-intensive sectors exhibit the most pronounced reduction in energy consumption following an increase in energy prices. In response to elevated energy costs, plants tend to upgrade their capital assets and invest in newer, presumably more energy-efficient technologies. The authors note a substantial decrease in energy usage and emissions among surviving plants in reaction to higher energy prices, with no significant impact on output. Moreover, they reveal that the magnitude of these effects varies based on initial output and energy intensity, as larger and more energy-intensive sectors tend to achieve more substantial reductions in energy consumption. This phenomenon transcends mere innovation strategies, given that energy-intensive firms also display a heightened likelihood of market exit in response to price hikes.

- Chile's manufacturing firms experience a significant increase in capital investment in response to fossil fuel price hikes, thereby supporting the weak version of the Porter hypothesis (Amann and Grover 2023). Evidence for the strong version remains mixed. In particular, the authors find strong heterogeneity in the observed results based on firm characteristics given that the Porter-type innovation mechanism is more pronounced for energy-intensive firms, and the strong version of the Porter hypothesis can only be confirmed for large firms.

- Looking at a selection of companies listed on the Shanghai and Shenzhen stock exchanges between 2007 and 2019, Zhang and Kong (2022) show that clean energy policies promote total factor productivity growth of energy firms. The authors identify efficiency improvements and technological innovation as the main drivers of improved productivity. Furthermore, the authors report some adverse effects of clean energy policies on the productivity levels of state-owned, large, and high-equity firms. Filippini et al. (2020) investigate the impact of a national energy efficiency program on firm-level productivity in the iron and steel sector in China. The authors report a positive and significant impact of the scheme on firm-level productivity, with little to no difference with respect to firm size or ownership structure.

- Calì et al. (2023) evaluate the direct and indirect impact of energy prices on firms' economic performance for 11 developing countries from 2002 to 2013. Using World Bank

firm-level survey data, the authors find that higher energy prices do not necessarily hamper economic performance. In some cases, higher energy prices can even enhance performance. The extent and direction of this effect are determined by the firm's energy intensity. Positive effects on firm profitability are only observed for energy-efficient firms. At the same time, energy prices are found to have no discernible effects on productivity. The authors also find considerable heterogeneity given that the performance impact varies depending on how energy intensive firms were before the reform, with firms that were already more energy efficient being at a competitive advantage. This outcome may imply that fuel subsidies are similar in effect to providing state aid to energy-inefficient firms, and the reform eliminates that very distortion to competition, benefiting the more efficient peers.

Firm-level responses to energy price increases vary depending on the energy carrier. Using firm-level data from small and micro enterprises in Indonesia in 2013, Rentschler and Kornejew (2018) explore the impact of price changes for electricity and various fossil fuel inputs on firm performance. The authors find that higher prices for all energy carriers are associated with improvements in energy efficiency. Calì et al. (2022) focus on medium to large manufacturing firms in two emerging economies, Mexico and Indonesia, and find that although surges in electricity prices affect plants' performance, increases in fuel prices lead to higher labor and total factor productivity and profits of manufacturing plants. The authors find strong evidence of capital upgrading of firms in response to a fossil fuel price hike where firms respond by upgrading capital and machinery, which, in turn, yields positive productivity outcomes. This effect is particularly pronounced for capital-intensive manufacturing sectors. In the same vein, Amann et al. (2021) analyze the effects of energy price hikes on manufacturing firms in Oman. They show that increases in fuel prices are causally linked to improvements in productivity and efficiency and lead to notable business upgrading. In both studies, such upgrading is observed in response to price increases for fossil fuels but not for electricity price increases. Electricity price increases are generally found to have a more significant impact on firm performance. Amann and Grover (2023) find that electricity price increases negatively affect firm-level productivity outcomes while fossil fuel prices drive capital upgrading in Chilean manufacturing firms. The heterogeneous impact of electricity and fossil fuel price increases in Indian manufacturing firms is also observed by Singer (2024). In particular, the author finds that lower electricity prices increase labor productivity, as well as output and employment, and electricity consumption.[20] Similar effects, with the exception of coal consumption, cannot be observed for coal prices.

20. The author also reports total variable cost increases in response to lower electricity prices, which is argued to be the result of plant scale-up. Conversely, coal price variations do not affect total production costs.

THREE

The Importance of Careful Policy Design

Well-designed policies can facilitate the adaptation process for firms by mitigating critical impacts and providing support during the transition to the new policy environment. Coady et al. (2006) and Iraldo et al. (2011) highlight issues concerning the fiscal and social costs of fuel subsidies and emphasize the need for careful policy design. Focusing on firm performance, the authors stress that internationally competitive firms are at a higher risk of suffering from input price interventions when they are not positioned to set prices. As reinforced in Arnold and Javorcik (2009), outward-looking firms may be more efficient and have better access to more modern technologies. This further motivates the need for an extensive and granular analysis of heterogeneous effects in firm response patterns. Heterogeneities may not only arise at the firm level but may also be influenced by the type of policy intervention. As Costantini, Crespi, and Palma (2017) illustrate, policies characterized by a balanced composition of "demand-pull and technology-push" instruments are most positively related to sustainable innovation patterns. In contrast, Cui et al. (2022) highlight that firms with a greater affirmation of environmental commitment are more responsible regarding their energy (electricity) consumption.

Supporting policies can facilitate the adaptation process for firms during the transition. Accompanying targeted support with transparent stakeholder engagement and a communications strategy, ideally starting before implementing a policy, allows firms to prepare and gradually adapt their production processes and structure. Complementing these efforts with measures that facilitate the adoption of new technologies (Amann et al. 2021) and alternative energy sources can assist firms in their adoption process. There is value to accompanying these measures with effective and clear communication on the policy directions and support available from the government. Additional measures, such as labor reskilling programs, can enhance labor mobility and thus the ability to substitute for energy; payroll tax cuts can support formal firms, which often exhibit a larger energy cost share, in responding to energy price increases; and targeted transfers to households can help micro and small firms stay in the market during the transition process. For example, Barkhordar, Fakouriyan, and Sheykhha (2018) illustrate that Iranian firms may face multiple barriers in their efforts to increase energy efficiency, including informational, financial, and regulatory barriers. The authors point out that different barriers severely impede firms, depending on their characteristics. Whereas information barriers seem more immediate for smaller-scale production processes, large-scale industries more often face financial barriers.

Finally, the extent to which revenue recycling may constitute a viable tool for offsetting the potentially negative effects of higher energy taxes remains largely unexplored, with selected evidence in British Columbia indicating that a revenue-neutral carbon tax may achieve emissions reduction while simultaneously boosting firm output (Ahmadi, Yamazaki, and Kabore 2022; Yamazaki 2022).

FOUR

Areas for Future Work

Based on the review of the recent literature on the firm-level impacts of energy prices, several areas for future research were identified, as summarized below.

1. **Granular analysis of firm responses.** Future research should undertake a more detailed examination of the mechanisms behind different firm responses to energy price increases. This effort would entail understanding the heterogeneity among firms in their response patterns, considering factors such as size, industry, and technological capabilities. By conducting granular analyses, researchers can uncover nuanced insights into which firms are most affected by energy price changes and how they adapt. This knowledge is crucial for policy makers because it can inform the design of targeted interventions that mitigate negative impacts on vulnerable firms while fostering resilience and innovation in others. Moreover, a deeper understanding of firm responses can help identify best practices and lessons learned, facilitating the development of more effective energy policies that balance environmental, economic, and social objectives.

2. **Connecting the missing dots.** Current firm-level surveys and commonly used performance metrics often do not effectively capture the full spectrum of response mechanisms used by firms faced with energy price increases. To address this gap, future research can add value by exploring novel data sources and methodologies to capture these nuances. Data from balance sheets, payment transactions, and employer-employee linkages can provide valuable insights into how firms navigate energy price fluctuations and can uncover previously hidden vulnerabilities. By connecting these missing dots, researchers can offer a more comprehensive understanding of the challenges firms face and the strategies they use to mitigate risks. In particular, further micro-founded research with a clear causal mandate analyzing the pass-through channel, the effect on skill-upgrading and labor displacement at the firm level, as well as external market engagement regarding sales and production is needed. This, in turn, can inform policy makers and stakeholders about the effectiveness of existing measures and identify areas where targeted support is needed

3. **Broadening the scope.** Much attention has been paid to the impact of energy price increases on firms in developed economies. Given the recent energy price liberalizations and implementation of automatic pricing mechanisms in many economies around the world (Coady et al. 2019), there is a pressing need for a more extensive analysis of this phenomenon in the developing world. Energy subsidies comprise a wide range of measures, and understanding, documenting, and comparing different ways of delivering subsidies across various countries is crucial for understanding the nexus between energy price changes and firm-level outcomes in light of different reforms (Couharde and Mouhoud 2020). This understanding is essential for ensuring the sustainability and inclusiveness of green policies. Furthermore, future research should explore the unique challenges and opportunities faced by firms in developing countries, considering factors such as infrastructure constraints, access to finance, and regulatory environments. By broadening the understanding of different channels through which subsidies affect firms, researchers can identify policy levers that promote improved firm performance, economic growth, environmental sustainability, and social equity in these contexts.

4. **Exploring policy incentives and targeted mitigation measures.** Recent literature underscores the importance of well-designed policy measures to mitigate the firm-level impact of energy price increases. Future research can add value by exploring the effectiveness of various policy incentives and targeted mitigation measures in different contexts. This work would entail assessing the quality and incentives structure of planned policy interventions, considering factors such as regulatory clarity, administrative efficiency, and stakeholder engagement. By evaluating the impact of specific policy measures on firm behavior and performance, researchers can identify strategies that foster a smooth transition to a low-carbon economy while minimizing adverse effects on businesses and workers.

5. **Emphasizing the use of fiscal resources.** The manner in which fiscal resources saved or freed up as a result of energy subsidy reform are used can significantly influence firm and sectoral outcomes. With a few notable exceptions, there is a gap in the literature regarding the firm-level effects of energy subsidy reform based on government revenue utilization. Future research can focus on modeling the impacts of different revenue allocation strategies on firm-level responses, behavior, productivity, and competitiveness. By conducting evidence-based analyses that explicitly link revenue use to firm-level outcomes, researchers can provide valuable insights for policy makers grappling with energy subsidy reform. This research can inform decision-making processes and help maximize the positive impact of subsidy reforms on both economic efficiency and social welfare.

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