# The Heterogeneous Impacts of Firm Upgrading on Energy Use*

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**Abstract**

This paper examines the influence of export activity on a firm's energy use, with a particular focus on the role of the upgrading process. We introduce a firm-level complexity index incorporating two dimensions: the complexity of the goods traded and the complexity of the destination markets served. Using a quasi-experimental shift-share research design (Borusyak et al., 2022), we demonstrate that external demand serves as an incentive for firms to engage in upgrading activities, resulting in a reduced energy intensity. We explore whether market forces are sufficient to incentivize firms to improve their complexity and thus enhance energy efficiency. The findings suggest the need for tailored industrial policies according to different firm sizes.

**JEL Codes:** F14, D22, O33, Q56

**Keywords:** Firm Upgrading; International Trade; Energy Use; Complexity; Structural Transformation; Economic Development

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# 1 Introduction

The energy intensity and efficiency are at the core of the green transition. Although policy makers are already implementing a variety of industrial policies to address this global challenge (Juhász et al., 2023; Ilyina et al., 2024), their effects on international trade have never been obvious. In fact, the international trade literature has found ambiguous effects of exports on firm-level energy intensity. Trade can induce exporters to upgrade their technology and thereby reduce their energy intensity (Forslid et al., 2018). However, trade can also induce exporters to adjust their product mix, making them more energy intensive (Barrows and Ollivier, 2018). Nor is the causality easy to sort out. Articles that consider the effects of export on firm-level energy efficiency often conflate causal effects with selection effects (Batrakova and Davies, 2012; Holladay, 2016; Forslid et al., 2018; Barrows and Ollivier, 2018).

In this paper, we provide causal evidence of trade-induced upgrading and its associated impact on firm-level energy intensity and efficiency. To do so, we employ a unique dataset that covers the universe of firms in Lithuania from 2000–2015. We then augment it with the customs data that contains the import and export volume of firms' product basket and their relevant trading partners. This granular information enables us to further leverage external datasets that are crucial for measuring firms' upgrading processes and the external demand shocks they are facing.

We begin by constructing a firm-level complexity index that captures the essence of firms' upgrading process according to Verhoogen (2023). This index captures not only the complexity of the goods traded, but also the complexity of the destination markets served. Hence, a firm can upgrade by trading more complex goods, trading with more complex countries, or both. In our sample, both of these dimensions contribute to the steady upgrading of firms in Lithuania.

We then examine how exogenous shocks to trade affect firm-level complexity. To separate the causal effects of external demand growth from unobservables that affect the energy efficiency of individual Lithuanian exporters, we construct firm-specific external demand shocks by combining aggregate (Lithuania-wide) product-specific foreign demand growth with firm-specific product sales shares, similar to Hummels et al. (2014); Mayer et al. (2021); Barrows and Ollivier (2021). Following the recent work on shift-share instruments, our identification is based on the exogeneity of the external demand growth shocks, that is, the "shocks view" as

in Borusyak et al. (2022).[1] While these shocks are exogenous to Lithuanian firms, their impact varies markedly across firms precisely because firms have different export baskets, hence the heterogeneous exposures to the exogenous shocks. In addition, the granularity of our product classification, as well as the observed variation in external demand, ensures the consistency of shift-share instrumental variable (SSIV) estimations in our context.

We find an increased external demand leads to a rise in the growth of firm-level complexity. This finding is robust across different specifications and identification methods. Building on this result, we then explore how the instrumented firm-level complexity growth affects firm's energy intensity. The results present a quite heterogeneous picture: small firms experience a substantial decrease in energy intensity with increasing complexity, whereas large firms exhibit only marginal energy efficiency improvements. In addition, the effects of firm's upgrading on energy intensity are more pronounced after the European Union (EU) accession in 2004, suggesting that the EU membership may act as a catalyst for firms to adopt cleaner production processes.

After establishing these findings on upgrading and energy intensity, we turn to a more policy-relevant analysis. Specifically, we explore whether market forces are sufficient to incentivize firms to improve their complexity and thus enhance energy efficiency. We find that financial constraints generally increase energy intensity, this negative impact can be alleviated when firms enhance their complexity, especially among the small firms. Employing firm-level markups, we then explore if firms can finance their upgrading by charging a higher markup. We find small firms temporarily charge a lower markup after upgrading, suggesting a tougher competition environment, whereas large firms can capitalize on their resources and thrive after upgrading.

These findings suggest some policy implications for the promotion of energy efficiency within export-oriented firms. First, there is the need for targeted interventions for smaller companies. Since the market mechanism has limited potential to incentivize firms to upgrade, a faster transition should encourage trade with more advanced economies on more complex products. Financial support in the early stages after upgrading is crucial for improving energy efficiency. Second, for large firms, a well-functioning capital market, a competitive banking sector with a robust regulatory environment, and other factors that make external finance con-

[1] As a robustness check, we also report results based on the traditional panel instrumental variable approach. Both approaches deliver the same results.

straints less binding are the key to reducing their energy intensity.

**Related Literature** Our paper contributes to several strands of the literature. There is a large literature on the applications of economic complexity indices following the pioneering work of Hidalgo et al. (2009), ranging over various fields and topics (Hidalgo, 2021). For instance, Stojkoski et al. (2023) integrated economic complexity metrics, traditionally derived from trade geography, with data on patent applications and research publications to improve predictions of inclusive green growth. The authors document robust improvements in explaining international variations in inclusive green growth, showcasing the combined influence of trade, technology, and research on economic growth, income inequality, and emission intensities. We contribute to this literature by constructing a firm-level complexity index that utilizes both the product-level complexity and the country-level complexity, which are the two most important aspects of firm's upgrading process (Verhoogen, 2023).

A large body of research has investigated the climate implications of trade on firm-level outcomes. The evidence in this literature is quite mixed. On the one hand, some papers find trade can reduce firm-level emissions through trade-induced technical change (Shapiro and Walker, 2018; Forslid et al., 2018; Akerman et al., 2021; Moench and Soofi Siavash, 2023), except Levinson (2009), which finds that technological development is the main driver of emission reduction, with trade only playing a minimal role. On the other hand, there are also papers that suggest that trade can increase firm-level emissions due to firms' adjustment of their product bundle (Barrows and Ollivier, 2021; Iqbal et al., 2021). We contribute to this literature by causally identifying a channel where trade induces firms to upgrade and reduces firm-level energy intensity.

As a consequence, our study also sheds light on the literature that explores how trade policies and regulations impact climate. For example, Li et al. (2023) uses the 2018 US-China trade war as a natural experiment and finds that greater exposure to Trump tariffs leads to lower regulation targets in China, inducing an increase in air pollution and carbon emissions. Brunel and Levinson (2021) investigate whether the relatively lax emission regulations in the US have turned the country into a pollution haven. They found increased emissions embodied in trade only through the scale effect, but no pollution haven was created. Shapiro and Walker (2018) found that more stringent environmental regulations encouraged the adoption of environmental technology, which was responsible for the majority of reduced emissions through lowered emission intensity. We contribute by focusing on the firm-level climate implications regarding

Lithuania's EU accession.

Our paper is also related to studies that explore the implications of structural transformation for participation in global value chains (GVC). Quite a few earlier studies focus on the technological upgrading effects via GVC participation and their implications for energy efficiency and intensity have been quite mixed (Wang et al., 2022; De Melo and Solleder, 2023). More recently, Atkin et al. (2024) find that the emergence of China in the GVC era has held back capability growth for a number of African countries who are pushed away from their most complex sectors, which China exports, and into their least complex sectors, which China imports. Our paper offers a joint treatment of firm-level upgrading through participation in GVC and its implications for climate. While most of these studies focus on developing countries and cross-country comparisons with a sectoral view, our paper provides a more granular analysis of a Central and Eastern European (CEE) country that underwent massive transformation since its EU accession.

The rest of the paper is organized as follows. Section 2 provides a detailed description of our data and how we utilize them to create our preferred measures. It also documents a summary of our raw data and our constructed measures. Section 3 discusses our empirical strategy for our causal analysis. Section 4 presents our benchmark empirical results, while Section 5 provides extensions and additional channels in reference to our benchmark analysis. Section 6 offers a discussion and policy implications in light of our findings. Section 7 concludes.

## 2 Data and Measurements

### 2.1 Data Sources

There are three primary datasets for our exercise: (i) the annual firm-level survey carried out by *Valstybės Duomenų Agentūra*, which is the official statistics department of Lithuania, (ii) product-level data from Lithuanian customs *Lietuvos Respublikos Muitinė*, and (iii) the global product-level trade data from CEPII's BACI database.

### Annual Survey of Enterprises

Our main data source comes from the annual survey of all the Lithuanian firms carried out by Statistics Lithuania from 1995-2019. The survey is mandatory for all types of firms[2] in Lithuania, except for sole proprietors or associations and public administrative entities. The dataset contains detailed firm-level information combining both balance sheets and income statements, including information about firms' birth and liquidation dates, employment, sectorial activity, ownership structure, assets, liabilities, equities, value-added, revenues and profits, etc. Unfortunately, there are two shortcomings of this data: (i) from 1995-1999, the reporting criteria were not compatible with international accounting standards, (ii) from 2016-2019, a significant portion of the above variables are missing.[3] Therefore, we provide summary statistics and our main analysis based on the period from 2000 to 2015.

We impose the following restrictions on the original dataset to obtain our sample of analysis. Firstly, we exclude enterprises with no continuous entries. Secondly, firms in financial and insurance activities are excluded, as well as those from agriculture, healthcare, and education since these firms are either poorly represented in the data or mostly sole proprietor firms and public entities. Thirdly, we winsorize firms that have revenue below or above the 2nd and 98th percentile in our sample period. This winsorization produce a final sample of 96,299 firms observed over 569,540 firm-year observations from 2000-2015.

### Lithuania Customs Data

We then merge the sample with customs data, which includes firm identifier, product code (HS8 digits, except 2010, which is HS6 digits), import source, export destination, and their respective volume[4]. The values are in litas before 2012, so we convert it to euros with the conversion ratio 3.4528 litas to 1 euro. To keep the product code consistent through the period of analysis, we aggregate the HS8 digit to HS6 digit, while maintaining the same firm-product(HS6)-source/destination pairs. This allow us to maintain a consistent database with firm-year-HS6- destination/origin information through the entire period of analysis.

[2]For a more detailed description of the data, see Constantinescu and Proškutė (2019).

[3]In addition, a reform implemented in 2019 altered the structure of labor costs by shifting the responsibility of social security contributions from companies to employees, the effects of which are not represented in our data.

[4]The customs data is available from 1995-2019, but to keep it consistent with our main analysis, we focus on the period 2000-2015.

**BACI data**

To compute external demand for Lithuanian firms, we take international trade flow data from CEPII's BACI database, which contains values of bilateral trade flows in the HS 6-digit product classification from 2000 to 2015. To make the product codes comparable across time, we convert all the HS6 codes to the 1992 version.

## 2.2 A Firm-level Complexity Index

During the period of our analysis, Lithuania is mostly in transition to a market-based economy.[5] Following the insight from Verhoogen (2023), firms' upgrading process not only benefits from their interactions with buyers or suppliers but also depends on the country they are trading with. Factors such as demand patterns, availability (and prices) of inputs, and know-how of the entrepreneurs themselves very often differ by country. Therefore, to account for the roles of these two dimensions, we utilize both the product-level and country-level data of complexity from the Atlas of Economic Complexity developed by the Harvard Growth Lab.

According to the Atlas webpage, the product complexity index captures the amount and sophistication of know-how required to produce a product,[6] while a country's complexity index is based on how diversified and complex the country's export basket is. In the context of our analysis, we start with the firm complexity index for each import and export market as follows:

$$\texttt{FCI}^{EX}_{ic,t} = \sum_j s^{EX}_{ijc,t} \texttt{Complexity}_{j,t}, \tag{1}$$

$$\texttt{FCI}^{IM}_{ic,t} = \sum_j s^{IM}_{ijc,t} \texttt{Complexity}_{j,t}. \tag{2}$$

Each index captures the average complexity score for all exported and imported varieties $j$, differentiated by destination and source countries, respectively. The higher the score, the more complexity is associated with the export and import baskets. However, this index ignores cross-country heterogeneity in complexity. That is, certain productive know-how, including sophisticated, unique know-how, is quite country-specific, hence the same variety can be pro-

[5] According to the IMF, Lithuania became an advanced economy in 2015 but completed its transition to a market-based economy in 2019.

[6] According to the Atlas website, *"The most complex products (that only a few, highly complex countries can produce) include sophisticated machinery, electronics and chemicals, as compared to the least complex products (that nearly all countries including the least complex can produce) including raw materials and simple agricultural products."*

duced quite differently in different countries.

Therefore, to account for those particular specialized know-hows from import and export partners, we augment the previous index in the following way:

$$\texttt{UFCI}_{i,t}^{EX} = \sum_c w_{c,t}^{EX} \texttt{FCI}_{ic,t}^{EX}, \tag{3}$$

$$\texttt{UFCI}_{i,t}^{IM} = \sum_c w_{c,t}^{IM} \texttt{FCI}_{ic,t}^{IM}, \tag{4}$$

where $w_{c,t} = \frac{\texttt{Complexity}_{c,t}}{\frac{1}{C}\sum_c \texttt{Complexity}_{c,t}}$ denotes the relative complexity of the country $c$ compared to the average country-level complexity at time $t$. Clearly, a country that sources or exports to an average country just gets an exact same updated index as the original one, whereas the country whose trade partners are more complex than the average "improves" the score (i.e., it lowers it) and otherwise if trade happens with less complex trade partners.

Finally, it is clear that the two indices could have been combined into a single index since the country-level complexity index weight only varies by country and time:

$$\texttt{UFCI}_{i,t}^{EX} = \sum_c w_{c,t}^{EX} \sum_j s_{ijc,t}^{EX} \texttt{Complexity}_{j,t} = \sum_c \sum_j s_{ijc,t}^{EX} w_{c,t}^{EX} \texttt{Complexity}_{j,t}, \tag{5}$$

$$\texttt{UFCI}_{i,t}^{IM} = \sum_c w_{c,t}^{IM} \sum_j s_{ijc,t}^{IM} \texttt{Complexity}_{j,t} = \sum_c \sum_j s_{ipc,t}^{IM} w_{c,t}^{IM} \texttt{Complexity}_{j,t}. \tag{6}$$

We take the absolute value of the minimum of the complexity index, $\min \texttt{Complexity}_{j,t}$, and add it up to the whole series of the complexity index. The new minimum measure is zero.

### 2.3 A First Look at the Data

The summary statistics in Table 1 offers valuable insights into the characteristics and performance metrics of firms observed between 2000 and 2015. These statistics provide the first glimpse of the dynamics within the business landscape, and shed light on various aspects of firm behaviour, economic performance, and market conditions. For instance, the mean revenue of €1,170,496 reflects the average sales of firms during the observed period. However, the wide standard deviation indicates significant variability in revenue across firms, suggesting diverse business models and market positions as well as firm size. Similarly, while the average employment of around 19 employees per firm provides an indication of workforce size, the considerable standard deviation of 132.42 highlights the heterogeneity in labour demand and

firm size within the dataset.

Furthermore, the mean export value between firms is €1.3 million, which means the average level of international trade activity between firms. The standard deviation of 8.5 million highlights the substantial variation in export performance, reflecting differences in market access, product competitiveness, and global economic conditions. Additionally, the average export of approximately 10 products per firm suggests a degree of diversification in export portfolios, with firms engaging in multiple product categories to access international markets.

The average expenditure on energy (€47 thousand) and cost of sales (€930 thousand) provide insights into firms' operating expenses and cost structures. The wide standard deviations indicate considerable dispersion in expenditure patterns and cost drivers, which may reflect differences in production processes, energy efficiency measures, and input prices between firms. Similarly, the mean total debt of €477,290 indicates the average level of financial leverage among firms. Variability in debt levels, as indicated by the standard deviation, suggests differences in financing strategies, risk profiles, and capital structure decisions between firms.

On the other hand, in terms of total factor productivity (TFP) and markup provide insights into firms' efficiency levels and pricing behaviour. The mean TFP of 2.55 suggests an average level of productivity between firms, while the average markup of 1.11 indicates firms' pricing power and market competitiveness. The distributional properties of these variables, including skewness and variability, offer further insight into the underlying drivers of firm performance and market dynamics.

Finally, in terms of firm complexity, the indices measured by UFCI and $\triangle$UFCI (in levels and growth) highlight firms' export complexity as crucial determinants of international trade decisions and market outcomes. The mean values of these variables provide indications of the levels and variability of export-related complexity within the dataset, highlighting the importance of strategic decision-making in global trade operations.

**Table 1.** Summary statistics

| | Mean | Median | Std. Dev. | Small (mean) | Large (mean) |
|---|---|---|---|---|---|
| Revenue | 1170496.03 | 103921.50 | 11243539.42 | 470017.12 | 11115233.09 |
| Employment | 19.1125 | 5 | 132.42 | 8.08962 | 175.606 |
| Export | 1302561.63 | 66948 | 8568029.59 | 474027.42 | 5002895.98 |
| Exporter products | 10.28 | 3 | 25.53 | 1 | 24 |
| Expenditure on Energy | 47177.41 | 1660 | 1205280.38 | 14943.58 | 504778.47 |
| Cost of Sales | 929668.44 | 55812 | 9563562 | 367302.19 | 8913612.00 |
| Total Debt | 477288.7 | 39881.5 | 4528501 | 223423 | 4081241 |
| log(TFP) | 2.55 | 2.58 | 0.71 | 2.60 | 2.20 |
| Markup | 1.11 | 1.07 | 0.18 | 1.11 | 1.12 |
| UFCI EX | 57.79 | 16.71 | 113.30 | 43.65 | 116.89 |
| △UFCI EX | 0.03 | 0.01 | 0.71 | 0.02 | 0.05 |

**Note**: Descriptive statistics are computed over the 569,540 firm-year observations corresponding to 96,299 firms observed between 2000 and 2015. Revenue corresponds to total sales revenue. Employment is the average number of employees within a year. Total debt is the sum of current liabilities and long-term debt. Export refers to the total export value at the firm level. Expenditure energy is the sum of expenditure on fuel, electricity, and energy. Cost of sales refers to the total costs of goods sold. Log(TFP) and markup are estimated based on the translog production function specification following the description in Appendix A.

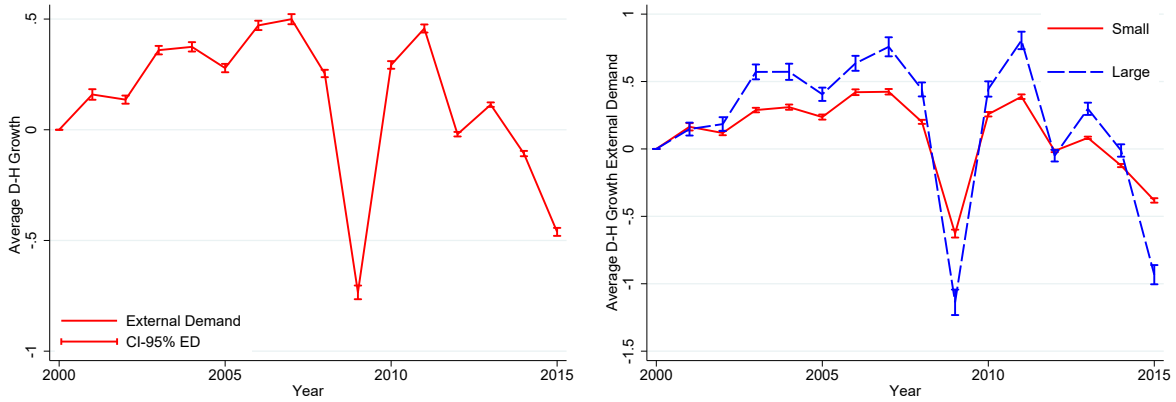
### External Demand

We investigate the temporal evolution of external demand in Figures 1.[7]. Initially, we observed a discernible upward trajectory, indicative of a favorable trend, that led to the onset of the financial crisis. Subsequently, in line with expectations, external demand underwent a period of negative growth, particularly pronounced in 2009, a consequence of the crisis's profound impact. However, following the gradual recovery commencing in 2011, there was a notable resurgence in economic activity. Despite this initial rebound, our analysis reveals a subsequent downward trajectory in external demand towards the end of our sample period in 2015. This nuanced pattern highlights the complex interplay of economic factors that influence the dynamics of external demand.

Moreover, in Figure 1, panel (b), we delineate the external demand encountered by various categories of firms, distinguishing between small and large enterprises. A discernible pattern emerges, indicating that large firms generally exhibit more robust growth compared to their smaller counterparts. However, it is noteworthy that large firms also manifest a more pronounced deceleration during the financial crisis, reflecting their heightened exposure to macroeconomic fluctuations.

[7] For the definition of external demand, see Section 3.

**Figure 1.** Growth of External Demand over time, Small vs Large Firms




**(A)** External Demand **(B)** External Demand by Size

**Description:** The figure plots the growth of external demand by size over the period 2000-2015.

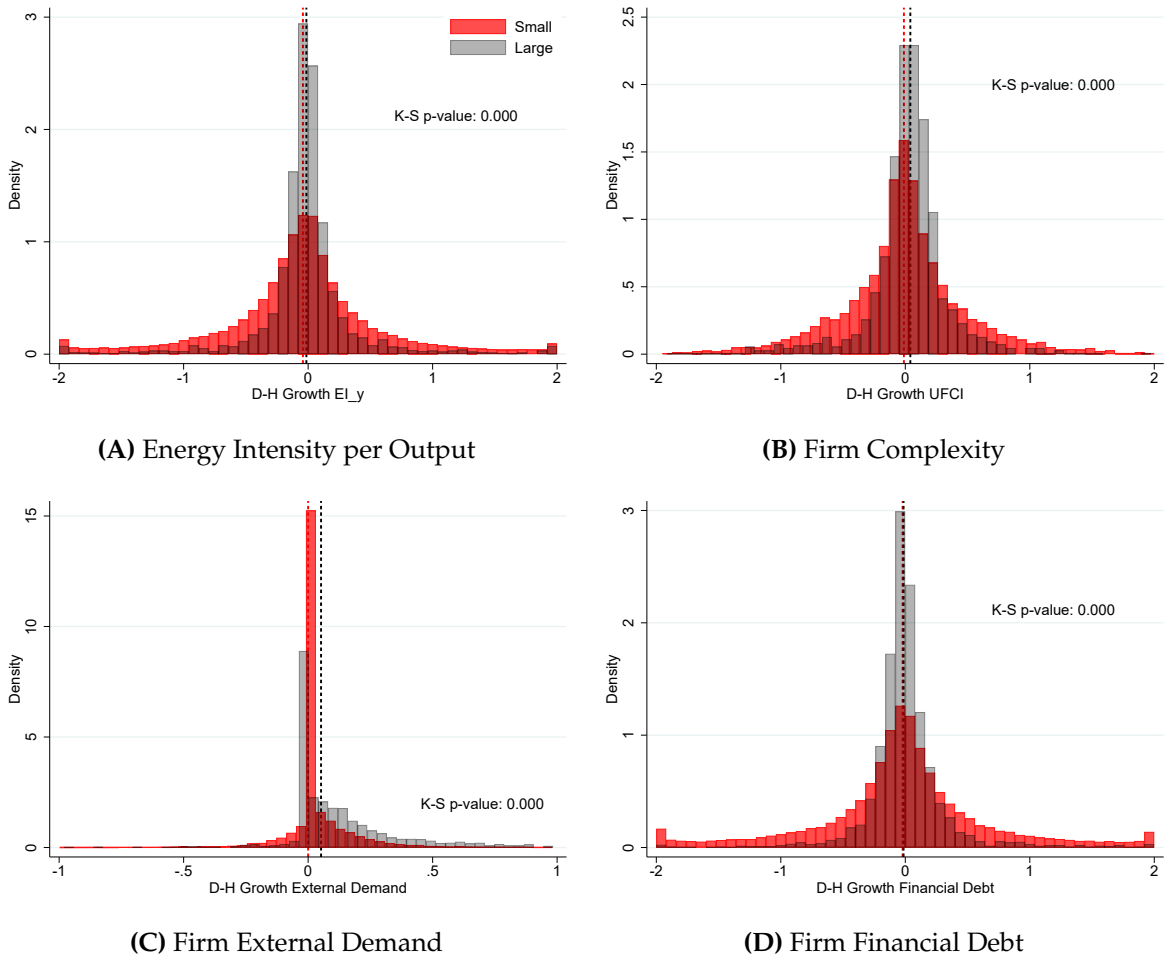
### Firm Characteristics

Delving deeper into the distributional characteristics of key variables of interest—namely energy intensity per output, firm complexity index, and firm debt—across small (50 employees or less) and large enterprises ($>$ 50 employees), Figure 2 sheds light on noteworthy patterns.

In panel (a), where we examine the distribution of energy intensity, this shows that large corporations tend to cluster around zero, with narrower tails. In contrast, small firms, while exhibiting a normal distribution, display a broader spread away from zero, indicating a greater variability in energy intensity. This disparity may reflect differing capacities for energy efficiency investments, with larger firms potentially having greater resources to optimize energy usage.

Similarly, panel (b) reveals a similar distribution pattern as in panel (a) for firm complexity among small and large firms. This suggests that firm size matters, complexity tends to follow a similar distribution, implying that factors influencing complexity are relatively different across different scales of operation.

**Figure 2.** Distribution of Firm Characteristics




**(A)** Energy Intensity per Output

**(B)** Firm Complexity

**(C)** Firm External Demand

**(D)** Firm Financial Debt

**Description:** The figure plots the firm characteristics by size over the period 2000-2015.

In contrast, panel (c) large firms exhibit a pronounced right tail, suggesting higher demand variability compared to their smaller counterparts. This asymmetry may stem from larger firms' exposure to diverse markets and their capacity to accommodate fluctuating demand through scale and flexibility.

Moving to panel (d), which focuses on firm financial debt, the majority of firms' debt growth is concentrated around zero, indicative of moderate changes in debt levels. However, small firms exhibit elongated tails in the distribution, signifying heightened variability and potentially greater susceptibility to financial risks. This divergence highlights the importance of financial management practices tailored to the unique characteristics of small businesses.

The Kolmogorov–Smirnov statistic reported in each panel tests the statistical distinction in distribution between small and large firms. The results suggest a significant divergence between these two groups across all dimensions considered, underscoring the impact of firm

heterogeneity on economic dynamics. This insight highlights the importance of tailored strategies and policies to address the unique challenges and opportunities faced by businesses of varying sizes.

# 3 Empirical Strategy

In this section, we lay out the identification strategy of our analysis. Broadly speaking, the idea is to employ techniques from the trade literature that suggest plausibly exogenous measures of foreign demand changes from year to year. The strategy is to construct weighted average foreign import demand in countries that Lithuania (henceforth, LT) tends to sell to, product by product, leaving LT's own export to the destinations out of the measure of import demand, and then instrumenting these measures with base-year weighted average shocks. Our primary identification uses the state-of-the-art shift-share design following Borusyak et al. (2022). In addition, we check the robustness of our setting using the traditional panel IV strategy, as in Barrows and Ollivier (2021).

## 3.1 Change in Product-level Export Demand

Focusing on an LT exporter producing product $j$ at time $t$, we can construct $X_{djt}$ as the aggregate import of product $j$ into destination $d$ from all countries except LT at time $t$ based on the BACI data. $X_{djt}$ therefore reflects the size of the export market of product $j$ in the country $d$ in $t$. The intuition is that subsequent changes in destination $d$'s imports of product $j$ from the world (except from LT) serve as a good proxy for the change in export demand faced by LT firms operating in market $(j, d)$. By leaving LT's own exports out of $X_{djt}$, we can almost eliminate the supply-side effects that jointly affect LT's exports and production.

Following the seminal work of Davis and Haltiwanger (1990), we compute the change in product-level export demand (i.e., the Davis-Haltiwanger growth rate) and the sum across destinations $d$ weighted by the relative importance of destination $d$ in the current year for LT firms:

$$\triangle ED_{jt,t-1} = \sum_{d \in \Omega_d} s_{djt,t-1} \frac{X_{djt} - X_{djt-1}}{\frac{1}{2}(X_{djt} + X_{djt-1})}, \tag{7}$$

where $s_{djt,t-1} \equiv \frac{1}{2}\left(\frac{X^{\text{from LT}}_{djt-1}}{\sum_l X^{\text{from LT}}_{ljt-1}} + \frac{X^{\text{from LT}}_{djt}}{\sum_l X^{\text{from LT}}_{ljt}}\right)$ stands for the share of exports that flow to destination $d$ in the total exports of $j$ from LT in the combined years $t$ and $t-1$, with $\sum_d s_{djt,t-1} = 1$.This

growth rate operates similarly to a first difference but preserves observations when the shock switches from 0 to a positive number or vice versa (a common feature with trade data), and takes an extremum value of -2 and 2. Note that $X_{djt}$ is based on CEPII's BACI data, while $X_{djt}^{\text{from LT}}$ is based on LT's trade data only.

One potential endogeneity issue comes from the fact that $\triangle ED_{jt,t-1}$ reflects the current-year shock (between $t-1$ and $t$) to foreign demand faced by LT producers of $j$. Although the change in $X_{djt}$ can arguably be taken as exogenous for an LT firm, the export shares $s_{djt,t-1}$ are likely to be determined in part by unobserved shocks to production in LT. To address this endogeneity concern, we can compute an IV for $\triangle ED_{jt,t-1}$ using base-period ($t_0$) LT export weights:

$$\triangle Z_{jt,t-1} = \sum_{d \in \Omega_d} s_{djt_0} \frac{X_{djt} - X_{djt-1}}{\frac{1}{2}(X_{djt} + X_{djt-1})}, \tag{8}$$

where $s_{djt_0} \equiv X_{djt_0}^{\text{from LT}} / \sum_l X_{ljt_0}^{\text{from LT}}$. In our benchmark, we use the export weights of 2003 as our base period.

### 3.2 Change in Firm-level Export Demand

We can then aggregate the product space of each firm to construct firm-level external demand shocks:

$$\triangle ED_{it,t-1} = \sum_{j \in \Omega_{it,t-1}} r_{ijt,t-1} \triangle ED_{jt,t-1}, \tag{9}$$

where $r_{ijt,t-1} \equiv \frac{1}{2}\left(\frac{V_{ijt-1}}{\sum_{h \in \Omega_{it-1}} V_{iht-1}} + \frac{V_{ijt}}{\sum_{h \in \Omega_{it}} V_{iht}}\right)$ stands for the export sales share of product $j$ in firm $i$'s total export sales in the combined years $t$ and $t-1$, and $\Omega_{it,t-1}$ is the set of products offered by firm $i$ in years $t$ and $t-1$.

Following the same argument in the product-level demand, we can compute the base-year weighted foreign demand instruments as follows:

$$\triangle Z_{it,t-1} = \sum_{j \in \Omega_{it_0}} r_{ijt_0} \triangle Z_{jt,t-1}, \tag{10}$$

where $\triangle Z_{jt,t-1}$ is computed in (10) and $r_{ijt_0} \equiv V_{ijt_0} / \sum_{h \in \Omega_{it_0}} V_{iht_0}$ is the export sales share of product $j$ in firm $i$'s total export sales in base year $t_0$, and $\Omega_{it_0}$ is the set of products produced in base year $t_0$. Note that $V_{ijt}$ is calculated using the trade data of LT only.

### 3.3 Identification based on Panel IV

Our instruments $\triangle Z_{jt,t-1}$ and $\triangle Z_{it,t-1}$ have been constructed in a similar way to standard shift-share/Bartik instruments. The time variation in our shocks only stems from the variation in the world export flows $X_{djt}$ and not in the product destination weights $s_{djt_0}$ or in the firm-product weights $r_{ijt_0}$, which are fixed at their value in the base period.

To identify the impact of foreign demand on firm and firm-product level outcomes, we estimate a standard difference-in-difference model in growth rates, instrumenting current-year weighted trade shocks with base-year weighted trade shocks. The identifying assumption is that once we control for arbitrary industry-by-year trends, variations in instrumented firm-specific demand shocks are uncorrelated with firm-specific technological shocks.

We can estimate the following equation at the firm level with the multi-way error structure:

$$\triangle UFCI^{EX}_{ikt,t-1} = \sum_{\tau=-z'}^{z} \beta_\tau \triangle ED_{it-\tau,t-1-\tau} + x'_{ikt}\beta + \alpha_i + \chi_t + \chi_{kt} + \epsilon_{ikt}, \tag{11}$$

where $\triangle UFCI^{EX}_{ikt,t-1} = (UFCI^{EX}_{ikt} - UFCI^{EX}_{ikt-1})/0.5(UFCI^{EX}_{ikt} + UFCI^{EX}_{ikt-1})$ denotes the Davis-Haltiwanger growth rate between $t$ and $t-1$ for the export complexity index of firm $i$ in industry $k$, and, as defined in equation (9), $\triangle ED_{it-\tau,t-1-\tau}$ stands for the firm-level demand shocks. Note that we base our model in differences to focus on growth, which we allow to have a firm-specific component, as captured by the firm fixed effect $\alpha_i$. The dynamics are controlled for by $\chi_t$ (common time fixed effects) and $\chi_{kt}$, the industry-year fixed effect (constructed as sectoral dummy interacted with time fixed effects), meant to capture industry-specific trends (each firm is a part of the sector, $k(i)$, though for notational simplicity we suppress that dependence). We also control for additional observables, as will be made clear when we cover the empirical results, in a vector $x_{ikt}$, which includes a lagged share of imports and exports with the core EU15 countries as well as a time dummy of EU entry to explore potential heterogeneities before and after belonging to the common market.[8] Further note, at the firm-level regression, we can associate each firm to a single industry based on the product code responsible for the largest share of exports for the firm over the whole period. Due to the reasons discussed above, $\triangle ED_{it-\tau,t-1-\tau}$ is instrumented by $\triangle Z_{it-\tau,t-1-\tau}$.

The first-difference specification in (11) eliminates a bias that would arise from a correlation

[8] The EU15 countries are the 15 countries in the European Union before the 2004 EU enlargement, which includes Belgium, Denmark, Germany, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Austria, Portugal, Spain, the United Kingdom and Sweden.

between non-time-varying firm characteristics and the level of demand shocks. We allow for various trends in the growth rate to capture potential joint dynamics with the external demand. The advantage of this specification lies in the fact that changes in demand shock $\triangle ED_{it,t-1}$ are substantially less likely to be correlated with firms' observable and unobservable characteristics than *levels* of export demand.

### 3.4 Identification based on the Shift-Share IV

The identification of the model in (11) rests on the validity of the instrument to capture a (conditional) exogenous variation of external demand from changes in the firm's complexity. Since firms choose product bundles and destination countries endogenously, we have to tackle these sources of endogeneity. That is why, as described above, our construction of foreign demand instruments includes product demand variation in foreign markets for the fixed (base-year) export shares at the firm level.[9] However, instead of relying on the linear panel IV regression and shares' exogeneity, we can also recast a firm-level regression to the shock (product) level based on the descriptions in the previous subsection. This identification strategy is based on the equivalence result, as recently covered by Borusyak et al. (2022).

Our model at the firm level exploits the shift-share structure: each firm can choose which products it produces, and which foreign markets it exports to. Each product receives an external demand shock based on global trade flows. Hence, each firm gets impacted differently, depending on its export bundle. In other words, the demand shocks are at the "product level", whereas the heterogeneous exposure shares are at the "firm-level". Since we observe multi-product exporters, we can construct firm-level instruments to uncover a causal effect of trade on upgrading (as captured by our complexity index).[10] For this strategy to work, the requirement $\mathbb{E}[\frac{1}{N}\sum_i[\triangle Z_{it,t-1} \times \epsilon_{it}]] = 0$ must hold, where the total number of all firms is $N$. Notice that, unlike the traditional requirement of $\mathbb{E}[\triangle Z_{it,t-1} \times \epsilon_{it}] = 0$, this may not be satisfied in the absence of an IID assumption, i.e., when $\mathbb{E}[\frac{1}{N}\sum_i[\triangle Z_{it,t-1} \times \epsilon_{it}]] \neq \mathbb{E}[\triangle Z_{it,t-1} \times \epsilon_{it}]$. If product demand shocks are assumed to be stochastic, then the IID sampling fails.

[9] Our instrument $\triangle Z_{it,t-1} = \sum_{j \in \Omega_{it_0}} r_{ijt_0} \triangle Z_{jt,t-1}$ is essentially a Bartik instrument, with $r_{ijt0}$ being the pre-EU product shares of each firm and $\triangle Z_{jt,t-1}$ being the product-level external demand growth.

[10] Goldsmith-Pinkham et al. (2020) argue from a model-based approach (i.e., diff-in-diff) that if the shares are exogenous, then it's sufficient to make the Bartik instrument valid. In the case of our analysis, we argue that the firm-product dichotomy in our setting is more suited to the design-based approach, as in Borusyak et al. (2022); that is, a change in external demand between products in global markets can help identify the impact of a change in demand-induced complexity (either upgrading or downgrading).

Lithuanian firms' complexity reacts to demand changes as well as changes in their supply choices. We controlled for demand shocks by looking at foreign trade partners' import demand for each product. That is arguably exogenous from the Lithuanian firm's perspective. To avoid endogeneity due to deliberate choice of product and trade partner choice, we picked base-year export shares. However, IID also requires no spillovers from one firm to another (general equilibrium effects might generate one firm's choices being dependent on another, i.e. when a firm's complexity changes due to product bundle and/or destination countries' changes, other firms might get incentivized to engage in similar reshuffling). Luckily, to explore if these concerns matter, we can resort to the equivalence result due to Borusyak et al. (2022).

They argue that a natural experiment within the shocks can still make the instrument valid, even if the shares are endogenous, based on a design-based approach. The aforementioned shift-share IV estimator's equivalence result supports this claim. The idea is based on the *Frisch-Waugh-Lovell theorem*, which allows us to separate all exogenous variables and fixed effects in the first stage, resulting in residualized firm complexity growth and firm demand shock. These residuals can be averaged across all firms, leveraging their heterogeneous product shares in the export bundles. The IV estimate obtained from the original firm-level IV procedure can then be equivalent to a "product-level" IV regression, with the model instrumented by product demand shocks with product weights. This procedure does not require independent and identically distributed (IID) sampling.

The residual of this shock-level procedure is defined as the average firm's residual, with more weight being placed on products that Lithuanian firms are exporting more. Hence, firm-level independent sampling is no longer required. What is needed instead is that the conditional product-level demand shocks are quasi-randomly assigned, meaning the expected value, conditional on product-level complexity growth error, exposure shares and observables, is constant. Additionally, there should be enough products to ensure that not all firms specialize in just a few and that there is weak correlation between shock errors. In our context, Lithuanian data provide sufficient opportunities for exogeneity and variation, making shift-share setting our preferred method.

The main reasons are as follows. First, the shocks in our setting are at the product level. That is, the demand for product $j$ is computed by aggregating all possible destinations of product $j$ while excluding LT. This part is essentially independent of any LT data. Second, for each product $j$, there are multiple firms within LT that export such products. So, the shock to

such a product can be treated as randomly assigned across all firms that export such product. That is, conditioning on any relevant firm-level unobservables and average exposure shares, the product-level growth rate based on world import demand is uncorrelated with firm-level supply shocks within LT. Third, there are close to 4000 products that LT exports, and for given unobservables and product shares, these two together produce many weakly dependent shocks.[11]

**Brief Discussion**

One might argue that even though our shares are already set at the pre-EU level, there still might be some unobservables that are forecastable based on these shares. That is, there still might be some unobserved product-level shocks that affect the residuals $\varepsilon_i$, even though it's uncorrelated with the product-level growth rate based on world import demand. Such a shock, for example, could come from a change in LT consumers' preferences, which is uncorrelated with the product growth rate outside of LT, but might influence the shares and, hence, create bias in the estimation.

We use a rich set of unobservables to control for firm's time-invariant, aggregate time, and sector-time variations. Hence, if such preference shocks are correlated to these dynamics, they would be controlled for. Our studied economy is small and very open (its openness ratio, defined as imports and exports over GDP, is around 150%, see Lastauskas and Stakenas, 2018). Hence, a domestic market constitutes just a tiny share of total sales for the largest exporters (Bernard et al., 2007; Melitz, 2003). Our methodology helps us capture those unobserved and observed changes in international demand that actually drive firms' complexity index, but are unimpacted by the LT firms' choices.

We take a random variation in the demand for firm-produced goods from all countries in the world across all goods. Simply put, our measure of international demand shocks capture changes in global economic conditions, consumer preferences, and market dynamics clearly outside what the LT firms' upgrading choices can impact. Our setting provides a quasi-experimental setting by exploiting a large number of products and their demand changes on global markets, the idiosyncratic nature of such shocks across firms and products, and weak dependence among shocks. We also ensure that industry-time trends are not driving our re-

[11] We perform falsification test according to the discussions in Borusyak et al. (2022) and report the test results in Appendix C.

sults.

Finally, our regression analysis also includes a set of observable controls like lagged trade shares with the core EU (both imports and exports) and a potential break in the impact after the EU accession. The experimental shift-share research design allows us to identify the causal effect of international demand shocks on firm complexity, providing causal insights into how firms respond to changes in global demand conditions.

# 4 Baseline Results

## 4.1 External Demand and Firm-level Complexity

We first utilize SSIV regression to explore the causal relationship between the growth of firms' external demand (△ED), the growth of firms' complexity (△UFCI), and EU accession (EU), under various specifications.

**Table 2.** First Stage: Impacts of External Demand on Complexity based on SSIV

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | △UFCI | △UFCI | △UFCI | △UFCI | △UFCI | △UFCI | △UFCI |
| △ED | 0.0914** | 0.0968** | | | 0.101*** | | |
| | (0.0444) | (0.0431) | | | (0.0375) | | |
| EU×△ED | | | 0.0647 | 0.0649 | | 0.0733* | 0.0731* |
| | | | (0.0424) | (0.0424) | | (0.0376) | (0.0375) |
| IMP share$_{t-1}^{EU15}$ | | ✓ | ✓ | | | | |
| EXP share$_{t-1}^{EU15}$ | | ✓ | ✓ | | | | |
| EU×IMP share$_{t-1}^{EU15}$ | | | | ✓ | | | |
| EU×EXP share$_{t-1}^{EU15}$ | | | | ✓ | | | |
| △IMP share$_{t-1}^{EU15}$ | | | | | ✓ | ✓ | |
| △EXP share$_{t-1}^{EU15}$ | | | | | ✓ | ✓ | |
| EU×△IMP share$_{t-1}^{EU15}$ | | | | | | | ✓ |
| EU×△EXP share$_{t-1}^{EU15}$ | | | | | | | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year×Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 43,574 | 43,359 | 43,359 | 43,359 | 40,275 | 40,275 | 40,275 |
| Product IV | Z_product | Z_product | Z_prod×EU | Z_prod×EU | Z_product | Z_prod×EU | Z_prod×EU |
| LM statistic | 119.382 | 80.648 | 75.533 | 75.552 | 65.779 | 61.754 | 61.751 |
| Wald F statistic | 155.693 | 124.584 | 119.412 | 119.493 | 103.916 | 99.633 | 99.629 |
| Hansen J statistic | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. △ED is the external demand defined in Equation (4.3), △UFCI is the Davis-Haltiwanger growth rate defined in Equation (4.5). △Export Share$_{t-1}^{EU15}$ stands for the lagged change in firm-level export share to EU15 countries. Similarly for the import share. EU is a dummy variable that takes value one after 2004.

In column 1 of Table 2, the positive coefficient in △ED suggests that an increase in external demand growth causes a significant increase in firm-level complexity, controlling for year and year-industry fixed effects. When controlling for the level (column 2) or the change (column 5) of firms' lagged import and export share to EU15, the positive coefficient on △ED increases both economically and statistically. This aligns with the existing literature that emphasizes the positive impact of foreign demand on firm-level outcomes (Barrows and Ollivier, 2021; Forslid

et al., 2018).

The positive relationship suggests that firms experiencing higher foreign import demand tend to exhibit greater complexity in their operations. This phenomenon could be attributed to several factors. Firstly, increasing foreign demand can require companies to diversify their product offerings or adapt existing products to meet the specific needs of international markets (Forslid et al., 2018). This diversification can lead to a more intricate organizational structure as firms navigate varied product lines and customer requirements.

Secondly, responding to heightened foreign demand often involves engaging in global value chains, where firms collaborate with suppliers and partners across borders. Such cross-border collaborations can contribute to the increased complexity in managing the logistics, coordination, and quality control aspects of the supply chain (Shapiro, 2016). This aligns with the notion that participation in global value chains is associated with a higher level of organizational complexity (Zhong et al., 2021).

In addition, the positive relationship could also be indicative of the need for firms to invest in advanced technologies and innovative processes to meet the demands of a globalized market. These investments, while enhancing a firm's competitiveness, can concurrently lead to a more intricate operational landscape (Constantinescu and Proškutė, 2019). Furthermore, the positive relationship between foreign demand and firm complexity aligns with the findings of Akerman et al. (2021), who argue that exposure to international markets prompts firms to adopt more sophisticated and complex strategies to remain competitive.

Indeed, the results highlight that external demand plays a crucial role in shaping the growth trajectory of firm complexity. The implications extend beyond mere market expansion, encompassing strategic diversification, supply chain intricacies, and technological advancements. Thus, they provide valuable insights into the dynamics of international trade and its impact on firms' organizational structures.

In column 3, we explore whether the EU accession affects the growth of firm-level complexity, controlling for year and year-industry fixed effects. The results are insignificant whether we control the level of firms' lagged import and export share to EU15 (column 3) or their interactions with the EU dummy (column 4). However, if we control for the change of firms' lagged import and export share to EU15 (column 6) or their interaction with the EU dummy (column 7), we obtain some mild positive and significant results, suggesting that EU accession brings in a mild increase in the growth of firm-level complexity among those firms that exhibit

an increasing dependence to the EU15. This may indicate adjustments in firms' structures and strategies following changes in EU membership, reflecting the adaptability of businesses to evolving economic landscapes (Constantinescu and Proškutė, 2019). This could also be linked to market access benefits, regulatory harmonization, or other advantages conferred by EU integration Bai and Ru (2022); Wang et al. (2022).

**Table 3.** First Stage: Impacts of External Demand on Complexity based on Panel IV

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | △UFCI | △UFCI | △UFCI | △UFCI | △UFCI | △UFCI | △UFCI |
| △ED | 0.0156** | 0.0179** | | | 0.0232*** | | |
| | (0.00726) | (0.00761) | | | (0.00768) | | |
| EU×△ED | | | 0.00828 | 0.00813 | | 0.0144* | 0.0145* |
| | | | (0.00766) | (0.00765) | | (0.00778) | (0.00777) |
| IMP share$^{EU15}_{t-1}$ | | -0.00980 | -0.00870 | | | | |
| | | (0.0108) | (0.0108) | | | | |
| EXP share$^{EU15}_{t-1}$ | | 0.0294* | 0.0323** | | | | |
| | | (0.0151) | (0.0152) | | | | |
| EU×IMP share$^{EU15}_{t-1}$ | | | | -0.0106 | | | |
| | | | | (0.0113) | | | |
| EU×EXP share$^{EU15}_{t-1}$ | | | | 0.00200 | | | |
| | | | | (0.0159) | | | |
| △IMP share$^{EU15}_{t-1}$ | | | | | -0.00185 | -0.00166 | |
| | | | | | (0.00885) | (0.00884) | |
| △EXP share$^{EU15}_{t-1}$ | | | | | 0.00953 | 0.00928 | |
| | | | | | (0.0121) | (0.0121) | |
| EU×△IMP share$^{EU15}_{t-1}$ | | | | | | | -0.00292 |
| | | | | | | | (0.00941) |
| EU×△EXP share$^{EU15}_{t-1}$ | | | | | | | 0.00194 |
| | | | | | | | (0.0123) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year×Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 52,500 | 41,585 | 41,585 | 41,585 | 33,267 | 33,267 | 33,267 |
| Method | 2SLS | 2SLS | 2SLS | 2SLS | 2SLS | 2SLS | 2SLS |
| IV | Z_firm | Z_firm | Both | Both | Z_firm | Both | Both |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. △ED is the external demand defined in Equation (4.3), △UFCI is the Davis-Haltiwanger growth rate defined in Equation (4.5). △Export Share$^{EU15}_{t-1}$ stands for the lagged change in firm-level export share to EU15 countries. Similarly for the import share. EU is a dummy variable that takes value one after 2004.

As a robustness check for our finding, we repeat the same exercise using the traditional Panel IV approach (Table 3). The difference is that SSIV partials out controls effects (it treats them as nuisance), so we do not obtain any coefficients as compared to the Panel IV approach, but merely control for their variations. As can be seen below, the results are in line with those obtained via the SSIV approach. The additional insight here is that a higher export share to EU15 is associated with higher growth of firm-level complexity (columns 2 and 3), but after removing the potential linear trend for firms' import and export share, this association disappeared (columns 5-6).

### 4.2 Firm-level Complexity and Energy Intensity

In this subsection, we explore the relationship between the growth of firm-level complexity ($\triangle \text{UFCI}_{SSIV}$) and energy intensity through the lens of how EU membership may have played a role in shaping this relationship. In our benchmark analysis, we use the growth rate of energy expenditure over sales as the dependent variable ($\triangle \text{EI}_y$).[12] In Appendix B, we repeat the same exercise here with the growth rate of energy expenditure over the cost of sales as the dependent variable ($\triangle \text{EI}_{cogs}$). The main results are consistent across these two measures.[13]

In Table 4, the consistently negative coefficients associated with $\triangle \text{UFCI}_{SSIV}$ (column 1-2, 5) and its interaction with the EU dummy (columns 3-4, 6-7) across all specifications align with the economic intuition that more complex and technologically advanced firms tend to adopt energy-efficient practices (Constantinescu and Proškutė, 2019). In addition, after joining the EU in 2004, the relationship between firm complexity and energy intensity is more pronounced. This resonates with the literature emphasizing the role of EU regulations in promoting environmental sustainability (Levinson, 2009; Shapiro, 2016). This is because EU membership may act as a catalyst for firms to adopt cleaner production processes, aligning with the broader regulatory framework.

The level of lagged firms' import or export share to EU15 does not affect firms' energy intensity (columns 2-4), but the change of lagged firms' export share to EU15 ($\triangle \text{EXP Share}_{t-1}^{EU15}$) is positively associated with firms' energy intensity (columns 5-6), and its magnitude and significance rises after the EU accession (column 7). This suggests that after taking care of the potential linear trends within firms' import and export patterns, having an export product mix dominated by the EU markets, which are relatively closer, may be associated with lower productivity, and thus higher energy intensity.

#### Heterogeneity across firms

We examine the heterogeneous effects of firm-level complexity on energy intensity for both small (Table 5) and large (Table 6) firms. The results portrayed a diverging pattern for firms of different sizes. As can be seen, most of the findings in Table 4 are driven by small firms. This suggests that small firms with higher complexity might leverage advanced technologies and production processes, resulting in a more efficient use of energy resources. This is con-

[12] Our energy expenditure includes the firm's expenditure on gas, fuel and electricity.

[13] The robustness checks based on panel IV method are available upon request.

**Table 4.** Second Stage: Complexity and Energy Intensity

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00519*** | -0.00609*** | | | -0.00478** | | |
| | (0.00161) | (0.00186) | | | (0.00205) | | |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00635*** | -0.00637*** | | -0.00504** | -0.00503** |
| | | | (0.00185) | (0.00185) | | (0.00205) | (0.00205) |
| IMP $Share_{t-1}^{EU15}$ | | 0.00677 | 0.00682 | | | | |
| | | (0.0185) | (0.0185) | | | | |
| EXP $Share_{t-1}^{EU15}$ | | -0.00363 | -0.00350 | | | | |
| | | (0.0243) | (0.0243) | | | | |
| EU$\times$IMP $Share_{t-1}^{EU15}$ | | | | 0.0225 | | | |
| | | | | (0.0197) | | | |
| EU$\times$EXP $Share_{t-1}^{EU15}$ | | | | -0.0134 | | | |
| | | | | (0.0252) | | | |
| $\triangle$IMP $Share_{t-1}^{EU15}$ | | | | | 0.0158 | 0.0158 | |
| | | | | | (0.0172) | (0.0172) | |
| $\triangle$EXP $Share_{t-1}^{EU15}$ | | | | | 0.0515** | 0.0514** | |
| | | | | | (0.0220) | (0.0220) | |
| EU$\times\triangle$IMP $Share_{t-1}^{EU15}$ | | | | | | | 0.00655 |
| | | | | | | | (0.0186) |
| EU$\times\triangle$EXP $Share_{t-1}^{EU15}$ | | | | | | | 0.0617*** |
| | | | | | | | (0.0233) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 68,728 | 42,055 | 42,055 | 42,055 | 33,462 | 33,462 | 33,462 |
| R-squared | 0.153 | 0.134 | 0.134 | 0.134 | 0.131 | 0.131 | 0.131 |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. $\triangle$EXP $Share_{t-1}^{EU15}$ ($\triangle$IMP $Share_{t-1}^{EU15}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004.

sistent with studies highlighting the positive relationship between technological innovation and environmental performance (Porter and Linde, 1995). That is, well-designed environmental regulations can stimulate technological innovation and increase efficiency, particularly for small companies.

Contrary to small firms, the coefficients for the complexity of large firms are smaller in magnitude and not consistently statistically significant. This suggests that, for large firms, the relationship between complexity and energy intensity is less pronounced. Large firms may possess different organizational structures and resource optimization strategies that mitigate the impact of complexity on energy intensity. For instance, large firms often engage in diverse activities, and their energy consumption patterns might be influenced by a variety of factors beyond complexity, such as the scale of operations, diversification, and the global nature of their activities. Additionally, large firms are usually better resourced to leverage technology advancements to reduce energy intensity even for less complex goods. Lastly, the required change for large companies might be more extensive and thus longer to implement.

Focusing on the import and export perspective, small and large firms also deliver different

**Table 5.** Second Stage: Complexity and Energy Intensity for Small Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00553*** | -0.00849*** | | | -0.00726** | | |
| | (0.00224) | (0.00276) | | | (0.00321) | | |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00895*** | -0.00895*** | | -0.00795** | -0.00795** |
| | | | (0.00279) | (0.00279) | | (0.00324) | (0.00324) |
| IMP Share$^{EU15}_{t-1}$ | | -0.00883 | -0.00906 | | | | |
| | | (0.0246) | (0.0246) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | 0.0368 | 0.0362 | | | | |
| | | (0.0372) | (0.0371) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0111 | | | |
| | | | | (0.0260) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | 0.0248 | | | |
| | | | | (0.0386) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.00700 | 0.00681 | |
| | | | | | (0.0232) | (0.0233) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0668* | 0.0668* | |
| | | | | | (0.0356) | (0.0356) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | -0.00308 |
| | | | | | | | (0.0251) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0740** |
| | | | | | | | (0.0374) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 53,715 | 29,691 | 29,691 | 29,691 | 22,624 | 22,624 | 22,624 |
| R-squared | 0.175 | 0.154 | 0.154 | 0.154 | 0.149 | 0.149 | 0.149 |
| Firm Size | Small | Small | Small | Small | Small | Small | Small |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle UFCI$ based on SSIV in the first stage. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Small represents firms that have less than 50 employees.

messages. For small firms, having an export product mix dominated by the EU markets associates with higher energy intensity, and this association is even stronger after the EU accession. This indicates, among small firms, easier to trade with EU correlates with higher energy intensity. However, for the large firms, importing more from the EU15 is associated with higher energy intensity. Interestingly, after the EU accession, this positive association seems to vanish, indicating a potential shift towards more sustainable practices after joining the EU. This suggests that EU membership might enhance the positive environmental impact of firm complexity for large firms, possibly through access to cleaner inputs, technologies or regulatory pressures (Shapiro and Walker, 2018).

## 5 Extensions

After demonstrating that external demand provides the impetus for upgrading and leads to lower energy use, we shift our focus to analyzing a few *channels* through which complexity impacts firms. We first begin by exploring whether a firm's financial constraints impact firm's

**Table 6.** Second Stage: Complexity and Energy Intensity for Large Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00307 | -0.00222 | | | -0.00122 | | |
| | (0.00237) | (0.00256) | | | (0.00265) | | |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00240 | -0.00240 | | -0.00132 | -0.00133 |
| | | | (0.00255) | (0.00255) | | (0.00264) | (0.00264) |
| Import Share$^{EU15}_{t-1}$ | | 0.0429 | 0.0432 | | | | |
| | | (0.0275) | (0.0275) | | | | |
| Export Share$^{EU15}_{t-1}$ | | -0.0338 | -0.0338 | | | | |
| | | (0.0307) | (0.0307) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0423 | | | |
| | | | | (0.0300) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | -0.0417 | | | |
| | | | | (0.0325) | | | |
| $\triangle$Import Share$^{EU15}_{t-1}$ | | | | | 0.0430* | 0.0431* | |
| | | | | | (0.0243) | (0.0243) | |
| $\triangle$Export Share$^{EU15}_{t-1}$ | | | | | 0.0391 | 0.0391 | |
| | | | | | (0.0258) | (0.0258) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | 0.0385 |
| | | | | | | | (0.0265) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0513* |
| | | | | | | | (0.0278) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 14,345 | 11,928 | 11,928 | 11,928 | 10,472 | 10,472 | 10,472 |
| R-squared | 0.181 | 0.179 | 0.180 | 0.180 | 0.184 | 0.184 | 0.184 |
| Firm Size | Large | Large | Large | Large | Large | Large | Large |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle UFCI$ based on SSIV in the first stage. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Big represents firms that have more than 50 employees.

energy intensity during its upgrading process. We then move on to examine how markups respond to changes in instrumented complexity; it is an important channel as it sheds light on firm's ability to finance upgrading by charging a higher markup. In all these extensions, we will explore the role of the firm's size.

## 5.1 Firm Heterogeneity and Financial Constraints

Table 7 presents new insights into the relationship between firm financial constraints (constructed as in Whited and Wu (2006), WW), firm complexity, and energy intensity (see details on the construction of the WW index in Appendix D). The WW index captures firms' external financial constraints that are also aligned with firm characteristics.[14]

The first insight is that financial constraints on their own do not consistently play a significant role in explaining changes in energy intensity. When financial constraints do have an

[14]For robustness, we explore an alternative measure of financial circumstances, namely the financing cost ratio (the sum of amortization and interest payments of debt over firm sales), in the Appendix Tables A.7-A.9. Although there are some differences compared to our preferred, more comprehensive WW variable, we nevertheless find similar results.

**Table 7.** Financial Constraints, Complexity and Energy Intensity

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00516*** | -0.00605*** | | | -0.00472** | | |
| | (0.00161) | (0.00186) | | | (0.00205) | | |
| WW | 5.66e-05*** | 4.52e-05 | 4.49e-05 | 4.49e-05 | 5.52e-05* | 5.49e-05* | 5.49e-05* |
| | (1.78e-05) | (4.26e-05) | (4.27e-05) | (4.28e-05) | (2.99e-05) | (3.00e-05) | (2.99e-05) |
| $\triangle UFCI_{SSIV} \times$ WW | -6.15e-06*** | -5.11e-06*** | -5.09e-06*** | -5.15e-06*** | -6.31e-06*** | -6.29e-06*** | -6.24e-06*** |
| | (1.55e-06) | (1.94e-06) | (1.94e-06) | (1.95e-06) | (1.62e-06) | (1.62e-06) | (1.62e-06) |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00631*** | -0.00633*** | | -0.00499** | -0.00498** |
| | | | (0.00186) | (0.00186) | | (0.00205) | (0.00205) |
| IMP Share$^{EU15}_{t-1}$ | | 0.00697 | 0.00701 | | | | |
| | | (0.0185) | (0.0185) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | -0.00355 | -0.00342 | | | | |
| | | (0.0243) | (0.0243) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0227 | | | |
| | | | | (0.0197) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | -0.0133 | | | |
| | | | | (0.0252) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.0160 | 0.0159 | |
| | | | | | (0.0172) | (0.0172) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0515** | 0.0515** | |
| | | | | | (0.0220) | (0.0220) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | 0.00671 |
| | | | | | | | (0.0186) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0617*** |
| | | | | | | | (0.0233) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 68,728 | 42,055 | 42,055 | 42,055 | 33,462 | 33,462 | 33,462 |
| R-squared | 0.153 | 0.134 | 0.134 | 0.134 | 0.131 | 0.131 | 0.131 |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. WW stands for the Whited and Wu (2006) firm-level index of financial constraints. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004.

effect, firms tend to become more energy-intensive (less energy-efficient). However, a new result emerges from the significant interaction between financial constraints and upgrading (see the third explanatory variable in Table 7). Companies that simultaneously improved their complexity and faced higher financial constraints benefited by reducing energy intensity. Although the direct effect of WW is estimated with considerable noise, its mean effect is significantly larger than the negative interaction effect. Thus, financially constrained companies generally tend to become more energy-intensive, but this effect can be mitigated by upgrading (i.e., improving firm-level complexity).

Economic theory suggests that firms with higher debt levels may engage in riskier behavior, potentially prioritizing short-term financial obligations over long-term sustainability goals. Our findings complement the advice to address financial constraints in order to encourage firms to invest in energy-efficient technologies (Cagno et al., 2015), emphasizing the importance of having access to foreign markets and improving the traded goods basket. Interestingly, Freitas et al. (2023) argue that factors such as the complexity of exported products,

environmental regulations, and production technologies may lead to a positive correlation between energy intensity and export intensity in emerging economies. We find that in a more mature economy, complexity leads to lower energy intensity compared to that of an emerging market, and that other factors, such as access to finance, may influence the expected energy-saving outcomes.

We cover firm heterogeneity in more detail in Appendix D. Table A.5 covers small companies, whereas Table A.6 reports results for large firms. As in the baseline results, we observe consistently negative coefficients for firm complexity, highlighting the energy efficiency gains associated with greater firm complexity, even after controlling for financial constraints. In fact, smaller companies, known for their agility and adaptability, may be more adept at incorporating energy-efficient technologies (Bai et al., 2021). Like in Table 7, financial constraints are related to positive energy intensity change, though insignificant when conditioned on more variables, its effect can be made less harmful if it is simultaneously accompanied by the upgrading process. Small firms are again confirmed to benefit from the EU's membership in terms of more efficient energy use.

For large companies (see Table A.6), financial constraints play a significant role in energy use. Those large companies that struggle financially tend to increase energy intensity. However, this negative effect can be mitigated by an increase in complexity. There is no independent upgrading effect, unlike for small companies. This indicates that energy savings for large companies cannot be achieved solely by accessing more complex products and countries. Instead, they need to improve their financial position while also climbing the complexity ladder.

Our recommendations are more nuanced than simply addressing access to green technologies and energy-efficient practices due to financial constraints (Cecere et al., 2020; Yu et al., 2021). For larger firms require well-functioning capital markets, access to external finance, a robust regulatory environment, a competitive banking sector, and other factors that make external finance constraints less binding to achieve more energy-efficient production. For small firms, these factors alone are not sufficient. Since small firms have less access to advanced trade partners and more complex traded goods, improving such access would help them optimize energy use. Although financial constraints lead to less efficient production for small firms, the key lies in the upgrading process.

### 5.2 Firm-level Complexity and Markups

We move to exploring the role of exogenous changes in complexity on markups. Since pricing entails forward-looking behavior, we have divided the sample into small and large firms and are calculating local projections for six periods ahead (considering the possibility that it may take time for firm profits to be affected). In other words, we are analyzing the dynamic response of $h$-periods ahead markups to exogenous changes in firm-level complexity.

The local projection specification for the cumulative effect of the predicted change in $\triangle$UFCI on the Davis-Haltiwanger growth rate of firm-level markup is given by:

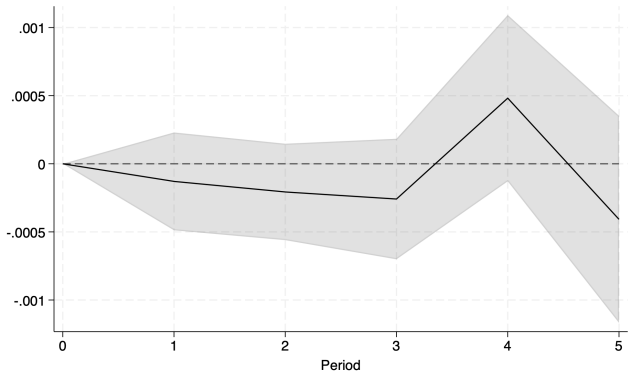
$$\Delta \text{Markup}_{ikt,t+h} = \alpha_i + \chi_t + \chi_{kt} + \beta_h \Delta \widehat{\text{UFCI}}^{\text{EX}}_{ikt,t-1} + \epsilon_{ikt,t+h}, \tag{12}$$

where $\Delta \text{Markup}_{ikt,t+h}$ is the Davis-Haltiwanger growth rate of firm-level markup for firm $i$ in industry $k$ at horizon $h$, $\Delta \widehat{\text{UFCI}}^{\text{EX}}_{ikt,t-1}$ is the predicted change in the export complexity index based on SSIV, $\alpha_i$ represents firm fixed effects, capturing time-invariant characteristics of each firm, $\chi_t$ denotes year fixed effects, capturing common shocks to all firms in a given year, $\chi_{kt}$ represents year-industry fixed effects, capturing industry-specific trends over time, and $\epsilon_{ikt,t+h}$ is the error term. The model is estimated for different horizons $h$ to capture the dynamic effects of changes in the export complexity index on firm-level markup growth.

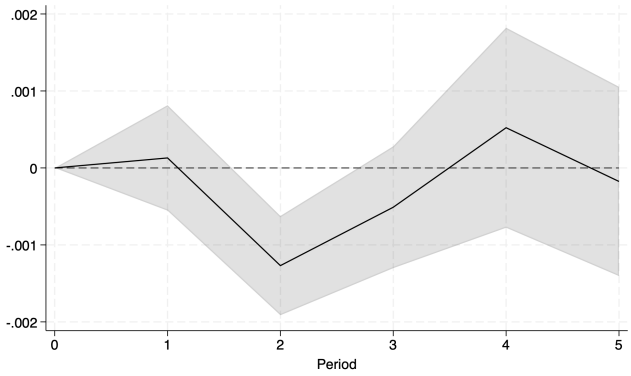
Figure 3 visualizes impulse responses, showing that markups are not significantly impacted for the overall sample. In other words, the average firm cannot expect to gain more market power when its complexity increases. However, these results obscure the important underlying heterogeneities. When we divide the sample into small and large firms, a different story emerges.

Small firms appear to face tougher competition after upgrading, as can be seen from the temporary reduction in their markups. This evidence echoes that of Atkin et al. (2024), who demonstrate, at a more aggregate level, that the dynamic gains or losses depend on whether more complex goods entail more or less competition. They empirically show the former, resulting in dynamic losses for less developed economies. In our case, smaller firms differ from larger firms (as seen in Figure 2), and they might face tougher competition after climbing up the complexity ladder in their product bundle. This is because larger and more productive firms are often the incumbents for these more complex goods. However, this fiercer competition effect is transitory, as markups eventually return to baseline levels (as shown in the

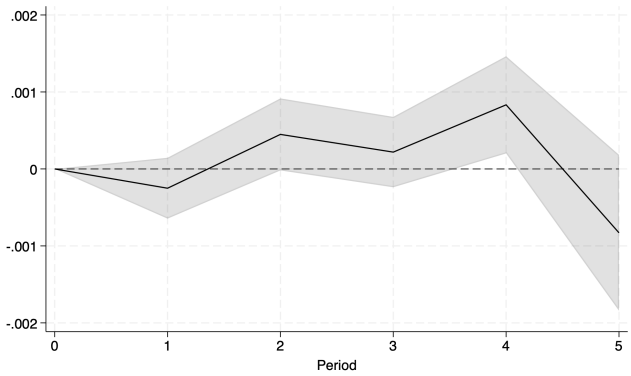
**Figure 3.** Local projections of markup growth & the predicted value of UFCI




**(A)** All Firms




**(B)** Small Firms




**(C)** Large Firms

**Description:** The figure plots cumulative impulse response functions identified by local projections (Jordà, 2005) with a 90% confidence interval. The vertical axis depicts the reaction of Davis-Haltiwanger growth rate of firm-level markup obtained via estimation of translog production function (see Appendix A) in response to a change in the predicted value of △UFCI based on SSIV in the first stage. Small firms are defined as having less than or equal to 50 employees, whereas large firms have more than 50 employees. Firm, year, and year-industry fixed effects are included. Standard errors are clustered at the firm level.

cumulative response in the figure).

The situation is different for large firms, which typically find it easier to compete, albeit after a significant delay (see panel (C) of Figure 3). The growing disparity between firms offers

a foundational understanding of how market power dynamics evolve, highlighting that larger firms increasingly dominate markets, affecting overall macroeconomic parameters. These firms can often engage in technological advancements and skill enhancements to improve their production processes and product quality, improving their efficiencies and expanding into new markets more effectively than their smaller counterparts (Van Reenen, 2018). The policy and infrastructure support toward large firms might also be instrumental in helping them maintain their market dominance (Brandt and Thun, 2016).

Several important policy recommendations emerge from our analysis. Small firms must be supported or incentivized in their upgrading process via targeted industrial policy, as trade alone can instead lead to tougher competition when they start serving more capable countries and/or producing more complex goods. Before they establish proper market shares, easier access to finance could increase the chance of survival after upgrading. For large firms, we recommend policies that facilitate easier and less costly trade with more advanced trade partners, which act as catalysts for upgrading.

## 6 Discussion and Policy Implications

Our study dives into the dynamics that govern the relationship between export activities, firm-level upgrading, and energy efficiency. These findings carry significant ramifications for policymakers, stakeholders, and businesses as they navigate the transition towards a greener economy.

The observed trends suggest unique challenges and opportunities faced by small and large firms. While smaller enterprises may have utilized increased profits pre-EU integration to invest in energy-efficient measures, the post-integration period shows a stagnation in such efforts. This highlights the need for sustained support mechanisms and tailored policies to support upgrading and energy efficiency initiatives among small companies (Trianni et al., 2013; Cagno et al., 2015).

In contrast, large firms, especially those with access to EU markets, exhibit a more nuanced response. While they may possess greater market power and potential productivity advantages, our findings suggest that exporters to the EU do not experience discernible benefits in terms of energy efficiency. This stresses the need for targeted interventions to ensure that large firms actively contribute to the green transition, rather than solely capitalising on market ad-

vantages (Bernard et al., 2007).

Tailored financing solutions and targeted policy interventions are essential for empowering firms to overcome barriers and undertake energy efficiency initiatives, contributing to sustainable development goals. Research by Bertoldi et al. (2021) highlights the importance of financing instruments in facilitating energy renovations. Our paper provides causal evidence that trade openness, particularly with more advanced economies, leads to firm complexity growth, which in turn improves energy efficiency. However, financially distressed and highly indebted companies experience significant delays in this process.

Market forces alone are insufficient to fund upgrading, especially for small firms, highlighting the need for proactive policy interventions. Policymakers must design initiatives targeting small firms, recognizing their significant potential for sustainable development (Forslid et al., 2018).

Additionally, fostering trade relationships with advanced economies can facilitate technology transfer and ease financing barriers, promoting firm-level upgrading and energy-efficient practices (He et al., 2020). As documented, small and large firms play different role and face different challenges in the upgrading process. Tailored interventions that address specific barriers to upgrading and energy efficiency can yield more effective outcomes and foster sustainable growth (Gerarden et al., 2017). By addressing these challenges, policymakers can pave the way for enhanced energy efficiency, reduced emissions, and more sustainable economic growth.

# 7 Conclusions

Our paper emphasizes the pivotal role of firm complexity in determining energy intensity and efficiency. Utilizing comprehensive data from the Lithuanian firm survey spanning 2000-2015, we introduce a novel firm complexity index that incorporates diverse factors such as destination and source countries, product mix, and trade relationships. By applying instrumental variables, including the state-of-the-art quasi-experimental shift-share method (Borusyak et al., 2022), we document causal connections between firm complexity (indicative of firm-level upgrading) and energy use.

Our study exploits shocks in foreign import demand, revealing a positive association with firm complexity and reinforcing existing literature on trade-induced efficiency gains. Further-

more, firm heterogeneity proves crucial, as we find a substantial reduction in energy intensity for small firms with increased complexity, whereas large firms exhibit a comparatively marginal improvement.

We identify markups as potential sources to fund upgrading for large firms, but no evidence that small firms could enjoy higher market power after an increase in their complexity. That calls for policy intervention to substitute for missing market reward for better and cleaner technology.

Additionally, we identify financial indebtedness as a significant factor holding firms back from capitalizing on upgrading and making their production more energy-efficient. Time and again, these findings underscore the need for targeted policies to address financial constraints, enabling firms to fully benefit from trade-induced efficiency gains and reduce their energy intensity.

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# APPENDIX

## A Production Function Estimation and Markups

We follow closely the procedure in Ding et al. (2023) to estimate the markups of individual firms using the production function approach (e.g., de Loecker and Warzynski, 2012; Yeh et al., 2022). Firm-level markup can be obtained through the following equation:

$$\mu_{it} \equiv \frac{e^c_{it}}{\alpha^c_{it}}, \tag{A.1}$$

where the variable input cost shares of output, $\alpha^c_{it}$, can be calculated directly from the data by taking the ratio of the cost of variable inputs costs over sales. To estimate the output elasticity $e^c_{it}$, we assume that the productivity component is Hicks neutral and consider a vector of technology parameters, $\boldsymbol{\theta}$, that are constant across time but vary across industries. Thus, we can write the production function as $Q_{it} = \Omega_{it}\tilde{F}(\boldsymbol{X}_{it}; \boldsymbol{\theta})$. In the data, we measure output $Q_{it}$ using firms' total sales revenue, $Y_{it}$, deflated by their industry-specific gross output deflator.

Let $y_{it}$ stand for the (log) real sales revenue and assume that the data contain potential measurement errors, $\epsilon_{it}$; the model to estimate is as follows

$$y_{it} = \omega_{it} + \tilde{f}(\boldsymbol{x}_{it}; \boldsymbol{\theta}) + \epsilon_{it},$$

where $x_{it} = (c_{it}, l_{it}, k_{it})$ refers to the vector of the real value of each input, expressed in logs.[15] To estimate $\boldsymbol{\theta}$, a simple approach would be to regress the (log) of sales revenue on inputs. However, as productivity levels, $\omega_{it}$, are unobserved this approach would yield biased estimates (García-Perea et al., 2021; de Ridder et al., 2022). To tackle this issue, we follow the two-step method proposed by Olley and Pakes (1996), relying on the identification strategy outlined in Ackerberg et al. (2015).

In the first stage, we assume that the unobserved productivity is a third-order expansion of the inputs denoted by the function $h(.)$. We then run an OLS on the following specification

$$y_{it} = g_t(\boldsymbol{x}_{it}; \boldsymbol{\theta}) + \epsilon_{it}, \tag{A.2}$$

[15] In the data, the variables refer to the real value of the variable input cost, $c_{it}$, wage bill, $l_{it}$, and the value of fixed tangible assets, $k_{it}$. Please refer to Ding et al. (2023) for the full description of the variables utilized in the estimation process.

where $g_t(\boldsymbol{x}_{it};\boldsymbol{\theta}) = h_t(\boldsymbol{x}_{it}) + \tilde{f}(\boldsymbol{x}_{it};\boldsymbol{\theta})$. Productivity is then computed as $\omega_{it} = \hat{g}_t - \tilde{f}(\boldsymbol{x}_{it};\boldsymbol{\theta})$. Note that we eliminate measurement error at this initial stage, but we cannot separate the production function component from productivity, since they both depend on inputs. Therefore, under the assumption that $\omega_{it}$ follows an AR(1) Markov process, we construct productivity innovations as $\xi_{it} = \omega_{it} - m(\omega_{it-1})$ and rely on moment conditions for identification.[16] Since productivity innovation should be unaffected by inputs selected before time $t$, the estimation of $\theta$ can be achieved using the following moment conditions

$$\mathbb{E}\left(\xi_{it}(\theta)\begin{bmatrix}\boldsymbol{z}_{it-1}\\ \boldsymbol{k}_{it}\end{bmatrix}\right) = \mathbf{0},$$

where $z_{it-1}$ represents an instrument vector including all one-period lagged values of every polynomial term containing $c_{it}$ and $l_{it}$ in the production function $\tilde{f}(\boldsymbol{x}_{it};\boldsymbol{\theta})$. The value of capital is fixed at its current value as it is assumed to be predetermined and, hence, should be orthogonal to the innovation $\xi_{it}(\theta)$.

To obtain the empirical markups, we assume the following translog functional form for the production function

$$\tilde{f}(\boldsymbol{x}_{it};\boldsymbol{\theta}) = \theta_c c_{it} + \theta_l l_{it} + \theta_k k_{it} + \theta_{cc} c_{it}^2 + \theta_{ll} l_{it}^2 + \theta_{kk} k_{it}^2 + \theta_{cl} c_{it} l_{it} + \theta_{ck} c_{it} k_{it} + \theta_{lk} l_{it} k_{it}. \tag{A.3}$$

Following the procedure described above, we estimate $\theta$ by GMM separately for each of the 2-digit industries in the data.Using the GMM estimates of equation (A.3), the firm-level markups are

$$\hat{\mu}_{it} = (\hat{\theta}_c + 2\hat{\theta}_{cc} c_{it} + \hat{\theta}_{cl} l_{it} + \hat{\theta}_{ck} k_{it}) \cdot \frac{\tilde{Y}_{it}}{C_{it}} = \frac{\hat{e}^c_{it}}{\tilde{\alpha}^c_{it}}, \tag{A.4}$$

where $\tilde{Y}_{it} = \exp(y_{it} - \hat{\epsilon}_{it})$ is the measurement-corrected sales and $\tilde{\alpha}^c_{it} = \frac{C_{it}}{\tilde{Y}_{it}}$ is the variable input costs over corrected sales revenue. Note that this approach to estimate markups also allows us to recover firm-level TFP, $\omega_{it}$, from the estimation of the production function.

# B Additional Tables

[16] We assume that $m(.)$ is a third-order expansion of the productivity measure (de Loecker and Warzynski, 2012).

**Table A.1.** Second Stage: Complexity and Energy Intensity

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ |
| $\triangle UFCI_{SSIV}$ | -0.00589*** | -0.00718*** | | | -0.00569*** | | |
| | (0.00164) | (0.00187) | | | (0.00207) | | |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00744*** | -0.00745*** | | -0.00596*** | -0.00595*** |
| | | | (0.00187) | (0.00187) | | (0.00207) | (0.00207) |
| IMP Share$^{EU15}_{t-1}$ | | 0.00687 | 0.00692 | | | | |
| | | (0.0187) | (0.0187) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | -0.00104 | -0.000914 | | | | |
| | | (0.0247) | (0.0247) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0217 | | | |
| | | | | (0.0199) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | -0.0122 | | | |
| | | | | (0.0257) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.0167 | 0.0167 | |
| | | | | | (0.0174) | (0.0174) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0503** | 0.0502** | |
| | | | | | (0.0224) | (0.0224) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | 0.00644 |
| | | | | | | | (0.0187) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0608** |
| | | | | | | | (0.0238) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 67,587 | 41,895 | 41,895 | 41,895 | 33,376 | 33,376 | 33,376 |
| R-squared | 0.152 | 0.134 | 0.134 | 0.134 | 0.132 | 0.132 | 0.132 |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_{cogs}$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over cost of sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004.

**Table A.2.** Second Stage: Complexity and Energy Intensity for Small Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle$EI$_{cogs}$ | $\triangle$EI$_{cogs}$ | $\triangle$EI$_{cogs}$ | $\triangle$EI$_{cogs}$ | $\triangle$EI$_{cogs}$ | $\triangle$EI$_{cogs}$ | $\triangle$EI$_{cogs}$ |
| $\triangle$UFCI$_{SSIV}$ | -0.00653*** | -0.0102*** | | | -0.00861*** | | |
| | (0.00228) | (0.00279) | | | (0.00326) | | |
| EU$\times\triangle$UFCI$_{SSIV}$ | | | -0.0106*** | -0.0106*** | | -0.00934*** | -0.00934*** |
| | | | (0.00281) | (0.00282) | | (0.00329) | (0.00329) |
| IMP Share$_{t-1}^{EU15}$ | | -0.00793 | -0.00814 | | | | |
| | | (0.0249) | (0.0249) | | | | |
| EXP Share$_{t-1}^{EU15}$ | | 0.0420 | 0.0414 | | | | |
| | | (0.0374) | (0.0374) | | | | |
| EU$\times$IMP Share$_{t-1}^{EU15}$ | | | | 0.0114 | | | |
| | | | | (0.0263) | | | |
| EU$\times$EXP Share$_{t-1}^{EU15}$ | | | | 0.0306 | | | |
| | | | | (0.0391) | | | |
| $\triangle$IMP Share$_{t-1}^{EU15}$ | | | | | 0.00831 | 0.00813 | |
| | | | | | (0.0235) | (0.0235) | |
| $\triangle$EXP Share$_{t-1}^{EU15}$ | | | | | 0.0696* | 0.0696* | |
| | | | | | (0.0361) | (0.0361) | |
| EU$\times\triangle$IMP Share$_{t-1}^{EU15}$ | | | | | | | -0.00364 |
| | | | | | | | (0.0253) |
| EU$\times\triangle$EXP Share$_{t-1}^{EU15}$ | | | | | | | 0.0782** |
| | | | | | | | (0.0379) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 52,660 | 29,573 | 29,573 | 29,573 | 22,570 | 22,570 | 22,570 |
| R-squared | 0.173 | 0.153 | 0.153 | 0.153 | 0.150 | 0.150 | 0.150 |
| Firm Size | Small | Small | Small | Small | Small | Small | Small |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle$EI$_{cogs}$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over cost of sales $\triangle$UFCI$_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. $\triangle$EXP Share$_{t-1}^{EU15}$ ($\triangle$IMP Share$_{t-1}^{EU15}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Small represents firms that have less than 50 employees.

**Table A.3.** Second Stage: Complexity and Energy Intensity for Large Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ | $\triangle EI_{cogs}$ |
| $\triangle UFCI_{SSIV}$ | -0.00345 | -0.00242 | | | -0.00160 | | |
| | (0.00239) | (0.00257) | | | (0.00265) | | |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00262 | -0.00263 | | -0.00170 | -0.00172 |
| | | | (0.00256) | (0.00256) | | (0.00264) | (0.00265) |
| IMP Share$^{EU15}_{t-1}$ | | 0.0415 | 0.0418 | | | | |
| | | (0.0278) | (0.0278) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | -0.0384 | -0.0383 | | | | |
| | | (0.0312) | (0.0311) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0390 | | | |
| | | | | (0.0303) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | -0.0420 | | | |
| | | | | (0.0329) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.0432* | 0.0433* | |
| | | | | | (0.0244) | (0.0244) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0351 | 0.0350 | |
| | | | | | (0.0262) | (0.0262) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | 0.0398 |
| | | | | | | | (0.0266) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0487* |
| | | | | | | | (0.0283) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 14,271 | 11,888 | 11,888 | 11,888 | 10,439 | 10,439 | 10,439 |
| R-squared | 0.181 | 0.179 | 0.179 | 0.179 | 0.183 | 0.183 | 0.183 |
| Firm Size | Large | Large | Large | Large | Large | Large | Large |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_{cogs}$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over cost of sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Big represents firms that have more than 50 employees.

# C Falsification Test

To assess the plausibility of the conditional quasi-random shock assignment in Borusyak et al. (2022), we implement the following falsification test of shock orthogonality in our SSIV setting. Table A.4 reports coefficients from regressions of firm-level covariates on our shift-share instruments (normalized to have a unit variance), controlling for year and year-industry fixed effects. HS4 digit-clustered exposure-robust standard errors are reported and obtained from equivalent firm-level IV regressions.

**Table A.4.** Summary statistics

| Balance variables | Coefficient | SE |
|---|---|---|
| Labor productivity | -37.1950 | 30.5795 |
| Labor share | -0.0009 | 0.0037 |
| Capital intensity | -0.0818 | 0.0537 |
| Fraction of part-time workers | -0.0137 | 0.0084 |
| Profit margin | 0.0008 | 0.0117 |
| Leverage ratio | -0.0006 | 0.0059 |
| Number of observations | | 35,376 |

**Note**: Labor productivity is defined as a firm's sales over its number of hours reported in a given year, labor share is defined as a firm's wage bill over its sales, capital intensity is defined as a firm's fixed tangible assets over its sales, the fraction of part-time workers is a firm's average number of part-time workers over its average number of employees, profit margin is defined as EBITDA over sales, and leverage ratio is firm's long-term debt over its total assets.

The six controls are labor productivity, labor share, capital intensity, fraction of part-time workers, profit margin, and leverage ratio. Broadly speaking, these measures reflect a firm's production characteristics. We find no statistically significant relationship between these variables and our shift-share instruments.

Notice that different from the case in Borusyak et al. (2022), where the authors can do the balance check both at the industry level (similar to our product level) and the location level (similar to our firm level), here in our case, we can only perform the balance check at the firm-level, not at the product-level. This is because our product-level information comes from the global 6-digit trade flow data from CEPII, which is exogenous to Lithuania. *In addition, our firm-level data does not contain additional information at the product level*. This means we cannot check whether product-level shocks predict any predetermined product-level variables.

# D Financial Constraints and Firm Heterogeneity

We construct our WW-index closely following the original definition in Whited and Wu (2006). It captures firms' external finance constraints that are consistent with firm characteristics. With only one component missing, namely the "DIVPOS", which is an indicator that takes the value of one if the firm pays dividends in cash. In our data, only 2013–2015 reports the total value of dividends, the information on whether it's paid out in cash was not available.[17] We believe that the missing of this information will not substantially change our results since many of the firms in our analysis are private firms and they do not necessarily pay dividends to their investors in cash.

**Table A.5.** Financial Constraints, Complexity and Energy Intensity: Small Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00544** | -0.00840*** | | | -0.00714** | | |
| | (0.00224) | (0.00276) | | | (0.00321) | | |
| WW | 0.000130** | 3.40e-05 | 3.36e-05 | 3.38e-05 | 4.42e-05 | 4.36e-05 | 4.36e-05 |
| | (5.65e-05) | (4.72e-05) | (4.73e-05) | (4.74e-05) | (3.47e-05) | (3.48e-05) | (3.47e-05) |
| $\triangle UFCI_{SSIV} \times$ WW | -1.13e-05*** | -6.20e-06** | -6.14e-06** | -6.24e-06** | -6.81e-06*** | -6.72e-06*** | -6.67e-06*** |
| | (3.12e-06) | (2.51e-06) | (2.51e-06) | (2.52e-06) | (2.55e-06) | (2.55e-06) | (2.54e-06) |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00885*** | -0.00885*** | | -0.00783** | -0.00783** |
| | | | (0.00279) | (0.00279) | | (0.00325) | (0.00325) |
| IMP Share$^{EU15}_{t-1}$ | | -0.00843 | -0.00867 | | | | |
| | | (0.0246) | (0.0246) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | 0.0370 | 0.0364 | | | | |
| | | (0.0371) | (0.0371) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0115 | | | |
| | | | | (0.0260) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | 0.0250 | | | |
| | | | | (0.0386) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.00725 | 0.00706 | |
| | | | | | (0.0233) | (0.0233) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0667* | 0.0668* | |
| | | | | | (0.0356) | (0.0356) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | -0.00281 |
| | | | | | | | (0.0251) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0739** |
| | | | | | | | (0.0374) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 53,715 | 29,691 | 29,691 | 29,691 | 22,624 | 22,624 | 22,624 |
| R-squared | 0.175 | 0.154 | 0.154 | 0.154 | 0.149 | 0.149 | 0.149 |
| Firm Size | Small | Small | Small | Small | Small | Small | Small |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. $\triangle$WW stands for the Whited and Wu (2006) firm-level index of financial constraints. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Small represents firms that have less than 50 employees.

[17] Within these three years, around 8% of firms in our sample that report non-zero dividends.

**Table A.6.** Financial Constraints, Complexity and Energy Intensity: Large Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00307 | -0.00220 | | | -0.00121 | | |
| | (0.00237) | (0.00256) | | | (0.00265) | | |
| WW | 4.58e-05*** | 0.000920** | 0.000921** | 0.000920** | 0.000760** | 0.000761** | 0.000761** |
| | (1.16e-05) | (0.000415) | (0.000416) | (0.000415) | (0.000357) | (0.000357) | (0.000357) |
| $\triangle UFCI_{SSIV} \times$ WW | -8.95e-06 | -8.91e-05* | -8.98e-05* | -8.98e-05* | -8.00e-05* | -8.06e-05* | -8.08e-05* |
| | (1.64e-05) | (4.75e-05) | (4.74e-05) | (4.74e-05) | (4.31e-05) | (4.30e-05) | (4.31e-05) |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00238 | -0.00238 | | -0.00131 | -0.00132 |
| | | | (0.00255) | (0.00255) | | (0.00264) | (0.00264) |
| IMP $\text{Share}_{t-1}^{EU15}$ | | 0.0426 | 0.0428 | | | | |
| | | (0.0275) | (0.0275) | | | | |
| EXP $\text{Share}_{t-1}^{EU15}$ | | -0.0393 | -0.0392 | | | | |
| | | (0.0307) | (0.0307) | | | | |
| EU$\times$IMP $\text{Share}_{t-1}^{EU15}$ | | | | 0.0419 | | | |
| | | | | (0.0299) | | | |
| EU$\times$EXP $\text{Share}_{t-1}^{EU15}$ | | | | -0.0419 | | | |
| | | | | (0.0325) | | | |
| $\triangle$IMP $\text{Share}_{t-1}^{EU15}$ | | | | | 0.0427* | 0.0428* | |
| | | | | | (0.0243) | (0.0243) | |
| $\triangle$EXP $\text{Share}_{t-1}^{EU15}$ | | | | | 0.0391 | 0.0390 | |
| | | | | | (0.0258) | (0.0258) | |
| EU$\times\triangle$IMP $\text{Share}_{t-1}^{EU15}$ | | | | | | | 0.0382 |
| | | | | | | | (0.0264) |
| EU$\times\triangle$EXP $\text{Share}_{t-1}^{EU15}$ | | | | | | | 0.0512* |
| | | | | | | | (0.0278) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 14,345 | 11,928 | 11,928 | 11,928 | 10,472 | 10,472 | 10,472 |
| R-squared | 0.181 | 0.180 | 0.180 | 0.180 | 0.184 | 0.185 | 0.185 |
| Firm Size | Large | Large | Large | Large | Large | Large | Large |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. WW stands for the Whited and Wu (2006) firm-level index of financial constraints. $\triangle$EXP $\text{Share}_{t-1}^{EU15}$ ($\triangle$IMP $\text{Share}_{t-1}^{EU15}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Big represents firms that have more than 50 employees.

Alternatively, as a robustness check of our channel, we explore the financing cost ratio (the sum of amortization and interest payment of debt over firm sales), and we the results are presented in the following tables.

**Table A.7.** Financial Constraints, Complexity and Energy Intensity

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00541*** | -0.00610*** | | | -0.00480** | | |
| | (0.00167) | (0.00192) | | | (0.00211) | | |
| Fin ratio | 0.261 | 0.929 | 0.927 | 0.940 | 1.298** | 1.296** | 1.284** |
| | (0.377) | (0.587) | (0.586) | (0.586) | (0.645) | (0.645) | (0.645) |
| $\triangle UFCI_{SSIV} \times$ Fin ratio | 0.0486 | 0.0105 | 0.0124 | 0.0131 | 0.0183 | 0.0212 | 0.0220 |
| | (0.0714) | (0.0721) | (0.0719) | (0.0718) | (0.0759) | (0.0757) | (0.0760) |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00637*** | -0.00640*** | | -0.00509** | -0.00508** |
| | | | (0.00192) | (0.00192) | | (0.00211) | (0.00211) |
| IMP Share$^{EU15}_{t-1}$ | | 0.00683 | 0.00688 | | | | |
| | | (0.0185) | (0.0185) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | -0.00376 | -0.00363 | | | | |
| | | (0.0243) | (0.0243) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0228 | | | |
| | | | | (0.0197) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | -0.0134 | | | |
| | | | | (0.0252) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.0158 | 0.0158 | |
| | | | | | (0.0172) | (0.0172) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0516** | 0.0515** | |
| | | | | | (0.0220) | (0.0220) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | 0.00653 |
| | | | | | | | (0.0186) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0615*** |
| | | | | | | | (0.0233) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 68,728 | 42,055 | 42,055 | 42,055 | 33,462 | 33,462 | 33,462 |
| R-squared | 0.153 | 0.134 | 0.134 | 0.135 | 0.131 | 0.132 | 0.132 |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. Fin ratio stands for the sum of amortization and interest payment of debt over firm sales. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004. Small represents firms that have less than 50 employees.

**Table A.8.** Financial Constraints, Complexity and Energy Intensity: Small Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00578** | -0.00872*** | | | -0.00835** | | |
| | (0.00232) | (0.00285) | | | (0.00329) | | |
| Fin ratio | 0.000525 | -0.0291 | -0.0282 | -0.00582 | -0.366 | -0.353 | -0.367 |
| | (0.452) | (0.813) | (0.813) | (0.812) | (0.905) | (0.905) | (0.905) |
| $\triangle UFCI_{SSIV} \times$ Fin ratio | 0.0710 | 0.0703 | 0.0720 | 0.0715 | 0.346 | 0.350 | 0.350 |
| | (0.162) | (0.206) | (0.206) | (0.206) | (0.241) | (0.242) | (0.241) |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00918*** | -0.00918*** | | -0.00907*** | -0.00907*** |
| | | | (0.00288) | (0.00288) | | (0.00332) | (0.00332) |
| IMP Share$^{EU15}_{t-1}$ | | -0.00885 | -0.00908 | | | | |
| | | (0.0246) | (0.0246) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | 0.0368 | 0.0362 | | | | |
| | | (0.0371) | (0.0371) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0111 | | | |
| | | | | (0.0260) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | 0.0247 | | | |
| | | | | (0.0387) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.00707 | 0.00687 | |
| | | | | | (0.0232) | (0.0233) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0666* | 0.0666* | |
| | | | | | (0.0356) | (0.0356) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | -0.00298 |
| | | | | | | | (0.0251) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0737** |
| | | | | | | | (0.0374) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 53,715 | 29,691 | 29,691 | 29,691 | 22,624 | 22,624 | 22,624 |
| R-squared | 0.175 | 0.154 | 0.154 | 0.154 | 0.149 | 0.149 | 0.150 |
| Firm Size | Small | Small | Small | Small | Small | Small | Small |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. Fin ratio stands for the sum of amortization and interest payment of debt over firm sales. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004.Big represents firms that have more than 50 employees.

**Table A.9.** Financial Constraints, Complexity and Energy Intensity: Large Firms

| Columns | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Dependent variable | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ | $\triangle EI_y$ |
| $\triangle UFCI_{SSIV}$ | -0.00265 | -0.00125 | | | 0.000323 | | |
| | (0.00244) | (0.00263) | | | (0.00272) | | |
| Fin ratio | 1.971** | 3.402*** | 3.403*** | 3.400*** | 4.645*** | 4.633*** | 4.627*** |
| | (0.826) | (0.851) | (0.851) | (0.854) | (0.938) | (0.938) | (0.936) |
| $\triangle UFCI_{SSIV} \times$ Fin ratio | -0.0423 | -0.119* | -0.118* | -0.118* | -0.192*** | -0.191*** | -0.191*** |
| | (0.0726) | (0.0680) | (0.0677) | (0.0679) | (0.0652) | (0.0652) | (0.0653) |
| EU$\times\triangle UFCI_{SSIV}$ | | | -0.00144 | -0.00144 | | 0.000210 | 0.000201 |
| | | | (0.00262) | (0.00263) | | (0.00272) | (0.00272) |
| IMP Share$^{EU15}_{t-1}$ | | 0.0426 | 0.0428 | | | | |
| | | (0.0275) | (0.0275) | | | | |
| EXP Share$^{EU15}_{t-1}$ | | -0.0397 | -0.0397 | | | | |
| | | (0.0308) | (0.0307) | | | | |
| EU$\times$IMP Share$^{EU15}_{t-1}$ | | | | 0.0429 | | | |
| | | | | (0.0300) | | | |
| EU$\times$EXP Share$^{EU15}_{t-1}$ | | | | -0.0415 | | | |
| | | | | (0.0325) | | | |
| $\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | 0.0434* | 0.0435* | |
| | | | | | (0.0243) | (0.0243) | |
| $\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | 0.0394 | 0.0393 | |
| | | | | | (0.0257) | (0.0258) | |
| EU$\times\triangle$IMP Share$^{EU15}_{t-1}$ | | | | | | | 0.0386 |
| | | | | | | | (0.0264) |
| EU$\times\triangle$EXP Share$^{EU15}_{t-1}$ | | | | | | | 0.0511* |
| | | | | | | | (0.0277) |
| Firm FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year$\times$Industry FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Observations | 14,345 | 11,928 | 11,928 | 11,928 | 10,472 | 10,472 | 10,472 |
| R-squared | 0.182 | 0.181 | 0.181 | 0.181 | 0.186 | 0.186 | 0.186 |
| Firm Size | Large | Large | Large | Large | Large | Large | Large |

**Note**: Clustered robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. $\triangle EI_y$ stands for the Davis-Haltiwanger growth rate of firm-level expenditure on energy over sales. $\triangle UFCI_{SSIV}$ is the predicted value of $\triangle$UFCI based on SSIV in the first stage. Fin ratio stands for the sum of amortization and interest payment of debt over firm sales. $\triangle$EXP Share$^{EU15}_{t-1}$ ($\triangle$IMP Share$^{EU15}_{t-1}$) stands for the change in firm-level lagged export (import) share to EU15 countries. EU is a dummy variable that takes value one after 2004.