Productivity gains from better performing EU buildings: evidence from EIBIS

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Abstract

Investment in energy efficiency are crucial for the energy transition to a carbon-neutral economy. However, many investment opportunities in energy-efficiency measures are missed, despite being financially sustainable. This study in an effort to increase the financial attractiveness of energy-efficiency investments looks at the relationship between building stock energy-efficiency standards and firm's productivity. It exploits information from a unique firm-level survey conducted by the EIB and a rich dataset. Results show that a positive and causal relationship exist from building stock energy-efficiency standards to productivity. This relationship is more pronounced for more productive firms and for the manufacturing and infrastructure sectors. Therefore, firms should weigh these benefits if the wish to make an overall informed decision when they assess energy-efficiency projects and not consider their direct cost effectiveness base only on energy savings.

Keywords

Non-energy benefits, building stock quality, productivity, European investment bank survey.

JEL-Classification: P28, Q41, Q48

1. Introduction

Energy efficiency is one of the cornerstones of EU Energy Policy (COM, 2018), and closely linked to its three main pillars: security (security of supply, import independence, safe production), sustainability (reducing greenhouse gas (GHG) emissions) and competitiveness (affordable energy for end-users, contribution to growth and jobs). This is why a new, more ambitious, target than that proposed initially by the EC in 2016 was agreed by the European Parliament and Council negotiators. In June 2018, the EU reached a deal on a new 32.5% energy-efficiency target for 2030, with an upwards revision clause by 2023.

Despite its importance, numerous reports and studies have shown that there is a gap between the energy efficiency measures that could be theoretically implemented and those that are actually realized (Hist and Brown, 1990). Many opportunities for investment in energy efficiency are missed, though being financially sustainable and requiring limited capital spending. A number of financial and non-financial barriers drives this non-adoption of cost-effective energy efficiency measures, which is known as "energy-efficiency gap". Investment barriers to energy efficiency measures can be classified into: behavioral, organizational and economic, are multi-faceted, diverse and often specific to individual technologies and sectors (Sorrel, et al. 2004). In addition to these, existing literature suggests that firms tend to focus on the direct energy impacts of energy-efficiency measures when assessing an energy-efficiency investment and tend to neglect other significant non-energy benefits (indirect impacts).

Non-energy benefits represent a diverse collection of effects that may range from increased productivity and decreased operation and maintenance costs to improved indoor work environments and positive effects on the external environment, for instance, a decrease in waste and emissions (e.g., Pye and McKane, 2000; Finman and Laitner, 2001). These benefits can arise from investment in production processes (replace of old equipment with state-of-art machinery) or support processes (e.g. lightning, heating, ventilation and cooling) depending on whether it concerns a direct or indirect energy use (Fleiter, 2012; Ramihisard et al., 2010). Nevertheless, some of these benefits, including productivity gains, are difficult to quantify because they are intangible. Probably this is the main reason why the empirical research into this link has been limited and little is known about how firms perceive non-energy benefits and if and how they are considered related to energy-efficiency investments.

Therefore, understanding, quantifying and properly incorporating the additional gains into cost-benefit analysis would more accurately depict the broader value of energy-efficiency measures. These benefits can significantly change the cost assessment of the technology and result in a more favorable evaluation (Worrell et al., 2001). At the project level, the effect of additional benefits on cost assessments could determine whether or not a project is undertaken. From a macro perspective, the evaluation of additional benefits will influence the assessment of the energy efficiency potential. Industry and sectoral modeling studies often exclude an (explicit) evaluation of the additional benefits in assessments of the potential for energy-efficiency improvement and miss capturing the potential gains associated with pursuing energy-efficiency measures.

In this context, this study contributes to the empirical literature of the productivity gains of energy-efficiency improvements, by exploiting information from a unique firm-level survey carried out by the European Investment Bank (EIBIS). EIBIS provides rich evidence, directly from firms, with a detailed breakdown by sector and size classes that are not available from existing statistics. Using this dataset, developments in productivity compared to costs, and buildings stock energy-efficiency standards are investigated within an empirical multivariate framework that controls for the firm's characteristics (such as size and sector of activity), production technology, the characteristics of the workforce, exposure to foreign markets etc. To the best of my knowledge, this is the first empirical study that looks at the impact of the quality of buildings stock on productivity in EU firms by using survey information to fill the severe data limitations and offering an alternative approach to measuring the energy-efficiency impacts.

Why would someone expect productivity gains from higher building stock energy-efficiency standards? Many case studies have shown that improved indoor environment, comfort, health, safety and reduced noise induced workers to be more engaged, productive and happier. An energy efficiency building effectively controls the flow of air, heat and moisture through the building. An efficient building maintains moderate temperatures, low humidity and increased air quality. A recent case study, conducted by researchers at the Harvard T.H. Chan School of public health's center for health and the Global Environment (CHGE) and SUNY Upstate Medical, proved that working in high-performing, green-certified buildings could improve employee decision-making. Workers in weak performing buildings appear to be less concentrated on their tasks and record higher rates of absenteeism.

The study is organised as follows: Section 2 provides a summary of the related literature. Section 3 and 4 deal with the data employed in this study and gives information on the conceptual framework. Section 5 discusses the empirical results and the last section contains the concluding remarks.

2. Literature Review

A number of studies (Mills and Rosenfeld 1996; Pye and McKance 2000; Worrell et al. 2003) have stressed the need to quantify additional benefits of energy efficiency investments, beyond their direct benefits of energy savings and energy saving costs. Most of them have investigated these benefits at an aggregated level (Finman and Laitner (2001), Worrell et al. (2003) and Lung et al. (2005), Skumatz and Dickerson (2000)), while others (Lilly and Pearson (1999), Pye and McKane (2000), Worrell et al. (2001) and Trianni et al. (2014) have focused on specific benefits. Although, there is not a clear definition for these benefits, the term non-energy benefits (NEBs) is the most commonly cited (Rasmussen, 2017).

IEA (2012, 2014) summarized the main research findings regarding the benefits of energy efficiency investments, by identifying fifteen classes of multiple benefits and classifying them into five categories based on their societal level (individual, sectoral, national and international): macroeconomic impacts, public budget impacts, health and well-being impact, energy delivery impacts and industrial sector impact. The latter benefit for firms includes reductions in resource use and pollution, improved production and capacity utilization, and less operation and maintenance, which leads to improved productivity and competitiveness. More recently, Nehler (2018) provided an updated systematic review of the academic literature on NEBs, discussing issues such as methods for observation, measuring, quantification and monetization of the benefits.

Nearly all studies on NEBs have followed an ex-post perspective and applied a case study approach to analyse the additional benefits of energy efficiency investment, before and after the implementation of specific measure. The first case studies were conducted in the USA around the year 2000 (Nehler, 2018) and more than ten years later similar studies took place in Europe too (Sweden, Denmark, Italy, Romania). In particular, Lille and Pearson (1999) based on five case studies estimated the energy cost savings and NEBs of energy efficiency measures and found that the savings from the latter benefits amounted to 24% of total savings. According to their findings, the majority (81%) of the observed NEBs were related to reductions in operation and maintenance cost and had financial implications. The inclusion of the NEBs reduced the payback period from 2.6 to 1.3 years and helped increasing the benefit/cost ratios, on average, by 27%.

Pye and McKane (2000) estimated the monetary values of the non-energy benefits of energy efficiency projects and included them in the investment cash flow analysis in an attempt to enhance the financial attractiveness of the projects and help the management realise the energy-efficiency opportunities. Specifically, they analysed three case studies to monetise the benefits from increased production, reduced emissions, reduced material use, improved product quality and reduced needs for cleaning and maintenance. According to their findings, factors, such as productivity gains are strong incentives for energy efficiency investments. Skumatz et al. (2000) also supported that energy efficiency projects, among other things, lead to improved productivity, greater product life, lower losses of product and better quality – reduced maintenance.

Similarly, Finman and Laitner (2001) investigated 77 case studies in the USA and found that in 52 of them the NEBs were equal to or greater than the energy savings and resulted in cutting the payback period of energy-efficiency projects by half, to almost 2 years. Likewise, Hall and Roth (2003), based on the businesses studied, estimated the NEBs at about 2.5 times the energy savings and concluded that some of the NEBs related to production, operating and maintenance, waste and emissions can be quantified, while for others such as the well-being of workers is more challenging. Lung et al. (2005) reached the same conclusion for improved working conditions (improved worker safety, reduced noise, improved air quality). Jacob (2006)

Fleiter et al. (2012) and Trianni et al. (2014) introduced the NEBs in the assessment framework of energy-efficiency investments. The first authors added to their questionnaires an explicit category for

NEBs and the latter three attribute categories (environmental, production and implementation). Both studies concluded that large positive NEBs result to higher adoption rates of energy-efficiency measures. However, it was Worrell et al. (2003), who applied the term productivity benefits and proposed a framework for evaluating productivity benefits related to energy efficiency technologies. The framework consists of four steps: first, identify and describe the productivity benefits; second, quantify the previously identified benefits to the extent possible; third, identify all necessary assumptions; and fourth, calculate the cost impacts of the productivity benefits (Worrell et al. 2003). This implies that a first step in the process of quantifying the benefits of energy efficiency is to define and categorise them in a way that can enable quantification. Further research on the additional benefits of energy efficiency is thus necessary, both at the empirical level, i.e. through collecting data, and at a theoretical level, i.e. by developing conceptual frameworks that can facilitate description of these benefits to improve the business case of energy efficiency investments (Cooremans 2015).

Another strand of the literature has specifically analyzed how facility improvements measures affect productivity. Loftness, et al. (2003) showed that better light and more natural light can improve office worker productivity and well-being. Their study supported that the productivity gains ranges from 0.7 to 23% with improved lighting design. The latter measure led to increases in reading comprehension, letter processing speed and a range of other tasks, as well as reduced absenteeism. Similarly, Seppanen et al. (2006) found that indoor office temperature is a key determinant of productivity. Their study revealed that work performance decreases with temperature above 24oC and at 30oC reaches 90% of the maximum. Hedge et al (2004) found also that when temperatures are low employees make more mistakes than at optimal room temperature and appear to be more distracted, while Loftness et al. (2003) identified eight studies linking individual control of workstation temperature with 0.2 to 3% gains in overall productivity. Another study (Gurtekin-Gelik, 2003) supported that noise can cause productivity losses in certain types of work. The estimated productivity gains from working under quieter conditions ranged between 1.8 and 19.8%. Finally, Wyon (2004) proved that improved ventilation, air filtration and cleanliness of duct systems can also result in energy efficiency gains, which could be from 6 to 9% in terms of work performance.

Compared to the previous studies, Montalbano and Nenci (2018) were the first, who investigated empirically the impact of energy efficiency improvements on the productivity and exporting behaviour of firms in Latin America empirically. They applied a Cobb-Douglas production function and assessed the correlation between energy intensity and productivity, after taking into account the heterogeneity of firms. Their results suggested a positive and heterogeneous impact across sectors and size classes, but as the authors acknowledged, energy intensity is considered as an imperfect proxy of energy efficiency (Patterson, 1996; Freeman et al. 1997; Proskuryakova and Kovalev, 2015).

3. Theoretical Considerations

The majority of existing studies that have empirically investigated the determinants of productivity assume that firm's outcome is determined by the Cobb-Douglas production function. This paper extends this production function by allowing the quality of building stock to affect the multifactor productivity (A), besides, physical and human capital, innovative activities and country, sector, size and time-specific dummies, as follows:

$$Y_{it} = A(\,X_{it},\, EE_{it})L_{it}^{a}K_{it}^{b} \qquad (1)$$

where Y_{it} is the output of firm i in period t, L_{it} is the number of full-time employees in firm i at time t, and K_{it} is the fixed capital stock of firm i in period t. X_{it} is a vector of various controls captures firm's export activity, ownership, innovative activities, size, years of operation, access to finance, country and its sector affiliation (4 industries)[1], EE_{it} are the perceptions of firms about the proportion of their building stock that satisfies high or highest energy efficiency standards in EIBIS.

The main testing hypothesis is to assess the relationship between building stock energy-efficiency standards and productivity. In this study, the firm's factor productivity (TFP) is measured in three different ways to corroborate the robustness of the empirical results (Ospina and Schiffbauer, 2010). First, it is measured as the residual of the Cobb-Douglas function based on the methodology of Olley and Pakes (1996). Second, the firm's productivity is measured as an index relative to the industry median, in line with Caves, Christensen and Diewert (1982) and as a third benchmark the labor productivity is used, defined as the ratio of firm value added to human capital.

The building stock energy-efficiency standards is expected to affect mainly labor productivity through improved indoor environment, comfort, health and safety. Measures that that reduce indoor air pollution, enhance thermal comfort, or improve factors associated with health or safety, such as the ability of exhaust heat recovery systems to decrease the likelihood of insufficient ventilation rates at certain times of day or in certain parts of a building influence significantly workers' productivity. Similar impact have measures that lead to reduced noise levels, such as the sound-insulating value of highly-efficient windows.

Some research has investigated the impact of temperature, while other studies have looked at indoor air quality. Other research efforts have looked at office design and its impact on worker happiness. Happier employees typically are more engaged and productive, and are more easily retained by the organization.

For example, in a study of the World Green Building Council, 81% of the office workers surveyed found trouble concentrating in high indoor temperature conditions and 65% of them indicated that it would take 25% longer than usual in such cases to complete their tasks. Similarly, Dell and Intel conducted surveys on worker views of smart building technology and concluded that that more smart building technology, when desired by employees, will lead to happier and more productive workers.

a. Measuring productivity

To calculate the first measure of productivity, I estimate input elasticities for each sector based on equation (1) in logs, as follows:

$$y_{it} = a_i^k k_{it} + a_i^l l_{it} + n_s + e_{it} \tag{2}$$

where lower letter cases indicate the natural logarithm of the original variables, a stands for input elasticities, n are country and sector specific effects and e represents the error term.

I investigate the possibility of heterogeneous coefficients by running a series of regressions on different sub-samples. In line with EIBIS design, I run separate regressions by sector affiliation. The combination of the country and sector dimensions would have entailed onto small sample sizes and therefore was not considered as an option for the current analysis. The null hypothesis of equal coefficients either across all sectors is rejected, which implies that there is little evidence of a common Cobb-Douglas production function across the different sub-samples. This implies that it better to calculate the productivity indicator based on the individual sector input elasticities.

Assuming that there is an endogeneity problem when estimating equation (2), as the firm's demand for labor is expected to depend on its contemporaneous productivity level, the Olley and Pakes (1996) is employed. The estimated input elasticities with the two procedures: OLS and Olley and Pakes, confirm that the second methodology provides more unbiased estimates (Table 1) . The magnitude of the labor

[1] To investigate the effect of the economic activity, firms were classified into four main sectors – Manufacturing, Construction, Services, and Infrastructure – based on the NACE (Nomenclature des Activités économiques dans les Communautées Européennes) classification of economic activities.

coefficients moved in the predicted direction and decreased for all sectors, while the capital coefficients increased for the two out of four sectors. This is an indication that the Olley-Peaks correction is working well.

The second measure for productivity based on Caves, Christensen and Diewert (1982) is calculated in relation to the sector level median, as follows:

$$TFP_{it} = (y_{ist} - \tilde{y}_{st}) - a_i^l \times (l_{ist} - \tilde{l}_{st}) - a_i^m \times (m_{ist} - \tilde{m}_{st}) - (1 - a_i^l - a_i^k) \times (k_{ist} - \tilde{k}_{st}) \quad (3)$$

Where y stands for sales, this time, m represents the intermediates inputs in addition to labor and fixed capital stock inputs and the tilde ( ) stands for the sector median of each variable. The input elasticities are estimated by assuming constant returns to scale.

Table 3A shows the correlation coefficients between the three different measures.[2] The correlation coefficient between the Olley and Pakes productivity and labor productivity is the highest with 0.6, while that of Caves et al. productivity with labor productivity is the lowest with 0.30. Given that these correlation indexes are not uniform, it is decided to report results for all three productivity measures.

b. Empirical strategy

After calculating the three productivity measures, the next step is to investigate the relationship between firm productivity and the quality of firms' building stock. The main objective is to determine how much of the variation in firm-level productivity is associated with variations in the quality of buildings. The model is almost similar for the three productivity measures and in has the following general form:

$$P_{it} = b_i \ EE_{it} + b_i^X X_{it} + \mu_i + n_s + e_{it} \quad (4)$$

Where P stands for the three productivity measures, X is a vector of firm-specific control variable, EE is the variable of interest-the quality of the building stock, m and n, s are country, sector and size effects, and e represents the error term. The vector of firm-specific control variables includes information about firms access to finance, international markets, legal status.

Further to this, I assess whether the impact of the explanatory variables on productivity measures is different across sectors, as in Montalbano and Nenci (2018) and across productivity levels, as in Velucchi and Viviani (2011). This is done by running separate regressions by industry-firm size groups and level of productivity. Specifically, the homogeneity assumption for industry-firm groups is tested based on OLS regressions, while for high/low labour productive firms are tested based on quantile regressions. The latter method calculates coefficient estimates at various quantiles of the productivity conditional distribution.

Finally, in an attempt to establish causality, I apply the instrumental variable approach by using internal and external instrumental variables. Taking advantage the subset of firms participated in more than two waves of EIBIS, the lagged values of the quality of buildings indicator, along with the information of firms about energy audits and the importance of energy costs on their investment decisions were used. Kalantzis and Revoltella (2019) found that both of the latter instruments play a crucial role in the quality of building stock. Energy audits are positively correlated with building's stock performance, while minor energy cost concerns are correlated negatively and vice versa. Both instruments can be considered as exogenous to the dependent variable, the three productivity measures.

[2] Van Biesebroeck (2003) estimated correlation indexes with a range of -0.02 to 0.99 for these measures of productivity and Ospina and Schiffbauer (2010) between 0.21 and 0.45.

4. Data

The data employed in this paper are from an unbalanced panel of the European Investment Bank Survey (EIBIS) for the period 2016 to 2018. The annual EIB Group Survey on Investment and Investment Finance is an EU-wide survey that gathers qualitative and quantitative information on investment activities by both small businesses (with between 5 and 250 employees) and larger corporates (with more than 250 employees), their financing requirements and the difficulties they face.

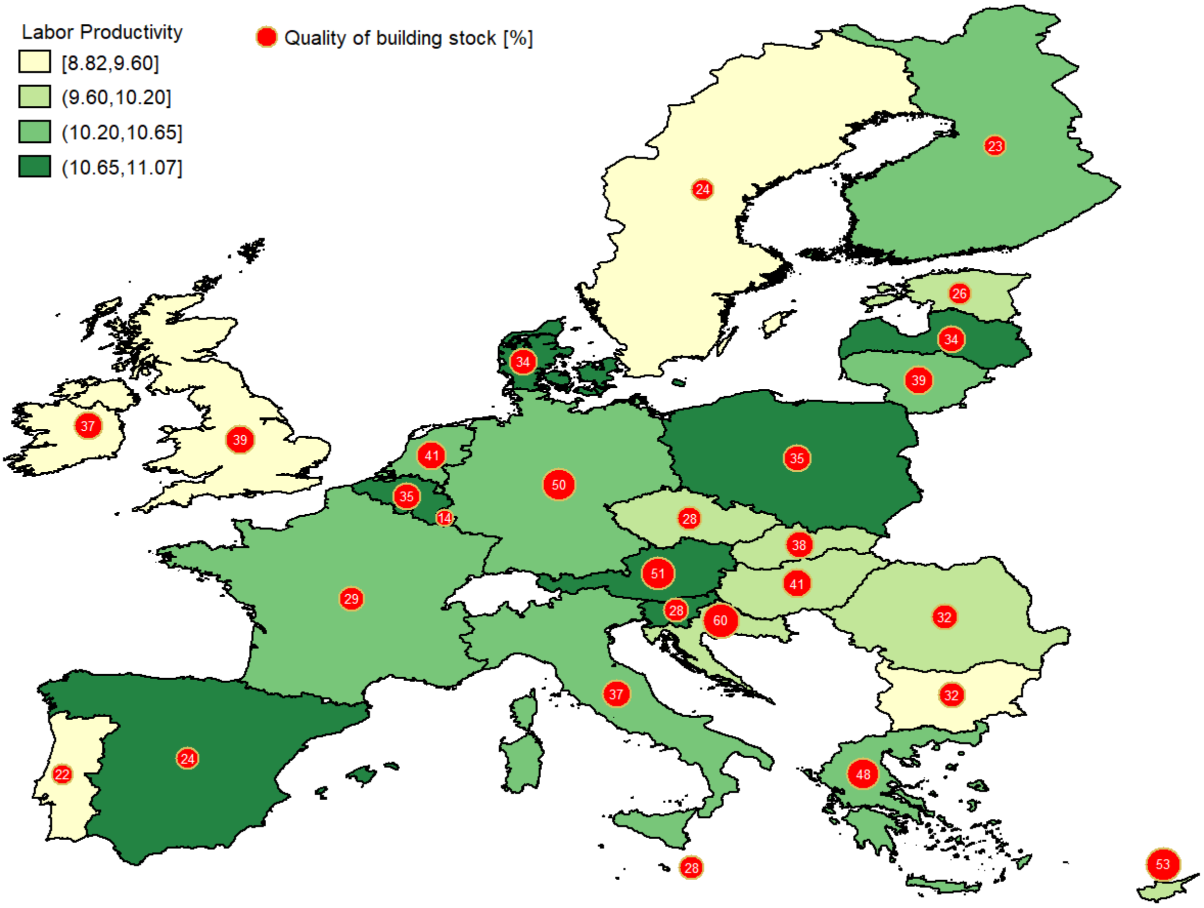
The survey involves interviews with some 12 500 businesses in total. Using a stratified sampling methodology, it is designed to be representative at the EU level; country level; and, for most countries, the sector group level (manufacturing, services, construction and infrastructure) as well as firm sizes class level (micro, small, medium and large). All survey respondents are sampled from the Bureau van Dijk ORBIS database and their answers were matched to reported firm's balance sheet and income statements.

EIBIS is carried out annually, with the first wave of interviews having taken place in 2016. The main advantage of this study dataset is that it provides information on the quality of building stock of firms, as well as other relevant variable for the energy profile of firms such as their decision to conduct an energy audit and the perception of firms about the importance of energy costs in their investment decisions. The dataset also include information about firms value-added, sales, fixed assets and number of employees, their exporting activity, ownership status, operating years, sector affiliation and access to finance.

The description and summary statistics of the explanatory variables are presented in Table 2. EIBIS data show that a firm has on average 210 employees and 12.7 million euro in value added. The average share of firms with exporting activities accounts for 45% and that around 12% of firms are owned by foreign firms. Total investments vary from zero to €15,800m, with an average of €5.2m. In the total sample, it appears that only 9% is finance constrained[3] and that on average a firm is almost 4.5 years old. Around 33% of firms on average conducted an energy audit and only one third of the total sample considers energy cost as minor obstacle for investments. Finally, the average share of building stock that satisfy higher energy-efficiency standards is perceived to be 35%. In addition, the correlation indexes between the covariates included in this analysis (Table 3B) are very low, indicating that the models do not suffer from multicolinearity.

[3] A firm is considered to be finance constrained according to EIBIS if one of the following four conditions is satisfied: 1) the firm sought a certain amount of financing but received (or was offered) a smaller amount (quantity constrained); 2) a firm sought external finance but did not obtain it (rejected); 3) a firm sought external finance but the cost of it was too high (price constraint); 4) a firm was discouraged from obtaining external finance due to the possibility of being rejected (discouraged).

Figure 1 Interaction between labor productivity and quality of building stock across EU countries



Note: The quality of building stock is measured as the share of building stock that satisfy higher energy-efficiency standards based on EIBIS

Looking at the labor productivity levels across countries for all sectors and size of firms and their respective perceptions about the quality of their building stock, it is not observed any clear pattern between the two. Denmark's labor productivity is the highest in the sample and above 25% that the level in Bulgaria, the country with the lowest level. Much greater is the heterogeneity in the perceptions of firms about their building stock quality. Low-income countries, including Croatia, Greece and Cyprus appear to have a better building stock quality than higher-income countries, such as Luxembourg, Sweden and Finland.

5. Results

This section presents the results of the empirical analysis. First, I estimate the relationship of the quality of buildings and the three productivity measures chosen for the pooled sample. Then, I investigate whether this relationship differs across sectors and productivity levels, given the heterogeneity observed in the production function estimations. Finally, I address causality by estimating the nexus of these two variables based on an instrumental variable approach.

Table 4 presents the results of the cross-section model (equation 4) on the overall sample where the dependent variable (3 measures of productivity) is regressed on a set of covariates controlling for unobservable and observable heterogeneity among firms. The visual inspection of the coefficients show that in all cases the coefficients have the expected sign and are statistically significant.[4] The first row of

[4] A fixed effect model was employed to test the main hypothesis but it was excluded from the analysis, as the fixed effects wash out the effect of the time-invariant variables such as the dummies for the exporting activity, the foreign ownership of firms and the quality of buildings stock standards.

the table indicates that the building energy-efficiency standards are positively correlated with all three productivity measures after controlling for the other firm-level productivity factors. On average firms that have buildings that satisfy 10pp higher energy efficiency standards, have almost 1% higher productivity levels based on Olley and Pakes (1996) and 0.5% based on Caves, Christensen and Diewert (1982) and 1.3% higher labor productivity.

Estimates in the three models point to some degree of sectoral and country heterogeneity. Firms in the manufacturing are less likely to benefit from higher productivity compared to infrastructure and construction sectors and to a lesser extend to the services sector. Likewise, medium and large firms record higher productivity levels compared to micro and small firms. The heterogeneity across countries in terms of productivity is more pronounced, with Denmark, Spain and Belgium presenting one of the highest levels and Bulgaria the lowest. Taking into account this heterogeneity, the impact of building stock energy-efficiency standards per sector was investigated, given that the production function across sectors usually differ.

On sectorial level, this impact varies across productivity measures and sectors. The testing hypothesis remains valid for all sectors, with the exception of the construction sector. The services and infrastructure sectors present the highest correlation of the buildings' energy efficiency standards with productivity, followed by the manufacturing sector. This correlation is almost similar for the three aforementioned sectors when it concerns labor productivity (0.14). For the latter productivity measure the correlation coefficient (0.09) of the construction sector is also statistical significant. Little evidence supporting the main testing hypothesis per sector is found only when productivity is measured based on the Caves, Christensen and Diewert (1982) methodology. However, the test of equality of coefficients across sectors reveals that the observed differences are not statistically significant for all productivity measures (Table 4).

As the distributions of the measured productivity variables depict substantial dispersion (table 2), the importance of the selected variables over the entire conditional productivity distribution is also tested, by running the OLS model with quantile regressions. Graphs 2-4 present both the OLS estimators and the 10 different quantile estimators in increments of 10% up to 90% quantile. Specifically, the dashed line shows the OLS coefficient included in Table x for each productivity measure. The dotted lines display the 95% confidence interval of the OLS coefficient. The solid line presents the coefficients of the 10 quantile-regressions. The shaded area depict the 95% confidence intervals of the quantile regressions.

According to these figures, the value of the estimated coefficients of the variable of interest i.e. quality of buildings varies significantly over the conditional labor productivity distribution, but remain within the range of the previous estimations. For all productivity measures, the estimated coefficients become more important at higher quantiles and much less relevant for low productivity firms, suggesting a systematic non-linearity in the relationship between the quality of buildings and productivity. This implies that high productivity firms are more incentivized to invest in measures, including energy efficiency that would help them to reduce costs and escape competition, the closer they are to the technological frontier.

Overall, the results point to a positive correlation between buildings' energy-efficiency standards and productivity for the EU firms. This nexus is more pronounced, as mentioned, in the two out of the three variables used to measure productivity, namely the Olley and Pakes and labor productivity measures. The testing hypothesis for the productivity measure defined based on Caves, Christensen and Diewert (1982) is only valid for the total sample and for the manufacturing and infrastructure sectors. Moreover, the findings suggest that this relationship is non-linear, given that the positive correlation is increasing in the productivity level of the firm.

Results also show that all the additional independent variables selected are particularly relevant in estimating the level of labor productivity and consistent with the theoretical predictions and the empirical findings in the literature. Specifically, the coefficient of the variable representing the foreign ownership and exporting and innovative activities are positive and highly significant. Productivity gains are higher in foreign owned firms than domestic firms (Melitz (2003) and Helpman, Melitz, and Yeaple (2004), especially in services and construction sectors. This impact on productivity gets smaller with the size i.e. smaller domestically owned firms are less productive. Higher is the productivity of firms that are medium and large sized, as well as in the manufacturing and construction sector Bartelsman and Doms (2000) and Van Biesebroeck (2005). Firms that have better access to finance are found to be more productive (Hallward-Driemeier, Wallsten, and Xu (2003) and Christopoulos and Tsionas (2004)). Finally, older firms appear to be on average associated with higher productivity levels, contrary to the findings of Bartelsman and Doms (2000) and Van Biesebroeck (2005).

Turning now to causality, Tables 5A-C summarizes the results of the instrumental variable (IV) approach. The first column of the documents the result of the first-stage regressions using the lagged value of the quality of buildings and the decision of firms to invest in energy-efficiency measures. The first-stage results show that all instruments are highly relevant to the quality of buildings. Their coefficients are statistically significant at 1% level and the joint hypothesis of zero coefficients is rejected at 1%, especially in the cases of labor and Olley and Pakes productivity measures and almost for all sectors. The quality of buildings depends significantly on previous year quality (0.5), energy audits are positively associated with higher building's stock energy-efficiency standards, by 10pp to 20pp, while when firms considered energy costs as a minor obstacle to investments their building stock satisfy around 5pp. lower energy-efficiency standards. The DW statistic confirms that the chosen instruments are not correlated and the Sargan test indicates that these instruments are uncorrelated with the error process, which suggests that they are valid for the analysis.

The results of the second stage of the instrumental variable approach are reported in the second column of each productivity measure. They reveal a positive causal relationship from energy-efficiency building's standards to all three productivity measures. This impact is statistically significant and ranges from around 0.10 for Olley and Pakes to marginally above 0.20 for labor productivity and Caves, Christensen and Diewert productivity. However, the results are more ambiguous for the productivity measure based on Caves, Christensen and Diewert when the analysis takes into account the sectorial dimension. The estimated coefficients are still positive but not statistically significant for all sectors, expect the infrastructure sectors. By contrast, on a sectorial level significant are found to be the coefficients of the quality of buildings in the manufacturing and infrastructure sectors for both labor productivity and the Olley and Pakes productivity. This impact seems to be higher for the infrastructure sector in both cases, ranging from 0.29 to 0.58. For the manufacturing sector, this impact is estimated at around 0.2. Therefore, someone could conclude that the overall causal relationship between building performance and productivity is driven by these two sectors: manufacturing and infrastructure or that the sector classification requires greater disaggregation.

6. Concluding Remarks and Policy Implications

The non-energy benefits of energy-efficiency investments is a less explored area for various reasons, including the intangible nature of the benefits and the difficulty to distinguish and quantify them. To that end, little is known about how firms understand these benefits and if and how firms incorporate them in the decision-making process for energy-efficiency investments. This study attempted to overcome the severe data limitation by exploiting information from a unique firm-level survey carried out by the European Investment Bank to identify the impact of better performing buildings, as a result of energy-efficiency investments, on firm's productivity.

To investigate this relationship an empirical multivariate framework, based on a Cobb-Douglas production function, was employed that controls for various, characteristics within and outside firm level. The analysis revealed that the three productivity measures estimated depict great heterogeneity especially across sectors and size of firms. Firms in the services sector record higher productivity levels, followed by infrastructure, construction and the manufacturing sectors. Similarly, medium and large sized firms appeared to be more productive than micro and small firms were. Across countries, there is not a clear pattern, with Denmark's productivity level being the highest and above 25% from the lowest observed level in Bulgaria. Much greater are the differences across countries with respect to firms' perception about the quality of their building stock. Firms in Croatia, Greece and Cyprus perceived to have building stock that satisfy higher energy-efficiency standards than firms in Sweden and Luxembourg.

After taking into account this heterogeneity, the results of the estimated models suggest that there is a positive and causal relationship from better performing buildings to productivity. The arguments of the various case studies that improved indoor environment, comfort, health, safety and reduced noise, seem to outweigh the investment costs of various energy-efficiency measures and induce employees to be more engaged, happier and productive proved be to rationale. Firms that have building stock that satisfy 10% higher energy-efficiency standards have, at least, 1% higher productivity levels based on the instrumental variable approach.

The analysis also indicated that the relationship between productivity and energy-efficiency standards is not constant across quantiles. By disentangling the effects of the effect of building stock energy-efficiency standards on different level of productivity measures, it was observed that the quality of building stocks is more relevant for highly productive firms than for low productive firms. The quantile regression approach shows that the medium estimates obtained by the OLS regressions do not capture the complex dynamics and heterogeneity of the EU firms' productivity.

This finding of the causal relationship between building stock energy-efficiency standards and firm's productivity could influence positively the decisions to undertake energy-efficiency projects. It is important for firms to understand that whatever savings are expected from energy-efficiency investments will be delivered, but they should weigh the many benefits of such projects and make an overall informed decision, without being required to only consider direct cost effectiveness based only on energy savings. Only in this way, the financial attractiveness of energy-efficiency investments will increase and firms will contribute to bridging the energy efficiency gap.

A caveat of the current study is the inability to express the impact of higher energy-efficiency standards in monetary units. While this impact can be quantified in percentage terms of the productivity measures calculated, it is difficult to difficult to define what does it mean for firms in terms of additional revenues or reduced costs. Another limitation is that the choice of the covariates included in this study was limited to the information contained in the survey, which was not originally intended to address issues related to the non-energy benefits of energy-efficiency investments.

Going forward, the analysis of productivity gains from better performing buildings should focus more on sector and country trends, on firm-level developments, rather on economy-wide aggregate impacts. This granular detail requires an improvement in the quality and availability of information. Dedicated surveys of firms, possibly covering the determinants of firms to invest in energy-efficiency measures could shed further light on the specific productivity gains from higher energy-efficiency standards in both production and support processes. In this context, an interesting avenue for future research is to better understand how the monetized productivity gains from various energy-efficiency measures affect firm's cash flows and their decision in energy-efficiency investments.

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Appendix

Table 1 Estimated input elasticities

Sample	OLS lnK	OLS lnL	OLS sum	Olley-Pakes lnK	Olley-Pakes lnL	Olley-Pakes sum	Difference	
Total	0.14***	0.94***	1.08	0.08**	0.88***	0.96	**-**	**-**
Manufacturing	0.16***	0.92***	1.08	0.17***	0.83***	1.00	+	**-**
Construction	0.13***	0.99***	1.12	0.13***	0.95***	1.08	**0**	**-**
Services	0.13***	0.91***	1.04	0.14***	0.84***	0.98	+	**-**
Infrastructure	0.13***	0.94***	1.07	0.08***	0.89***	0.97	**-**	**-**

Note: ***, **, * statistically significant at 1%, 5% and 10%. The estimated production function included country, time and sector specific effects

Table 2 Descriptive statistics

	N	**mean**	**sd**	**min**	**max**
O&P productivity	28,029	9.39	0.86	-2.77	16.70
CAVES et al. productivity	12,038	0.00	0.91	-8.93	7.59
Labor productivity	29,912	10.14	1.04	0.00	17.71
Building's performance	33,922	0.35	0.35	0.00	1.00
Energy audit	22,879	0.32	0.47	0.00	1.00
Investment obstacle (minor)-Energy costs	36,746	0.33	0.47	0.00	1.00
Employees	37,176	210.03	1,137	1.00	99,999
Fixed assets (M€)	31,838	47.30	1,240	0.00	180,000
Total investments (M€)	35,851	5.23	107	0.00	15,800
Exporter	37,040	0.45	0.50	0.00	1.00
Value-added (M€)	30,202	12.7	203	-3510	31,400
Foreign-owned	32,456	0.12	0.33	0.00	1.00
Age	37,165	4.37	0.88	1.00	5.00
Finance constrained	34,832	0.09	0.29	0.00	1.00

Table 3A Correlation indexes of endogenous variables

	O&P productivity	CAVES et al. productivity	Labor productivity
O&P productivity	1.00		
CAVES et al. productivity	0.40	1.00	
Labor productivity	0.63	0.30	1.00

Table 3B Correlation indexes of covariates

	Building's perform.	Energy audit	Energy cost concerns	Employees	Fixed assets	Investment	exporter	Foreign-owned	Age	Finance constrained	Value-added
Building's perform.	1.00										
Energy audit	0.22	1.00									
Energy cost concerns	-0.02	0.00	1.00								
Employees	0.05	0.07	0.00	1.00							
Fixed assets	0.04	0.11	-0.01	0.24	1.00						
Investment	0.02	0.04	0.03	0.03	0.12	1.00					
exporter	0.06	0.13	0.07	0.05	-0.01	0.02	1.00				
Foreign-owned	0.00	0.13	0.02	0.03	0.03	0.05	0.19	1.00			
Age	0.05	0.14	0.03	0.00	0.04	0.01	0.11	0.02	1.00		
Finance constrained	-0.03	-0.01	0.01	-0.01	0.02	-0.01	0.00	-0.06	-0.05	1.00	
Value-added	0.03	0.11	0.00	0.43	0.57	0.10	0.05	0.04	0.05	0.00	1.00

Table 4 Pooled estimations: productivity and energy-efficiency standards

	TOTAL			MANUFACTURING			CONSTRUCTION			SERVICES			INFRASTRUCTURE		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
VARIABLES	O&P	CAVES	LABPROD	O&P	CAVES	LABPROD	O&P	CAVES	LABPROD	O&P	CAVES	LABPROD	O&P	CAVES	LABPROD
Building's performance	0.08***	0.06**	0.13***	0.09***	0.08*	0.14***	0.02	0.05	0.09***	0.07**	-0.00	0.14***	0.12***	0.11*	0.15***
Operating years	0.02***	-0.02*	0.04***	0.01	-0.01	0.03**	0.01	-0.04*	0.04***	0.06***	0.01	0.09***	-0.01	-0.05**	-0.01
Finance constrained	-0.11***	-0.08**	-0.12***	-0.10***	-0.13**	-0.11***	-0.05	-0.05	-0.06*	-0.15***	-0.08	-0.16***	-0.13***	-0.08	-0.13***
Exporting activity	0.19***	0.21***	0.22***	0.16***	0.10**	0.21***	0.10***	0.08*	0.13***	0.37***	0.25***	0.41***	0.09***	0.31***	0.08***
Foreign owned	0.24***	0.20***	0.25***	0.17***	0.09**	0.21***	0.30***	0.33***	0.30***	0.39***	0.16***	0.39***	0.20***	0.50***	0.18***
Constant	8.51***	-0.46***	9.93***	8.59***	-0.18	10.11***	8.67***	-0.65***	10.06***	8.11***	-0.47**	9.51***	9.47***	-0.49**	10.37***
Observations	22,667	10,006	23,778	7,006	3,141	7,326	4,829	2,162	5,108	5,369	2,339	5,634	5,463	2,364	5,710
R-squared	0.20	0.02	0.43	0.06	0.01	0.47	0.03	0.04	0.46	0.10	0.03	0.37	0.07	0.06	0.43
Country effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector effects	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Size effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
H0: Testing for heterogeneous coefficients of building's performance between sectors															
Chi-square	5.81	2.01	2.31												
P-value	0.12	0.57	0.51												

Note: ***, **, * statistically significant at 1%, 5% and 10%.

Table 5A Instrumental variable approach: TFP based on Olley and Pakes (1996)

	TOTAL		MANUFACTURING		CONSTRUCTION		SERVICES		INFRASTRUCTURE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	First	Second	First	Second	First	Second	First	Second	First	Second
VARIABLES	Building's perform.	O&P productivity	Building's perform.	O&P productivity	Building's perform.	O&P productivity	Building's perform.	O&P productivity	Building's perform.	O&P productivity
Energy audit	0.12***		0.09***		0.15***		0.13***		0.12***	
Building's perform. (t-1)	0.46***		0.47***		0.48***		0.45***		0.45***	
Minor cost concerns	-0.02**		-0.01		-0.00		-0.05***		-0.01	
Building's performance		0.10**		0.14*		0.00		-0.03		0.29***
Observations	6,436	6,436	2,007	2,007	1,395	1,395	1,492	1,492	1,542	1,542
R-squared	32%	26%	32%	10%	36%	6%	30%	15%	34%	10%
IV F-stat		753.7		223.8		182.4		162		162.7
Durbin pval		0.507		0.373		0.945		0.391		0.173
Sargan		0.886		0.0887		0.993		0.0854		0.242

Table 5B Instrumental variable approach: TFP based on Caves, Christensen, and Diewert (1982)

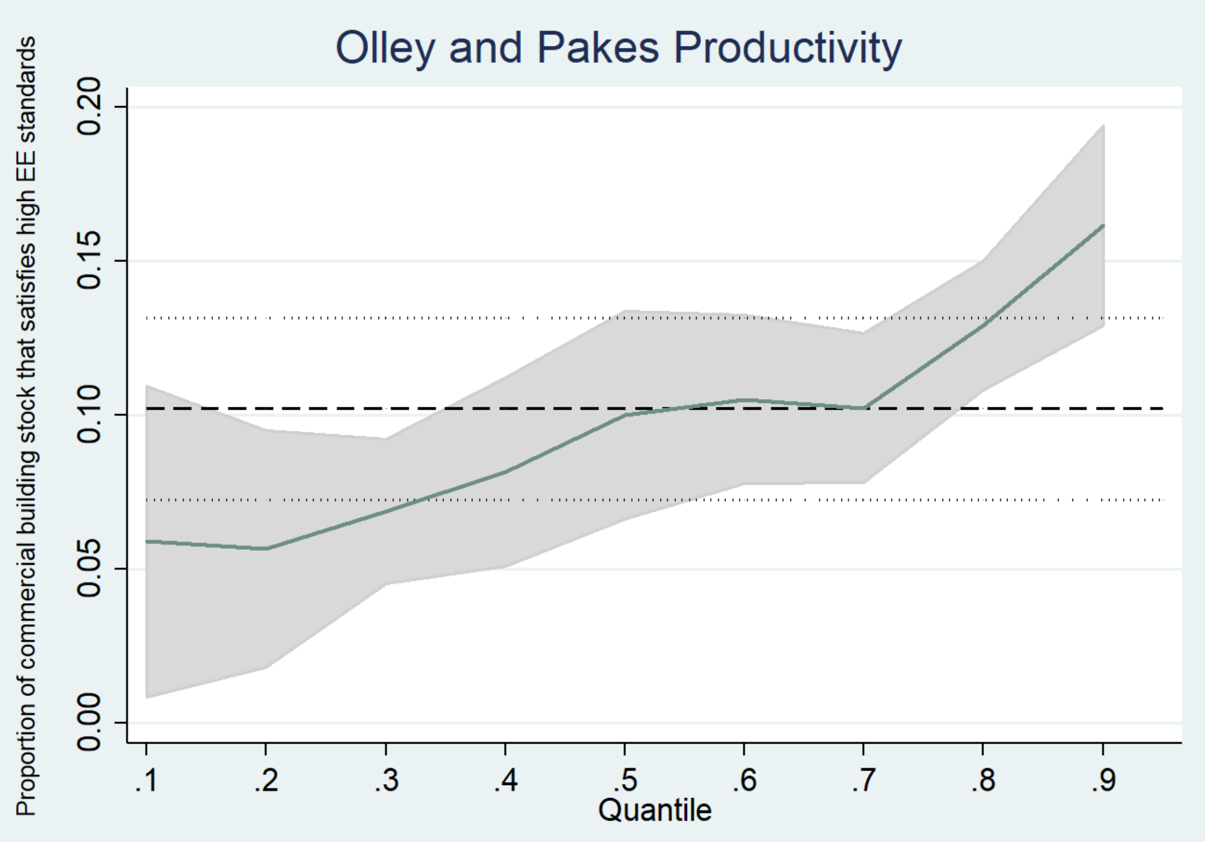
	TOTAL		MANUFACTURING		CONSTRUCTION		SERVICES		INFRASTRUCTURE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	First	Second	First	Second	First	Second	First	Second	First	Second
VARIABLES	Building's perform.	CAVES productivity	Building's perform.	CAVES productivity	Building's perform.	CAVES productivity	Building's perform.	CAVES productivity	Building's perform.	CAVES productivity
Energy audit	0.13***		0.09***		0.16***		0.20***		0.11***	
Building's perform. (t-1)	0.49***		0.54***		0.44***		0.43***		0.47***	
Minor cost concerns	-0.01		0.02		-0.00		-0.06**		-0.02	
Building's performance		0.21**		0.18		0.01		0.07		0.58**
Observations	2,258	2,258	731	731	505	505	509	509	513	513
R-squared	32%	5%	37%	7%	33%	9%	32%	9%	36%	9%
IV F-stat		286.9		110		49.69		62.17		55.41
Durbin pval		0.304		0.688		0.488		0.639		0.0297
Sargan		0.456		0.324		0.548		0.174		0.180

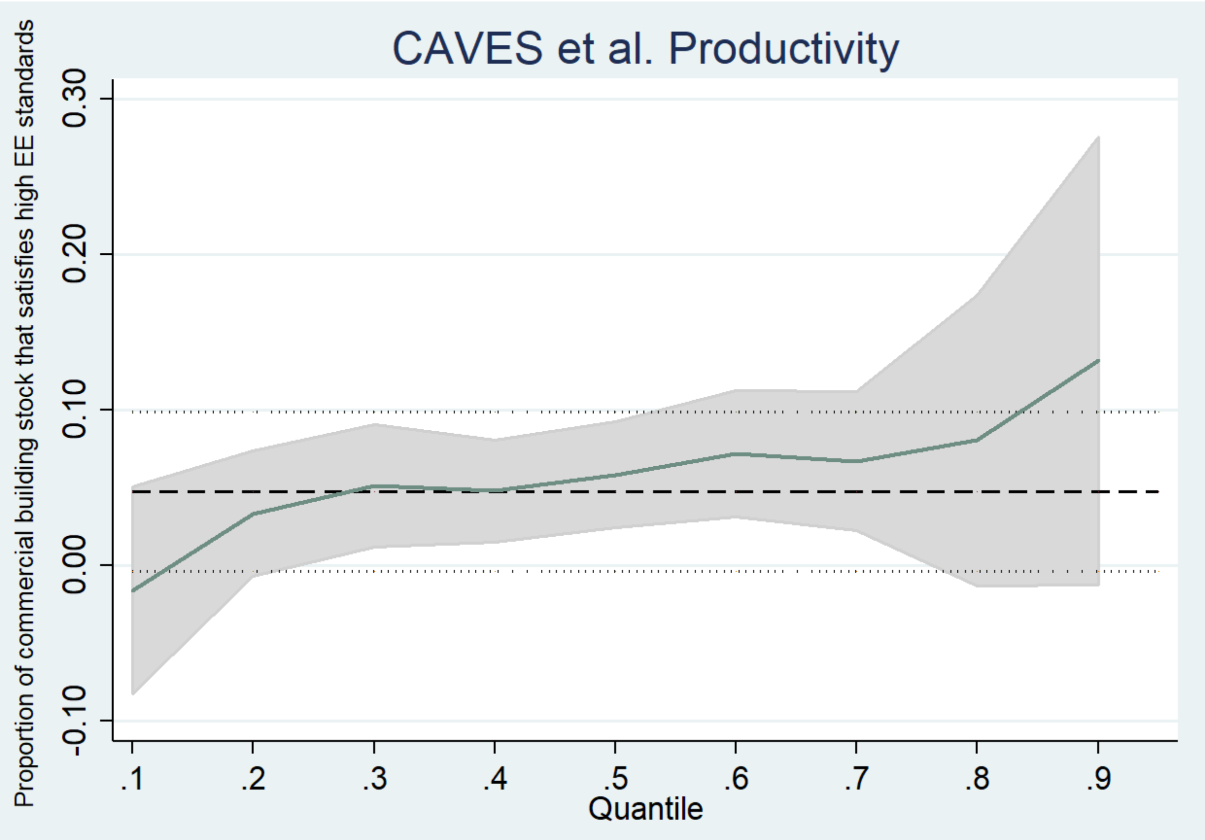
Table 5C Instrumental variable approach: Labor productivity

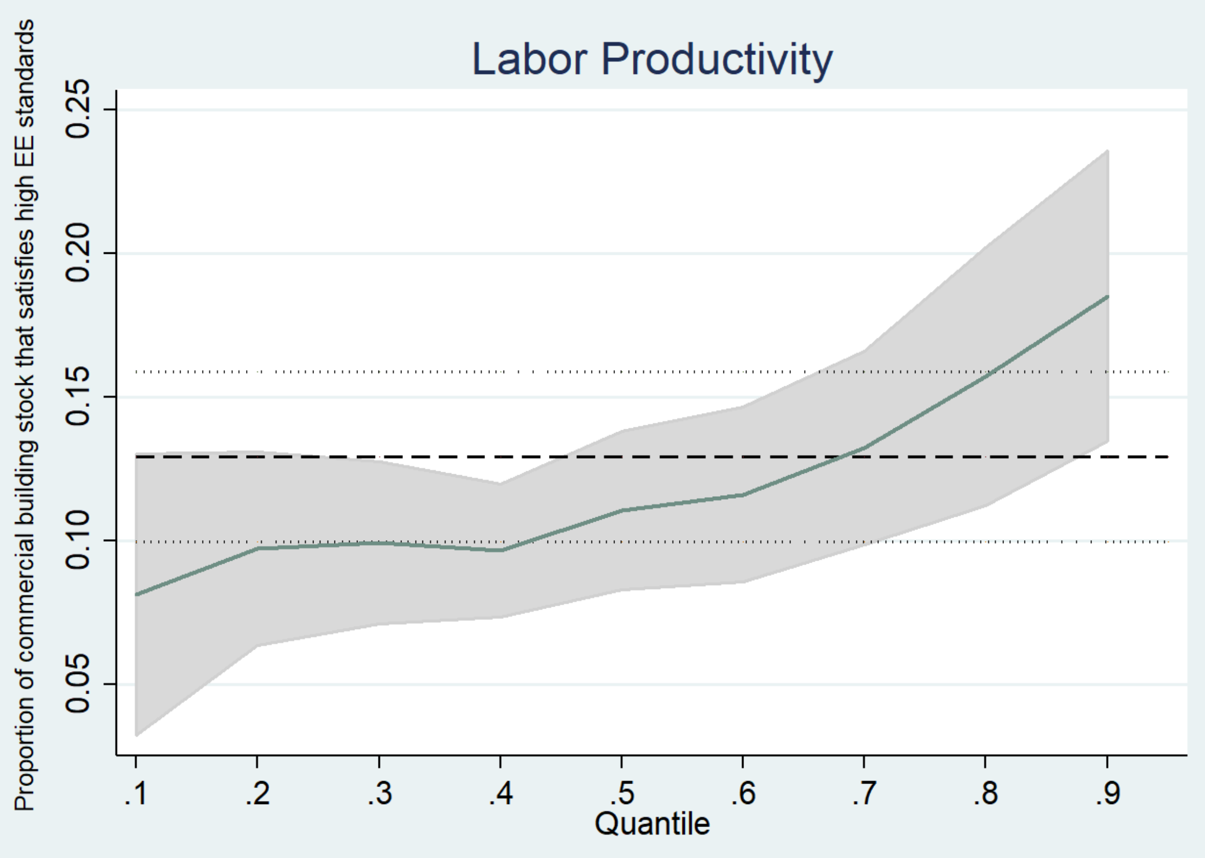
	TOTAL		MANUFACTURING		CONSTRUCTION		SERVICES		INFRASTRUCTURE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	First	Second	First	Second	First	Second	First	Second	First	Second
VARIABLES	Building's perform.	Labor productivity	Building's perform.	Labor productivity	Building's perform.	Labor productivity	Building's perform.	Labor productivity	Building's perform.	Labor productivity
Energy audit	0.12***		0.09***		0.16***		0.13***		0.12***	
Building's perform. (t-1)	0.46***		0.47***		0.47***		0.45***		0.45***	
Minor cost concerns	-0.02**		-0.01		-0.00		-0.04***		-0.01	
Building's performance		0.23***		0.23***		0.11		0.15		0.39***
Observations	6,654	6,654	2,074	2,074	1,453	1,453	1,540	1,540	1,587	1,587
R-squared	32%	50%	33%	56%	35%	59%	30%	44%	34%	49%
IV F-stat		774.4		237		185.7		164.3		169.5
Durbin pval		0.0205		0.175		0.536		0.846		0.0503
Sargan		0.555		0.0392		0.863		0.260		0.257

Note: ***, **, * statistically significant at 1%, 5% and 10%. The estimation included firm control variables, country, time, sector and size specific effects.

Figures 2-4 Quantile regressions: Nexus between productivity and building stock energy-efficiency standards






Labor Productivity
Proportion of commercial building stock that satisfies high EE standards
0.05
0.10
0.15
0.20
0.25
.1
.2
.3
.4
.5
.6
.7
.8
.9
Quantile