OECD Economics Department Working Papers No. 1378

Energy prices, environmental policies and investment: Evidence from listed firms

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https://dx.doi.org/10.1787/ef6c01c6-en

OECD

Unclassified **ECO/WKP(2017)10**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **20-Mar-2017**

English - Or. English

ECONOMICS DEPARTMENT

ECO/WKP(2017)10
Unclassified

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JT03411055

Complete document available on OLIS in its original format

English - Or. English

Abstract/Résumé

Energy prices, environmental policies and investment - evidence from listed firms

The 2°C (or less) limit on global warming agreed at the UN Climate Change Conference of 2015 in Paris effectively implies that manufacturing industries in developed countries have to undertake significant investments, in particular in more energy efficient production technology. To implement policies making the most of such a change, policymakers need to know what consequences climate policies have on business investment. This paper sheds light on the relationship between environmental policies, energy prices and firm-level investment using a sample of listed firms over the period 1995-2011 in 30 OECD economies. Higher energy price inflation is associated with a small, but statistically significant decrease in total investment across firms, though in the most energy intensive sectors, total investments are actually found to increase. However, for domestic investment, effects of higher energy price inflation are negative, independent of the energy intensity of industries. The gap in reactions between total and domestic investment is likely driven by increased offshoring in response to higher energy price inflation, in line with the Pollution Haven Hypothesis. We also find tentative evidence that the negative effects of rising energy prices on investment can be largely attributed to tightening upstream environmental policies.

JEL classification codes: E22, Q41, Q58

Keywords: energy prices, investment, environmental policies.

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Prix de l’énergie, politique environnementales et investissement – Preuve par les entreprises cotées

L’accord international de la Conférence de Paris de 2015 sur le climat qui fixe un objectif de limitation du réchauffement mondial entre 1,5 °C et 2 °C signifie que les industries manufacturières dans les pays avancés devront effectuer des investissements majeurs, en particulier dans des technologies de basse consommation énergétique. Pour mettre en œuvre les politiques qui apporteront cette transformation, les responsables politiques doivent connaitre les conséquences des politiques environnementales sur l’investissement des entreprises. Ce papier analyse la relation entre les politiques environnementales, le prix des énergies et l’investissement des entreprises en utilisant un échantillon de sociétés cotées dans 30 pays de l’OCDE pour les années 1995-2011. Une inflation des prix d’énergie est associée avec une réduction de l’investissement petite mais statistiquement significative bien que l’investissement total augmente dans les secteurs à haute consommation d’énergie. Toutefois, pour l’investissement domestique, l’effet de l’inflation des prix de l’énergie est négative, et ce, indépendamment du secteur. Cette différence entre l’investissement total et domestique peut probablement être expliquée par une augmentation des délocalisations en réponse à une inflation des prix de l’énergie, conformément à l’hypothèse des havres de pollution. En outre, nos résultats suggèrent que l’effet d’une inflation des prix de l’énergie vient des politiques environnementales en amont plus strictes.

Codes JEL: E22, Q41, Q58

Mots-clés: prix de l’énergie, investissement, politiques environnementales.

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ENERGY PRICES, ENVIRONMENTAL POLICIES AND INVESTMENT – EVIDENCE FROM LISTED FIRMS

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Main findings

The 2°C (or less) limit on global warming agreed at the UN Climate Change Conference of 2015 in Paris implies that in order to cut emissions manufacturing industries in developed countries have to undertake significant investments, in particular in more energy efficient production technology. To implement the necessary policies for such a change, policymakers need to know what consequences environmental policies, or more specifically climate policies, have on business investment. This paper sheds light on the empirical relationship between energy prices and firm-level investment using insights from reactions of listed firms to changes in sectoral energy prices over 1995-2011 in 30 OECD economies. To the extent that energy prices are affected by environmental policies, in particular climate policies, it provides insights on the potential effects of more stringent policies on investment.

The main findings can be summarised as follows:

- Higher energy price inflation is associated with an economically small but statistically significant decrease in total investment across firms. Reactions among sectors appear heterogeneous: in the most energy intensive sectors, total investments are actually found to increase following higher growth in energy prices.
- Turning to domestic investment, effects of higher energy price inflation are negative, independent of the energy intensity of industries. Therefore, the increase in total investment experienced by energy intensive firms is likely driven by increased offshoring in response to higher energy price inflation. Such effects are in line with the Pollution Haven Hypothesis, and addressed directly in a separate paper (ECO/CPE/WP1(2016)27).
- By linking part of the variation in energy prices to environmental policies, we find evidence that the negative effects of rising energy prices on investment can largely be attributed to tightening upstream environmental policies through their impact on energy prices.

1. Introduction

1. The UN Climate Change Conference 2015 in Paris brought about an international agreement to limit the increase of global temperature to below 2°C (or lower) – a threshold chosen based on large downside risks once breached (Burke et al., 2015). To achieve this target, significant efforts need to be undertaken, in particular as based on 2015 national action plans the UNFCCC stated that the actions planned so far would only limit global warming to between 2.7°C and 3°C this century.

1. This paper is part of the joint work of the Economics Department and Environment Directorate under the Green Growth Workstream. The authors are members of the Economics Department of the OECD. The authors would like to thank, Christian Kastrop, Jean-Luc Schneider, Giuseppe Nicoletti, Naomitsu Yashiro, Mark Baker, Paul O'Brien (from the Economics Department), Grégoire Garsous (Trade and Agriculture Directorate), Shardul Agrawala and Nils-Axel Braathen (from the Environment Directorate), Kurt Van Dender and Johanna Arlinghaus (from the Center for Tax Policy and Administration), Richard Baron (from the General Secretariat) and Silvia Albrizio (Bank of Spain) for very useful comments and suggestions. Special thanks go to Catherine Chapuis (who was with the Economics Department at the time this paper was written) for excellent statistical assistance and to Sarah Michelson (also from the Economics Department) for excellent editorial support.

2. Industry directly emits around a fifth of the total greenhouse gas emissions globally (IPCC, 2014) and contributes indirectly to a significant share of energy and transport related emissions. Hence, a notable effort to limit climate change needs to involve the manufacturing sector. In order to comply with the 2°C threshold by 2030 the global share of total abatement that should take place in the manufacturing sector is estimated between 19% and 38%, depending on industrial classification and methodology (McKinsey, 2013; and OECD, 2012). The majority of abatement opportunities arise from improvements in the energy efficiency of industrial equipment, often requiring investments in new equipment, technologies and innovation.

3. This paper sheds light on the relationship between sector-specific energy prices and firm-level capital investment. Such insights, on how and to what extent energy price changes affect capital expenditure, are important in designing policy packages to best incentivise firms to cut emissions. We contribute to this debate by estimating reduced-form panel regressions using firm-level data from listed firms. The focus on listed firms is data driven, but is appealing in light of increasing evidence that firm-specific movements in large firms help to explain major parts of aggregate fluctuations (see Gabaix, 2013; for evidence using US data). Importantly, by using listed firms, we exclude by definition young firms, especially small start-ups.

4. The results show that an increase in energy price inflation is associated with an economically small but statistically significant decrease in total (i.e. encompassing both domestic and outward FDI) investment on average, originating mostly from lower investment by firms in less energy-intensive sectors. The higher the energy intensity the smaller the negative effect; and at high levels of energy intensity there is a positive effect on total investment. The effect on domestic investment is, however, found negative across all energy intensities. Thus our results point to an increase in pollution-haven type of offshoring – a question investigated further in a dedicated paper using the same dataset (ECO/CPE/WP1(2016)27). Furthermore, we are able to find evidence that the above effects are largely due to tightening upstream environmental policies that affect energy prices.

5. The paper is organised as follows. Section 2 discusses the relationship between environmental policies and investment. Section 3 sums up the relevant literature. Section 4 introduces the empirical methodology. Section 5 describes the dataset. The empirical results are discussed in Section 6, together with some robustness checks and extensions. The final section concludes and draws some policy implications. Appendices provide a detailed summary of the relevant literature, the data and the estimation results.

2. Theoretical motivation

6. Research on the relationship between environmental policies and investment in fixed capital is scarce (see Table A3.1 for a summary). The effects of these policies are likely to vary across firms and activities – creating new business opportunities for some, while on the other hand increasing the costs of business or, in more extreme cases, even directly limiting or banning activity. A key transmission channel for environmental policies is through firms' production costs. For example, measures to reduce emissions, like environmental taxes on energy use, tradable emission permits or binding emission limits, are likely to have cost-increasing impacts for a polluting firm either through directly increasing the cost of production or by increasing the costs of inputs like energy.

7. Tightening environmental policies have both static and dynamic implications for investment. By increasing firms' production costs, everything else equal, they may reduce output and returns on investment. However, higher energy prices also imply a change in relative input prices with the effect on investment depending on the sign of the elasticity of substitution between energy and capital. If energy input and capital are complements (substitutes), higher energy prices have negative (positive) effects on

investment (Constantini and Paglialunga, 2014). A challenge in assessing the elasticity of substitution is how to model the production function, especially whether to choose a three (capital, labour, energy) or four input (capital, labour, energy plus a material input) factor model. Frondel and Schmidt (2002) show, that this choice has far-reaching implications on the estimated coefficients of the elasticity of substitution. Partly because of these modelling complexities, Constantini and Paglialunga (2014) conclude their review of the evidence on the elasticity of substitution of energy and capital that "although there are a large number of empirical estimates, no unanimous conclusion has been reached yet". Hence, all in all, the switch-over to cleaner production may require an increase in investment, or a change in the composition of ongoing investment.

8. A potential link from environmental policies to investment is also provided by the so-called Porter Hypothesis. This hypothesis states that well-designed environmental regulation may induce firms to become more productive and competitive (Porter, 1991; see Koźluk and Zipperer, 2014, for a discussion). To gain such previously overlooked efficiency gains, firms may need to temporarily increase investment – e.g. in more efficient machinery or technology.

9. Xepapadeas and de Zeeuw (1998) provide a simple model to discuss impacts of more stringent environmental policies on investment and productivity. Profit-maximising firms can choose to invest or disinvest in different vintages of capital: older and less efficient but cheaper machines or newer, more efficient but also more expensive ones. More stringent environmental regulation increases the cost of production and thus decreases output via the downsizing effect, which consequently has a negative impact on investment (and reduces the total capital stock). However, tighter regulations also induce a modernisation effect - in practice by tilting the capital to newer machines and increased scrapping of old ones (reducing the average age of capital). The modernisation effect has an ambiguous effect on total investment, as investment in older (cheaper) technology falls while investment in newer (more expensive, but more efficient) technology increases. The total investment effect depends on the interplay between the downsizing and modernisation effects. Interestingly, since newer technology is less polluting and at the same time more productive, even with less total investment, the productivity of the entire capital stock and consequently profits may turn out higher.

10. Finally, in line with the Pollution Haven Hypothesis, more stringent environmental policies can also induce firms to shift some of their production abroad, into countries with laxer regulation (see Koźluk and Timiliotis, 2016, for a discussion). In this case, outward foreign direct investment could increase if firms decide to build up production facilities, at the expense of domestic investment. Hence the impact on total investment is ambiguous and a key point in studying the relationship between investment and environmental policies consists of disentangling domestic and foreign investment. Even an increase in total investment following tighter regulation would not necessarily lead to a desirable environmental outcome if it were due to a shift in emissions to another country via FDI.

11. Firm responses to energy price increases can provide insights on the reaction of firm investment to environmental policies, in particular upstream, energy-related climate policies. This insight is the more relevant the more the manufacturing sector is expected to need to invest in energy efficiency to reach climate targets (McKinsey, 2013; OECD, 2012). Still, significant caution is required in drawing insights for broader environmental policies (Box 1).

Box 1. Energy prices and environmental policy stringency

Energy prices have been used as proxies for climate mitigation policies (see for example Aldy and Pizer, 2014) but to what extent they can serve as a direct proxy for environmental policies is debatable. Taking the firms' perspective, one simple way to look at environmental policies is that they increase the (implicit or explicit) price of environmental inputs.[1] The firm's reaction, hence, can be expected to be similar to that of the increase in prices of other inputs into production. Energy inputs appear as a particularly attractive candidate in this respect, due to the close relation with some – but by no means all - key environmental impacts. For example, in most countries a large share of the manufacturing sector's CO_2 emissions is indirect, via energy consumption. Consequently, fluctuations in energy prices will reflect, inter alia, both market-based upstream policies (e.g. a carbon tax) and command and control regulations (e.g. air pollution norms) relevant to energy and the firm's exposure to a tightening of climate mitigation policies will to a large extent be via a higher energy price paid.

One the other hand, there are also significant differences between the incentives coming from environmental policies and energy prices:

- *Temporary vs. permanent effects.* Changes in environmental policies, which are under direct control of the government, may be perceived as more permanent than shocks to energy prices – hence providing longer-term investment and adjustment incentives.
- *Local vs. global shocks.* Global energy price shocks may be less important in affecting the comparative advantage across countries than domestic changes in environmental policies – with differing impacts on domestic and foreign investments.
- *Input reduction vs. end-of-pipe incentives.* Higher energy prices will create incentives to reduce energy inputs (and associated environmental externalities) and are flexible regarding the choice of compliance mechanisms. For example, firms facing higher energy prices may be more inclined to invest in energy efficiency, but may choose to pay more for energy use or reduce energy intensive activity. On the other hand, broader environmental policies can also incentivise end-of-pipe investments (e.g. a scrubber or filter) or leave no choice but to invest (e.g. to fulfil a mandatory standard).

We address the above issues directly, in particular, in the second step, we investigate the role of upstream environmental policies on investment, through energy prices. To the extent that upstream policies are correlated with downstream policies – not an unreasonable assumption, given that environmental policymakers are likely to target environmental externalities across the entire production and consumption chain – such an approach will capture more general effects of environmental policies, in particular those related to climate and air pollution. However, particular types of downstream policies that are not related to energy-related pollutants will not be captured.

In practice, the OECD's environmental policy stringency (EPS) indicator and other proxies of environmental policies are significantly correlated with energy prices indices at the country level (Garsous and Koźluk, 2016; Sato et al. 2015).[2] However, a direct advantage of the Sato et al. (2015) energy price for our analysis is that they are available at the industry level – one level closer to our analysis. EPS is only available at the national level. Therefore in this paper a potential alternative to the energy price indicator is proposed by interacting the EPS indicator with a proxy for energy intensity also end-of-pipe measures will feed through to energy price

1. Obviously, this is a simplification, as environmental policies can also affect the design of the product, e.g. in order to limit environmental impacts of its use.

2. For details on the EPS see Box 2 in the Appendix.

3. Related literature

12. Country-specific empirical evidence tends to associate more stringent environmental policies with downsizing and lower investment. Greenstone (2002) exploits a natural experiment and looks at the differences in investment (and output) between plants in counties with binding environmental regulations and plants from the same industry in counties where environmental regulation is not a constraint. Aggregating the estimated effects, the study argues that, as a result of the Clean Air Act Amendments, counties with binding regulations saw a fall in employment (590,000 jobs), investment (USD 37 billion, 1987 prices) and output (USD 75 billion, 1987 prices) relative to counties with non-binding regulations

over 1972-1987. Nelson et al. (1993) find a positive effect of increased state-level expenditure on air quality enforcement on the age of the capital stock using data on US electric utilities in 1969-1983 – again implying a prevalence of the downsizing effect. On the other hand, Hamamoto (2006) finds that in Japanese manufacturing industries increased industry pollution abatement expenditure over the 1972-1982 period was associated with a reduction in the average age of the capital stock and higher R&D investment, which can be interpreted as a domination of the modernisation effect.

13. The impact of environmental policies on the composition of investment has also received some attention. Previous literature tend to distinguish between classical, "productive" investment and "environmental" (or regulation induced) investment – such as pollution abatement and control or environmental R&D investment – which has the primary goal of yielding environmental rather than economic returns. For example, filters or scrubbers induced by environmental regulations do not increase conventionally-measured productivity or efficiency. If such environmental investments were as productive as conventional investment, profit-maximising firms would have undertaken them anyway independently of environmental regulation.

14. Garofalo and Malhotra (1995) provide evidence of a modest crowding out effect of investment in pollution abatement on productive investment. Stricter environmental regulation that would increase abatement capital by 1% would reduce the manufacturing capacity of an industry by 0.2%. Gray and Shadbegian (1998) show that investment in pollution abatement in US paper mills over 1980-1990 had little to no impact on gross investment – i.e. abatement investment crowded out other investment. On the other hand, Kneller and Manderson (2012) find no effect of environmental regulations (proxied by pollution abatement costs) on gross investment, but an increase in investment in environmental friendly technology for UK manufacturing industries over 2000-2006.[2]

15. Cross-country studies have been limited by the availability of data, in particular by the dearth of cross-country proxies of environmental policy and comprehensive and comparable firm-level investment data. Leiter et al. (2011) is the only cross-country panel study, using data from manufacturing industries in 21 European countries over 1998-2007. Proxying environmental regulation with industry's expenditure on environmental protection and country-industry revenues from environmental taxation, they find positive impacts on different types of investment: machinery and buildings and total investment. The effect of regulation on investment is found to be non-linear with diminishing investment effects at higher levels of regulation.

4. Empirical approach

16. Empirical studies of business investment frequently rely on neoclassical theory - like Tobin's (1969) q-theory of investment or the theory of user cost of capital - or on ad hoc empirical specifications like the error correction model:

- The q-theory states that a firm will invest if the market value of an additional unit of investment is greater than the cost of the investment. It assumes that all information determining investment is already reflected in the market value to cost ratio (Tobin's q). Market expectations on the effects of announced policy measures (or any other important information) are already incorporated in the market price and hence an empirical specification would only be able to

2. Studies using private pollution abatement costs and expenditures (PACE) as a proxy for the stringency of environmental policies generally suffer from identification and endogeneity issues, as PACE usually includes investments already – e.g. in filters or energy efficiency, hence is more a measure of response to the policy rather than the policy itself.

identify the difference in unanticipated policy changes - limiting the applicability for the case of environmental policies.

- The user cost of capital theory predicts that a firm invests if the rate of return exceeds the cost of capital. A disadvantage is that calculating the user cost of capital requires data on firms' asset composition and corporate taxes, which are not readily available at the firm level.

- The error correction model (ECM) allows an empirical specification of the adjustment process, assuming some functional form for an equilibrium relationship, often derived from a model of static factor demand. However, the ECM suffers from the potential problem of confounding the parameters of the adjustment and expectation processes (Bond and Van Reenen, 2007). Furthermore, the specification of the long-run equilibrium relationship between output and capital is not straightforward in a firm-level context. Whether this long-run relationship is the same for all firms within an industry, or within country, or within an industry-country combination is a priori not clear and might depend on various industry, and country characteristics.

17. We focus on an empirical specification for investment consistent with the firms' optimal demand for capital derived from a production function with three inputs: capital, labour and energy. In this setting, the demand for capital depends, inter alia, on the price of energy (Holly and Smith, 1989). In turn, any change in business conditions, such as changes in the prices of energy or other inputs, would imply changes in the capital stock – to an extent depending on the elasticities of substitution between capital, labour and energy. Consequently, the change in the capital stock - which is equal to investment minus depreciation - is related inter alia to changes in energy prices. A similar approach to model the influence of energy prices on levels of economic outcomes has been taken by Cournède (2010) who employs a three-factor Cobb-Douglas production function in order to model the relationship between the level of potential output and oil prices. In the same vein, Albrizio et al. (2016) employ an empirical specification that relates changes in productivity growth to changes in environmental policy stringency.[3]

18. Formally, our approach consists in estimating the following regression equation:

$$\frac{I_{isct}}{K_{isct}} = \alpha_i + \beta_1 * \Delta EPI_{sct-1} + \sum_j \gamma_j * X_{isct}^j + \sum_t \theta_t * d_t + \varepsilon_{isct} \qquad (1)$$

19. where *i* indexes firms, *s* sectors, *c* countries and *t* time. We measure the ratio of investment to the capital stock using the book values of firm-level capital expenditure (*I*) and capital stock (*K*). The resulting average investment ratio in our sample is 5.64%, with a median of 3.87%. ΔEPI measures the three-year moving average of energy prices inflation.[4] α_i denotes a firm-specific intercept, X^j the j-th control variable, and d_t the year dummies.

20. Figure A1.1 shows the time series evolution for G7 countries. The investment ratio tends to be persistent, with a downward trend since the 1990s. The outbreak of the financial crisis seems to have a negative impact on investment ratios in all G7 countries, which suggests a separate robustness check whether empirical results hold when omitting the period since the financial crisis. Figure A1.2 shows the

3. The approach taken in this paper is also consistent with the companion paper (ECO/CPE/WP1(2016)27), whereby energy prices affect the split between the stocks of domestic and foreign assets of a company.

4. A moving average specification has been used by Albrizio et al. (2014) and builds on the argument that investment is usually planned ahead; a reaction to energy prices may thus take some time.

time series evolution for each of the 10 sectors considered in our analysis. The different pattern across sectors suggests that energy prices may have a heterogeneous impact on the investment ratio. Thus further below we will extend our basic model to allow for sector-level heterogeneity.

21. We use firm fixed effects and time dummies to control for all time-invariant variation across countries and any common variation through time.[5] Firm fixed effects capture unobservable firm characteristics that could influence investment and would otherwise lead to an omitted variable bias. Examples include firm-specific management culture or human capital endowment effects of the geographical location. The firm fixed effects also control for all time-invariant factors that are country- or sector-specific.

22. With firm fixed effects, the identification of the parameter estimates comes from the within-firm time-series variation. Thus we capture the effects of changes in policy variables (as measured by changes in energy price inflation) and not the effects of different levels of regulation (or price levels). This is important given that firms may be able to secure individual energy supply contracts, with prices that differ in levels from the industry prices. Fixed effects will allow control for level differences across firms.[6] Finally, following Bond et al. (2003), the firm level fixed effect can take care of the firm-specific depreciation rate of capital, to the extent that this rate is not affected by energy prices themselves.

23. Time dummies remove confounding factors that are common to all countries in our sample, such as global supply shocks and global price trends in energy prices (e.g. increases in oil prices). Once the global drivers of energy prices are controlled for, the remaining variation of energy prices reflects primarily domestic changes in post-tax prices that are subject to energy taxes or emission limits imposed at the energy sector (Sato et al. 2015), as well as other regulatory policy and domestic energy supply shocks (e.g. deregulation of energy markets).

24. To further diminish concerns with omitted variables, we use a set of control variables at the country, industry and firm-level, depicted by X. For example, higher future demand for the firms' products can lead firms to increase investment. We model this relationship by including the current level of firms' sales, scaled by total assets. We also include the country-level output gap and real interest rates and control for (non-environmental) policy variables, using the OECD's employment protection legislation indicator (EPL), financial development (proxied by stock market size plus outstanding domestic credit scaled by GDP) and the regulatory impact indicator (Egert and Wanner, 2016).[7]

25. We allow for some sector-level heterogeneity by interacting financial development and EPL with a sector-level variable to account for differences in the extent to which firms in different sectors are exposed to the influence of these factors .[8] We take layoff rates as a measure of sector-level exposure to EPL. Layoff rates are calculated as the percentage ratio of yearly layoffs over total employment. Industries

5. We also test a specification with country-time and industry-time effects, but results are not significantly different, see Table A2.3 column 5.

6. The focus on averaged, longer-term changes in the energy prices eventually adopted in this paper has an additional advantage: over the longer term, firm-specific energy prices can be expected to follow the developments in industry level prices.

7. At the time of writing this paper the OECD's Regulatory Impact indicator for the broad country sample considered in our regressions was only available up to 2009. Thus we only include this indicator in the pre-crisis regressions.

8. Sector-level exposure variables are calculated pre-sample based on US data because the US is generally seen as a low regulation country

with high layoff rates are assumed to be more exposed to employment legislation, because they change their labour force more frequently. We measure the sector-level exposure to financial development with dependency on external finance (as in Rajan and Zingales, 1998) calculated as the share of capital investment not financed by retained earnings and thus measures the share of investment not financed through internal funds. This approach is in line with previous research (Rajan and Zingales 1998; and for environmental policy applications Albrizio et al. 2014; and Koźluk and Timiliotis, 2016). Finally, in order to diminish endogeneity concerns both EPL and financial development variables are lagged one period.

5. Data

26. We use firm-level data from Thomsons Reuters Worldscope. Worldscope collects mandatory balance sheet data for listed companies in 75 countries since 1985 and is frequently used to study firm-level investment (e.g. Kang and Piao, 2015). Since important firm characteristics, like investment and sales, have to be reported mandatorily in firms' balance sheets, a main advantage of Worldscope lies in its reliability and the potential to draw from a rich set of firm-level controls.

27. Worldscope comes with two caveats. First, while the coverage is extensive, it concerns only listed companies. Thus, the sum of investments of reporting firms in a country is only a fraction of aggregate business investment, in particular in countries that rely more on debt financing (e.g. Germany, Belgium, Japan) and have therefore a lower share of listed companies (relative to e.g. the United States or the United Kingdom, which rely more on equity financing). Hence insights generalise to capital investment of non-listed firms, if their business decisions in response to environmental policies are similar to those of listed companies. Second, Worldscope investment figures also include investment in foreign subsidiaries. This can be problematic when aiming to assess the impact of domestic (environmental) policies on domestic capital investment. This issue is developed in a companion paper that uses the same data set to explore the Pollution Haven Hypothesis (ECO/CPE/WP1(2016)27).

28. To shed more light on these caveats, we compare capital investments from Worldscope with capital investments from national sources. We aggregate firm-level manufacturing investment from Worldscope up to the country-level and compare with economy-wide business investment in the manufacturing industry from the OECD STAN database. OECD STAN provides data based on national accounts. On average, Worldscope investment covers around 22% of total economy-wide business investment in manufacturing industries, but coverage reaches around 50% in 8 OECD countries on average across time. At the same time, the evolution of the aggregated Worldscope and STAN series highly and significantly correlate after controlling for global and specific country patterns. Over 1990-2009, a one percent increase in investment from the OECD STAN database is associated with a significant 0.67 percent increase in aggregated firm-level investment (see Appendix I for further details).[9] Furthermore, Figure A1.1 compares the time series of the investment ratio from Worldscope firm-level data with national accounts to see whether there are any substantial differences in terms of levels or trends over time. The investment ratio from Worldscope tends to be more volatile but levels and broad patterns over time are comparable.

29. Recent work on the implications of micro-level fluctuations on country-level aggregates show that a large part of the time series of output can be explained by movements in the largest firms. For the case of the United States, Gabaix (2011) reports that around one third of fluctuations in GDP results from

9. In this case, the sample is limited by the time-series availability of OECD STAN. Overall, the exercise comparing aggregated firm-level investment from Thomson Reuters Worldscope to relevant national accounts data follows a very similar exercise performed in Chapter 4 of the IMF's World Economic Outlook 2015 (IMF, 2015).

the 100 largest firms, all of which are listed. The same paper speculates based on a literature review that the co-movement of top companies and the aggregate may be higher outside the United States (e.g. in Asia or Europe) as the United States tends to be more diversified. Hence, although Worldscope investment constitutes only a part of national investment, it can provide insights on a more general phenomenon.

30. In this paper, we use energy price indexes constructed by Sato et al. (2015). These energy price indexes are constructed for 12 sectors in 48 countries over 1995-2011, by weighting country-level fuel prices for four different types of fuel – oil, gas, coal and electricity – by the consumption of these fuels in each country-sector:

$$EP_{ist} = \sum_j \frac{F_{ist}^j}{\sum_j F_{ist}^j} . P_{it}^j = \sum_j w_{ist}^j . P_{it}^j$$

where F_{ist}^j is input consumption of fuel j for industrial sector s, in country i at time t, and P_{it}^j is the (log) price of fuel j in country i at time t. Fuel prices of oil, gas, coal and electricity, and their respective sectoral consumption shares come from the IEA Energy End-Use Prices database, which provides details on the domestic end-use energy prices paid by industrial users in manufacturing sectors (IEA, 2012). Energy prices are 12-month averages and include taxes paid by industry (in particular excise and environmental taxes) but exclude VAT and recoverable taxes and levies. The prices are deflated and converted to constant 2010 USD.

31. Sato et al. (2015) provide two versions of the index, with different weighting schemes. Throughout this paper we employ the Fixed-weight Energy Price Level (FEPL), which uses fixed weights from the baseline year 2010. Hence, the variation in the FEPL comes solely from the changes in domestic energy prices and not from the changes in consumption shares. As changes in relative prices can be driven by changes in industry energy consumption baskets, the FEPL is free of such fuel substitution effects. Using fixed pre-sample weights (FEPL), reduces concerns with endogeneity, whereby firms' investment into more energy efficient technology would change the fuel input combination. However, in practice both indexes are highly correlated.

32. Sato et al. (2015) find that taxes can explain a substantial part of the variation in energy prices. The tax component is able to explain 80% to 90% of the cross-country variation of coal prices, 60% of the variation in electricity prices, 50% to 80% for oil. For natural gas this relationship is much weaker, with only about 20% being explained by differences in taxes, likely due to gas prices being strongly conditioned on the geography of transport infrastructure and long-term contracts.

33. The energy price indexes are also significantly (positively) correlated with the OECD's Environmental Policy Stringency indicators and World Economic Forum's survey-based environmental stringency score. They also correlate significantly with measures of environmental performance – such as country energy intensities, CO_2 energy intensities, Yale's Environmental Performance Indexes, Industry Adjusted Emission Intensities (IAEI) from combustion and processes (Sato et al. 2015; OECD, 2016).

34. Our dataset comprises 70,497 observations from 30 OECD over 22 years (1995-2011) and 10 manufacturing industries (Chemical and Petrochemical; Food and Tobacco; Iron and Steel; Machinery; Non-ferrous Metals; Non-metallic Minerals; Paper, pulp and print; Textile and leather; Transport equipment; Wood and wood products) (Table A1.2 in the Appendix). The exact coverage in estimations

depends on the model specification, due to differences in data availability of the variables in each country dataset. The dataset is cleaned with standard procedures.[10]

6. Empirical results

6.1 Baseline investment equation

35. On average, higher energy price inflation is associated with lower overall investment. The estimated coefficient of the energy price index is negative and significant (Table A2.1 column 1). This result is robust to including a broad set of additional control variables, which come with the expected sign: an increase in employment protection legislation is associated with a decrease in the investment ratio – we interpret this as higher costs of adjusting the labour force reducing expected returns to investment, in line with previous findings (Calcagnini et al., 2014). Higher levels of financial development and firm-level sales are positively associated with investment.

6.2 Sector-level heterogeneity

36. The scope for increasing energy efficiency via additional investmentin the wake of energy price increases may differ across sectors. Therefore we allow sectors to react differently to an increase in energy price inflation depending on their energy intensity (EnI) (see Appendix A1 for more details) by estimating the following equation:

$$\frac{I_{isct}}{K_{isct}} = \alpha_i + \beta_1 * \Delta EPI_{sct-1} + \beta_2^L * EnI^L{}_s * \Delta EPI_{sct-1} + \beta_2^H * EnI^H{}_s * \Delta EPI_{sct-1} + \sum_j \gamma_j * X_{isct}^j + \sum_t \theta_t * d_t + \varepsilon_{isct} \qquad (2)$$

37. In a first step, we impose an identical reaction in high and low energy intensity sectors ($\beta_2 \equiv \beta_2^L = \beta_2^H$). Later we relax this assumption and allow for an asymmetric reaction. The estimated coefficient (β_1) of an increase in energy price inflation is negative and significant at the 5% level (Table A2.1 column 2). The interaction of energy intensity and energy price inflation (β_2) is positive and highly significant. Thus, the overall sign of the effect of an energy price increase depends on the combination of the two estimated coefficients and the energy intensity of the sector considered.

38. When allowing for a non-symmetric reaction of low and high energy intensity sectors (Table A2.1 column 3), we note that there is no evidence of asymmetry, and the estimated effects are significant for both low and high energy intensity sectors.

39. Figure 1 shows how the investment ratio would react to a change in energy price inflation similar to the difference between the Polish and German experience over our sample. First, we order countries by average energy price inflation over time and sectors. The baseline growth in energy prices is taken as the median growth in energy prices across countries (equivalent to the growth in energy prices in Poland in our sample) and compared with high energy prices growth - the 75th percentile (equivalent to the growth in

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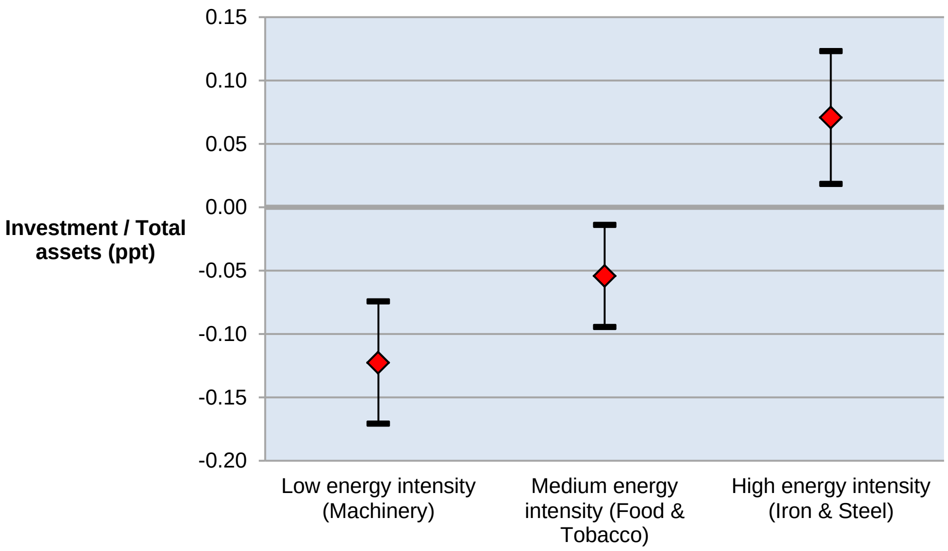
10. All firm-level variables used in the empirical analysis are winsorised at the 1% and 99% level to eliminate large outliers. Obvious key-punch errors, (e.g. values of variables below zero when the variable cannot take on zero values from an accounting perspective, such as total assets) are dropped. Firms that have a time series of investment less than four years are excluded, to avoid new firms which may have quite specific, start-up investment decisions.

German energy prices). The results can hence be interpreted as the expected annual change in the average investment ratio of Polish firms, if energy prices over the sample were to grow as fast as in Germany.

40. We calculate the overall effects for three different levels of energy intensity: high (e.g. Iron and Steel), medium (Food and Tobacco) and low (Machinery). For all assessments we use the most conservative model, i.e. the model with a full set of control variables (Table A2.1 column 2). Figure 1 shows these point estimates together with 90% confidence bands. The economic size of the overall effect is relatively small. All else equal, firms in low energy intensity sectors tend to decrease their investment ratio by around -0.12 percentage points (relative to an average annual investment ratio of 5.6%). For comparison, a similar change would be achieved by a 0.08 point increase in the EPL indicator – equivalent to less than one 50-th of the difference between the United States (lowest EPL value in our sample) and Portugal (highest EPL value in our sample). On the contrary, firms in high energy intensive sectors tend to increase their investment ratio by around 0.07 percentage points with higher energy price inflation.

Figure 1. Effect of higher energy price inflation on the investment ratio



Notes*:* The effect on the investment ratio associated with energy price inflation equivalent to the 75th percentile (e.g. growth in energy prices in Germany across our sample) compared to the median change (e.g. growth of energy prices in Poland) for different values of energy intensity. Low energy intensity refers to the machinery sector, medium energy intensity to the - the Food and Tobacco sector and high energy intensity to the Iron and Steel sector. The centre point estimate is plotted together with the 95% confidence intervals. The graph is based on the results from Table A2.1 column 2.

6.3 The role of policies

41. As highlighted in Box 1, post-tax energy prices can provide useful inference for studying the reaction of firms to more stringent environmental policies and in particular climate policies. Such prices reflect, among other things, environmental policies in the upstream energy sectors (such as a carbon tax). We check this idea in two ways:

- First, we regress the investment ratio directly on the EPS indicator. Two key limitations of this approach are that (i) the EPS varies only at the country-year level and has no sectoral dimension (see Box 2 in the Appendix for details on the EPS) and (ii) the EPS entails conflicting investment incentives. While some environmental policies (e.g. climate policies) raise energy prices incentivising firms to reduce energy consumption (either through investment in new technologies, more efficient machinery, directly reducing energy use or decreasing production),

other environmental policies, such as for instance those addressing air pollution, will also provide incentives to invest in end-of-pipe solutions (e.g. filters, scrubbers).

- Second, we use the EPS indicator to single out the part of changes in energy prices that result from upstream environmental policies on energy. For example, the policy driven price changes can be deemed to be more permanent and, therefore, more relevant for investment decisions that should be based on structural factors.

42. Table A2.2 re-estimates all specifications with EPS instead of energy prices. In all specifications, the coefficients on EPS are insignificant.[11] However, as discussed above EPS could change the composition of investment, without an aggregate effect. For example, Kneller and Manderson (2012) find that environmental policies increase investment in abatement technology which crowds out other types of investment. Hence, it is plausible that while higher energy prices (and possibly more stringent climate policies) are associated with less investment, environmental policies in general do not affect overall investment but shift investment into end-of-pipe solutions.

43. Table A2.4 decomposes energy price inflation into a part which is due to environmental policy ("policy component") and a residual component (which includes all effects that cannot be explained by environmental policies). This is done by projecting energy price inflation on EPS growth. We then re-estimate equation (2) including both the policy-driven and residual components of changes in energy prices as explanatory variables. Coefficient estimates on these two components allow some cautious inference on whether our main findings on energy prices, reflect indirect effects of changing upstream environmental policies (Table A2.5). Indeed, the policy part of energy price inflation is statistically significant with a negative sign. In addition also the interaction with energy intensity is significant, suggesting sector-level heterogeneous effects. We treat this as a confirmation that the negative association between energy price inflation and investment results at least partly from changes in upstream environmental policies that are perceived to be persistent over time.

6.4 Extensions and robustness checks

44. Our main results (Table A2.1) are robust to restricting the sample in terms of years and countries. Firstly, we restrict the sample to the pre-crisis period, given the marked impact of the global financial crisis on firm-level investment – mainly due to liquidity constraints and heightened political uncertainty (IMF, 2015). Column 2 of Table A2.3 reports the results, with little effects on our estimates.

45. The main effect of energy price inflation does not change when we consider the regulatory impact indicator as a further control variable (Table A2.3 column 3). The estimated coefficient of the regulatory impact indicator is highly significant and comes with a negative sign. This implies that less competition on product markets leads to less investment and confirms previous findings (Alesina et al., 2005 and Egert and Wanner, 2016).

46. Given that a quarter of our sample is composed of US firms, repeating the estimations excluding the US can be used as a simple test of the general validity of the results. Estimates, as reported in Table A2.3 column 4 are not significantly affected. Furthermore, the baseline results are robust to alternative empirical specifications and approaches. The broad cross-country dataset with three dimensions (firm, country and sector) over time implies that many possible factors at different dimensions may affect investment and, if not accounted for could lead to an omitted variable bias. The baseline specification

11 . The specification without controls is likely to yield biased estimates as the EPS is the only country-specific (or country-industry-specific, in the interaction case) variable.

includes firm fixed effects and country and industry controls. As an alternative, we estimate the equations with country-year and sector-year fixed effects in order to control for all time-varying sector and country effects. The results are robust (Table A2.3 column 5).

47. The results also broadly hold when a dynamic panel specification is adopted and estimated with a one-step system GMM estimator that instruments lags of the dependent variable with further lagged levels and differences as proposed by Arellano and Bond (1991) (Table A2.6). The base and the interaction effect remains strongly statistically significant.

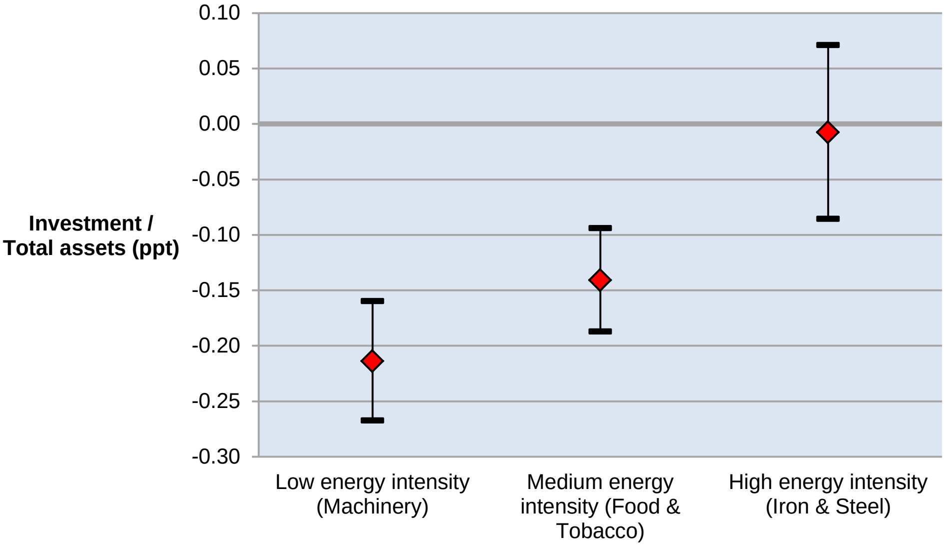
6.4.1 Energy price level effects

48. The effect of an increase in energy prices could also depend on the actual energy price level. At a low level an increase might just not be enough of an incentive to change to a less polluting production technology – firms may choose to just absorb the increase in costs. We test this hypothesis by further interacting energy price inflation with a dummy variable that indicates whether over the entire period the energy price of a sector-country combination lies above or below the sector median energy price level.[12]

49. Figure 2 and Figure 3 show the overall effect for low and high levels of energy prices for three levels of energy intensity respectively (based on results in Table A2.1 column 4). For low levels of energy prices, the overall effect is negative and significant at the 1% level, but not for the most energy intensive sectors. The overall effect with high levels of energy prices is however positive for the most energy intensive sectors. This heterogeneous effect could reflect the existence of a tipping point – at high energy prices, further price increases leave "dirty" sectors no choice but to undertake additional investment – at home (e.g. in energy efficiency) or abroad. At low levels of energy prices and energy intensity an increase in energy price inflation from the median to the 75th percentile can be associated with an investment ratio fall of around -0.21 percentage points. At high levels of energy prices and energy intensity, an increase leads to an estimated increase in the investment ratio by 0.18 percentage points. This should be compared to an average investment ratio of 5.6%.

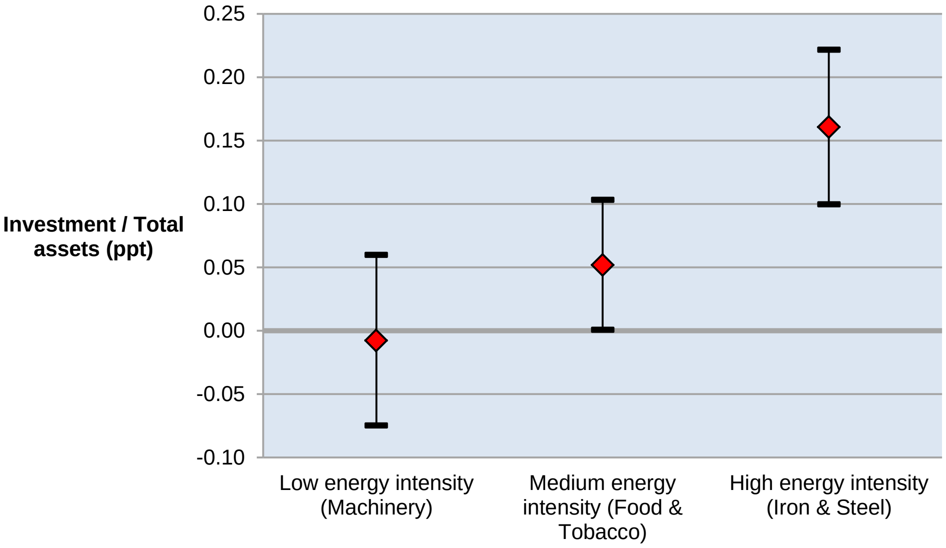
12. For this purpose we employ the variable weight energy price index which is designed for cross-country comparisons (Sato et al., 2015).

Figure 2. Effect of an increase in energy price inflation at low price levels



Notes: Low levels of energy prices depict that the energy price index is below the median (pooled over all sectors). The effect on the investment ratio associated with an increase of energy price inflation from the median (Poland) to the 75th percentile of all changes in energy prices (Germany) for different values of energy intensity. Low energy intensity refers to minimum value of ED, medium energy intensity to the median value of ED and high energy intensity to the maximum value of ED. The point estimate is presented with 95% confidence intervals. The graph is based on the results from Table A2.1 model (4).

Figure 3. Effect of an increase in energy price inflation at high price levels



Notes: High energy prices depict that the energy price index is above the median (pooled over all sectors). The effect on the investment ratio associated with an increase of energy price inflation from the median (Poland) to the 75th percentile of all changes in energy prices (Germany) for different values of energy intensity. Low energy intensity refers to minimum value of ED, medium energy intensity to the median value of ED and high energy intensity to the maximum value of ED. The point estimate is presented with 95% confidence intervals. The graph is based on the results from Table A2.1 model (4).

6.4.2 Separating domestic investment from foreign investment

50. The findings of higher total investment in the most energy intensive sectors in reaction to higher energy price inflation may seem counterintuitive. Potential explanations could include the fact that more energy intensive sectors have no choice but to invest in the modernisation of their capital stock, or that they have more alternatives for energy efficient investment than low energy intensity sectors. However, the use of total investment may hide differential effects of an increase in energy prices on domestic and foreign investment. Since total investment consists of domestic investment and investment abroad, a change in total investment does not necessarily reflect a change in domestic investment. Worldscope also provides data on foreign capital which we use to construct a measure of domestic investment.[13]

51. In Table A2.1 column 5 and column 6 we provide results from the specification with the full set of controls and compare the effects on total and domestic investment. Data on foreign capital stocks are not available for the full sample of firms as in previous regressions; hence the number of observations is considerably smaller. In order to better compare total and domestic investment we also provide estimated coefficients with total investment as a dependent variable using the set of firms where we have data on domestic investment.

52. Figure 4 compares the overall effect of an increase in energy prices for total and domestic investment. The sample is markedly smaller, which may explain the lower significance of the estimates. However, even in this reduced sample we find a similar pattern of effects on total investment – negative effects for least energy intensive sectors and increases in the most energy intensive sectors. However, this pattern is no longer present for domestic investment. Regardless of energy intensity levels, effects of energy price inflation appear negative and significant (at 90%). Moreover, they are not significantly different from each other – even if there are some differences in the point estimates. Since the difference between total and domestic investments is foreign investment, this points to the fact that in response to higher energy prices, firms in our sample tend to invest more abroad. These results are in line with findings from Garsous and Koźluk (2016), who find significant positive impacts of higher energy prices on foreign assets of firms. Interestingly, this finding also holds once energy price inflation is decomposed into the environmental policy and residual components, confirming that the effect can be at least in part empirically attributed to (upstream) environmental policy tightening (Table A2.5 column 7 and 8).

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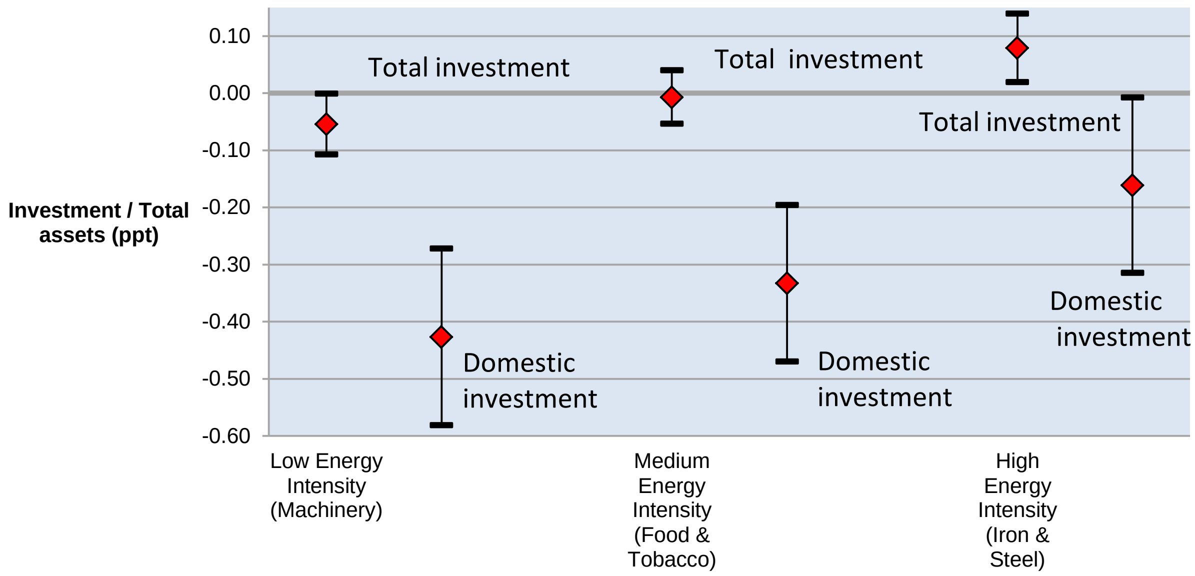
13. We calculate the amount of domestic investment by subtracting (book-value) foreign investment from (book-value) total investment.

Figure 4. Effect of an increase in energy price inflation on total and domestic investment



Notes*:* The effect on the investment ratio associated with an increase in energy price inflation from the median (Poland) to the 75th percentile (Germany) for different values of energy intensity. Low energy intensity refers to minimum value of ED, medium energy intensity to the median value of ED and high energy intensity to the maximum value of ED. The point estimate is presented with 90% confidence intervals. The graph is based on the results from Table A2.1 column 5 and column 6.

7. Concluding remarks

53. This paper examines the relationship between firm-level investment and energy price inflation. An increase in energy price inflation is on average associated with lower total investment, but there is considerable heterogeneity among sectors. Firms in less energy intensive sectors tend to see total investment fall in light of higher energy price inflation, in particular if energy prices remain nevertheless low – possibly reflecting the decision to absorb the higher energy costs rather than to invest in efficiency improvements. More energy intensive sectors tend to increase total investment in reaction to higher energy price inflation – in particular when the price level is already high. The estimated reactions to energy price inflation can be attributed to tightening domestic environmental policies in the (upstream) energy sectors.

54. Offshoring provides a tentative explanation for these cross-sectoral differences, and for the increase in total investment in the most energy-intensive sectors. The effects of higher energy price inflation on domestic investment are negative, regardless of energy intensity of industries. This suggests that outward FDI, particularly in energy intensive sectors, may be increasing in reaction to higher domestic energy prices – in line with the pollution haven hypothesis and the findings of Garsous and Koźluk (ECO/CPE/WP1(2016)27), who address this issue directly. Nevertheless, the overall effects tend to be small.

55. The results need to be cast in the appropriate context – they have been found for a sample of listed firms, which tend to be relatively large, well-established firms. While the aggregate investment of listed manufacturing firms tends to be in line with total aggregate investment in manufacturing, the results cannot provide insights on investment in start-ups, which could be affected differently. Higher energy prices, or more stringent climate policies, create opportunities for new, energy efficient technologies. To the extent these are provided by innovative new entrants, the effects will not be captured in our analysis. Moreover, energy prices (or environmental policies) may also affect the scrapping rate of existing capital – an issue not addressed directly in this paper. This question is difficult to analyse, as the scrapping rate is not directly observed, and is hence left for future research.

56. Overall, climate policies, like a carbon tax, should raise energy prices, but, according to our findings, are unlikely on their own to stimulate investment, at least among existing firms. Policymakers may need to look more closely at the overall structural, regulatory and macroeconomic policy conditions for investment, when aiming to stimulate the adoption and development of new and cleaner technologies.

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APPENDIX I - DATA

A1.1 Representativeness

1. In order to check whether capital investments from Worldscope are correlated with economy-wide business investments we run a panel regression of the growth of firm-level investments aggregated at the country-level on capital investments from OECD STAN, which is based on national accounts. In line with our previous analysis, we restrict our sample to the manufacturing industry. Table A2.1 presents the results of this panel regression. The two aggregate measures of investment are strongly related: a 1 percent increase in economy-wide business investment leads to a 0.67 percent increase in firm-level investments for 1990-2009. For 2001-2009, we find a higher value of 0.88 percent. The results are statistically significant.

Table A1.1 Comparison of investment figures from Worldscope and OECD STAN

	(1) 1990-2009	(2) 2001-2009
Capital Investment from OECD STAN	0.6680*** (0.2399)	0.8753* (0.4932)
Observations	360	161
Adj. R squared	0.1434	0.1296

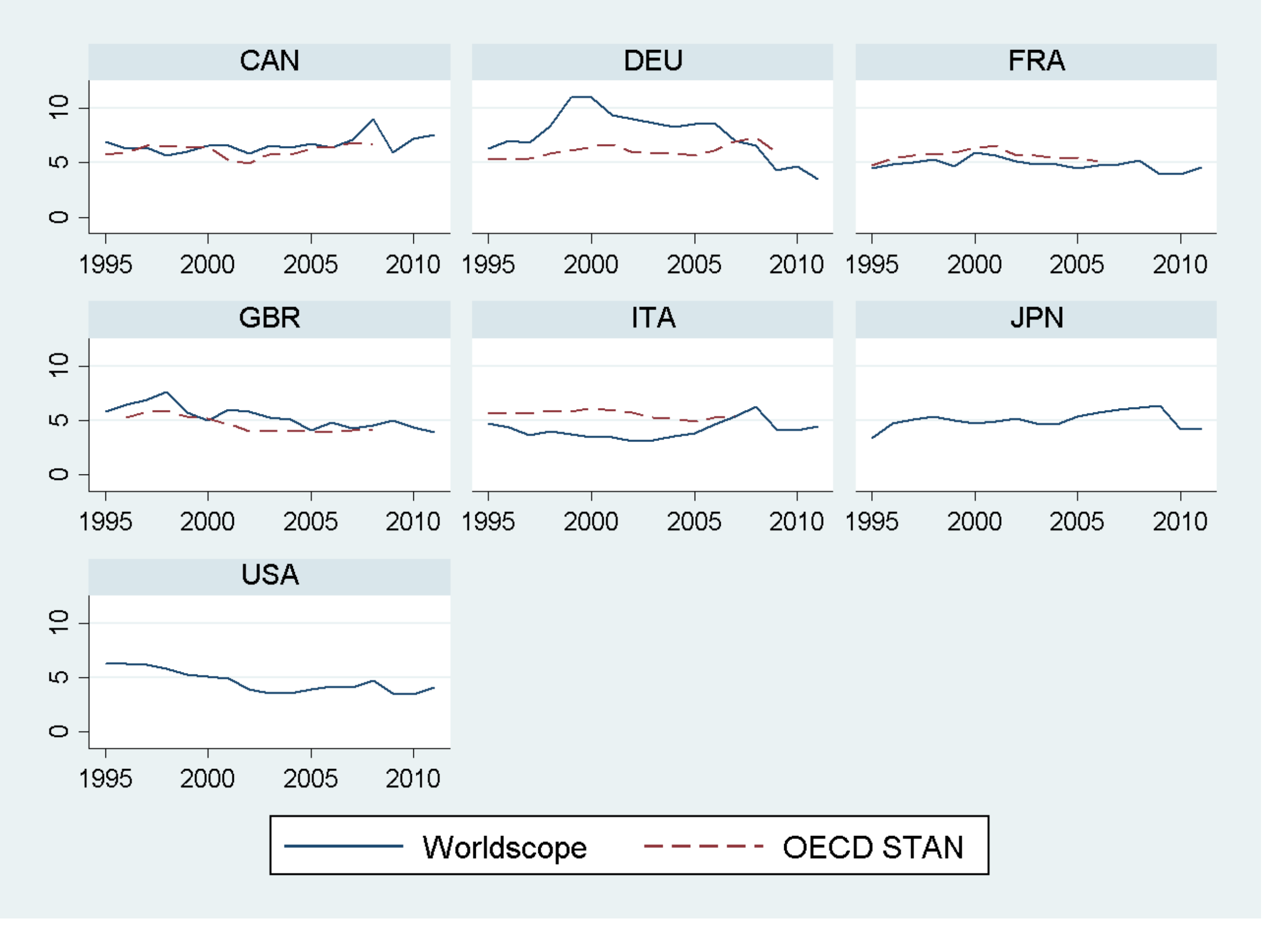
Notes: This table depicts the results from a panel regression of growth in capital investment in manufacturing industries from OECD STAN, which is based on national accounts, on growth in capital investment from Worldscope. The firm-level data from Worldscope is summed up at the country-level. The panel regression also includes dummies for each year and country fixed effects, which are not reported due to brevity of presentation. Standard errors in brackets are robust to autocorrelation and heteroskedasticity. *** denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table A1.2 Country sample

OECD	Country	Firm-year observations
Y	Australia	803
Y	Austria	451
Y	Belgium	535
Y	Canada	2,412
Y	Switzerland	1,313
Y	Chile	87
Y	Czech Republic	62
Y	Germany	2,610
Y	Denmark	17
Y	Spain	586
Y	Finland	736
Y	France	2,893
Y	UK	3,882
Y	Greece	660
Y	Hungary	164
Y	Ireland	121
Y	Italy	1,273
Y	Japan	18,399
Y	Korea	7,634
Y	Mexico	332
Y	Netherlands	612
Y	Norway	315
Y	New Zealand	133
Y	Poland	962
Y	Portugal	218
Y	Slovakia	4
Y	Slovenia	60
Y	Sweden	1,455
Y	Turkey	1,729
Y	USA	20,039
Total	30	70,497

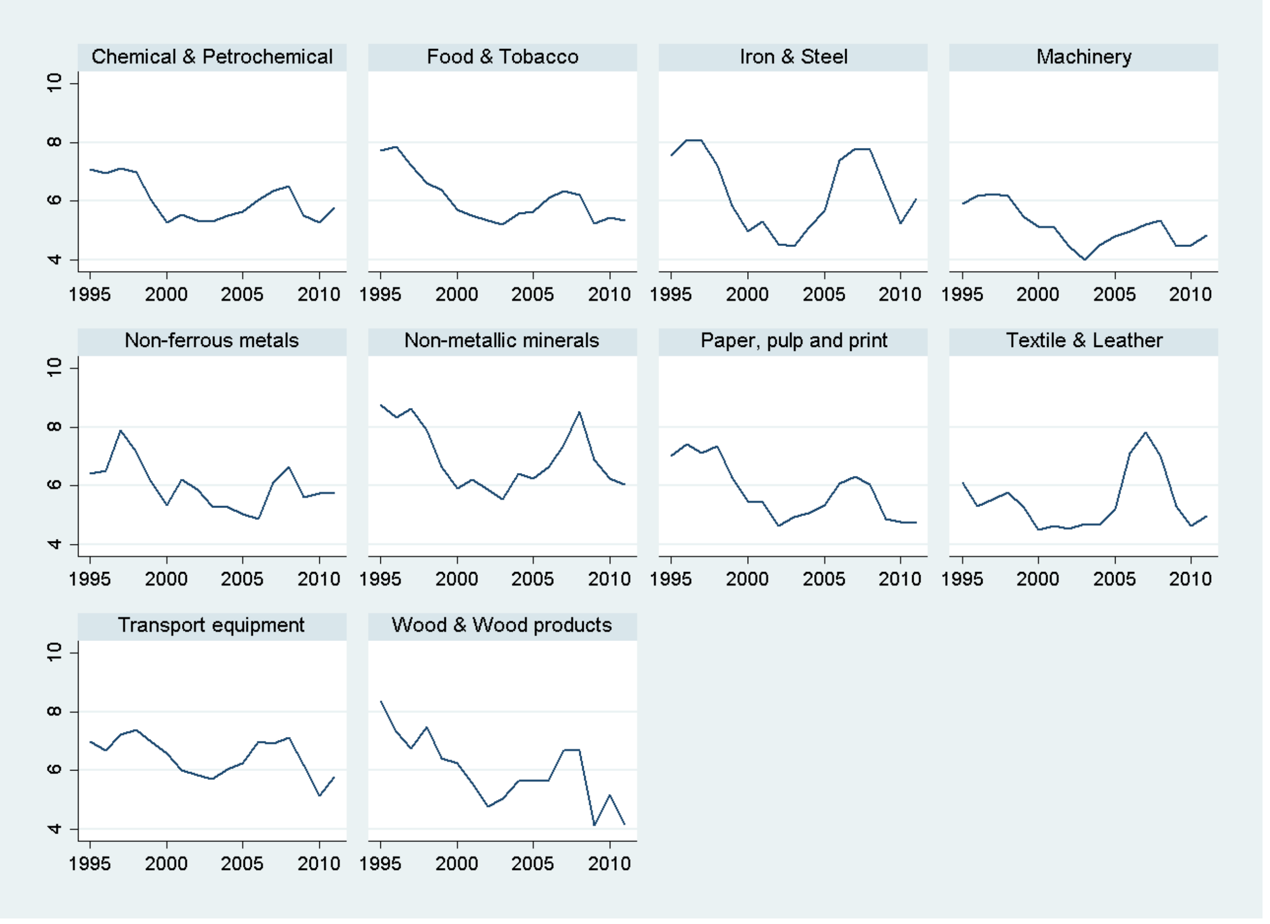
Notes: This table shows the country coverage of the dataset..

Figure A1.1 Time series evolution of the investment ratio (in %) for G7 countries



Notes: The figures show the time series evolution of the investment ratio in G7 countries. The investment ratio in this figure is calculated as sum of total investment over the sum of total assets. The red line is based on firm-level balance sheet data from Worldscope, whereas the red line consists of sector-level data from the OECD STAN database, which data source is national accounts. Data from OECD STAN is only available up to 2009 and does not provide a measure of the capital stock for the US or Japan. The investment ratio is denoted in percentage.

Figure A1.2 Time series evolution of the investment ratio for different sectors

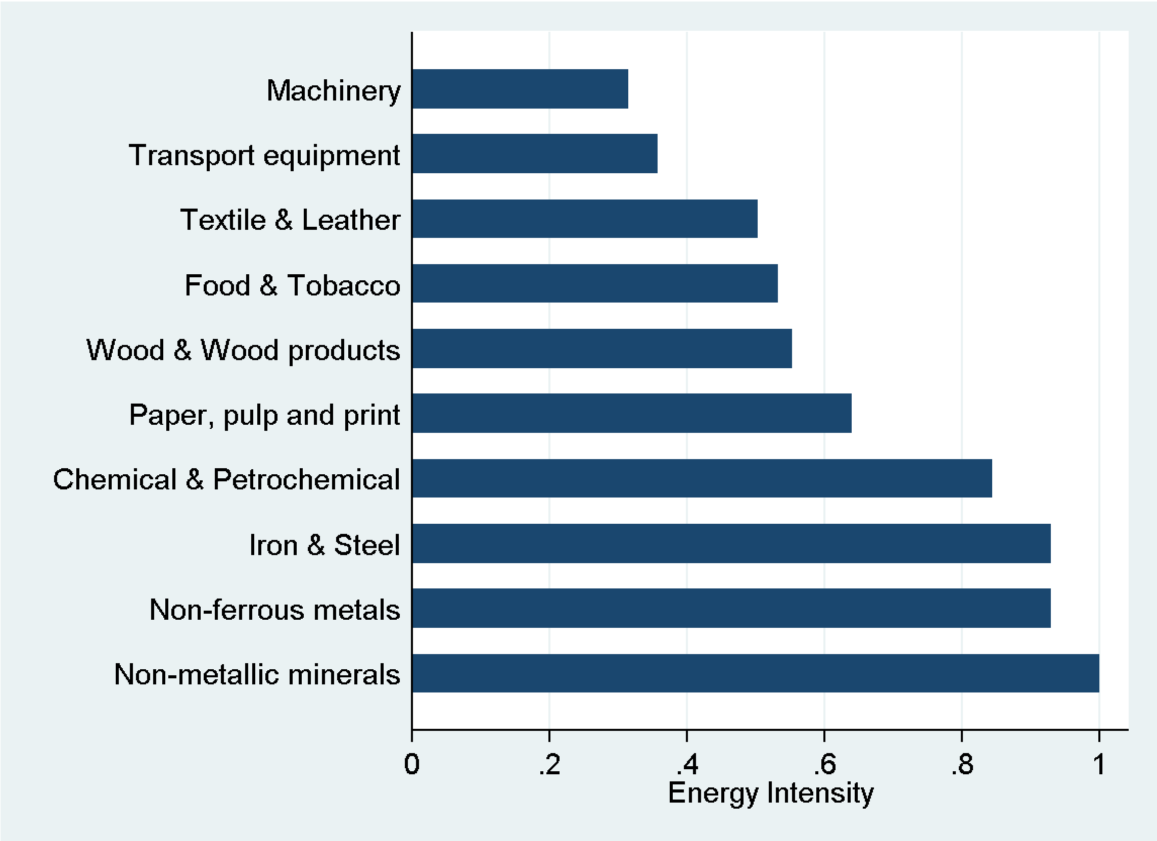


Notes: The figures show the time series evolution of the investment ratio (investment / total capital) in all sectors. We take the mean for each sector and each year in order to aggregate up from the firm level. The investment ratio is denoted in percentage.

A1.2 Energy intensity of industries

2. To allow for the impact of environmental policies to differ by sector, we introduce an "energy intensity" interaction term. Energy intensity is based on the share of electricity, water and gas inputs in total inputs to the production of each industry. It is an in-sample country average, covering 1990-2009. Data for the construction of this variable are sourced from OECD STAN Input-Output tables. It has been demeaned before application.

Figure A1.3 Energy intensity by sector

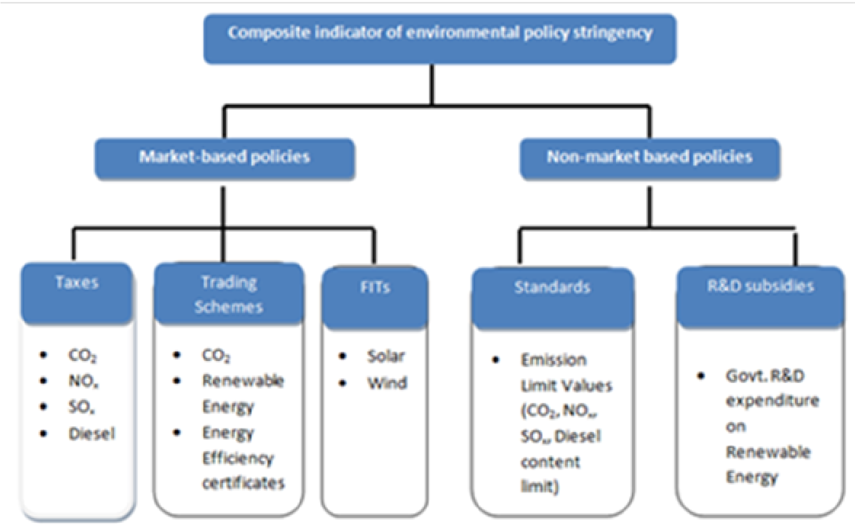


Notes: The classification is broadly based on NACE Rev.1.1 and hand-matched to the SIC two-digit codes from Worldscope. Energy intensity is derived from the OECD Input-Output tables and rescaled between 0 and 1.

Box 2. The environmental policy stringency index

The environmental policy stringency (EPS) indicator was developed by the OECD (Botta and Koźluk, 2014). This indicator covers most OECD countries plus the BRIICS – Brazil, Russia, India, Indonesia, China and South Africa – as international trade and global value chains increasingly rely on the participation of emerging economies over the period 1990-2012. It combines information on 14 market-based and nonmarket policy instruments. Regulations are equally weighted within each category and aggregated into a single indicator. The regulations included focus primarily on energy and transport activities and address mainly climate and air pollutants. Hence, it is based on the assumption that the stringency in key upstream sectors can be representative of that of the entire economy. The indicator ranges from 0 to 6, where 0 is associated with lax and 6 is associated with more stringent policies (see figure below). While a simple proxy, the EPS indicator has a number of advantages for the purpose of this exercise. It is based directly on the measurement of the stringency of policy instruments but exhibits significant positive correlations with e.g. survey-based measures of perceptions of environmental policy stringency. The indicator is also relatively stable with respect to the weighting and aggregation method. Finally, the EPS indicator has broad coverage in terms of countries and time jointly.

The structure of the EPS index



Alternative potential proxies of environmental policy stringency include pollution abatement costs (Tobey, 1990; Grossman and Kruger, 1993; Levinson and Taylor, 2008), the Executive Opinion Survey of the World Economic Forum (Kellenberg, 2009), differences in observed and predicted pollution levels (Combes et al., 2014) or industry level energy prices (Sato et al., 2015; Sato and Dechezlepretre, 2015). All available proxies have drawbacks. Pollution abatement costs are driven by environmental policies, but also by the state of technology, degree of competitive pressures, access to capital, resource prices, R&D policies, etc. Survey-based indexes are by nature exposed to self-reporting bias, problematic interpretation of the time series and respondent sample selection issues. Environmental outcomes based measure of stringency may be driven by factors such as endowments, history, geographical and market conditions, availability of technologies.

APPENDIX II - ESTIMATION RESULTS

Table A2.1 Results with energy price inflation

Dependent variable: Investment / Total Assets	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	Sector-level heterogeneity	Asymmetric sector-level heterogeneity	Level effects	Total investment where domestic available	Domestic investment
Energy Intensity * EPI Inflation (MA) (t-1)		0.0872***			0.0648***	0.1252***
		(0.0141)			(0.0171)	(0.0402)
EPI Inflation (MA) (t-1)	-0.0107*	-0.0132**	-0.0121		-0.0057	-0.0795***
	(0.0057)	(0.0057)	(0.0085)		(0.0073)	(0.0216)
Low Price level: Energy Intensity * EPI Inflation (MA) (t-1)				0.0931***		
				(0.0208)		
High Price level: Energy Intensity * EPI Inflation (MA) (t-1)				0.0759***		
				(0.0193)		
Low Price level: EPI Inflation (MA) (t-1)				-0.0372***		
				(0.0067)		
High Price level: EPI Inflation (MA) (t-1)				0.0160**		
				(0.0071)		
Low Energy Int. * EPI Inflation (MA) (t-1)			0.0933**			
			(0.0402)			
High Energy Int. * EPI Inflation (MA) (t-1)			0.0829***			
			(0.0288)			
Layoff rates * Employment Protection (t-1)	-0.0036***	-0.0037***	-0.0037***	-0.0036***	-0.0031***	-0.0098***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0007)	(0.0023)
Dependency External Fin. * Fin. Dev. (t-1)	0.0120*	0.0107*	0.0107*	0.0127*	0.0042	-0.0024
	(0.0065)	(0.0065)	(0.0065)	(0.0065)	(0.0088)	(0.0262)
Observations	68,334	68,334	68,334	68,334	35,633	35,633
Adj. R2	0.412	0.413	0.413	0.413	0.447	0.0574

Notes: All models include firm- and time fixed effects, sales over total capital, lagged out gap and lagged real interest rates as further controls. Estimated coefficients are not shown due to brevity of presentation. EPI inflation (MA) denotes the three-year moving average of changes in the energy price indicator. Energy intensity is the share of electricity, water and gas inputs in total inputs to the production of each industry. Low and high levels are defined as being above or below the pooled median. The energy intensity has been demeaned before application. Low energy intensive sectors thus have a negative sign. Time sample: 1995-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.

Table A2.2 Results with environmental policy stringency

Dependent variable: Investment / Total Assets	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	Sector-level heterogeneity	Asymmetric sector-level heterogeneity	Level effects	Total investment where domestic available	Domestic investment
Energy Intensity * EPS (MA) (t-1)		-0.0033			0.0106	0.0219
		(0.0057)			(0.0067)	(0.0187)
EPS Tightening (MA) (t-1)	0.0004	0.0003	-0.0035		-0.0030*	0.0053
	(0.0014)	(0.0015)	(0.0036)		(0.0017)	(0.0054)
Low Price level: Energy Int. * EPS Tightening (MA) (t-1)				0.0075		
				(0.0082)		
High Price level: Energy Int. * EPS Tightening (MA) (t-1)				-0.0227***		
				(0.0086)		
Low Price level: EPS Tightening (MA) (t-1)				-0.0031		
				(0.0026)		
High Price level: EPS Tightening (MA) (t-1)				0.0013		
				(0.0018)		
Low Energy Intensity * EPS Tightening (MA) (t-1)			-0.0229			
			(0.0175)			
High Energy Intensity * EPS Tightening (MA) (t-1)			0.0116			
			(0.0137)			
Layoff rates * Employment Protection (t-1)	-0.0046***	-0.0046***	-0.0046***	-0.0046***	-0.0040***	-0.0143***
	(0.0006)	(0.0006)	(0.0006)	(0.0005)	(0.0007)	(0.0020)
Dependency External Fin. * Fin. Dev. (t-1)	0.0106**	0.0107**	0.0108**	0.0109**	0.0077	-0.0070
	(0.0049)	(0.0049)	(0.0049)	(0.0049)	(0.0075)	(0.0182)
Observations	83,273	83,273	83,273	83,273	44,516	44,516
Adj. R2	0.410	0.410	0.410	0.411	0.442	0.0591

Notes: All models include firm- and time fixed effects, sales over total capital, lagged out gap and lagged real interest rates as further controls. Estimated coefficients are not shown due to brevity of presentation. EPS inflation (MA) denotes the three-year moving average of changes in the energy price indicator. Energy intensity is the share of electricity, water and gas inputs in total inputs to the production of each industry. Low and high levels are defined as being above or below the pooled median. The energy intensity has been demeaned before application. Low energy intensive sectors thus have a negative sign. Time sample: 1995-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.

Table A2.3 Robustness checks

Dependent variable: Investment / Total Assets	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
	Baseline With sector-level heterogeneity	**Prior financial crisis**	**Prior financial Crisis + Regimpact**	**W/o USA**	**Country/Year + Sector/Year FE**
Energy Intensity * EPI Inflation (MA)	0.0872***	0.0944***	0.0548***	0.0620***	0.0501**
	(0.0141)	(0.0161)	(0.0193)	(0.0180)	(0.0225)
EPI Inflation (MA)	-0.0132**	-0.0283***	-0.0110	0.0054	-0.0576***
	(0.0057)	(0.0064)	(0.0078)	(0.0073)	(0.0198)
Regimpact indicator (t-1)			-0.3297***	-0.3608***	
			(0.0921)	(0.0906)	
Layoff rates * Employment Protection (t-1)	-0.0037***	0.0000	-0.0023	-0.0053***	-0.0014
	(0.0006)	(0.0009)	(0.0020)	(0.0006)	(0.0020)
Dependency External Fin. * Fin. Dev. (t-1)	0.0107*	0.0137*	0.0136	0.0059	0.0074
	(0.0065)	(0.0076)	(0.0089)	(0.0072)	(0.0073)
Observations	68,334	51,176	40,258	48,586	74,265
Adj. R2	0.413	0.435	0.468	0.415	0.435

Notes: All models include firm- and time fixed effects, sales over total capital, lagged out gap and lagged real interest rates as further controls. Estimated coefficients are not shown due to brevity of presentation. EPS inflation (MA) denotes the three-year moving average of changes in the energy price indicator. Energy intensity is the share of electricity, water and gas inputs in total inputs to the production of each industry. Low and high levels are defined as being above or below the pooled median. The energy intensity has been demeaned before application. Low energy intensive sectors thus have a negative sign. Time sample: 1995-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.

Table A2.4 Decomposition of energy prices

Dependent variable: Energy price index	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
EPS	3.4239***	3.3101***	3.3555***	3.2413***	3.4809***
	(0.0077)	(0.0121)	(0.0227)	(0.0052)	(0.0291)
Observations	53,990	20,486	7,958	93,693	5,347
R-squared	0.7854	0.7838	0.7327	0.8062	0.7285
	(6)	(7)	(8)	(9)	(10)
EPS	3.3210***	3.2527***	3.5061***	3.2284***	3.1156***
	(0.0216)	(0.0139)	(0.0164)	(0.0145)	(0.0285)
Observations	7,829	13,896	15,701	14,384	2,994
R-squared	0.7518	0.7974	0.7435	0.7757	0.7998

Notes: This table reports results from sector-wise linear projections of the energy price index on the EPS indicator. Model (1) is the Chemical and Petrochemical sector, (2) Food and Tobacco, (3) Iron and Steel, (4) Machinery, (5) Non-ferrous metals, (6) Non-metallic minerals (not mining/quarrying), (7) Paper, pulp and print, (8) Textile and leather, (9) Transport equipment and (12) Wood and wood products. Time sample: 1995-2011. *, **, *** denote significance at the 10, 5, and 1% level respectively.

Table A2.5 Results based on decomposed energy prices

Dependent variable: Investment / Total Assets	(1)	(2)	(3)	(4)	(6)	(7)	(8)
	Baseline	Prior financial crisis	Prior financial Crisis + Regimpact	W/o USA	Country/Year + Sector/Year FE	Total inv. when domestic inv. available	Domestic investment
Energy Int. * EPI Inflation - Policy Part	0.0896***	0.0947***	0.0549***	0.0549***	0.0503**	0.0775***	0.1374***
	(0.0146)	(0.0164)	(0.0194)	(0.0186)	(0.0246)	(0.0182)	(0.0423)
EPI Inflation - Policy Part	-0.0108*	-0.0288***	-0.0116	0.0071	-0.0866***	-0.0097	-0.0702***
	(0.0061)	(0.0067)	(0.0081)	(0.0074)	(0.0330)	(0.0079)	(0.0237)
Energy Int. * EPI Inflation - Residual Part	0.0885***	0.0954***	0.0544***	0.0587***	0.0481**	0.0722***	0.1300***
	(0.0142)	(0.0161)	(0.0192)	(0.0182)	(0.0237)	(0.0175)	(0.0409)
EPI Inflation - Residual Part	-0.0114*	-0.0286***	-0.0113	0.0060	-0.0565***	-0.0088	-0.0722***
Regimpact indicator (t-1)			-0.3343***	-0.3752***			
			(0.0960)	(0.0909)			
Layoff rates * Employment Protection (t-1)	-0.0038***	0.0000	-0.0022	-0.0053***	-0.0014	-0.0028***	-0.0100***
	(0.0006)	(0.0009)	(0.0020)	(0.0007)	(0.0020)	(0.0007)	(0.0023)
Dependency External Fin. * Fin. Dev. (t-1)	0.0099	0.0137*	0.0135	0.0047	0.0072	0.0039	-0.0026
	(0.0065)	(0.0076)	(0.0090)	(0.0072)	(0.0073)	(0.0088)	(0.0262)
Observations	68,180	51,091	40,191	48,485	74,110	35,551	35,551
Adj. R2	0.4806	0.5170	0.5529	0.4835	0.5115	0.5135	0.1704

Notes: All models include firm- and time fixed effects, sales over total capital, lagged out gap and lagged real interest rates as further controls. Estimated coefficients are not shown due to brevity of presentation. EPS inflation (MA) denotes the three-year moving average of changes in the energy price index. Energy intensity is the share of electricity, water and gas inputs in total inputs to the production of each industry. Low and high levels are defined as being above or below the pooled median. The policy and residual variation of energy price inflation are calculated by sector-wise linear projecting energy prices on EPS. The energy intensity has been demeaned before application. Low energy intensive sectors thus have a negative sign. Time sample: 1995-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.

Dynamic panel model

3. We check the robustness of our empirical model by testing the effects of energy price increases in a dynamic panel framework. A dynamic panel model has the advantage that the lagged dependent variable already controls for large parts of the firm-level time-varying variation, reducing concerns with a potential omitted variable bias. Although we control for firm-level sales over total assets other firm-level variables potentially could be drivers of investment as well. The lagged dependent structure controls for other firm-level factors up to the lag considered in the specification and hence provides a parsimonious way to deal with omitted variable bias. To check the robustness of our baseline regression we estimate a dynamic panel model with two lags of the dependent variable.

4. We compare within estimator results with results from a one-step system GMM estimator that instruments lags of the dependent variable with further lagged levels and differences as proposed by Arellano Bond (1991). In a panel model with fixed effects and lagged dependent variables estimated with the within estimator, the fixed effects correlates with the error term biasing our coefficient estimates. Nickell (1981) shows that the bias decreases with growing T. Hence, by using the within estimator consistency of our estimates depends on a T argument. In the case of the system GMM estimator this bias is addressed by instrumenting the lagged dependent variables with further lagged levels and differences of the investment ratio. The consistency argument then depends on N, which is large in our case. Table A2.6 provides further information on the specification of the System GMM estimator.

5. The results from a dynamic panel model stay qualitatively the same (Table A2.6). For higher levels of pollution intensity an increase in energy prices associates with relatively more investment. The base effect of an increase in energy prices differs between the model estimated with the within estimator and the System GMM estimator. With the System GMM estimator the base effect is strongly statistically significant. This difference might be due to the Nickell bias which is removed by the instrumental variable strategy embedded in the System GMM estimator. Furthermore important key model diagnostics indicate that the System GMM specification appears valid. The overall effect of an increase in energy prices using the System GMM estimator resembles the pattern in Figure 1. For low, medium and high levels of pollution intensity the overall effect is significant at least at the 5% level. With low and medium levels of pollution intensity the overall effect points to a negative association of an increase in energy prices and investment, whereas with high pollution levels the overall effect has a positive sign.

Table A2.6 Dynamic panel models

Dependent variable: Investment / Total Assets	(1)	(2)	(3)	(4)
	Within	System-GMM	Within	System-GMM
Investment / Total Assets (t-1)	0.1616***	0.4618***	0.1829***	0.4196***
	(0.0096)	(0.0920)	(0.0088)	(0.0999)
Investment / Total Assets (t-2)	-0.0651***	0.0752	-0.0584***	0.0866
	(0.0072)	(0.0807)	(0.0069)	(0.0820)
Energy Int. * Energy Price Inflation (MA)	0.0747***	0.0820***		
	(0.0129)	(0.0173)		
Energy Price Inflation (MA)	-0.0066	-0.0199**		
	(0.0052)	(0.0086)		
Layoff rates * Employment Protection (t-1)	-0.0026***	0.0010**	-0.0027***	0.0011**
	(0.0005)	(0.0004)	(0.0005)	(0.0005)
Dependency External Fin. * Fin. Dev. (t-1)	0.0025	0.0013***	0.0028	0.0015**
	(0.0060)	(0.0005)	(0.0048)	(0.0006)
Energy int. * EPS Tightening (MA)			-0.0006	0.0187**
			(0.0049)	(0.0075)
EPS Tightening (MA)			0.0004	0.0069***
			(0.0013)	(0.0019)
Long-run coefficients				
Energy Int. * Energy Price Inflation (MA)	0.0826***	0.1770***		
	(0.0143)	(0.0380)		
Energy Price Inflation (MA)	-0.0073	-0.0430**		
	(0.0058)	(0.0167)		
Energy Int. * EPS Tightening (MA)			-0.0006	0.0378***
			(0.0056)	(0.0142)
EPS Tightening (MA)			0.0004	0.0140***
			(0.0015)	(0.0025)
Observations	62,104	62,836	71,668	72,280
Adj. R2	0.442	-	0.445	-
Hansen J-Test	-	0.696	-	0.744
AR(2)-Test	-	0.732	-	0.511

Notes: The one-step System GMM estimator uses levels and differences from lag three to eight to instrument for the lagged dependent variables. All models include firm- and time fixed effects as well as sales/total capital lagged out gap, lagged real interest rates as further controls. Estimated coefficients on these additional controls are not shown due to brevity of presentation. EPI inflation (MA) denotes the three-year moving average of lagged changes in the energy price indicator. Energy intensity is based on the share of electricity, water and gas inputs in total inputs to the production of each industry. Time sample: 1995-2011. Firm clustered standard errors in parentheses. *, **, *** denote significance at the 10, 5, and 1% level respectively.

APPENDIX III - OVERVIEW OF RELEVANT LITERATURE

Table A3.1 Overview of relevant literature

AUTHOR	LHS VARIABLE(S)	SAMPLE	TIME PERIOD	PROXY FOR ENVIRONMENTAL REGULATION	METHODOLOGY	MAIN RESULT
Leiter et al. 2011	Gross investment Investment in new buildings Investment in machinery Productive investment	9 manufacturing industries from 21 European countries (Eurostat)	1998-2007	Industry's total expenditure on environmental protection (Eurostat) Country-industry's total revenue from environmental taxation (Eurostat)	Panel model with country-year and industry fixed effects	Positive, significant impact on all types of investment Squared terms suggest that higher levels of regulation lead to decrease in investment
Böhringer et al. 2012	Growth in gross value added	23 German manufacturing industries	1996-2002	Not applicable	Dynamic panel model with industry and year fixed effects	Ex-post higher investment in environmental-friendly technologies foster production growth Costs of compliance with environmental regulation has no effect
Kneller and Manderson 2012	Environmental R&D Total R&D Investment in integrated environmental protection expenditures Total investment	25 UK manufacturing industries	2000-2006	Pollution abatement costs	Dynamic panel with internal instruments to control for potential endogeneity of abatement costs	Higher regulation increases R&D and investment in green technology No effects of higher regulation on total R&D and investment
Hamamoto 2006	R&D expenditure Age of capital stock TFP growth	5 Japanese manufacturing industries	1966-1976 (R&D) 1972-1982 (age of capital stock)	Pollution abatement costs	Panel model with industry fixed effects and a time trend	Environmental regulation have positive effect on R&D expenditure Increased regulation leads to a decreased age of capital stock, i.e. modernisation and/or downsizing effects Increased R&D induced by environmental regulation leads to higher TFP growth

Greenstone 2002	Employment Output Investment	US plant level data from 3,070 counties	1967-1987	Regulatory differences in the Clean Air Act between counties	Panel model with plant-, industry-year, and county-year fixed effects	Regulated counties (compared to unregulated counties) see a large fall in output and investment
Xepapadeas and de Zeuuw 1999	Not applicable	Not applicable	Not applicable	Not applicable	Theoretical model in which profit-maximizing firms can invest in different types of machines (old, dirty, cheap vs. new, expensive, clean)	Environmental regulation changes the structure of the capital stock which affects positively productivity Channels: Modernization (i.e. investment in new machines) or downsizing or both
Gray and Shadbegian 1998	Investment	US paper plants	1980-1990	Time-varying index of environmental regulation based on each state's air and water pollution control program in 1987	Panel model with firm and year fixed effects	New plants in highly regulated states use cleaner technology Small (to non-existing) negative effect of regulation on investment at existing plants Significant relationship negative correlation between productive investment and abatement investment
Garofalo and Malhotra 1995	Non-abatement capital stock	Manufacturing industries in 34 US states	1983-1989	Abatement capital	Panel model with state and year fixed effects	Modest negative effect of higher regulation on investment
Nelson et al. 1993	Age of capital stock Plant emissions	44 US privately owned electric utilities	1969-1983	Enforcement expenditure of the state air quality management agency	Simultaneous equation model on pooled data	Environmental regulation increases the age of the capital stock (i.e. leads to less investment)