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Analysis

The relationship between international financial reporting standards, carbon emissions, and R&D expenditures: Evidence from European manufacturing firms

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ABSTRACT

This study examines the impact of research and development (R&D) expenditures on carbon dioxide (CO2) emissions prior to and under the mandatory adoption of International Financial Reporting Standards at the firm level within the manufacturing sectors of three European countries, i.e. Germany, France and the U.K. Estimation of a threshold autoregressive model using quarterly data from 1998 to 2011 reveals that in the post-IFRS mandatory adoption year R&D expenditures show a reduction in CO2 emissions to firms, i.e. rising CO2 abatement. This is likely due to the presence of incentives provided by the new accounting disclosure regime. Our results remain robust in terms of a sector analysis, firm size, and the introduction of the European Union Emission Trading Scheme (EU-ETS) across the three countries.

1. Introduction

Carbon dioxide emission reductions can be achieved, among other means, through technological changes and investments in R&D. Jones (2002) and Vollebergh and Kemfert (2005) argue that innovations enhance labor and capital productivity, which is crucial for economic growth. Investment in R&D has an impact on technological changes, an assumption which receives support by the 'new growth theory' or 'induced technological change' literature (Vollebergh and Kemfert, 2005). Thus, technological changes and investment in R&D are common denominators for achieving both CO2 abatement and economic growth. Along these lines, Parry et al. (2003) assess whether the welfare gains from technological innovation leading to CO2 emission reductions are larger or smaller than the 'Pigouvian' welfare gains from optimal pollution control. Their empirical findings indicate that such welfare gains from innovation are smaller than those from pollution control, while Jaffe et al. (2005) claim that R&D generates positive externalities that contribute to both welfare gains and pollution control. As noted by Edenhofer et al. (2005), there is a close link between reducing emission cost efficiently and economic growth, in the sense that cost efficient abatement decreases the costs in terms of growth foregone.

Related to the role of R&D investment in the reduction of carbon emissions is the impact of environmental information disclosure by firms. Mason (2008) notes that firms have been increasing environmental information disclosure to satisfy requests from external regulatory bodies and the general public. Indeed, such information disclosure may be far ranging in light of the absence of authoritative accounting guidance (Bebbington and Larrinaga-Gonzalez, 2008). Studies in the relevant literature suggest that environmental information disclosure is important not only to enable various stakeholders to make informed decisions, but also to control business risk and develop competitive advantage (Kolk and Pinkse, 2007). Deegan and Haque (2009) argue that while carbon emissions are the core theme of climate change, information relevant to climate change should also include management approaches and other external factors related to climate change issues. Therefore, firms are under increasing public and regulatory pressure to disclose the impacts of business conduct on the environment and society (Simnett et al., 2009).

In light of the importance of R&D investment and the need for environmental information disclosure this study examines the impact of R&D expenditures (an accounting information item) on carbon dioxide (CO2) emissions prior to and under the mandatory adoption of

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International Financial Reporting Standards (IFRS) within the European Union (EU). The improvement in emission accounting disclosures is expected to have a direct impact on the way firms cope with their targeted emission reductions by improving the efficiency of their R&D expenditures to develop green products and green methods of transactions. Furthermore, the EU has demonstrated a greater willingness to cooperate with regulatory bodies and various non-governmental environmental groups in managing and disclosing carbon emission information (Kolk et al., 2008; Oberthur, 2007). Ellerman and Buchner (2008) reveal that after 2005, European firms demonstrated decreasing trends in their carbon dioxide emissions, though others claim that this decreasing trend is attributed exclusively to the global recession (Spies and Stilwell, 2009).

Our analysis is undertaken at the firm level within the manufacturing sectors of three European countries, i.e. Germany, France and the U.K., using quarterly data from 1998 to 2011. The study focuses on manufacturing firms, since this is the sector that undertakes the bulk of total business R&D. Moreover, we consider the R&D expenditures as an accounting item for which measurements under IFRS are likely to differ considerably from measurements under domestic accounting practices across the three EU countries prior to the mandatory introduction of the IFRS. To the best of our knowledge, no study has investigated the impact of accounting information associated with R&D expenditures on CO2 emissions and, in particular, prior to and after the adoption of IFRS.

Section 2 provides a brief overview of the IFRS and the eco-innovation literature. Section 3 presents the empirical methodology with results reported in Section 4. Concluding remarks are given in Section 5.

2. Overview of IFRS and the Eco-innovation Literature

All EU publicly traded firms have been required to prepare consolidated financial statements based on the International Financial Reporting Standards (IFRS), a main-stream financial reporting system. As of January 1, 2005 all EU listed firms had to adopt IAS/IFRS in order to prepare their consolidated financial statements, as an attempt to enhance the competitiveness of the European capital markets by establishing a single set of homogeneous and internationally recognized standards (Soderstrom and Sun, 2007). The adoption of IFRS initiated the computation of a common consolidated accounting system, which is expected to contribute to the elimination of certain impediments to a full harmonization as well as to greater capital market efficiency, leading to a lower cost of capital and increasing access to financing by firms. This is a major regulatory financial reporting change in the history of accounting reporting and in the convergence of national accounting systems (Agostino et al., 2008; Beneish et al., 2009; Guerreiro et al., 2008; Schipper, 2005; Whittington, 2005). The adoption of a capital-market oriented set of accounting standards would improve the transparency and comparability of financial statements over the use of past national GAAP (Hail et al., 2010). Nevertheless, a certain strand of literature highlights the high costs of transition towards IFRS (Cascini, 2008; Christensen et al., 2007), while Djatej et al. (2009) find that IFRS adoption increases public information but decreases private information.

In December 2004, the International Reporting Interpretations Committee (IFRIC) released Article 3, Emission Rights, in an attempt to address how participants should account for cap and trade emission trading schemes. According to Article 3, emission allowances, whether issued by governments or purchased in the market, are intangible assets to be accounted for in accordance with Article 38 of IFRS, Intangible Assets. Despite the withdrawal of IFRIC 3 in June 2005 there remains a number of existing standards that provide authoritative guidance on the relevant accounting that firms must use in forming their policies for carbon-related transactions. Firms must interpret the existing standards based on the pattern of their particular business model, strategy, and transactions. This includes providing relevant disclosures of policies, transactions and balances included in their financial statements. Therefore, the critical question is whether the new accounting regime of the mandatory adoption of IFRS is suitable for a carbon-constrained world.

Based on Article 38, Changes in the Market Value of Intangibles, i.e. emission allowances held and R&D, are recognized in equity. Within this framework firms should assess the technical feasibility of the intangible asset, the availability of resources (technical or financial) to complete it, the ability to reliably measure the expenses, and the ability to justify whether the asset will generate future economic benefits (Tsoligkas and Tsalavoutas, 2011). Daske and Gebhardt (2006) and Barth et al. (2008) provide evidence that the perception of disclosure quality increased around IAS adoptions. Based on this accounting reporting environment, EU firms have enhanced their data collection and reporting capabilities in disclosing their sustainability performance as well as in developing guidelines to enhance reporting. The improvement in emission accounting disclosures is expected to have a direct impact on the way firms cope with their target of emission reductions by improving the efficiency of their R&D expenses to develop green products and green methods of transactions.

This study contributes to the research on the identification of eco-innovations targeting pollutant emissions and the extension of this literature on both environmental and firm performances. Such eco-innovation activities accentuate the importance of environmental management systems (with their dual purpose of reducing environmental impacts and enabling firms to achieve enhanced organizational learning on environmental matters), leading to cleaner, cost-saving technologies while reducing the incomplete information within a firm (Khanna et al., 2009; Wagner, 2008). The IFRS regime in part represents an organizational eco-innovation in allowing firms to adopt new environmental strategies and regulatory structures to reduce industrial pollution and waste along with improving product quality by introducing environmentally superior inputs of production (Anton et al., 2004). Moreover, mandatory regulations (i.e. IFRS) drive firms to adopt eco-innovating systems, since high polluting firms could face greater risks of penalties if their pollution levels are not reduced.

Konar and Cohen (2001) show that variables related to environmental performance has a substantial impact on both pollutant emissions and the financial performance of firms. Brunnermeier and Cohen (2003) employ panel data on manufacturing firms in studying environmental innovations to find that such innovation expenses affect abatement measures. Similar results are reported by Frondel et al. (2004) in the case of European manufacturing firms. Popp (2005) argues that direct or indirect environmental regulations create 'win–win' situations in which firms enjoy high profits and produce 'clean-green' products, since such environmental regulations boost R&D expenditures and, thus, lead to economic growth. Rennings et al. (2006) discuss the effects of environmental management systems on firms' innovation activities and competitiveness across European firms to show that eco-innovation activities contribute to the integration of environmental management through information spillovers across firms and, thus, to stronger competitiveness. Arimura et al. (2007) also document the positive effect of regulation on green R&D expenditures. Horbach (2008) argues that such environmental innovations (i.e. in our case a IRFS regime) are similar to regulatory activities that promote cleaner production technologies, while Del Rio Gonzalez (2009) documents the role of regulation pressures as a primary driver in adopting cleaner technology for a number of Spanish manufacturing industries.

We focus on the question of whether differences in value relevance exist and if so, to what extent such differences are driven by the mandatory adoption of IFRS for the accounting item of R&D expenditures. Furthermore, we consider the R&D accounting item for which measurements under IFRS are likely to differ considerably from measurements under domestic accounting practices across the three EU countries prior to the mandatory introduction of the international standards (Wyatt, 2008). Finally, we focus on manufacturing given its relatively high environmental impact and innovation potential (Mazzanti and Zoboli, 2009).

3. Econometric Methodology and Data

The basic (linear) econometric model in reduced form is:

$$CO2_t = \alpha CO2_{t-1} + \beta R\&D_t + Z_t\delta' + \varepsilon_t \quad (1)$$

where CO2 is per capita CO2 emissions in year t; α and β are scalar coefficients; R&D represents research and development expenditures; δ is a vector of parameters; Z is a vector of control variables which includes real per capita GDP, oil prices, and trade openness; and ε is an error term.[1]

Eq. (1) is based on the environmental Kuznets curve following Holtz-Eakin and Selden (1995), Suri and Chapman (1998), Taskin and Zaim (2000), Antweiler et al. (2001), Cole and Elliott (2003), Friedl and Getzner (2003), Copeland and Taylor (2004), and Lanne and Liski (2004), through the inclusion of trade and oil prices in the specification. Though there is some debate in the literature on the use of per capita emissions versus aggregate emissions, we use per capita emissions for several reasons.[2] First, although the geographic distribution of CO2 emissions does not influence the climatic impact of those emissions, the per capita distribution usually affects the political economy of negotiating multilateral climate change agreements. Countries with lower per capita emissions (i.e., developing countries or with different accounting standards) may expect countries with higher per capita emissions (i.e., industrialized countries or with different accounting standards) to undertake a greater effort toward mitigating climate change. This discrepancy in effort allocation may reflect industrialized countries' larger contribution to climate change (a 'responsibility' notion of equity) or greater resources (an 'ability to pay' notion). In lieu of periodically renegotiating ad hoc emission obligations, some policymakers have suggested explicit rules to the assignment of emission rights or obligations that would encourage the participation of developing countries. For example, in a per capita emission allocation scheme an aggregate quantity of greenhouse gas emissions would be set and then allocated among all (participating) countries according to population. Second, emissions on a per capita basis are the most important criteria for deciding the rights to environmental space, as a direct measure of 'human welfare' (Marland et al., 2003). Such an approach has gained the support of some nongovernmental organizations and academics that support a per capita emission allocation (Bodansky, 2004). A per capita scheme would allocate emission rights in a vastly different way than aggregate emissions, which reflects variations in economic development; climate; and policies for land use, energy, and the environment. If emissions converged over time, then this concern about the distinction between the use of per capita emissions and aggregate emissions maybe less important. If per capita emissions did not converge, then a per capita emission allocation would result in substantial resource transfers through international emission trading or the relocation of emissions-intensive economic activity.

Quarterly data on R&D expenditures were obtained from the *Datastream* database for the period 1998 to 2011. In particular, data on R&D expenditures from 1230 listed manufacturing firms in three EU countries, i.e. Germany, France and the U.K., were compiled.[3] We have selected these three countries on the grounds that in two of them, the U.K. and France, the domestic accounting standards are more compatible with the IFRS (a common law regime), while in the case of Germany, the deviation of domestic-based accounting was greater vis-à-vis the accounting information resulting from the switch to IFRS (civil law regime). For instance, in Germany, all R&D expenditures had to be expensed immediately, whereas in the U.K., although expenditures on research had to be expensed immediately, development expenses might be capitalized and periodically amortized if certain preconditions are fulfilled, in conformity with IAS 38.

We also obtain from *Datastream* the value of their total assets, a variable that will permit us to divide our sample into 'large firms' and 'small firms' samples. At this point it is worth emphasizing that our sample accounts for the fact that it involves only firms (across all three countries) that immediately adopted the new financial reporting.[4] At the same time, our sample does not include firms that were not affected by the IFRS mandate because they already reported under IFRS on a voluntary basis since 2002–2003. In addition, we match quarterly emission data (CO2 emissions in thousands of CO2 metric tons associated with fossil fuel burning and gas flaring) from the same 1230 manufacturing firms collected from several sources: the European Commission (Community Independent Transaction Log, CITL) and the *Bloomberg* database. Based on data availability for CO2 emissions, we end up with 507 manufacturing firms from the U.K., 305 firms from France, and 418 firms from Germany.

In addition, we extract information from *Datastream* on population used to generate real (constant prices at 2000 international prices) GDP per capita, oil (spot) prices as well as exports and imports. Holtz-Eakin and Selden (1995) show a link between real output and CO2 emissions for 130 countries. Suri and Chapman (1998) who also provide evidence in favor of such a link for 33 countries using a panel fixed effects model. By contrast, Hettige et al. (2000) provide results that reject the association between real output and CO2 emissions while Taskin and Zaim (2000) claim that this association holds only for countries with sufficiently high GDP per capita. Copeland and Taylor (2004) examine additional factors affecting CO2 emissions and find that output impacts emissions. The inclusion of oil prices is attributed to the fact that higher oil prices may induce the manufacturing sector to switch to less energy consuming technologies, and thus, decrease emissions. Friedl and Getzner (2003) find that CO2 emissions closely follow oil prices in the case of Austria, while Lanne and Liski (2004) conclude that oil prices correspond to a shift toward a stable downward trend in emissions. We also measure trade openness using the sum of exports and imports as a share of nominal GDP. Larger trade openness may result in more pollution due to greater exports of energy intensive products. Moreover, technology diffusion becomes easier through international trade. As a result, the net effect of free trade on CO2 emissions depends on the relative strength of each opposing effect, implying that its sign is an empirical issue. Finally, all variables are denoted in natural logarithms.

In addition to an aggregate analysis, we also classify firms into six sectors based on the two digit classification system: Electricity and Heat, Paper and Paper Products, Basic Metals, Coke and Refined Petroleum Products, Textiles, and Chemicals. Based on this classification, Table 1 reports the number of firms by in each country.

Given the specification in Eq. (1) we will employ the threshold autoregressive (TAR) model developed by Tong and Lim (1980) and Tong (1983). The model partitions the one-dimensional Euclidean

[1] In response to a referee's comment, we investigated the inclusion of R&D expenditures lagged one period; however, it was statistically insignificant.

[2] In the literature, however, there has been a debate (the issue was raised by one of the referees) about the selection of per capita emissions or the aggregate emissions. According to the referee, what matters for global warming is aggregate emissions, thus, by using per capita emissions researchers do not recognize the impact of improved efficiency on total emissions. In this manner, there could be a rebound effect whereas higher efficiency leads to growth and, thus, more energy use and more emissions in return.

[3] We select only R&D expenditures because R&D capitalization data were not available. Moreover, R&D capitalization was not allowed, thus not reported by firms prior to the mandatory adoption.

[4] EU allowed for a transitional period until 2007.

Table 1
Firm classification by country and sector.

U.K. (507)
Electricity and heat: 36
Paper and paper products: 75
Basic metals: 79
Coke and refined petroleum products: 93
Textiles: 65
Chemicals: 129
France (305)
Electricity and heat: 32
Paper and paper products: 38
Basic metals: 61
Coke and refined petroleum products: 54
Textiles: 36
Chemicals: 84
Germany (418)
Electricity and heat: 51
Paper and paper products: 55
Basic metals: 79
Coke and refined petroleum products: 81
Textiles: 48
Chemicals: 104

Notes: total number of firms in parentheses with the number of firms disaggregated by sector.

space into τ number of spaces, using piecewise and locally linear autoregressions to map the regime-switching dynamics of an observed sequence. Depending on the threshold variable relative to a threshold value, coefficients of a linear autoregressive (AR) process and hence the linear relationship can vary across different regimes. Let us consider the single-threshold and implied two-regime canonical representation of an ergodic stationary series (y_t, i.e. $CO2_t$), with pth order linear AR processes and possibly differing degrees of persistence in each regime:

$$y_y = \begin{cases} \omega_0 + \sum_{i=1}^{p} \omega_i y_{t-i} + v_{1t} & \text{if } q_t \le \tau \\ \xi_0 + \sum_{i=1}^{p} \xi_i y_{t-i} + v_{2t} & \text{if } q_t > \tau \end{cases} \tag{2}$$

where the q in model (2) is the threshold variable and characterizes the discontinuous and nonlinear structure of model parameters; in our case the q matches the R&D expenditures variable, while the τ matches the year 2005. The one-dimensional stochastic process, y_t, is split into two spaces at switch-point τ such that the series follows one AR(p) process for $q_t \le \tau$, and another process for $q_t > \tau$. These differing and asymmetric AR processes characterize nonlinearity in one-dimensional stochastic space. Using a Heaviside indicator function $I_t(q_t, \tau)$, the two separate AR(p) processes in model (2) can be nested into a single model with constant residual variance across regimes as:

$$y_t = I_t[\omega_0 + \sum_{i=1}^{p} \omega_i y_{t-i}] + (1 - I_t)[\xi_0 + \sum_{i=1}^{p} \xi_i y_{t-i}] + e_t \tag{3}$$

$$I_t(q_t, \tau) = \begin{cases} 1 & \text{if } q_t \le \tau \\ 0 & \text{if } q_t > \tau \end{cases}. \tag{4}$$

The $I_t(q_t, \tau)$ in model (4) represents a step-function in that it takes a value 1 if the break-regressor $\{q_t\}$ is below the threshold and a value 0 if it is above the threshold. The stochastic term, e_t, in model (3) follows the usual Gaussian i.i.d. properties, such as $E\{e_t\} = 0$, $E\{e_t^2\} = \sigma_e^2$, and $Cov\{e_i e_j\} = 0$.

Table 2
Panel unit root tests.

Country	Variables	LLC Test	IPS test (with trend)
U.K.	CO2	−2.174	−2.251
	ΔCO2	−8.585*	−9.425*
	R&D	−1.773	−1.385
	ΔR&D	−5.265*	−5.065*
	gdp	−1.649	−1.844
	Δgdp	−6.975*	−9.591*
	oilp	−1.589	−1.721
	Δoilp	−6.259*	−8.182*
	trade	−1.269	−1.179
	Δtrade	−7.947*	−6.856*
France	CO2	−1.308	−1.048
	ΔCO2	−7.577*	−5.417*
	R&D	−1.664	−1.189
	ΔR&D	−8.109*	−6.348*
	gdp	−1.728	−1.219
	Δgdp	−9.005*	−6.096*
	oilp	−1.174	−1.690
	Δoilp	−6.372*	−9.541*
	trade	−1.559	−1.892
	Δtrade	−6.329*	−8.006*
Germany	CO2	−1.263	−1.006
	ΔCO2	−7.163*	−6.004*
	R&D	−0.965	−1.018
	ΔR&D	−6.019*	−6.148*
	gdp	−1.227	−1.114
	Δgdp	−7.336*	−7.183*
	oilp	−1.439	−1.183
	Δoilp	−8.901*	−7.374*
	trade	−1.457	−1.581
	Δtrade	−8.338*	−8.841*

Notes: the null hypotheses of the LLC and IPS tests are that the series contain a unit root. An * denotes statistical significance at the 1% level.

4. Empirical Analysis

4.1. Statistical Tests for Unit Roots and Threshold Effects

Stationary time series are required for our study. At the outset, the statistical properties of all the variables under investigation are examined by testing for the presence of unit roots. There are a variety of panel unit root tests, which include Levin et al. (2002) and Im et al. (2003), among others. Levin et al. (2002) assume homogeneity in the dynamics of the autoregressive coefficients for all panel units while Im et al. (2003) allow for heterogeneity in the dynamics of the autoregressive coefficients. For both panel unit root tests the null hypothesis is a unit root while the alternative hypothesis is the absence of a unit root. The results in Table 2 indicate that the variables are integrated of order one at the 1% significance level.[5]

Next, the Hansen (1996) F-test is used to test the null hypothesis of a linear relationship between CO2 emissions and R&D expenditures against particular threshold alternatives. Hansen (1996) makes use of a bootstrap method which simulates the asymptotic distribution of the test under the null hypothesis of linearity. More specifically, the test computes the bootstrap value of the likelihood ratio (LR) statistic defined as:

$$LR = \left[\varepsilon_{jt}{}^2 - e_{jt}(\tau)^2\right] / \sigma^2(\tau) \tag{5}$$

where ε_{jt}^2 is the sum of squared errors from the OLS regression (with no thresholds), while $e_{jt}(\tau)^2$ is the sum of squared errors from the regression with thresholds. The corresponding p-value of the test is calculated as the percentage of draws for which the simulated statistic exceeds the actual value. The Hansen test also corrects for

[5] The RATS (Version 7.1) and GAUSS software packages were used in the empirical analysis.

Table 3
Hansen F-test.

Country	F-test
U.K.	8.7*
France	12.4*
Germany	9.6*

Notes: the null hypothesis is a linear relationship between CO2 and R&D expenditures with the alternative of a particular threshold relationship between CO2 and R&D expenditures. An * indicates rejection of the null hypothesis at 1% significance level.

heteroskedasticity. The results are reported in Table 3 which reveals the presence of threshold effects.[6]

4.2. Nonlinear Estimates

According to the TAR process defined in Eqs. (3) and (4), when the regression under investigation can be characterized by a two-regime TAR system, our empirical model can be expressed as:

$$\begin{aligned}\Delta CO2_t = {} & (\alpha_{10} + \beta_{11} CO2_{t-1} + \delta_{12}\,\Delta R\&D_t + \delta_{13}\,\Delta gdp_t + \delta_{14}\,\Delta oilp_t \\ & + \delta_{15}\,\Delta trade_t) I_t (R\&D_t \leq 2005) + (\alpha_{20} + \beta_{21} CO2_{t-1} \\ & + \delta_{22}\,\Delta R\&D_t + \delta_{23}\,\Delta gdp_t + \delta_{24}\,\Delta oilp_t \\ & + \delta_{25}\,\Delta trade_t)(1 - I_t)(R\&D_t > 2005) + e_t.\end{aligned} \tag{6}$$

The no threshold model was treated as a dynamic panel and estimated through the Arrelano and Bond (1991) general method of moments (GMM) methodology. The GMM estimation approach makes use of all available lagged values of the dependent variable as well as of all available lags of the exogenous regressors as instruments. The results are reported in Table 4 for the aggregate manufacturing sector. For comparison purposes, the first column displays estimates for a linear specification that ignores the threshold effect. The remaining columns provide the estimates of the TAR model. The results of the linear model in the first column indicate that R&D expenditures do not have a statistically significant impact on CO2 emissions in each of the three countries. In terms of the control variables, income exerts a positive and statistically significant influence on CO2 emissions while oil prices yield a statistically significant negative effect in each of the three countries. In terms of trade openness, there is a statistically significant positive effect in each of the three countries. The explanatory power (adjusted R^2) of the linear model is around 36%, 28%, and 27% for the U.K., France, and Germany, respectively.

The empirical findings from the nonlinear version of the model suggest that R&D expenditures do not exert a statistically significant impact on CO2 emissions during the period prior to the mandatory adoption of the IFRS in each of the three countries. By contrast, the impact of R&D expenditures on CO2 emissions is negative and statistically significant after 2005. This negative association remains robust in each of the three countries and documents that as long as R&D expenditures increase, firms tend to spend more on innovative 'green products' and/or 'green technologies', leading to the reduction of CO2 emissions. In other words, the adoption of the IFRS regime simply maps R&D in a more 'accurate' way than national GAAPs. The coefficients for the control variables are statistically significant with the expected sign. By considering the threshold effect, the explanatory power increases to 51% (U.K.), 54% (France), and 59% (Germany) in relation to the linear model. Our empirical findings for Germany validate those reached by Horbach et al. (2011) in finding that environmental management systems trigger cleaner, cost-saving technologies by overcoming incomplete information within firms.

4.3. Robustness Tests: Sector Analysis

In the EU, firms that perform the vast majority (80%) of the EU R&D belong to the manufacturing high-tech sectors. However, at the same time, the weight of these sectors in the EU economy has decreased. According to Barbier et al. (2004), the best way to evaluate greenhouse gas mitigation policies, notwithstanding the possibility of reliance on Kyoto's flexibility mechanisms, is to undertake a sector analysis of emission trends to distinguish between so-called one-off mitigation options that may have been pursued or are awaiting a clear policy signal from those that will require more structural efforts in order to deliver significant reductions in the medium term. Barbier et al. (2004) argues that over the last ten years total EU industry energy-related CO2 emissions decreased by about 10%, and accounted for 17% of the region's total. The sectors utilized in our empirical analysis account for roughly 78% of the total. While some sectors have undergone declines in industrial production along with continuing improvements in energy efficiency, the reduction in CO2 emissions is caused either by a substitution of direct fossil fuel use by electricity use or by employing 'greener technologies'.

Table 4
Results of linear and TAR models: aggregate manufacturing sector.

Variables	Linear model	Threshold model	
		$R\&D_t \leq 2005$	$R\&D_t > 2005$
U.K.			
Constant	0.035(0.246)	0.018(0.114)	0.017(0.110)
$\Delta CO2_{-1}$	0.468(5.429)*	0.571(6.449)*	0.316(4.208)*
ΔR&D	0.081(1.135)	0.068(1.219)	−0.196(−5.672)*
Δgdp	0.134(3.584)*	0.150(4.448)*	0.173(4.329)*
Δoilp	−0.162(−4.283)*	−0.219(−4.893)*	−0.248(−4.842)*
Δtrade	0.053(1.549)***	0.125(2.109)**	0.146(4.762)*
R^2-adjusted	0.36	0.51	
JB	[0.31]	[0.40]	[0.44]
ARCH(4)	[0.26]	[0.33]	[0.37]
LM(4)	[0.37]	[0.22]	[0.27]
France			
Constant	0.042(0.241)	0.039(0.218)	0.034(0.158)
$\Delta CO2_{-1}$	0.375(4.227)*	0.428(4.284)*	0.327(4.772)*
ΔR&D	0.046(0.522)	0.024(0.466)	−0.162(−4.503)*
Δgdp	0.124(4.078)*	0.152(4.661)*	0.178(4.238)*
Δoilp	−0.132(−3.548)*	−0.193(−4.672)*	−0.352(−4.766)*
Δtrade	0.043(1.265)	0.054(1.769)***	0.178(4.427)*
R^2-adjusted	0.28	0.54	
JB	[0.19]	[0.26]	[0.30]
ARCH(4)	[0.23]	[0.28]	[0.35]
LM(4)	[0.32]	[0.29]	[0.39]
Germany			
Constant	0.039(0.368)	0.036(0.740)	0.038(0.085)
$\Delta CO2_{-1}$	0.349(3.918)*	0.386(4.405)*	0.284(4.072)*
ΔR&D	0.052(0.673)	0.031(1.089)	−0.328(−5.984)*
Δgdp	0.153(4.117)*	0.290(4.645)*	0.274(4.753)*
Δoilp	−0.143(−3.907)*	−0.183(−4.482)*	−0.371(−4.581)*
Δtrade	0.122(2.895)**	0.152(4.619)*	0.236(4.217)*
R^2-adjusted	0.27	0.59	
JB	[0.43]	[0.36]	[0.40]
ARCH(4)	[0.22]	[0.19]	[0.24]
LM(4)	[0.29]	[0.27]	[0.36]

Notes: JB is the Jarque–Bera test for normality of the residuals, ARCH(r) is the LM test of no autoregressive conditional heteroskedasticity up to order r and LM(q) denotes (the F variant of the) LM test of no serial correlation in the residuals up to and including order q. t-statistics are reported in parentheses while p-values are in brackets. *, ** and *** denote statistical significance at 1%, 5% and 10% levels, respectively.

[6] Based on a referee's suggestion, we also employed the Bai and Perron (1998) multiple-break test to detect, if possible, the presence of a second break date, i.e. the impact of the recent global crisis in 2008, on the grounds that the decline in emissions throughout Europe could be attributed to this event. The results did not provide empirical support for the 2008 date as a potential break date. The results are available upon request from the authors.

Table 5A
Results of linear and TAR models for U.K.: sector analysis.

Variables	Linear model	Threshold model	
		$R\&D_t \le 2005$	$R\&D_t > 2005$
Electricity and heat			
Constant	0.028(0.094)	0.020(0.438)	0.068(0.794)
$\Delta CO2_{-1}$	0.327(4.127)*	0.384(4.404)*	0.322(4.173)*
ΔR&D	0.035(0.047)	0.041(1.183)	−0.218(−6.918)*
Δgdp	0.175(4.264)*	0.175(4.162)*	0.270(4.238)*
Δoilp	−0.242(−4.018)*	−0.276(−4.248)*	−0.278(−4.329)*
Δtrade	0.044(0.583)	0.074(1.891)***	0.195(4.452)*
R^2-adjusted	0.25	0.43	
JB	[0.19]	[0.16]	[0.21]
ARCH(4)	[0.17]	[0.28]	[0.37]
LM(4)	[0.26]	[0.25]	[0.30]
Paper and paper products			
Constant	0.218(0.864)	0.231(0.788)	0.153(1.239)
$\Delta CO2_{-1}$	0.327(4.448)*	0.287(4.127)*	0.362(4.781)*
ΔR&D	0.023(0.618)	0.014(0.783)	−0.273(−4.504)*
Δgdp	0.238(4.231)*	0.186(4.238)*	0.274(4.327)*
Δoilp	−0.237(−4.018)*	−0.206(−3.442)*	−0.269(−4.519)*
Δtrade	0.048(1.224)	0.062(3.347)*	0.138(4.671)*
R^2-adjusted	0.22	0.44	
JB	[0.35]	[0.29]	[0.32]
ARCH(4)	[0.18]	[0.27]	[0.35]
LM(4)	[0.27]	[0.21]	[0.24]
Basic metals			
Constant	0.184(0.661)	0.162(0.593)	0.302(1.485)***
$\Delta CO2_{-1}$	0.318(4.771)*	0.384(5.128)*	0.308(4.515)*
ΔR&D	0.028(0.731)	0.014(1.116)***	−0.286(−5.915)*
Δgdp	0.288(4.569)*	0.259(4.892)*	0.318(5.477)*
Δoilp	−0.185(−4.255)*	−0.236(−4.148)*	−0.303(−4.255)*
Δtrade	0.118(2.632)**	0.112(2.542)**	0.181(5.671)*
R^2-adjusted	0.28	0.48	
JB	[0.27]	[0.19]	[0.27]
ARCH(4)	[0.20]	[0.19]	[0.29]
LM(4)	[0.28]	[0.24]	[0.30]
Coke and refined petroleum products			
Constant	0.063(0.357)	0.129(0.629)	0.235(1.571)***
$\Delta CO2_{-1}$	0.529(6.709)*	0.594(7.109)*	0.371(4.782)*
ΔR&D	0.038(0.672)	0.024(0.081)	−0.329(−5.851)*
Δgdp	0.361(5.783)*	0.242(3.904)*	0.421(5.673)*
Δoilp	−0.245(−4.551)*	−0.205(−3.966)*	−0.292(−4.671)*
Δtrade	0.041(1.972)***	0.071(2.863)**	0.216(4.893)*
R^2-adjusted	0.23	0.43	
JB	[0.17]	[0.18]	[0.29]
ARCH(4)	[0.21]	[0.23]	[0.35]
LM(4)	[0.24]	[0.12]	[0.27]
Textiles			
Constant	0.083(0.792)	0.117(0.529)	0.203(1.335)***
$\Delta CO2_{-1}$	0.253(4.218)*	0.328(4.803)*	0.293(4.117)*
ΔR&D	0.070(1.136)	0.039(0.322)	−0.328(−4.326)*
Δgdp	0.218(4.106)*	0.204(3.355)*	0.297(4.904)*
Δoilp	−0.231(−3.734)*	−0.173(−3.893)*	−0.261(−4.583)*
Δtrade	0.048(0.581)	0.032(1.359)***	0.138(4.583)*
R^2-adjusted	0.19	0.39	
JB	[0.36]	[0.27]	[0.32]
ARCH(4)	[0.27]	[0.28]	[0.31]
LM(4)	[0.42]	[0.35]	[0.38]
Chemicals			
Constant	0.062(0.519)	0.126(1.794)***	0.261(2.741)**
$\Delta CO2_{-1}$	0.404(5.892)*	0.494(5.183)*	0.395(4.188)*
ΔR&D	0.042(1.083)	0.031(0.422)	−0.389(−5.018)*
Δgdp	0.348(4.562)*	0.281(3.329)*	0.362(4.974)*
Δoilp	−0.231(−3.956)*	−0.228(−3.632)**	−0.274(−4.357)*
Δtrade	0.063(1.148)	0.038(0.541)	0.141(4.671)*
R^2-adjusted	0.25	0.47	
JB	[0.27]	[0.18]	[0.34]
ARCH(4)	[0.22]	[0.19]	[0.32]
LM(4)	[0.28]	[0.35]	[0.41]

Notes: similar to Table 4.

Table 5B
Results of linear and TAR models for France: sector analysis.

Variables	Linear model	Threshold model	
		$R\&D_t \le 2005$	$R\&D_t > 2005$
Electricity and heat			
Constant	0.052(0.238)	0.050(0.682)	0.103(1.245)
$\Delta CO2_{-1}$	0.416(4.948)*	0.468(5.239)*	0.512(4.794)*
ΔR&D	0.048(0.658)	0.027(0.642)	−0.174(−5.239)*
Δgdp	0.279(3.904)*	0.164(4.341)*	0.228(4.765)*
Δoilp	−0.163(−3.605)*	−0.138(−3.380)*	−0.211(−4.184)*
Δtrade	0.061(1.237)	0.052(0.735)	0.134(4.074)*
R^2-adjusted	0.23	0.40	
JB	[0.15]	[0.12]	[0.31]
ARCH(4)	[0.21]	[0.18]	[0.24]
LM(4)	[0.20]	[0.26]	[0.39]
Paper and paper products			
Constant	0.068(0.077)	0.131(0.602)	0.152(1.673)***
$\Delta CO2_{-1}$	0.288(4.204)*	0.322(4.405)*	0.295(4.177)*
ΔR&D	0.073(1.042)	0.062(0.731)	−0.194(−5.107)*
Δgdp	0.232(3.783)*	0.163(4.631)*	0.236(4.588)*
Δoilp	−0.152(−3.892)*	−0.117(−3.438)*	−0.171(−4.672)*
Δtrade	0.060(1.108)	0.039(3.348)*	0.084(4.328)*
R^2-adjusted	0.20	0.42	
JB	[0.24]	[0.19]	[0.35]
ARCH(4)	[0.19]	[0.21]	[0.29]
LM(4)	[0.44]	[0.31]	[0.40]
Basic metals			
Constant	0.172(0.521)	0.152(0.883)	0.321(2.590)**
$\Delta CO2_{-1}$	0.523(5.891)*	0.592(7.108)*	0.437(4.962)*
ΔR&D	0.063(1.109)	0.046(1.244)	−0.305(−6.721)*
Δgdp	0.264(4.144)*	0.225(4.723)*	0.283(4.446)*
Δoilp	−0.177(−4.381)*	−0.140(−3.893)*	−0.209(−4.642)*
Δtrade	0.071(2.084)**	0.047(1.804)***	0.141(3.893)*
R^2-adjusted	0.21	0.44	
JB	[0.20]	[0.19]	[0.32]
ARCH(4)	[0.24]	[0.24]	[0.36]
LM(4)	[0.23]	[0.26]	[0.28]
Coke and refined petroleum products			
Constant	0.057(0.322)	0.116(0.741)	0.211(2.673)**
$\Delta CO2_{-1}$	0.510(5.873)*	0.622(5.913)*	0.373(4.473)*
ΔR&D	0.042(0.619)	0.026(0.643)	−0.328(−5.436)*
Δgdp	0.271(3.988)*	0.235(3.904)*	0.311(4.783)*
Δoilp	−0.160(−4.173)*	−0.164(−4.217)*	−0.203(−5.773)*
Δtrade	0.056(1.644)***	0.042(2.573)**	0.102(4.073)*
R^2-adjusted	0.26	0.49	
JB	[0.19]	[0.15]	[0.32]
ARCH(4)	[0.24]	[0.20]	[0.31]
LM(4)	[0.29]	[0.21]	[0.35]
Textiles			
Constant	0.134(1.124)	0.122(0.793)	0.184(1.310)***
$\Delta CO2_{-1}$	0.316(4.227)*	0.364(4.237)*	0.312(4.436)*
ΔR&D	0.057(0.504)	0.042(0.613)	−0.319(−4.515)*
Δgdp	0.257(4.236)*	0.236(3.906)*	0.318(4.652)*
Δoilp	−0.251(−3.708)*	−0.231(−4.031)*	−0.260(−4.641)*
Δtrade	0.052(4.436)*	0.057(2.893)**	0.087(4.512)*
R^2-adjusted	0.20	0.48	
JB	[0.21]	[0.22]	[0.39]
ARCH(4)	[0.26]	[0.26]	[0.43]
LM(4)	[0.35]	[0.29]	[0.32]
Chemicals			
Constant	0.134(0.782)	0.136(1.183)	0.246(1.763)***
$\Delta CO2_{-1}$	0.529(5.983)*	0.566(5.893)*	0.493(4.782)*
ΔR&D	0.058(1.223)	0.040(1.112)	−0.397(−5.583)*
Δgdp	0.274(4.683)*	0.325(4.341)*	0.393(5.218)*
Δoilp	−0.236(−3.905)*	−0.189(−4.117)*	−0.225(−3.984)*
Δtrade	0.061(2.431)**	0.045(1.349)***	0.079(4.531)*
R^2-adjusted	0.26	0.50	
JB	[0.27]	[0.25]	[0.38]
ARCH(4)	[0.26]	[0.18]	[0.39]
LM(4)	[0.39]	[0.20]	[0.34]

Notes: similar to Table 4.

Table 5C
Results of linear and TAR models for Germany: sector analysis.

Variables	Linear model	Threshold model	
		$R\&D_t \leq 2005$	$R\&D_t > 2005$
Electricity and heat			
Constant	0.048(0.583)	0.064(0.583)	0.204(1.303)***
$\Delta CO2_{-1}$	0.538(6.138)*	0.584(7.021)*	0.385(5.835)*
ΔR&D	0.074(1.103)	0.051(0.764)	−0.351(−5.336)*
Δgdp	0.385(4.644)*	0.324(4.437)*	0.314(4.531)*
Δoilp	−0.184(−4.094)*	−0.125(−4.479)*	−0.274(−4.552)*
Δtrade	0.076(0.765)	0.054(1.077)	0.218(4.466)*
R^2-adjusted	0.27	0.50	
JB	[0.24]	[0.21]	[0.34]
ARCH(4)	[0.29]	[0.26]	[0.31]
LM(4)	[0.27]	[0.29]	[0.33]
Paper and paper products			
Constant	0.062(0.436)	0.138(0.783)	0.139(2.562)**
$\Delta CO2_{-1}$	0.306(4.932)*	0.341(4.380)*	0.288(4.652)*
ΔR&D	0.061(0.487)	0.057(1.448)***	−0.403(−5.905)*
Δgdp	0.252(4.256)*	0.271(4.783)*	0.328(4.661)*
Δoilp	−0.152(−3.977)*	−0.140(−4.005)*	−0.178(−4.672)*
Δtrade	0.084(1.662)***	0.062(4.210)*	0.080(4.581)*
R^2-adjusted	0.19	0.46	
JB	[0.24]	[0.23]	[0.33]
ARCH(4)	[0.26]	[0.25]	[0.39]
LM(4)	[0.35]	[0.29]	[0.40]
Basic metals			
Constant	0.074(0.684)	0.127(0.783)	0.172(1.505)***
$\Delta CO2_{-1}$	0.482(5.128)*	0.535(5.905)*	0.581(4.683)*
ΔR&D	0.074(1.256)***	0.062(1.562)***	−0.337(−4.941)*
Δgdp	0.242(4.321)*	0.257(3.893)*	0.296(4.531)*
Δoilp	−0.142(−4.125)*	−0.124(−3.805)*	−0.195(4.551)*
Δtrade	0.074(3.461)**	0.059(1.484)***	0.136(4.006)*
R^2-adjusted	0.23	0.49	
JB	[0.26]	[0.24]	[0.37]
ARCH(4)	[0.28]	[0.26]	[0.34]
LM(4)	[0.32]	[0.22]	[0.41]
Coke and refined petroleum products			
Constant	0.116(0.525)	0.134(0.604)	0.160(2.658)**
$\Delta CO2_{-1}$	0.491(5.774)*	0.535(5.933)*	0.425(4.449)*
ΔR&D	0.052(0.781)	0.041(0.673)	−0.314(4.906)*
Δgdp	0.277(4.136)*	0.289(3.784)*	0.369(5.122)*
Δoilp	-0.136(−3.684)*	−0.127(−3.571)*	−0.184(4.217)*
Δtrade	0.041(1.385)***	0.032(1.088)	0.094(3.955)*
R^2-adjusted	0.25	0.50	
JB	[0.28]	[0.25]	[0.32]
ARCH(4)	[0.29]	[0.27]	[0.31]
LM(4)	[0.36]	[0.22]	[0.33]
Textiles			
Constant	0.076(0.477)	0.124(0.763)	0.162(1.358)***
$\Delta CO2_{-1}$	0.327(4.328)*	0.382(4.217)*	0.305(4.337)*
ΔR&D	0.063(0.769)	0.040(0.816)	−0.282(−4.771)*
Δgdp	0.246(3.672)*	0.229(4.238)*	0.279(4.439)*
Δoilp	−0.227(−3.630)*	−0.171(−3.669)*	−0.205(−4.215)*
Δtrade	0.035(3.217)*	0.042(2.577)**	0.087(4.761)*
R^2-adjusted	0.24	0.48	
JB	[0.16]	[0.18]	[0.34]
ARCH(4)	[0.28]	[0.29]	[0.32]
LM(4)	[0.34]	[0.31]	[0.43]
Chemicals			
Constant	0.065(0.592)	0.093(1.137)	0.158(1.881)***
$\Delta CO2_{-1}$	0.528(6.339)*	0.584(5.238)*	0.427(4.481)*
ΔR&D	0.051(0.793)	0.042(0.821)	−0.327(−6.148)*
Δgdp	0.234(4.105)*	0.258(3.717)*	0.384(4.720)*
Δoilp	−0.184(−3.792)*	−0.165(−4.329)*	−0.213(−4.652)*
Δtrade	0.057(1.328)***	0.040(1.219)	0.105(4.332)*
R^2-adjusted	0.27	0.54	
JB	[0.25]	[0.25]	[0.37]
ARCH(4)	[0.27]	[0.19]	[0.29]
LM(4)	[0.31]	[0.32]	[0.44]

Notes: similar to Table 4.

Table 6A
Results of linear and TAR models for U.K.: firm size.

Variables	Linear Model	Threshold model	
		$R\&D_t \leq 2005$	$R\&D_t > 2005$
Large firms			
Constant	0.044(0.825)	0.041(0.652)	0.063(0.682)
$\Delta CO2_{-1}$	0.522(5.731)*	0.589(5.935)*	0.473(4.783)*
ΔR&D	0.062(0.571)	0.052(1.843)***	−0.247(−6.923)*
Δgdp	0.235(4.437)*	0.241(4.328)*	0.304(4.366)*
Δoilp	−0.179(−4.652)*	−0.228(−4.233)*	−0.259(−4.693)*
Δtrade	0.074(2.682)**	0.116(2.604)**	0.152(4.559)*
R^2-adjusted	0.33	0.56	
JB	[0.34]	[0.22]	[0.32]
ARCH(4)	[0.20]	[0.23]	[0.31]
LM(4)	[0.39]	[0.29]	[0.30]
Small firms			
Constant	0.048(0.842)	0.029(0.682)	0.093(1.544)***
$\Delta CO2_{-1}$	0.385(4.331)*	0.402(4.842)*	0.353(4.731)*
ΔR&D	0.042(0.605)	0.031(1.142)	−0.152(−4.877)*
Δgdp	0.163(4.329)*	0.137(4.833)*	0.237(4.709)*
Δoilp	−0.126(−4.138)*	−0.106(−4.551)*	−0.158(−4.437)*
Δtrade	0.041(2.373)**	0.032(2.308)**	0.131(4.905)*
R^2-adjusted	0.28	0.41	
JB	[0.25]	[0.18]	[0.35]
ARCH(4)	[0.28]	[0.26]	[0.39]
LM(4)	[0.44]	[0.27]	[0.54]

Notes: similar to Table 4.

Therefore, we focus on the six manufacturing sub-sectors identified in Table 1 to determine which manufacturing sector exhibits the strongest (if any) association between R&D expenditures and CO2 emissions prior to and after the mandatory adoption of IFRS. The results are reported in Tables 5A–5C.

Focusing on the threshold model, the sector analysis in the U.K. (Table 5A) reveals that the Chemical sector has the largest negative impact of R&D expenditures on CO2 emissions after the mandatory adoption of IFRS with a coefficient estimate of −0.389 followed by Coke and Refined Petroleum Products (−0.329); Textiles (−0.328); Basic Metals (−0.286); Paper and Paper Products (−0.273); and Electricity and Heat (−0.218). In the case of France (Table 5B), the Chemical sector also has the largest negative impact of R&D expenditures on CO2 emissions after the mandatory adoption of IFRS with a coefficient estimate of −0.397 followed by Coke and Refined Petroleum Products (−0.328); Textiles (−0.319); Basic Metals (−0.305); Paper and Paper Products (−0.194); and Electricity and Heat (−0.174). For Germany (Table 5C), the Paper and Paper Products sector has the largest negative impact of R&D expenditures on CO2 emission after the mandatory adoption of IFRS with a coefficient estimate of −0.403 followed by Electricity and Heat (−0.351); Basic Metals (−0.337); Chemicals (−0.327); Coke and Refined Petroleum Products (−0.314); and Textiles (−0.282). Finally, in all cases the control variables are statistically significant and yield the expected sign.

4.4. Robustness Tests: Firm Size

Perman et al. (2003) argue that larger firms with a large R&D budget are likely to plan for a longer horizon, while Shah et al. (2008) indicate that prior to the adoption of IFRS there was no clear cut size advantage of larger U.K. firms over smaller firms with respect to R&D expenditures. Tsoligkas and Tsalavoutas (2011) argue that large firms are more effective in differentiating products or product lines with higher quality innovations vis-à-vis small firms, thus R&D expenditures are more important for large firms. In our study, it is expected a priori that large firms' R&D expenditures have a greater impact on CO2 emission reductions. Therefore, we investigate any size-related consequences of the impact of R&D expenditures on CO2 emission reduction after the IFRS mandatory adoption. To this

Table 6B
Results of linear and TAR models for France: firm size.

Variables	Linear Model	Threshold model	
		$R\&D_t \leq 2005$	$R\&D_t > 2005$
Large firms			
Constant	0.052(0.683)	0.048(0.558)	0.106(1.549)***
$\Delta CO2_{-1}$	0.429(4.283)*	0.451(4.405)*	0.322(4.372)*
ΔR&D	0.058(0.613)	0.046(1.230)	−0.250(−4.329)*
Δgdp	0.262(4.672)*	0.218(4.229)*	0.295(4.675)*
Δoilp	−0.237(−4.872)*	−0.216(−4.239)*	−0.249(−4.374)*
Δtrade	0.064(2.552)**	0.132(4.205)*	0.162(4.783)*
R^2-adjusted	0.34	0.53	
JB	[0.26]	[0.19]	[0.37]
ARCH(4)	[0.25]	[0.23]	[0.32]
LM(4)	[0.44]	[0.38]	[0.50]
Small firms			
Constant	0.037(0.588)	0.042(0.672)	0.058(1.187)
$\Delta CO2_{-1}$	0.362(4.288)*	0.389(4.128)*	0.302(4.118)*
ΔR&D	0.035(0.761)	0.048(1.072)	−0.183(−4.905)*
Δgdp	0.185(4.347)*	0.153(4.238)*	0.264(4.668)*
Δoilp	−0.138(−4.439)*	−0.185(−4.123)*	−0.164(−4.142)*
Δtrade	0.049(3.549)*	0.060(3.894)*	0.134(4.548)*
R^2-adjusted	0.30	0.42	
JB	[0.27]	[0.19]	[0.34]
ARCH(4)	[0.34]	[0.35]	[0.42]
LM(4)	[0.35]	[0.28]	[0.39]

Notes: similar to Table 4.

Table 6C
Results of linear and TAR models for Germany: firm size.

Variables	Linear Model	Threshold model	
		$R\&D_t \leq 2005$	$R\&D_t > 2005$
Large firms			
Constant	0.065(1.547)***	0.052(0.549)	0.104(2.310)**
$\Delta CO2_{-1}$	0.563(6.328)*	0.597(5.384)*	0.479(4.873)*
ΔR&D	0.061(0.577)	0.041(2.328)**	−0.385(−5.548)*
Δgdp	0.201(4.684)*	0.243(4.659)*	0.294(4.893)*
Δoilp	−0.271(−4.328)*	−0.243(−4.659)*	−0.303(−4.869)*
Δtrade	0.125(2.484)**	0.075(4.328)*	0.163(4.906)*
R^2-adjusted	0.32	0.56	
JB	[0.34]	[0.27]	[0.45]
ARCH(4)	[0.29]	[0.24]	[0.47]
LM(4)	[0.43]	[0.41]	[0.56]
Small firms			
Constant	0.046(0.894)	0.021(0.469)	0.074(1.213)
$\Delta CO2_{-1}$	0.376(4.283)*	0.402(4.984)*	0.328(4.547)*
ΔR&D	0.040(0.573)	0.025(1.105)	−0.204(−5.762)*
Δgdp	0.184(4.117)*	0.163(4.342)*	0.248(4.842)*
Δoilp	−0.171(−4.549)*	−0.164(−5.329)*	−0.188(−4.663)*
Δtrade	0.066(3.229)*	0.048(3.905)*	0.105(4.784)*
R^2-adjusted	0.25	0.40	
JB	[0.18]	[0.18]	[0.27]
ARCH(4)	[0.25]	[0.26]	[0.35]
LM(4)	[0.32]	[0.30]	[0.41]

Notes: similar to Table 4.

end, we split the total sample into two ('large firms' and 'small firms') by making use of the median statistic in terms of their total assets. Firms above the median are classified as 'large' while those below the median are classified as 'small'. The size results based on firm size are reported in Tables 6A–6C.

The empirical findings in Tables 6A–6C verify the literature on R&D. In particular, in all three countries firm size plays an important role regarding the impact of R&D expenditures on CO2 emissions prior to and after the mandatory adoption of IFRS. With respect to large firms in the U.K. and Germany, R&D expenditures prior to the adoption of IFRS had a marginally significant positive impact on CO2 emissions whereas after the adoption of IFRS the impact was negative and statistically significant. In the case of France, R&D expenditures yielded a negative and statistically significant impact on CO2 emissions only after the adoption of IFRS. In terms of small firms, R&D expenditures had a negative and statistically significant impact of CO2 emissions only after the adoption of IFRS across all three countries. Furthermore, in all cases the control variables are statistically significant with the expected sign. Given the magnitude of the coefficient estimates, this impact seems to be more substantial with respect to the large firms, indicating that these firms have the resources to provide for greater R&D activities related to the innovation and development of 'green products' and 'green technologies' vis-à-vis the small firms whose resources are limited.

4.5. Robustness Tests: EU-ETS Concurrent Factor

It is also possible that the introduction of IFRS coincided with other economic, regulatory or institutional changes. Such a change was the introduction of the EU Emission Trading Scheme (EU-ETS) that also came into effect in 2005. Given this institutional event, we expand our model (6) to allow for the estimation of separate IFRS and EU-ETS effects. Under this new assumption, the model appears as follows:

$$\begin{aligned}\Delta CO2_t = {} & (\alpha_{10} + \beta_{11}\,\Delta CO2_{t-1} + \beta_{12}\,\Delta R\&D_t + \delta_{12}\,\Delta gdp_t + \delta_{13}\,\Delta oilp_t \\ & + \delta_{14}\,\Delta trade_t) I_t (R\&D_t \leq 2005) + (\alpha_{20} + \beta_{21}\,\Delta CO2_{t-1} \\ & + \beta_{22}\,\Delta R\&D_t + \delta_{22}\,\Delta gdp_t + \delta_{23}\,\Delta oilp_t + \delta_{24}\Delta trade_t)(1-I_t)(R\&D_t \\ & > 2005) + \gamma ETS_t + e_t.\end{aligned} \tag{7}$$

To discriminate between IFRS adoption and the EU-ETS effect, which is not directly tied to the implementation of accounting standards, but potentially affecting CO2 emissions, we have included in model (7) a separate control variable for the EU-ETS directive (measured as a dummy variable that is equal to 0 until December 2004 and 1 thereafter). The results are reported in Table 7 and show that the coefficient γ is negative but statistically insignificant, while the results related to the IFRS adoption remain unaffected (see Table 4 for comparison). Thus, the EU-ETS directive is likely not responsible for the documented impact of R&D expenditures on CO2 emissions following the adoption of the IFRS accounting regime.

5. Concluding Remarks

This empirical study examines the extent to which R&D expenditures impact CO2 emissions prior to and after the mandatory adoption of International Financial Reporting Standards (IFRS) in three EU countries, i.e. the U.K., France and Germany. R&D expenditures are a policy instrument which influences technological changes and, thus, abatement costs and economic growth. This is likely due to the presence of incentives, provided by the mandatory adoption of a better accounting disclosure regime offered by IFRS to save energy by producing more 'green products' and/or more renewable energy technologies. In spite of the fact it takes time for these expenditures to have an impact, they are very effective in leading to substantial carbon dioxide emission reductions. To serve this goal, the methodology of the TAR approach was used to capture the mandatory adoption of IFRS. In particular, we constructed both a linear model and a TAR model for CO2 emissions, the latter of which uses R&D as a threshold variable. The TAR model performs better than the linear model and exhibits greater explanatory power.

Our empirical findings suggest that in the post-IFRS mandatory adoption year our accounting item of interest, R&D expenditures, yielded a reduction in CO2 emissions across all three countries. In other words, we observe an increase in CO2 abatement. Our results remain robust in terms of a sector analysis, firm size, and introduction of the EU-ETS across the three countries. These results might be of interest to regulators and policy makers as well as to capital market participants in the EU. In particular, policy makers must evaluate alternatives to facilitate energy saving policies, renewable energy

Table 7
Results of the linear and TAR model: EU-ETS concurrent factor.

Variables	Linear model	Threshold model	
		$R\&D_t \leq 2005$	$R\&D_t > 2005$
U.K.			
Constant	0.095(0.652)	0.038(0.328)	0.036(0.393)
$\Delta CO2_{-1}$	0.475(5.466)*	0.428(5.239)*	0.419(5.661)*
ΔR&D	0.046(0.873)	0.058(0.811)	−0.273(−4.983)*
Δgdp	0.284(4.521)*	0.210(4.119)*	0.218(4.794)*
Δoilp	−0.164(−4.784)*	−0.294(−4.882)*	−0.284(−4.822)*
Δtrade	0.116(4.148)*	0.141(3.783)*	0.177(4.549)*
ETS	−0.048(−0.806)	−0.076(−1.248)	
R^2-adjusted	0.20	0.53	
JB	[0.37]	[0.29]	[0.46]
ARCH(4)	[0.24]	[0.25]	[0.32]
LM(4)	[0.35]	[0.35]	[0.52]
France			
Constant	0.061(0.489)	0.036(0.252)	0.062(0.473)
$\Delta CO2_{-1}$	0.528(6.006)*	0.484(5.538)*	0.462(5.940)*
ΔR&D	0.041(0.538)	0.029(0.429)	−0.249(−5.892)*
Δgdp	0.238(4.188)*	0.175(4.356)*	0.194(4.566)*
Δoilp	−0.264(−4.329)*	−0.263(−4.018)*	−0.290(−4.762)*
Δtrade	0.161(4.085)*	0.124(3.269)**	0.191(4.889)*
ETS	−0.054(−0.659)	−0.65(−1.304)	
R^2-adjusted	0.24	0.57	
JB	[0.36]	[0.30]	[0.46]
ARCH(4)	[0.29]	[0.18]	[0.35]
LM(4)	[0.34]	[0.23]	[0.44]
Germany			
Constant	0.068(0.599)	0.037(0.584)	0.073(1.085)
$\Delta CO2_{-1}$	0.562(5.893)*	0.527(5.872)*	0.504(6.348)*
ΔR&D	0.045(0.620)	0.032(1.128)	−0.358(−5.459)*
Δgdp	0.341(4.237)*	0.218(4.218)*	0.282(4.894)*
Δoilp	−0.356(−4.448)*	−0.252(−4.336)*	−0.341(−4.478)*
Δtrade	0.394(4.437)*	0.158(3.541)*	0.250(4.420)*
ETS	−0.042(−0.548)	−0.065(−1.109)	
R^2-adjusted	0.28	0.52	
JB	[0.25]	[0.20]	[0.32]
ARCH(4)	[0.29]	[0.24]	[0.31]
LM(4)	[0.41]	[0.34]	[0.47]

Notes: similar to Table 4.

sources, and new green technologies and products for further reductions in CO2 emissions.

Our results also have several policy implications regarding tax incentives. Investors involved in large capital intensive R&D activities targeted toward emission reduction or abatement technology are seeking tax incentives to mitigate their risks. These incentives might include research and development tax concessions and/or investment allowances. Extended R&D concessional treatment for capital expenses incurred on greenhouse gas reducing activities through the expanded definition of eligible R&D expenditures are expected to encourage innovative responses to CO2 emission reductions. The strengthening of R&D 'green innovative activities' could also impact firms' performance and attract attention from capital market participants.

Furthermore, the study extends the research on eco-innovation as it relates to firm accounting standards and environmental-regulatory policies. Future research could be pursued to expand the analysis to additional countries (including even countries that have not signed the Kyoto protocol, i.e. the U.S.) as well as examine the capitalization component of R&D.

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