www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2023, 73(2), pp. 221–236

Original scientific paper

UDC: 911.2:504
https://doi.org/10.2298/IJGI2302221S

Received: January 19, 2023
Reviewed: May 11, 2023
Accepted: June 25, 2023

REGIONAL ISSUE, INNOVATION, AND THE ECOLOGICAL FOOTPRINT

Vladislav Spitsin[1,2], Darko B. Vuković[3,4], Elena Akerman[5,6], Ludmila Borilo[1], Natalia Chistyakova[1,6]*

[1]Tomsk State University, Siberian Institute of the Future, Centre for Sustainable Development, Tomsk, Russia; e-mails: spitsin_vv@mail.ru; borilo@mail.ru
[2]Tomsk State University of Control Systems and Radioelectronics, Department of Economics, Tomsk, Russia
[3]Perm National Research Polytechnic University, Department of Economics and Industrial Engineering, Perm, Russia; e-mail: vdarko@hotmail.rs
[4]Geographical Institute "Jovan Cvijić" SASA, Belgrade, Serbia
[5]Tomsk State University, Institute of Economics and Management, Tomsk, Russia; e-mail: aker@tomsk.gov.ru
[6]Tomsk Polytechnic University, School of Engineering Entrepreneurship, Tomsk, Russia; e-mail: worldperson@mail.ru

Abstract. This paper models the relationship between economic development and environmental progress. It investigates the relationship between investment in innovation and uncontained emissions in the selected Russian regions from 2013 to 2018. The database contains information for 72 locations and is comprised of 432 observations (panel data, 72 regions multiplied by 6 years). Random-effects regression models have been applied to analyze panel data. In a study of 72 Russian regions over the period of 2013–2018, this research demonstrates that the growing research and development (R&D) intensity of regional firms leads to a larger ecological footprint and growing emission intensity. These effects are negatively moderated by the per capita income of the region's residents and regional enrollment in higher education. The effects are positively moderated by the export intensity of regional firms. The results suggest that economic and ecological aspects of sustainable development are at odds with each other and indicate that regional policymakers should account for the negative ecological externalities of economic development when devising policies aiming to facilitate regional growth.

Keywords: ecological footprint; investment in innovation; uncontained emissions; sustainable development; Russia

1. Introduction

Sustainable development implies the simultaneous pursuit of economic, social, and ecological agendas (Carayannis & Campbell, 2019). While social and ecological dimensions of the triple bottom line are rarely seen as incompatible (Muñoz & Cohen, 2017), the relationship between economic development and ecological progress is often argued to be much harder to balance (York et al., 2004). The logic of economic growth often assumes the need to invest in

*Corresponding author, e-mail: spitsin_vv@mail.ru

ecological sustainability (Jorgenson & Burns, 2007), and the well-known Friedman (1970) doctrine places no expectation of responsible development on business owners and operators, leaving it instead in the hands of the government (Ahmed et al., 2022). The growing awareness around the need for sustainable development and the elevation of this agenda to the forefront by the United Nations ([UN] 2016) have prompted many to suggest that the key to pursuing the triple bottom line lies in innovative development, where agents of innovation purposefully tackle the ecological dimension as they plan their economic goals at the same time (Elkington, 2018). Yet, whether investments in innovation are always beneficial from an ecological viewpoint is not clear. Other things being equal, absent substantial government subsidies to green innovation or severe sanctions aimed at environmental violators, firms may follow the tenets of the Friedman (1970) doctrine and pursue innovative efforts targeting economic benefits at the cost of the ecological agenda. Pollution haven effects are well acknowledged in the literature (Berry et al., 2021), and we suggest that the innovative efforts of firms may often be financed by environmental degradation.

Besides, not all investments in innovation are created equal. Unless the ecological implications of investments into new products or processes are explicitly taken into account, rational firms with a short- to medium-term planning horizon may choose to ignore the negative externalities of their innovative efforts and sacrifice the environment in their myopic pursuit of immediate payoffs—a behavior resembling the well-known "tragedy of the commons" (Garrity, 2012). We suggest that some regional characteristics are likely to steer the innovative efforts of regional firms toward responsible development, whereas others may promote myopic development at the cost of ecology. Specifically, in regions that are relatively advantageous in terms of their level of economic development and in regions with above-average representation of the young, educated elite, one may expect to see innovative efforts aimed, among other goals, at the reduction of negative ecological externalities. At the same time, regions that are advantageously positioned to pursue extensive as opposed to intensive development opportunities (e.g., those that provide ample options for resource- and low-value-added exports) are less likely to put ecological consideration at the forefront. In other words, while investment in innovation may be seen as a necessary step in curbing environmental pollution, by itself it is not a sufficient step, and studying contingency factors may provide important insights into uncovering the role of innovation in balanced development along the triple bottom line trajectory.

We have studied the relationship between investment in innovation and uncontained emissions in a sample of Russian regions over the period from 2013 to 2018. Ecological considerations have not been prioritized by the Russian government, so efforts at curbing pollution are likely to be steered by the demands of the population, institutionalized norms, and economic pressures that businesses have to operate under. As such, this research setting represents a natural laboratory to study the effects of these factors on environmental outcomes without governmental intervention.

The paper proceeds as follows. In the next section, we provide a literature overview and develop testable hypotheses that link the identified factors to environmental pollution. This is followed by the explanation of our methodological approach, the introduction of our data, and the presentation of regression results. Next, we discuss our results and offer implications for policymakers and decision-makers. The paper concludes with a discussion of the limitations of the study and suggestions for future research.

2. Literature background

The UN has proclaimed the movement toward the simultaneous pursuit of economic, social, and ecological goals a vital priority for sustainable development (UN, 2016). However, the fact that such a proclamation had to be made in the first place indicates that, by themselves, the tripartite goals often framed as profits, people, and planet (Slaper & Hall, 2011) are in opposition to each other. Had such goals been naturally aligned, there would have been no need to explicitly push this triune agenda. Instead, economic agents are driven by the Friedman (1970) doctrine, where their first and foremost responsibility is providing economic benefits to shareholders, and social and ecological considerations are seen as merely constraints to be dealt with because ignoring those would subject the firms to harsh penalties imposed by the regulators. Friedman (1970) decries the attempts of businessmen to claim the pursuit of goals beyond mere profits, including desirable social ends, avoiding pollution, and other goals of the contemporary crop of reformers, as disingenuous and bordering on socialism, and makes it clear that promoting such goals is not, and should not be, the businesses' responsibility.

Free from government pressure, the argument goes, businesses strive to do more with less (Anokhin et al., 2021; Carson, 1993). Whenever there is an opportunity to support this relentless pursuit of greater efficiency—that is, innovation—with resources that need not be paid for, it is a manager's preference, in fact an obligation, to seek advancement at no cost to shareholders, unless the shareholders explicitly pursue some "eleemosynary" goal (Friedman, 1970). This comes remarkably close to the "tragedy of the commons" described in the literature in detail (Frischmann et al., 2019), where making a particular resource freely available to all leads to its expedient exhaustion by some, such that all suffer in the end. That is, powered by the Friedman doctrine, business managers strive toward innovation as a way to improve efficiency and enrich shareholders. In the process, they are likely to damage the common goods by, for instance, refusing to contain emissions for fear of a negative impact on their bottom line, such that the benefits to a few (shareholders) come at a cost to many (residents whose environments are damaged by uncontained emissions). In other words, absent specific regulatory, institutional, or economic pressures on the existing firms aimed at limiting pollution, the innovative activity that enthusiastic supporters of the UN sustainable development agenda have come to associate with the simultaneous pursuit of profits, people, and planet benefits is unlikely to produce the outcomes desired. Much like the positive relationship between entrepreneurship and innovation that is assumed to be universally relevant but in fact is only observed in rich countries (Anokhin & Wincent, 2012), the positive relationship between innovation and sustainable development is likely to be observed in a narrow subset of fairly unique circumstances (Spitsin et al., 2021). One may only expect to see the positive effect of innovation on social or ecological outcomes if they are explicitly demanded by the basic rules of society, both those embodied in law and those embodied in ethical custom (Friedman, 1970).

Taken together, this suggests that everything else being equal, investments by regional firms in innovative ends may increase rather than decrease emissions and worsen the overall ecological footprint that businesses impose on their environments. It is the realization of this unfortunate outcome that has brought the need for policy makers to balance economic development with social and ecological outcomes to the fore and necessitated creating governmental programs such as subsidies to sustainable energy and a "carbon tax" (Metcalf, 2019; Nicolini & Tavoni, 2017)—that is, both the carrot and the stick—to direct economic development to more sustainable trajectories. Absent such policies and the institutional, ethical, and similar pressures on "the basic rules of society", investments in research and development (R&D) are likely to result in the worsening of ecological conditions. Stated formally,

Hypothesis 1. R&D intensity of regional firms is positively related to environmental pollution in the region.

Although the difference in economic development of regions within a country is probably less pronounced than across countries (Pittau et al., 2010), evidence suggests that there are major disparities across regions in many economies, including China (Lee et al., 2012; Vuković & Wei, 2010), Russia (Bradshaw & Vartapetov, 2003), Australia (Stilwell & Jordan, 2007), Canada (Maroto, 2016), and the United States (US; Lynch et al., 1998). Typically, one may see such disparities in countries characterized by a vast territory that contains vastly different climates (e.g., Canada, China, and Russia) or unequal access to trade routes and seaports (e.g., China and the US). While across countries, researchers distinguish between factor-, efficiency-, and innovation-driven economies (Schwab et al., 2002; Vuković et al., 2012), it is unknown whether the same classification could be applied to regions within countries. Nevertheless, there are reasons to assume that this may be the case. For instance, with respect to China, there was considerable debate in the literature about two decades ago with respect to its economic development stage, with some sources suggesting it was still primarily factor-driven and others claiming it was in the efficiency-driven stage (Schwab et al., 2002). It appears that the explanation for this disagreement may lie in the fact that some regions may have been characterized by factor-driven logics, while others were in fact efficiency-driven. Similarly, the vast territories of the US and Canada may have regions, some of which are clearly innovation-driven while others are efficiency-driven. As for Russia, it may have regions of all three kinds, and it is thus essential to account for its level of development when making predictions with respect to the relationship between innovation and environmental pollution.

In efficiency-driven environments, and more so in factor-driven environments, economic catch-up is the primary consideration (Tan, 2005). Moreover, because such regions lag behind the technological frontier, they may be ill-positioned to adopt technologies that are at the forefront (Anokhin & Wincent, 2012). In that most "green" technologies have only come into existence recently and are relying on new industries and extensive technological development, it is reasonable to assume that less developed environments, even if they were to prioritize the ecological agenda, would be disadvantaged in adopting those and, as such, would demonstrate a disproportionate negative impact of investments in innovation that their resident firms are qualified to pursue. At the same time, regions that are best developed economically and in essence define the technological frontier are not only qualified to pursue those but also feel less pressure from other regions to catch up, do not have to prove to their residents their success in catching up (Petrović et al., 2017), and may afford to invest in innovation that provides benefits beyond pure economics, such as curbing emissions to ensure residents well-being. In other words, the positive association between investments in innovation and environmental pollution that we hypothesized earlier in the paper is especially likely to be observed in relatively poor regions, whereas in the wealthier environments it may be weakened if not reversed. Stated formally,

Hypothesis 2. The relationship between the R&D intensity of regional firms and environmental pollution in the region is negatively moderated by the level of economic development in the region.

The Friedman (1970) doctrine makes an important exception to the presumed universal character of business managers' drive to pursue the economic well-being of their shareholders: when the basic rules of society—those embodied in law and those embodied in ethical custom—demand that some benevolent or "eleemosynary" aspects be integrated into the goals generally pursued by economic actors. As we conduct our analysis within the context of one country, legal distinctions are likely to be less prominent. Besides, Russia is not known for its aggressive pursuit of ecological ends (Newell & Henry, 2016). As such, any considerations likely to sway rational economic actors toward the pursuit of ecological considerations in addition to the economic ones are likely to be driven by the ethical considerations embedded in the basic rules of society.

We propose that the rules of society are more likely to incorporate the acknowledgement of the need for maximizing other dimensions of firm performance beyond profits, such as ecological footprint, when the prevalence of highly educated individuals in the region is high. Importantly, we suggest that it is the prevalence of young individuals currently enrolled in higher education institutions, not the share of individuals with higher degrees as such that is likely to drive the ecological agenda. Several considerations appear important. Youth is generally more mobile and has fewer anchors, such that the degree of dissemination of ideas advocated by youth is typically superior to that of the overall population (Cairns & Smyth, 2011). Younger people are also more likely to be well-informed of the general trends in society, in contrast to their older counterparts, who are embedded in their routines and may be overwhelmed with expectations of and obligations toward others (Carstensen, 1995). Greta Thunberg's ecological activism is a case in point. Given the recency of the UN sustainable development program, older individuals are less likely to be informed about it or may not find it as meaningful or appealing as the younger generation. As such, the impetus for change in the way corporations think of their goals is likely to come from the educated young elite.

It may be questioned whether younger individuals have the means to effectuate the change in society to which corporate managers would respond by incorporating the ecological dimension into their agenda. In that young individuals currently enrolled in higher education institutions likely come from families where one or both parents have higher education (Mullen et al., 2003), which is typically associated with subsequent economic advancement (Hout, 2012), university students are likely to be embedded in circles of decision-makers, and while they may not have the means to impose their agenda on the older generation by force, through their embeddedness in their daily lives, they may serve as effective ambassadors of the new agenda. Besides, younger people are known to have an above-average propensity to become entrepreneurs (Hatak et al., 2015), and since entrepreneurship is linked to innovation (Audretsch, 2006), are likely to affect the innovative trajectories of their own and their partners' businesses. Given how prominent the ecological agenda is to the young, educated elite, it is reasonable to propose that the positive relationship between investments in innovation by regional firms and uncontained emissions is less prominent, if not reversed, in regions with an above-average prevalence of higher education enrollment. Stated formally,

Hypothesis 3. The relationship between the R&D intensity of regional firms and environmental pollution in the region is negatively moderated by the prevalence of higher education enrollment in the region.

At the same time, there are factors that may exacerbate the R&D intensity-environmental pollution relationship postulated in Hypothesis 1. Specifically, the extent to which regional firms rely on exports may have this unfortunate effect on uncontained emissions in the region. There are several considerations that may be taken into account to explain this conjecture, specifically in the context of Russia.

First, the predominance of the export-oriented mining industry in the structure of the Russian industry could lead to a high probability of environmental consequences (Mironenko & Kolchugina, 2012). That is, the higher export intensity of regional firms may serve as an indication of ecologically suspect industries being prevalent in the region, which may have negative consequences for emissions.

Second, even in countries that are at the forefront of global development, the nature of innovation in such industries is often fraught with negative ecological externalities (Endl et al., 2021). The fracking (hydraulic fracturing) controversy in the US is a case in point.

Finally, exporting necessitates transportation, and transportation is a “dirty” industry (Wang et al., 2020). That is, even if investments in innovation needed to boost the export potential of regional firms do not directly cause too much pollution, the heavy transportation that follows must add to emissions that cannot be controlled. This has an indirect effect on the ecological footprint of regional efforts to innovate. Taken together, this suggests:

H4. The relationship between the R&D intensity of regional firms and environmental pollution in the region is positively moderated by the export intensity of regional firms.

3. Methods and data

3.1. Data

The study uses a sample of Russian regions over the period 2013–2018. The database contains data from the Rosstat (2022). We also excluded autonomous districts and regions with missing data for key indicators. In all, our database contains information for 72 regions of Russia and is comprised of 432 observations (72 regions multiplied by 6 years).

3.2. Variables

3.2.1. Dependent variable

Based on previous research (Dong et al., 2018), we use emission intensity as a dependent variable. Emission intensity is calculated as the ratio of uncaptured air emissions from stationary sources in the region to the value of sales by regional firms (tons of emissions per 1 billion rubles of products sold).

3.2.2. Independent and moderator variables

As our principal independent variable, we use regional R&D intensity, calculated as the ratio of R&D investments by regional firms to regional sales, expressed as a percentage (Chen & Lee, 2020). Our moderators include per capita income (Behera & Dash, 2017), calculated as the average monthly income per capita in the region in thousand rubles; higher education enrollment (Li et al., 2021), defined as the ratio of the number of students to the population of the region, multiplied by 100%; and export intensity (Cheng et al., 2019), defined as the ratio of the export-related revenue of regional firms to their overall sales, multiplied by 100%.

3.2.3. Control variables

To account for the impact of other factors that may affect regional emission intensity, we control for a number of variables that may affect regional environmental pollution. Specifically, we controlled for the startup rate (Nakamura & Magani, 2020) proxied with the ratio of the number of new firms to the region's population, multiplied by 100%, contained emission share calculated as the ratio of the mass of captured emissions to the mass of all emissions from stationary sources within the region, multiplied by 100% (Sakai & Barrett, 2016), scientists per capita calculated as the ratio of the number of scientists in the region to the overall region's population, multiplied by 100% (Thompson & Thompson, 1987), and a dummy variable border region that captures whether or not the region is located at the land border of Russia with foreign countries (Anokhin, 2013).

Descriptive statistics and correlations are provided in Table 1. As can be seen, correlations are within the conventional limits with none exceeding .70, such that it is possible to utilize these variables in the regression analysis.

Table 1. Descriptive statistics and correlations between variables

Variables	Mean	*SD*	1	2	3	4	5	6	7	8
Startup rate	0.20	0.09	1.00							
Contained emission share	57.78	25.71	0.15**	1.00						
Scientists per capita	0.25	0.25	0.37***	0.15**	1.00					
Border region	0.46	0.50	–0.12*	0.21***	–0.22***	1.00				
Regional R&D intensity	0.64	0.55	0.13**	–0.04	0.62***	–0.05	1.00			
Income per capita	25.46	7.43	0.21***	0.06	0.32***	–0.13**	–0.03	1.00		
Higher education enrollment	2.80	0.93	0.30***	0.08	0.13**	–0.01	0.15**	–0.22***	1.00	
Export intensity	11.58	13.76	0.07	0.05	–0.11*	–0.16***	–0.27***	0.47***	–0.27***	1.00
Emission intensity	307.08	269.06	–0.06	0.08^{λ}	–0.28***	0.07	–0.13**	–0.13**	–0.13**	0.2***

Note. ****p* < .001, ***p* < .01, **p* < .05.

3.3. Models and estimation

Because our dataset is panel in nature, we could not utilize ordinary least squares regression. Two of the estimation techniques most often used with panel data are fixed effects and random effects. Due to the fact that one of our variables, border region, is time-invariant, we opted to analyze our data using a random effects estimator. The general expression for a regression model with random effects is as follows:

$$Y_{it} = \text{Intercept} + X_{it} \cdot \beta + \mu_i + \varepsilon_{it} \qquad (1)$$

where Intercept is a constant, X_{it} is variables and β is coefficients for variables, μ_i is a random error invariant in time for each object, and ε_{it} is model regression residual.

Altogether, we present three models in Table 2. Model 1 is a reference point model that only includes control variables. Model 2 adds a regional R&D intensity to the set of predictors and is used to test Hypothesis 1. Model 3 adds three moderator variables and their interactions with the regional R&D intensity variable. This model serves to test Hypotheses 2–4.

Table 2. Regression models and their variables

N	Variables	Model 1	Model 2	Model 3
1	Startup rate	+	+	+
2	Contained emission share	+	+	+
3	Scientists per capita	+	+	+
4	Border region	+	+	+
5	Regional R&D intensity		+	+
6	Income per capita			+
7	Higher education enrollment			+
8	Export intensity			+
9	Regional R&D intensity·Income per capita			+
10	Regional R&D intensity·Higher education enrollment			+
11	Regional R&D intensity·Export intensity			+

According to Table 2, the formula of regression model with random effects for Model 1 will be as follows. Equations for Models 2 and 3 are constructed similarly according to the data in Table 2.

$$\text{Emission intensity} = \text{Intercept} + \beta_1 \cdot \text{Startup rate} + \beta_2 \cdot \text{Contained emission share} + \beta_3 \cdot \text{Scientists per capita} + \beta_4 \cdot \text{Border region} + \mu_i + \varepsilon_{it} \quad (2)$$

Next, we visualize the resulting models. Using the obtained graphs, we formulate recommendations to regional managers on economic development without increasing environmental pollution. Following Marquardt (1980), we standardize predictor variables to minimize the multicollinearity problems. Calculations were performed using the R programming language.

4. Results and discussion

Model 1, which contains only control variables, is highly significant and accounts for the variance in the dependent variable. Based on the calculations in Table 3, the following expression describes Model 1. Equations for models 2 and 3 are constructed similarly according to the data in Table 3.

$$\text{Emission intensity} = 307.08 + 75.72 \cdot \text{Startup rate} - 45.70 \cdot \text{Contained emission share} - 72.73 \cdot \text{Scientists per capita} + 19.83 \cdot \text{Border region} + \mu_i + \varepsilon_{it} \quad (3)$$

The relationships between control variables and emission intensity are in line with the extant literature (Stricker, 2007; Zeng & Ren, 2022). Specifically, startup rate exerts a positive impact on emission intensity, while contained emission share and scientists per capita have a negative impact.

Model 2, which adds regional R&D intensity, increases the explanatory power substantially compared to Model 1. As hypothesized, R&D intensity exerts a positive impact on regional pollution. Adding R&D intensity to the set of predictors increases the predictive power of our previous model by over 15%, which indicates a very prominent impact of this variable in support of Hypothesis 1.

Model 3 adds three moderators and includes the interaction effects of R&D intensity with them. The model is highly significant and explains over 20% more variance in regional pollution compared to Model 2. Overall, R^2 reaches 45.8%. The effect of R&D intensity on emission intensity is negatively moderated by per capita income and higher education enrollment, but positively moderated by the export intensity of regional firms. In other words, Hypotheses 2, 3, and 4 are supported by Model 3. Table 3 documents the results of hypothesis testing.

Table 3. Regression results

Variables	Model 1	Model 2	Model 3
Intercept	307.08*** (28.43)	307.08*** (28.95)	332.90*** (28.75)
Startup rate	75.72*** (12.93)	74.00*** (11.80)	43.85*** (11.19)
Contained emission share	–45.70** (17.25)	–24.40 (16.33)	–27.37 λ (14.14)
Scientists per capita	–72.73** (27.61)	–172.71*** (29.76)	–86.01** (28.79)
Border region	19.83 (29.40)	1.10 (29.95)	–9.45 (29.14)
Regional R&D intensity		150.86*** (16.59)	108.89*** (18.05)
Income per capita			–66.26*** (18.61)
Higher education enrollment			26.89 λ (15.38)
Export intensity			34.85 λ (18.97)
Regional R&D intensity·Income per capita			–106.58*** (11.64)
Regional R&D intensity·Higher education enrollment			–93.67*** (9.89)
Regional R&D intensity·Export intensity			52.10* (20.90)
R^2	.082	.234	.458
ΔR^2	–	0.152	0.224
Fit statistic	$\chi 2(4) = 42.31$	$\chi 2(5) = 136.80$	$\chi 2(11) = 374.75$
p	<0.001	<0.001	<0.001

Note. Dependent variable: Emission intensity. Standard errors in parentheses. ***$p < .001$, **$p < .01$, *$p < .05$, λ p < .10.

To ease the interpretation of the interaction effects, we plot the moderated relationship between R&D intensity and emission intensity in Figure 1 (with per capita income as a moderator), Figure 2 (with higher education enrollment as a moderator), and Figure 3 (with export intensity as a moderator).

To plot the graphs, we use the following technique: Figure 1 shows the effect of R&D intensity on Emission Intensity with the moderator Income per capita. The rest of the variables in Model 3 have average values. Because all variables except the dependent variable are standardized, their average values are equal to zero. We get the following function:

$$\text{Emission intensity} = 332.90 + 108.89 \cdot \text{R\&D intensity} - 66.26 \cdot \text{Income per capita} - 106.58 \cdot \text{R\&D intensity} \cdot \text{Income per capita} \quad (4)$$

Since Income per capita is a moderator, then we analyze cases where this variable takes the values +1 (+1 standard deviation) and –1 (–1 standard deviation). We get two functions, the graphical visualization of which is shown in Figure 1. In all cases, we plot the effects of R&D at one standard deviation above and below the mean of moderator variables.

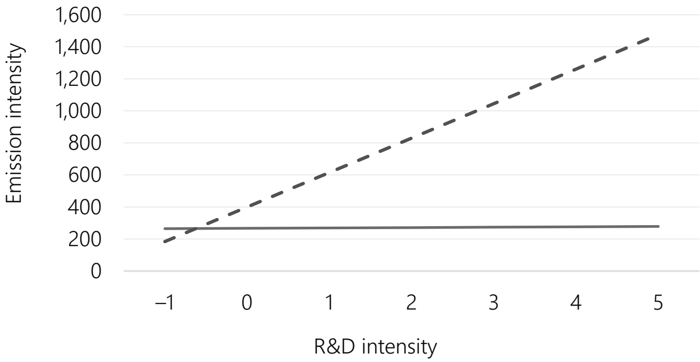

Figure 1. Regional R&D intensity and emission intensity in high and low per capita income regions. *Note.* Solid line represents regions with high per capita income, dashed line represents regions with low per capita income.

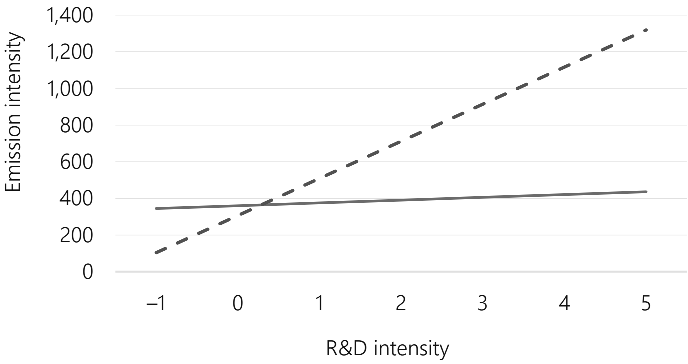

Figure 2. Regional R&D intensity and emission intensity in high and low higher education enrollment regions. *Note.* Solid line represents regions with high enrollment in higher education institutions, dashed line represents regions with low enrollment in higher education institutions.

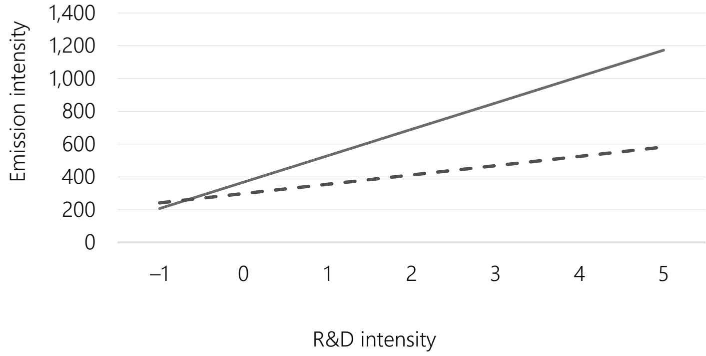

Figure 3. Regional R&D intensity and emission intensity in high and low export intensity regions.
Note. Solid line represents regions with high export intensity, dashed line represents regions with low export intensity.

In line with our hypotheses, we see that overall, the relationship between R&D intensity and emission intensity is positive; that is, R&D intensity is detrimental from an ecological standpoint. This relationship is particularly pronounced in regions with below-average per capita income, below-average higher education enrollment, and above-average export intensity. At the same time, the relationship flattens in economically prosperous regions, near-flattens in regions characterized by above-average higher education enrollment and weakens significantly in regions that are low on export intensity. At more extreme values of our moderators, the relationship between R&D intensity and emission intensity may reverse, thus suggesting that there are circumstances where investment in research and development by regional firms may in fact be beneficial for ecological outcomes.

We have conducted an additional investigation into this matter. The values of moderators that turn the relationship between R&D intensity and emission intensity negative are as follows: For per capita income, the sign of the relationship flips when the moderator reaches 1.02 standard deviations above the mean value. For higher education enrollment, the sign flips at 1.16 standard deviations above the mean. For export intensity, the point at which the sign shifts are more extreme: the relationship turns negative at levels of export intensity below 2.09 standard deviations below the mean. Such instances are relatively uncommon, and one needs to exercise caution before taking our results too far.

Overall, our results confirm that the relationship between R&D intensity and emission intensity is context-specific. As such, discerning policymakers would be wise to consider important contingencies when developing their development policies and recommendations.

The study carried out additional tests to check the robustness of the results obtained. The LM test (Breusch-Pagan Lagrange Multiplier) showed that there are pronounced panel effects in the regression models, and the OLS method is not suitable. Random-effects models are valid and appropriate. At the same time, serial correlation and heteroscedasticity were found in the constructed regression models. This fact requires checking the significance of the obtained regression coefficients. The paper applies robust covariance matrix estimation for Model 3, which is robust to errors due to heteroscedasticity and serial correlation (Table 4). In both cases, robust estimates confirm the significance of the coefficients for the tested variable (Regional R&D intensity) and its interaction with three moderator variables.

Table 4. Robustness check of regression coefficients in Model 3

Variables	Model 3 (robust to heteroscedasticity and serial correlation)	Model 3 (robust to small sample and heteroscedasticity and serial correlation)
Intercept	332.90*** (37.55)	332.90*** (39.28)
Startup rate	43.85*** (11.22)	43.85*** (11.86)
Contained emission share	–27.37 λ (16.45)	–27.37 (17.62)
Scientists per capita	–86.01** (30.19)	–86.01** (32.96)
Border region	–9.45 (35.20)	–9.45 (36.52)
Regional R&D intensity	108.89* (42.32)	108.89* (47.87)
Income per capita	–66.26*** (19.94)	–66.26** (21.66)
Higher education enrollment	26.89 (17.96)	26.89 (18.84)
Export intensity	34.85 (22.51)	34.85 (25.20)
Regional R&D intensity·Income per capita	–106.58** (32.68)	–106.58** (36.77)
Regional R&D intensity·Higher education enrollment	–93.67*** (26.71)	–93.67** (29.52)
Regional R&D intensity·Export intensity	52.10 λ (26.55)	52.10 λ (29.83)

Note. Dependent variable: Emission intensity. Standard errors in parentheses. ***$p < .001$, **$p < .01$, *$p < .05$; λ $p < .10$.

5. Limitations, conclusion, and future research

Our conceptual development suggests, and our empirical results prove, that in the absence of systematic governmental actions aimed at curbing pollution, left to their own devices, firms behave in ways consistent with the well-known Friedman (1970) doctrine and choose to pursue innovative ends at the cost of their environments. As such, the classic notion of the tragedy of the commons, well known in economics, once again proves instrumental in explaining the observed pattern of relationship between economic development and ecological outcomes. It thus appears that by themselves, the economic and ecological dimensions of the sustainable development goals advanced by the UN are inherently at odds with each other, and absent governmental intervention, they are unlikely to find natural alignment.

We also show that this relationship between R&D intensity and emission intensity is not uniform but rather context-dependent. Thus, the positive impact of R&D intensity on pollution weakens in regions that demonstrate high per capita incomes among their residents. Looked at differently, it suggests that in relatively disadvantaged regions, the negative impact of R&D is more pronounced. That is, less developed regions need advanced environmental protection policies as they try to bring about economic development. Otherwise, the negative externalities of innovative development may outweigh the benefits that regional policymakers expect to obtain from supporting regional innovation.

Likewise, regions characterized by above-average enrollment in higher education are likely to see the positive impact of regional investment in R&D on emission intensity weaken. Change, including heightened commitment to sustainable development, requires passionate leadership, and a young, educated elite is often the hidden force driving the change for the better. At the same time, regions that do not promote education are unlikely to benefit ecologically from the increased innovative efforts of regional firms. This, again, suggests important insights for policymakers and indicates that systematic support of higher education is an essential element that is beneficial well beyond regional economic advancement.

Export intensity exacerbates the impact of R&D intensity on regional pollution, at least in the context of a resource-oriented economy. Mining and extracting natural resources is a "dirty" industry, and intensifying regional exports may bring about a noticeable increase in environmental pollution. Moreover, because export intensity implies more intense transportation of goods within and beyond the region, emissions intensify as a transportation by-product. While the implications for policymakers are less clear, these results may suggest that policymakers may be wise to consider changing the industrial makeup of their territories, and while they may not do so directly, they have a number of indirect means at their disposal that may be instrumental in this regard, including tax benefits and licensing decisions. Future research would be wise to explore this question in detail.

Our results need to be considered in light of the study's limitations. First of all, our study is conducted in the context of a single country, which, although it is the largest on the planet in terms of its territory, may not be the most representative setting for studying the relationship between economic development and environmental pollution globally. Still, given the sheer size of the Russian Federation, the insights gained from this study are worthy of scholarly attention.

Second, if anything, the effects found to be significant in the present study are likely to be stronger than what our calculations indicate. Future research would be wise to consider ways in which current estimates of environmental pollution may be freed from statistical bias.

Taken together, our results support the notion that the economic and ecological goals of sustainable development are often in opposition to each other. As such, policymakers should take this notion into account when developing their economic development policies to ensure that economic growth does not disadvantage country residents in an ecological sense. Moreover, inasmuch as environmental pollution is impossible to contain within a single country, neighboring countries should attend to the economic development processes in less developed economies lest negative externalities spill over beyond the territory of the countries aiming to facilitate growth.

Acknowledgements

This study was supported by the Tomsk State University Development Programme ("Priority-2030").
Funding: Mendeleev Foundation No. 2.2.4.22 State Registration № 122053100114-8 05.31.2022.

References

Ahmed, Z., Ahmad, M., Rjoub, H., Kalugina, O. A., & Hussain, N. (2022). Economic growth, renewable energy consumption, and ecological footprint: Exploring the role of environmental regulations and democracy in sustainable development. *Sustainable Development*, *30*(4), 595–605. https://doi.org/10.1002/sd.2251

Anokhin, S. (2013). Venture migration: a quest for a low-hanging fruit? *Entrepreneurship & Regional Development*, *25*(5–6), 423–445. https://doi.org/10.1080/08985626.2012.758316

Anokhin, S. A., Spitsin, V., Akerman, E., & Morgan, T. (2021). Technological leadership and firm performance in Russian industries during crisis. *Journal of Business Venturing Insights, 15*, Article e00223. https://doi.org/10.1016/j.jbvi.2021.e00223

Anokhin, S., & Wincent, J. (2012). Start-up rates and innovation: A cross-country examination. *Journal of International Business Studies*, *43*(1), 41–60. https://doi.org/10.1057/jibs.2011.47

Audretsch, D. (2006). *Entrepreneurship, Innovation and Economic Growth*. Edward Elgar Publishing.

Behera, S. R., & Dash, D. P. (2017). The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region. *Renewable and Sustainable Energy Reviews, 70*, 96–106. https://doi.org/10.1016/j.rser.2016.11.201

Berry, H., Kaul, A., & Lee, N. (2021). Follow the smoke: The pollution haven effect on global sourcing. *Strategic Management Journal*, *42*(13), 2420–2450. https://doi.org/10.1002/smj.3288

Bradshaw, M. J., & Vartapetov, K. (2003). A New Perspective on Regional Inequalities in Russia. *Eurasian Geography and Economics*, *44*(6), 403–429. https://doi.org/10.2747/1538-7216.44.6.403

Cairns, D., & Smyth, J. (2011). *I wouldn't mind moving actually*: Exploring student mobility in Northern Ireland. *International Migration, 49*(2), 135–161. https://doi.org/10.1111/j.1468-2435.2009.00533.x

Carayannis, E. G., & Campbell, D. F. (Eds.). (2019). *Smart Quintuple Helix Innovation Systems How Social Ecology and Environmental Protection are Driving Innovation, Sustainable Development and Economic Growth*. Springer. https://link.springer.com/book/10.1007/978-3-030-01517-6

Carson, T. (1993). Friedman's Theory of Corporate Social Responsibility. *Business & Professional Ethics Journal, 12*(1), 3–32. https://www.jstor.org/stable/27800897

Carstensen, L. L. (1995). Evidence for a Life-Span Theory of Socioemotional Selectivity. *Current Directions in Psychological Science*, *4*(5), 151–156. https://doi.org/10.1111/1467-8721.ep11512261

Chen, Y., & Lee, C. C. (2020). Does technological innovation reduce CO_2 emissions? Cross-country evidence. *Journal of Cleaner Production*, *263*, Article 121550. https://doi.org/10.1016/j.jclepro.2020.121550

Cheng, X., Chen, L., & Sun, R. (2019). Modeling the non-point source pollution risks by combing pollutant sources, precipitation, and landscape structure. *Environmental Science and Pollution Research*, *26*(12), 11856–11863. https://doi.org/10.1007/s11356-019-04384-y

Dong, F., Yu, B., Hadachin, T., Dai, Y., Wang, Y., Zhang, S., & Long, R. (2018). Drivers of carbon emission intensity change in China. *Resources, Conservation and Recycling*, *129*, 187–201. https://doi.org/10.1016/j.resconrec.2017.10.035

Elkington, J. (2018). 25 Years Ago I Coined the Phrase "Triple Bottom Line." Here's Why It's Time to Rethink It. *Harvard Business Review*, *25*, 2–5. https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it

Endl, A., Tost, M., Hitch, M., Moser, P., & Feiel, S. (2021). Europe's mining innovation trends and their contribution to the sustainable development goals: Blind spots and strong points. *Resources Policy, 74*, Article 101440. https://doi.org/10.1016/j.resourpol.2019.101440

Friedman, M. (1970). A Friedman doctrine - The Social Responsibility of Business Is to Increase Its Profits. *The New York Times*. https://www.nytimes.com/1970/09/13/archives/a-friedman-doctrine-the-social-responsibility-of-business-is-to.html

Frischmann, B. M., Marciano, A., & Ramello, G. B. (2019). Retrospectives: Tragedy of the Commons after 50 Years. *Journal of Economic Perspectives*, *33*(4), 211–228. https://doi.org/10.1257/jep.33.4.211

Garrity, E. J. (2012). Tragedy of the Commons, Business Growth and the Fundamental Sustainability Problem. *Sustainability, 4*(10), 2443–2471. https://doi.org/10.3390/su4102443

Hatak, I., Harms, R., & Fink, M. (2015). Age, job identification, and entrepreneurial intention. *Journal of Managerial Psychology*, *30*(1), 38–53. https://doi.org/10.1108/JMP-07-2014–0213

Hout, M. (2012). Social and Economic Returns to College Education in the United States. *Annual Review of Sociology*, *38*, 379–400. https://doi.org/10.1146/annurev.soc.012809.102503

Jorgenson, A. K., & Burns, T. J. (2007). The political-economic causes of change in the ecological footprints of nations, 1991–2001: a quantitative investigation. *Social Science Research*, *36*(2), 834–853. https://doi.org/10.1016/j.ssresearch.2006.06.003

Lee, B. S., Peng, J., Li, G., & He, J. (2012). Regional Economic Disparity, Financial Disparity, and National Economic Growth: Evidence from China. *Review of Development Economics*, *16*(2), 342–358. https://doi.org/10.1111/j.1467-9361.2012.00666.x

Li, H., Khattak, S. I., & Ahmad, M. (2021). Measuring the impact of higher education on environmental pollution: new evidence from thirty provinces in China. *Environmental and Ecological Statistics*, *28*, 187–217. https://doi.org/10.1007/s10651-020-00480-2

Lynch, J. W., Kaplan, G. A., Pamuk, E. R., Cohen, R. D., Heck, K. E., Balfour, J. L., & Yen, I. H. (1998). Income inequality and mortality in metropolitan areas of the United States. *American Journal of Public Health*, *88*(7), 1074–1080. https://doi.org/10.2105/ajph.88.7.1074

Maroto, M. (2016). Fifteen Years of Wealth Disparities in Canada: New Trends or Simply the Status Quo? *Canadian Public Policy*, *42*(2), 152–167. https://doi.org/10.3138/cpp.2015-040

Marquardt, D. W. (1980). Comment: You Should Standardize the Predictor Variables in Your Regression Models. *Journal of the American Statistical Association*, *75*(369), 87–91. https://doi.org/10.1080/01621459.1980.10477430

Metcalf, G. E. (2019). On the Economics of a Carbon Tax for the United States. *Brookings Papers on Economic Activity*, *Spring*, 405–484. https://doi.org/10.1353/eca.2019.0005

Mironenko, N., & Kolchugina, T. (2012). Export-Oriented Model of Sustainable Development in Russia (From the "Dutch Disease" to Innovative Development). *Geography, Environment, Sustainability*, *5*(1), 112–119. https://doi.org/10.24057/2071-9388-2012-5-1-112-119

Mullen, A. L., Goyette, K. A., & Soares, J. A. (2003). Who Goes to Graduate School? Social and Academic Correlates of Educational Continuation after College. *Sociology of Education*, *76*(2), 143–169. https://doi.org/10.2307/3090274

Muñoz, P., & Cohen, B. (2017). Towards a social-ecological understanding of sustainable venturing. *Journal of Business Venturing Insights*, *7*, 1–8. https://doi.org/10.1016/j.jbvi.2016.12.001

Nakamura, H., & Managi, S. (2020). Entrepreneurship and marginal cost of CO_2 emissions in economic development. *Economic Analysis and Policy*, *67*, 1–14. https://doi.org/10.1016/j.eap.2020.05.004

Newell, J. P., & Henry, L. A. (2016). The state of environmental protection in the Russian Federation: a review of the post-Soviet era. *Eurasian Geography and Economics*, *57*(6), 779–801. https://doi.org/10.1080/15387216.2017.1289851

Nicolini, M., & Tavoni, M. (2017). Are renewable energy subsidies effective? Evidence from Europe. *Renewable and Sustainable Energy Reviews*, *74*, 412–423. https://doi.org/10.1016/j.rser.2016.12.032

Petrović, M. D., Gelbman, A., Demirović, D., Gagić, S., & Vuković, D. B. (2017). The examination of the residents' activities and dedication to the local community–an agritourism access to the subject. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, *67*(1), 37–52. https://doi.org/10.2298/IJGI1701037P

Pittau, M. G., Zelli, R., & Gelman, A. (2010). Economic Disparities and Life Satisfaction in European Regions. *Social Indicators Research*, *96*(2), 339–361. https://doi.org/10.1007/s11205-009-9481-2

Rosstat. (2022). *Regioni Rossii: Socialno-экономičeskie pokazateli* [Regions of Russia: Socio-economic indicators]. https://rosstat.gov.ru/storage/mediabank/LkooETqG/Region_Pokaz_2020.pdf

Sakai, M., & Barrett, J. (2016). Border carbon adjustments: Addressing emissions embodied in trade. *Energy Policy*, *92*, 102–110. https://doi.org/10.1016/j.enpol.2016.01.038

Schwab, K., Porter, M. E., & Sachs, J. D. (2002). *The Global Competitiveness Report 2001–2002*. https://static1.squarespace.com/static/5d59c0bdfff8290001f869d1/t/5f046e88f3633a029cee2f89/1594125961234/Global+Competitiveness+Report+2001-2002.pdf

Slaper, T. F., & Hall, T. J. (2011). The Triple Bottom Line: What Is It and How Does It Work? *Indiana Business Review*, *86*(1), 4–8. http://www.ibrc.indiana.edu/ibr/2011/spring/pdfs/article2.pdf

Spitsin, V., Vukovic, D., Anokhin, S., & Spitsina, L. (2021). Company performance and optimal capital structure: evidence of transition economy (Russia). *Journal of Economic Studies*, *48*(2), 313–332. https://doi.org/10.1108/JES-09-2019-0444

Stilwell, F., & Jordan, K. (2007). *Who Gets What? Analysing Economic Inequality in Australia*. Cambridge University Press.

Stricker, P. (2007). *Toward a Culture of Nature: Environmental Policy and Sustainable Development in Cuba*. Lexington Books.

Tan, L. (2005). The Paradox of Catching Up. In L. Tan (Ed.), *The Paradox of Catching Up* (pp. 163–172). Palgrave Macmillan. https://doi.org/10.1057/9780230598072_6

Thompson, W. R., & Thompson, P. R. (1987). National Industries and Local Occupational Strengths: The Cross-Hairs of Targeting. *Urban Studies*, *24*(6), 547–560. https://doi.org/10.1080/00420988720080781

United Nations. (2016). *The sustainable development goals report 2016*. https://unstats.un.org/sdgs/report/2016/

Vuković, D., Jovanović, A., & Đukić, M. (2012). Defining competitiveness through the theories of new economic geography and regional economy. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, *62*(3), 49–64. https://doi.org/10.2298/IJGI1203049V

Vuković, D., & Wei, L. (2010). Regional competitiveness: the case of western China. *Journal of the Geographical Institute Jovan "Jovan Cvijić" SASA*, *60*(1), 107–124. https://doi.org/10.2298/IJGI1001107V

Wang, C., Wood, J., Wang, Y., Geng, X., & Long, X. (2020). CO_2 emission in transportation sector across 51 countries along the Belt and Road from 2000 to 2014. *Journal of Cleaner Production*, *266*, Article 122000. https://doi.org/10.1016/j.jclepro.2020.122000

York, R., Rosa, E. A., & Dietz, T. (2004). The Ecological Footprint Intensity of National Economies. *Journal of Industrial Ecology*, *8*(4), 139–154. https://doi.org/10.1162/1088198043630487

Zeng, J., & Ren, J. (2022). How does green entrepreneurship affect environmental improvement? Empirical findings from 293 enterprises. *International Entrepreneurship and Management Journal*, *18*(1), 409–434. https://doi.org/10.1007/s11365-021-00780-4