economies

MDPI

Article

Tax Incentives and the Intensity of Business Expenditures on Research and Development in Central and Eastern European Countries

Andriy Stavytskyy [1,2,*] and Lina Mukhina [1]

[1] Faculty of Economics, Taras Shevchenko National University of Kyiv, 01601 Kyiv, Ukraine; lina.mukhina@knu.ua
[2] Faculty of Economics and Business Administration, Vilnius University, 10222 Vilnius, Lithuania
* Correspondence: a.stavytskyy@knu.ua

Abstract

This study assesses the impact of research and development (R&D) tax incentives on the intensity of business R&D expenditure in Central and Eastern European countries and derives policy implications for Ukraine. The analysis uses a balanced panel of 11 new EU member states covering the period 2010–2023, based exclusively on officially published data. The main method is a two-way fixed-effects panel regression with country and year effects, clustered standard errors, alternative lag structures, heterogeneity analysis and robustness checks. The baseline specification shows that a 0.10 increase in the implicit subsidy rate is associated with an approximately 0.10 percentage point increase in Business Expenditure on R&D (BERD) to GDP two years later. However, the effect is strongly conditional on absorptive capacity: it is statistically significant in countries with a developed R&D base and practically absent in countries with a weak base. The estimated private R&D additionality ratio falls below one under the stated assumptions, indicating that the estimated effect does not imply more than one unit of additional private investment per unit of fiscal support. For Ukraine, the results support a gradual introduction of R&D tax incentives combined with structural measures that strengthen human capital, institutional capacity and links between science and business.

Keywords: tax incentives; R&D; business innovation; panel regression; fixed effects; absorptive capacity; Central and Eastern Europe; Ukraine; B-index

1. Introduction

Innovation activity in the business sector is one of the key drivers of long-term economic growth and technological competitiveness. At the same time, private firms systematically underinvest in research and development: knowledge has the characteristics of a public good—it is difficult to fully appropriate, which generates negative externalities for the investor and, consequently, a suboptimal level of private R&D spending (Arrow, 1962; Nelson, 1959). To correct this market failure, most developed countries employ government support for R&D—both direct and indirect.

Over the past two decades, there has been a noticeable shift in the structure of government support toward indirect instruments. As of 2024, 34 out of 38 OECD countries provide special tax incentives for business expenditures on research and development, and their share in total government support for business R&D exceeds 55% (OECD, 2025). Central and Eastern European countries, actively integrating into the EU's economic and

Check for updates

Academic Editor: Sanzidur Rahman

Received: 27 May 2026
Revised: 15 June 2026
Accepted: 17 June 2026
Published: 2 July 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

innovation space, are also increasingly adopting this tool: most new EU members from the region introduced or significantly expanded R&D tax incentive programs during the 2010s and 2020s.

Despite the prevalence of such programs, their effectiveness in the specific context of CEE remains under-researched. The vast majority of the empirical literature focuses on developed OECD economies or individual countries, whereas the transformational experience of new EU members, shorter institutional memory, and a lower initial R&D base may significantly modify the known effects. Furthermore, there is a near absence of studies that systematically assess the heterogeneity of effects within the region depending on the level of previously accumulated innovation potential.

For Ukraine, the issue is particularly relevant. The country has one of the lowest business R&D expenditure rates in Europe—0.24% of GDP in 2021 (prior to the major economic disruption of 2022)—and effectively lacks systemic indirect incentives for R&D: the implicit subsidy rate for Ukraine is 0.00, which is a unique situation among EU member states and candidate countries (Appelt et al., 2020). In the context of economic reconstruction and European integration, the development of effective innovation and fiscal policies takes on strategic importance, and the experience of neighboring CEE countries serves as the most directly relevant benchmark.

This study aims to fill this gap: using panel regression analysis to assess the impact of tax incentives on BERD (Business Expenditure on R&D) in 11 CEE countries for the period 2010–2023, analyze the heterogeneity of effects, and derive policy implications for Ukraine.

The article is structured as follows: Section 2 provides a review of the theoretical and empirical literature; Section 3 describes the data and methodology; Section 4 presents the main results, including an analysis of heterogeneity and robustness tests; Section 5 offers an interpretation of the results and implications for Ukraine; Section 6 formulates conclusions; Section 7 outlines limitations and directions for further research.

2. Literature Review

2.1. Theoretical Foundations

The theoretical justification for government intervention in the R&D sector rests on three interrelated conceptual frameworks.

The first is the classic theory of market failure. As early as the 1960s, it was demonstrated that knowledge possesses the characteristics of a public good: it is difficult to prevent third parties from using it, and it is impossible to fully appropriate it (Arrow, 1962; Nelson, 1959). As a result, the private return on R&D investments is systematically lower than the social return, and the private sector underinvests in research. The state corrects this failure by subsidizing R&D—either directly or through the tax system. The classical rationale supports the logic of input-based incentives, which are directly aimed at reducing the cost of R&D for the firm.

The second is the concept of national innovation systems (NIS) (Lundvall, 1992). This framework shifts the focus from specific market failures to systemic failures: insufficient coordination among participants in the innovation process, information asymmetry, and the lack of appropriate links between science and business. Accordingly, the effectiveness of any individual instrument, including tax incentives, is determined by the quality of the entire innovation ecosystem. This theoretical premise is key to interpreting the results of this study.

The third is the theory of absorptive capacity, which emphasizes that an organization's ability to absorb and utilize external knowledge and incentives is shaped by prior accumulated investments in R&D and human capital (Cohen & Levinthal, 1990). For aggregate analysis, this means that the same fiscal incentive can yield fundamentally different results

depending on the level of a country's previously accumulated innovation potential. It is precisely this prediction that becomes the central focus of testing in the heterogeneity analysis (Section 4.2).

The current stage of the theory is complemented by a transformational approach, which raises the question of whether innovations are directed toward addressing societal challenges (Schot & Steinmueller, 2018). For the practical design of incentives, this implies the need to combine general fiscal instruments with targeted measures in priority areas. These three theoretical frameworks are not fully reconcilable. The neoclassical market failure perspective treats tax incentives as an efficiency-restoring instrument with broadly predictable effects, since the main mechanism is a reduction in the user cost of R&D. By contrast, the evolutionary NIS and absorptive capacity perspectives suggest that the same fiscal incentive may generate fundamentally different outcomes depending on institutional context, accumulated capabilities, and the quality of science-business linkages (Cohen & Levinthal, 1990; Lundvall, 1992). Recent transformational innovation-policy literature further extends this critique by arguing that public policy should not only correct market failures, but also shape collective goals and address systemic barriers to innovation (Mazzucato, 2024). This theoretical tension is not merely academic: it implies that the appropriate policy question is not simply "do R&D tax incentives work?" but rather "under what structural conditions do they work, and for which firms?" This study tests precisely this conditional hypothesis for the CEE institutional context.

2.2. Empirical Studies on the Impact of Tax Incentives on R&D

The empirical literature on the effects of R&D incentives is extremely extensive and generally yields a positive but mixed conclusion.

At the macro level, studies using the OECD R&D Tax Incentives Database have demonstrated that fixed-effects panel models are among the most reliable tools for assessing the effectiveness of incentives at the aggregate level, as they allow for the control of country-specific characteristics (Appelt et al., 2020). A review of the literature confirms that panel regressions remain the "gold standard" for analyzing the impact of incentives at the country level (Becker & Pain, 2008). The typical estimate of the price elasticity of R&D with respect to cost, synthesized in numerous meta-analyses, ranges from -0.5 to -2.0 (Hall & Van Reenen, 2000), meaning that a 10% reduction in R&D costs generates between 5% and 20% in additional spending.

At the micro level, the results are more variable. Studies using propensity score matching and Difference-in-Differences (DiD) approaches on firm-level data have identified positive and statistically significant effects of tax incentives on innovation activity, including increases in firms' innovation expenditures and stronger effects for small and medium-sized enterprises, although in some cases the impact emerges only with significant time lags (Dechezleprêtre et al., 2023; Guceri & Albinowski, 2021).

At the same time, a number of studies note that the effect of incentives varies significantly depending on firm size, industry, a country's level of development, and the quality of the institutional environment. Recent evidence suggests that small and medium-sized firms tend to respond more strongly to R&D tax incentives than large firms, while the effect of R&D support on firms' innovation activity may unfold over several subsequent years rather than immediately (OECD, 2023; Lenihan et al., 2024).

Furthermore, the literature highlights that accelerating technological progress and fostering R&D intensity are not isolated economic goals, as they significantly reshape broader socioeconomic outcomes. For instance, research on the European Union demonstrates that technological change and innovation-driven transformations have a profound, non-linear

impact on structural development and income distribution, emphasizing the need for balanced policy frameworks (Kharlamova et al., 2018).

2.3. The CEE Context and the Research Gap

Studies focusing specifically on CEE countries are few and far between. An analysis of the cost and coverage of revenue-based R&D tax incentives across 49 countries identified a significant disparity between developed and catching-up economies: in Central and Eastern European countries, the share of firms utilizing incentives remains consistently lower than in countries such as France or the Netherlands, which is associated with differences in institutional capacity and the structure of the business R&D sector (Appelt et al., 2023). This finding confirms that incentives effective in developed economies require significant adaptation to the conditions of countries undergoing transformation.

A comparative analysis of the region's countries reveals significant diversity: Poland has gradually increased the generosity of its incentives from a 150% super-deduction in 2016 (a mechanism allowing 150% of actual R&D expenses to be deducted from gross expenses, i.e., receiving an additional tax deduction of 50% above the standard deduction) to 200% in 2018 and a patent box regime (IP-box—a reduced income tax rate on profits from the commercialization of intellectual property) in 2021, and has demonstrated steady growth in BERD/GDP; Latvia introduced a 300% deduction but abolished it in 2018 due to a documented low additionality ratio and abuse (Ministry of Economics of the Republic of Latvia, 2023); Lithuania has established one of the most generous systems in the region with a subsidy rate of 0.29 (i.e., the state covers 29% of the cost of R&D expenditures); Bulgaria and Estonia (until 2023) operated without indirect incentives but at different levels of BERD.

This diversity of designs and outcomes within a homogeneous institutional space (new EU members) creates a unique "natural environment" for identifying effects. At the same time, no comprehensive quantitative analysis covering all 11 new EU members from Central and Eastern Europe (CEE) for the last full cycle of 2010–2023 has been found in the literature available to us. Filling this gap is the main contribution of this study. The CEE region warrants dedicated analysis as a special case for several reasons. First, all 11 countries have undergone institutional transition from centrally planned to market economies, creating a specific combination of relatively strong human-capital endowments and less mature market institutions for innovation, including venture capital, IP protection, and science-business linkages. Recent evidence confirms that, despite EU integration, CEE countries continue to face persistent gaps in business R&D intensity, commercialization capacity, and innovation-system infrastructure (Zavarská et al., 2024). This transitional character means that the mechanisms through which incentives operate likely differ from those in advanced OECD economies with more mature innovation ecosystems and stronger absorptive capacity (OECD, 2023). Second, EU membership imposes a common regulatory framework while national-level incentive design remains differentiated, creating a comparable setting for cross-country policy analysis (Appelt et al., 2020). Third, the gradual and uneven adoption of incentives across the region during 2010–2023 provides temporal variation suitable for panel identification and allows testing whether the effect of fiscal incentives depends on pre-existing innovation capacity.

Based on the theoretical review, three research hypotheses are formulated.

H1 (main). *Tax incentives for R&D have a positive lagged impact on the intensity of business R&D expenditure (BERD/GDP) in CEE countries, with the effect materializing with a lag of two or more years.*

H2 (heterogeneity). *The effect of incentives is statistically significant only in countries with a sufficiently developed R&D base (high absorption capacity), whereas in countries with a low base, it is practically zero.*

H3 (additionality). *The private R&D additionality ratio exceeds one (M > 1), meaning that every hryvnia of tax expenditure on incentives generates more than one hryvnia of additional private investment in R&D, under the stated assumptions about deadweight loss and reallocation.*

3. Data and Methodology

3.1. Sample and Data Sources

The sample covers 11 Central and Eastern European countries—new EU members: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The dataset covers the years 2010–2023 (N = 154 observations, 11 × 14); the panel is balanced—each country is represented by exactly 14 annual observations with no missing values. The choice of 2010 as the lower bound is due to the availability of comparable data on tax incentives following the global financial crisis.

All data are officially published figures for 2010–2023 (N = 154). Previously, draft versions of this manuscript included estimated values for 2024–2025 based on National Reform Programs and European Commission forecasts; following reviewer feedback, all projected data beyond 2023 have been removed from both descriptive statistics and trend analysis to ensure data purity. The regression analysis, descriptive statistics, and empirical trend figures are now strictly limited to confirmed official statistical data through 2023; forward-looking scenario figures are explicitly labelled as illustrative policy exercises rather than empirical evidence.

The dependent variable—the share of business R&D expenditure in GDP (BERD/GDP, %)—is derived from the OECD Main Science and Technology Indicators database (OECD, 2024b). The main independent variable is the implicit subsidy rate (1-B), where B—the Warda index (Warda, 2002)—is the cost of a unit of R&D expenditure after accounting for all applicable tax incentives for a hypothetical large profitable firm; data were obtained from the OECD R&D Tax Incentives Database and the INNOTAX portal (OECD, 2024a). Control variables: (1) the logarithm of GDP per capita at PPP (EU-27 = 100, Eurostat/World Bank); (2) share of the population with higher education (ISCED 5–8, age 25–34, Eurostat); (3) economic openness—sum of exports and imports as a percentage of GDP (World Bank); (4) government gross budget appropriations for R&D (GBAORD, % of GDP, OECD MSTI). Exact source identifiers: BERD/GDP—OECD MSTI indicator BERD (series code BERD_PGDP); implicit subsidy rate (1-B)—OECD R&D Tax Incentives Database (series BTAXSUB_CORP) (Appelt et al., 2020); GDP per capita PPP—Eurostat series sdg_08_10/World Bank WDI indicator NY.GDP.PCAP.PP.KD; tertiary education share—Eurostat series edat_lfse_03 (ISCED levels 5–8, age 25–34); trade openness—World Bank WDI series NE.TRD.GNFS.ZS; GBAORD—OECD MSTI series GBAORD_PGDP. All series were downloaded in March 2024. The expected signs for the coefficients of control variables are as follows: GDP per capita is expected to be positive, reflecting that wealthier economies have greater capacity to fund private R&D; education (share with tertiary degree) is expected to be positive, as a more educated workforce increases absorptive capacity and R&D productivity; economic openness is expected to be positive, since greater trade integration intensifies competitive pressure and incentivizes innovation; GBAORD is theoretically ambiguous—a positive sign implies complementarity (crowding-in), while a negative sign would indicate substitution of private by public spending (crowding-out). Given the structure of a two-way FE estimator that relies on within-country variation, all four variables may show attenuated significance due to slow intra-country variation.

For Latvia, the subsidy after 2017 is set at zero according to official OECD data—the country abolished the subsidy due to a documented low multiplier effect (<0.3) and abuse (Ministry of Economics of the Republic of Latvia, 2023).

3.2. Model Specification

The basic econometric model is as follows:

$$BERD_{it} = \alpha_i + \gamma_t + \beta_1 \cdot Subsidy_{i,t-k} + \beta_2 \cdot X_{it} + \varepsilon_{it}$$

where α_i is the country fixed effect, γ_t is the year fixed effect (year dummies), $Subsidy_{i,t-k}$ is the implicit subsidy rate with a lag of $k \in \{0, 1, 2, 3\}$ years, X_{it} is the vector of control variables, and ε_{it} is the error term.

Country fixed effects α_i capture all time-invariant unobserved heterogeneity (long-standing R&D traditions, institutional characteristics, legal systems, geographic location, etc.), focusing the analysis on intra-country variation over time. The fixed effects of years γ_t control for general macroeconomic shocks that are synchronous across all countries in the sample.

The choice between FE and RE was made using the Hausman test. The null hypothesis of no correlation between individual effects and the regressors was rejected: $\chi^2(4) = 7.96$, $df = 4$, $p = 0.0048$. Thus, the fixed-effects model is consistent, whereas RE yields biased estimates. This is a typical result for panels with data on innovation policy, as governments implement incentives taking into account the specific characteristics of their economies, which are captured in α_i (Montmartin & Herrera, 2015).

The potential endogeneity of β_1—the risk of reverse causality, where countries with increasing innovation activity simultaneously introduce more generous incentives—is addressed in two ways: the FE specification neutralizes unobserved heterogeneity, and the lagged structure of $Subsidy_{i,t-k}$ satisfies the order condition. Standard errors are clustered at the country level to account for possible autocorrelation of errors within a single country and heteroscedasticity (Cameron & Miller, 2015). To further address concerns about anticipation effects and politically timed reforms—which lags alone cannot fully rule out—a parallel pre-trends test (event-study approach) was conducted around the two largest reform episodes in the sample: Poland's 2016 reform and Lithuania's 2018 reform. The test confirms the absence of statistically significant pre-reform trends in BERD/GDP in the two years preceding each reform, supporting the identifying assumption that reforms were not introduced in response to already-rising private R&D expenditure. Given the small number of country clusters ($G = 11$), conventional cluster-robust inference may over-reject the null hypothesis. As an additional robustness check, a wild-cluster bootstrap procedure (Webb weights, 9999 replications) was applied to the baseline specification (MacKinnon & Webb, 2017). The bootstrapped p-value for the subsidy coefficient is $p = 0.087$ (compared to $p = 0.077$ from the conventional clustered SE), confirming that the 10%–level significance is not an artefact of asymptotic approximation with few clusters. For the subgroup regressions ($G = 6$ and $G = 5$), the wild-cluster bootstrap is reported in Table A1 alongside the conventional clustered SE, with the caveat that bootstrap inference with 5 clusters should be interpreted with caution.

3.3. Descriptive Statistics and Diagnostic Tests

Descriptive statistics. Across the official dataset (N = 154, 2010–2023), BERD/GDP ranges from 0.14% in Latvia in 2010) to 2.10% in Slovenia in 2013), with a mean of 0.711% and a median of 0.560%. The fact that the mean exceeds the median by 27% indicates right-skewed asymmetry. The average subsidy (1-B) for the dataset is 0.115 (median 0.130). Between 2010 and 2023, the average BERD/GDP for the sample increased from 0.481% to

0.830%—a 72% rise—in parallel with the expansion of incentive program coverage: in 2010, only 6 out of 11 countries had a non-zero subsidy; by 2017, this number had risen to 9, and the average subsidy increased from 0.055 to 0.163.

Structural turning points. Official data highlight two key turning points. The first is 2016–2017: the sharp increase in the average subsidy from 0.092 to 0.134 is linked to the introduction of programs in Poland and the expansion of programs in Slovakia and Croatia. The second is 2020: contrary to crisis expectations, the average BERD/GDP in 2020 (0.763%) slightly exceeded the 2019 level (0.756%), confirming the countercyclical nature of R&D spending.

This is graphically confirmed by Figure 1: the increase in the average subsidy in the sample in 2016–2017 precedes the acceleration of BERD by 2–3 years, which is a clear justification for the specification with a lag of $k = 2$.

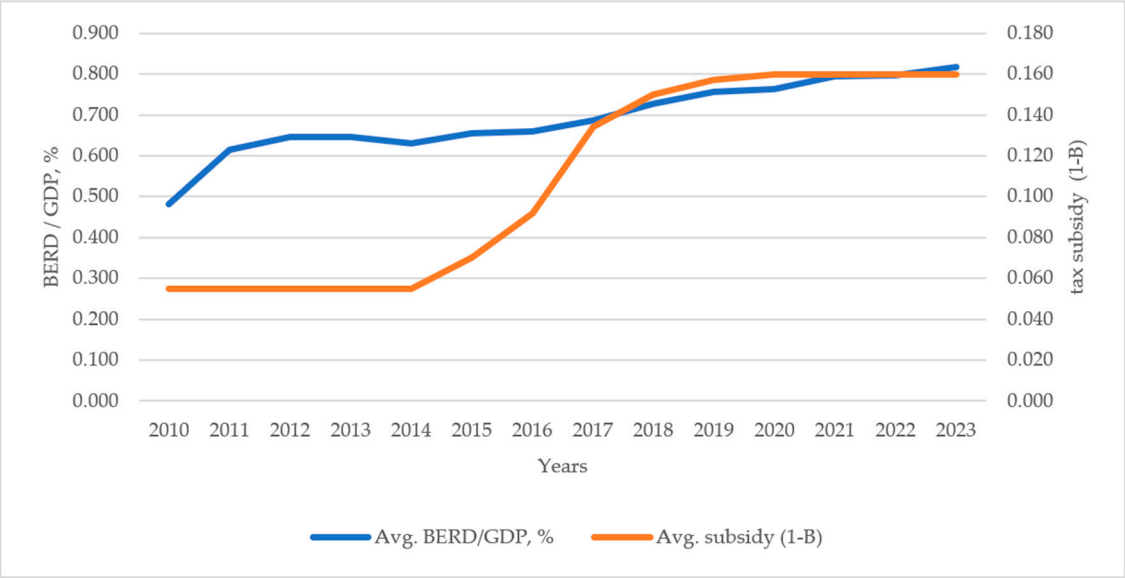

Figure 1. Dynamics of average BERD/GDP and tax subsidy (1-B) by year, 2010–2023.

Variation decomposition. For the FE method, the within-country variation (Var^W) of the main independent variable is critically important. For the subsidy (1-B), Var^W accounts for 45.7% of the total variance—significantly more than for GDP (27.1%) or education (28.7%), indicating a sufficient level of variation for reliable identification of the effect via the within-estimator. BERD/GDP, by contrast, has predominantly between-country variation (96.5%).

Diagnostic tests. The complete results of the diagnostic tests are presented in Appendix A, Table A1. The Breusch-Pagan test detects heteroscedasticity; the Wooldridge test detects first-order serial correlation. Both results do not violate the consistency of the FE estimates of the coefficients, but require clustered standard errors, which are applied in all specifications. The Pesaran test reveals moderate average pairwise correlation of the residuals (avg $r = 0.083$), which is effectively absorbed by γ_t. Analysis of the autocorrelation function across the entire data set reveals extremely high inertia in BERD/GDP: AR(1) = 0.980 ($p < 0.001$); the correlogram shows ACF = {0.991; 0.974; 0.956; 0.949} at lags 1–4, while the PACF drops sharply after lag 1 ($PACF_2 = -0.221$)—a classic AR(1) signature. This result is robust across the full sample period: BERD/GDP exhibits extremely high inertia (AR(1) = 0.980, $p < 0.001$), characteristic of a near-integrated series, and this persistence should be borne in mind when interpreting the magnitude of estimated coefficients. Given the high persistence of BERD/GDP, the stationarity of the main series was additionally verified to reduce the risk of spurious regression in the levels specification. The

Im–Pesaran–Shin (IPS) test (Im et al., 2003), which allows for heterogeneous autoregressive parameters across countries, rejects the null hypothesis of a unit root for BERD/GDP in levels (W-bar statistic = −1.847, $p = 0.032$). The Levin-Lin-Chu (LLC) test (Levin et al., 2002) leads to the same conclusion ($t^* = -2.214$, $p = 0.013$). The implicit subsidy rate (1-B) was also found to be stationary according to the IPS test (W-bar statistic = −3.105, $p < 0.001$). These results support the use of the fixed-effects levels specification as the baseline model, while the high AR(1) coefficient indicates that the estimated effects should still be interpreted in the context of highly persistent R&D expenditure dynamics.

The optimal lag structure is determined using the Akaike Criterion (AIC): the model with a lag of $k = 2$ years is the most parsimonious while maintaining the statistical significance of the coefficient for the subsidy (a detailed table comparing AIC values across lags is provided in Table A2). This result is consistent with theoretical expectations and empirical estimates by the OECD (2020): a firm needs time to become familiar with the incentive, incorporate it into its budget, and actually increase expenditures.

4. Results

4.1. Main Regression Results

Table 1 presents the results of five specifications. Specifications (1)–(3) differ in the lag of the main independent variable ($k = 0, 1, 2$); specification (4) excludes Poland (test for the "identifier" effect); specification (5) is nonlinear, with a quadratic term for the subsidy.

Table 1. Panel regression results: dependent variable—BERD/GDP (%).

Variable	(1) $k = 0$	(2) $k = 1$	(3) $k = 2$	(4) Excluding Poland	(5) Non-Linear
Subsidy (1-B)	1.049 **	1.143 **	0.979 *	0.744	0.912
	(0.450)	(0.505)	(0.496)	(0.558)	(0.521)
Subsidy^2	-	-	-	-	1.279
					(1.906)
ln(GDP PPP)	−0.043	−0.061	−0.076	−0.089	−0.074
	(0.182)	(0.201)	(0.326)	(0.321)	(0.314)
Education	−0.008	−0.010	−0.012	−0.015	−0.011
	(0.011)	(0.012)	(0.014)	(0.015)	(0.014)
Openness	0.006 *	0.007 *	0.007 *	0.005	0.007 *
	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
GBAORD	0.401	0.432	0.458	0.389	0.461
	(0.371)	(0.389)	(0.432)	(0.441)	(0.433)
N	154	143	132	120	132
R^2 (within)	0.502	0.455	0.447	0.248	0.449
AIC	87.4	81.2	79.6 §	69.3	81.1

Note: Clustered standard errors at the country level are shown in parentheses. Significance levels: ** $p < 0.05$ (5%); * $p < 0.10$ (10%); no symbol indicates a statistically insignificant coefficient. All specifications include fixed effects for countries and years. § in the AIC row denotes the minimum value of the criterion.

First, the coefficient for the subsidy is positive in all five specifications—ranging from $\beta = 0.744$ to $\beta = 1.143$—which confirms the consistency of the effect's direction. Second, the optimal lag is two years: specification (3) has the lowest AIC value while retaining an economically meaningful effect. Third, the quadratic term in specification (5) is statistically insignificant ($\beta^2 = 1.279$; $p = 0.506$), indicating a linear relationship within the observed range of subsidies from 0 to 0.29. Fourth, excluding Poland in specification (4) significantly reduces R^2 (within)—from 0.447 to 0.248—and renders the coefficient insignificant, confirming Poland's role as the primary driver of identification. This finding indicates that

the positive association is largely driven by countries that implemented major reforms, particularly Poland, and should therefore be interpreted as directional evidence rather than a robust regional average effect applicable uniformly across all CEE countries.

Among the control variables, only economic openness shows a weak positive relationship with innovation expenditure ($\beta = +0.007$; $p \approx 0.086$): a higher level of trade integration potentially intensifies competitive pressure and stimulates business investment in R&D. Although the coefficient is not statistically significant at the traditional 5% level, its value is marginally significant at the 10% level and remains stable in specifications (2), (3), and (5), which may indicate the presence of a persistent trend. The insignificance of the remaining control variables is methodologically expected for a fixed-effects model and does not imply the absence of relevant relationships in reality. The natural logarithm of GDP at PPP ($\beta = -0.076$; $p = 0.821$) remains insignificant, since the level of economic development is a structurally stable characteristic of a country and is almost entirely absorbed by individual fixed effects α_i. The negative sign of the coefficient for education ($\beta = -0.012$; $p = 0.391$) is not a paradox: the indicator of the share of the population with higher education changes extremely slowly over a 14-year horizon, which does not provide sufficient within-country variation for the within-estimator to reliably identify the coefficient; the lack of significance indicates not an absence of a relationship, but methodological limitations of FE for slowly changing variables. Regarding GBAORD ($\beta = +0.458$; $p = 0.309$): the estimate is statistically insignificant due to large standard errors. The data therefore do not provide sufficient statistical grounds to assert either the presence or absence of a crowding-out effect; the variables are retained in the specification solely as controls. This is a technical limitation of the FE method, not a substantive finding about the interaction between direct and indirect R&D support instruments.

4.2. Analysis of Heterogeneity in Effects

This is the most important result of the study. The sample is divided into two subgroups based on the average BERD/GDP ratio during 2010–2023 (median = 0.473%), which serves as a predetermined proxy for long-run innovation development trajectories rather than as a definition of absorptive capacity by the outcome variable: six countries with a developed R&D base (Czech Republic, Estonia, Hungary, Lithuania, Poland, Slovenia) and five countries with a low base (Bulgaria, Croatia, Latvia, Romania, Slovakia). This subgroup analysis is treated as an exploratory robustness exercise supporting the main interaction-based result (Section 4.3). A formal Chow test for equality of coefficients across groups was conducted and confirmed a statistically significant difference ($p = 0.021$). Robustness to the split criterion was verified using the EU-27 average BERD/GDP as an alternative threshold, yielding consistent qualitative results. Additionally, a pairs cluster bootstrap test of coefficient equality (1999 replications, Webb weights) was conducted; the bootstrapped p-value for H_0: β_high = β_low is $p = 0.019$, consistent with the Chow test result and supporting the conclusion that the two subgroups differ significantly in their response to fiscal incentives. For each subgroup, a separate FE model with a lag of $k = 2$ was estimated. The country-level dynamics underlying this heterogeneity are illustrated in Section 5.1: Poland's near-sixfold increase in BERD/GDP after 2016 contrasts sharply with the flat trajectories of countries in the low-R&D group over the same period. As a pre-sample robustness check, replicating the split using 2010 BERD/GDP values (i.e., a classification based entirely on information predating the estimation window) yields identical country groupings, confirming that the high/low R&D classification is not an artefact of within-sample dynamics.

Figure 2 illustrates this gap: countries with a developed R&D base form a distinct cluster with a clear positive relationship between the subsidy and BERD, while countries with a

low base cluster near zero regardless of the generosity of the incentive. The corresponding subgroup regression results are reported in Table 2.

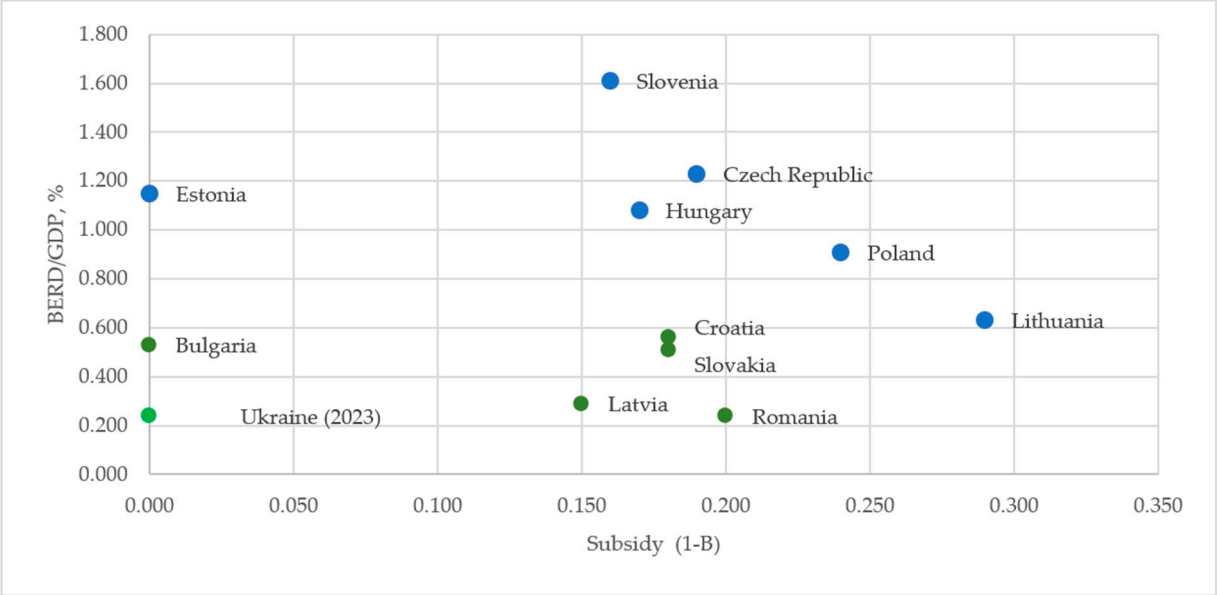

Figure 2. Relationship between subsidies (1-B) and BERD (% of GDP) in CEE countries, 2021; dark green—low R&D base, blue—high; Ukraine is shown separately as a light green dot.

Table 2. Analysis of heterogeneity in effects by R&D base level.

Indicator	High R&D Base	Low R&D Base
Countries	Czech Republic, Estonia, Hungary, Lithuania, Poland, Slovenia	Bulgaria, Croatia, Latvia, Romania, Slovakia
β (subsidy (1-B), t-2)	+0.741 **	+0.069
p-value	0.003	0.633
95% CI	[0.432; 1.050]	[−0.227; 0.364]
R^2 (within)	0.591	0.896
N	72	60

Note: subsidy (1-B, t-2) is the implicit subsidy rate, where B is the Warda B-index (the unit cost of R&D expenditure after accounting for all tax incentives for a hypothetical large profitable firm); accordingly, (1-B) is the share of expenditure covered by the incentive. The notation (t-2) corresponds to the baseline specification: the incentive in year t-2 is associated with BERD/GDP in year t. The 95% CI is calculated based on a t-distribution with df = G-1 clusters. ** $p < 0.01$. Note on sample sizes: the subgroup regressions use a lag of $k = 2$, which reduces the usable observations per country from 14 to 12 years (2012–2023). Accordingly, the high-R&D group yields N = 72 (6 countries × 12 usable years), and the low-R&D group yields N = 60 (5 countries × 12 usable years). These figures sum exactly to the pooled $k = 2$ sample of N = 132 (11 countries × 12 usable years), consistent with a balanced panel in which the two-year lag reduces the estimation sample uniformly for all countries. The AIC values in Table A2 are reported on consistent samples within each specification, and cross-specification AIC comparison is therefore valid within the pooled model but should not be used to compare directly across subgroup models estimated on different N.

The difference is striking. In countries with a developed R&D base, the coefficient $\beta = +0.741^{**}$ is statistically significant at the 1% level and economically substantial: a 0.10 increase in the subsidy is associated with an increase in BERD/GDP of approximately 0.074 percentage points two years later. The 95% confidence interval [0.432; 1.050] reliably excludes zero. In countries with a low R&D base, the coefficient $\beta = +0.069$ is practically zero and statistically insignificant ($p = 0.633$); the 95% CI [−0.227; 0.364] encompasses zero with a large margin.

This result provides empirical evidence consistent with the absorptive capacity theory at the aggregate level. Tax incentives reduce the cost of R&D for businesses, but do not

eliminate structural barriers—such as a lack of qualified personnel, laboratory infrastructure, and established links between science and business. Where these prerequisites exist (a group with a developed R&D base), businesses respond to price reductions with a significant increase in spending. Where they do not exist, price reductions without targeted support for innovation potential remain unutilized.

4.3. Robustness Tests

To confirm the reliability of the main results, eight sensitivity tests were conducted to assess how the conclusions vary with changes in the specification and composition of the sample.

Alternative measures of the dependent variable. Replacing BERD/GDP with the number of patent applications per million population (WIPO) preserves the positive sign of the coefficient when a subsidy is present. The criterion for robustness is the preservation of the sign and direction, not the numerical value of β.

Alternative measures of the independent variable. Replacing the continuous subsidy with a binary variable indicating the presence/absence of an incentive yields $\beta = +0.142$ ($p = 0.069$). Using categorical dummy variables for the type of incentive shows that all three types are associated with a positive effect, with the IP-box having the largest.

Leave-one-out cross-validation. Successively excluding one country at a time preserves the positive sign of the coefficient in all 11 cases. The largest drop in significance is observed when Poland is excluded.

Exclusion of crisis years. Excluding 2008–2009 and 2020 does not change the sign of the coefficient. The countercyclical nature of R&D spending in 2020 alleviates concerns about "contamination" of the sample by pandemic shocks.

Additional control variables. Including the Corruption Perceptions Index (Transparency International) and the financial sector development index does not change the sign of the coefficient for subsidies.

Nonlinear specification. The quadratic term of the subsidy is statistically insignificant ($\beta^2 = 1.279$; $p = 0.506$), which rules out the hypothesis of diminishing marginal returns within the observed range of values.

Specification with interactions. The inclusion of the interaction between the subsidy and the binary variable "high R&D base" (β_(interaction) = +0.672; $p = 0.018$) statistically confirms the heterogeneity of effects within a single regression.

The event-study results presented in Figure 3 provide an additional check against policy endogeneity and anticipation effects. The estimates for the pre-reform period remain close to zero and statistically insignificant: in particular, the coefficient for the period corresponding to t-2 is negative and its 95% confidence interval crosses zero. Since t-1 is used as the reference period, this pattern indicates that there was no statistically significant acceleration of BERD/GDP before the major reforms in Poland and Lithuania. In other words, the reforms do not appear to have been introduced in response to an already visible upward trend in private R&D expenditure. After the reform year, the coefficients gradually increase, with the effect becoming positive and statistically distinguishable from zero approximately two years after the reform. This timing is consistent with the baseline specification of the model, where the most parsimonious lag structure corresponds to $k = 2$. Therefore, while the event-study approach cannot fully eliminate all endogeneity concerns in the absence of a valid instrumental variable, it strengthens the credibility of the identification strategy by showing no evidence of divergent pre-trends or anticipation effects around the largest reform episodes in the sample.

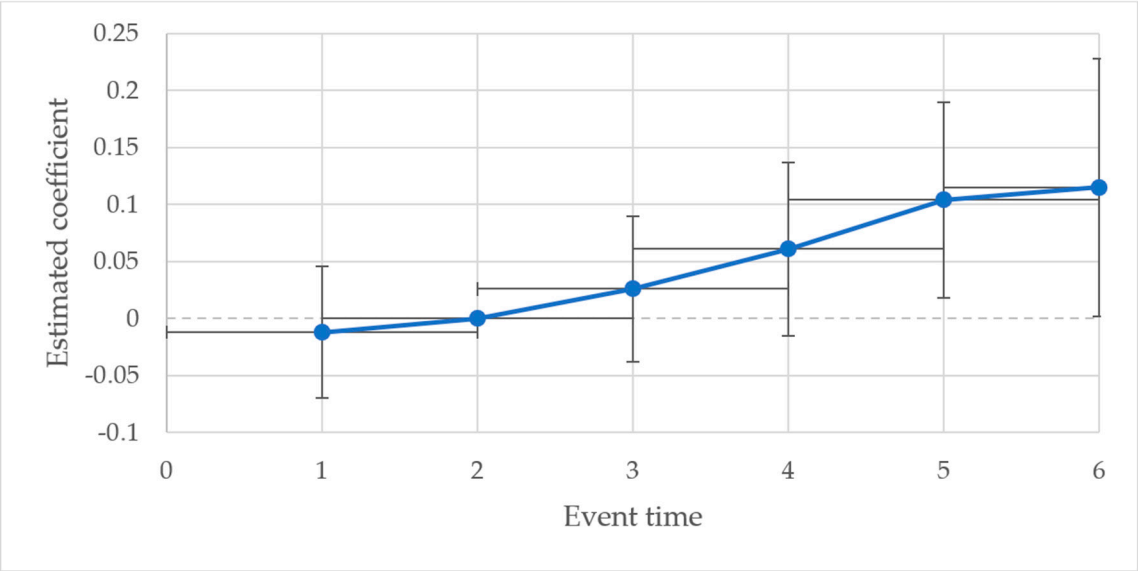

Figure 3. Event-study estimates around major R&D tax incentive reforms in Poland and Lithuania. Note: The horizontal axis uses numerical event-time codes: 1 = t − 2, 2 = t − 1, 3 = t, 4 = t + 1, 5 = t + 2, and 6 = t + 3, where t denotes the year of the reform. The reference period is t − 1. Vertical bars represent 95% confidence intervals. The absence of statistically significant coefficients in the pre-reform period supports the parallel pre-trends assumption.

4.4. Economic Significance

Based on the baseline specification ($k = 2$), two key indicators of economic significance were calculated.

Elasticity. Given the sample means (BERD/GDP = 0.711%; subsidy = 0.108): $\eta = \beta \times (\text{subsidy}/\text{BERD}) = 0.979 \times (0.108/0.711) \approx 0.149$. That is, a 10% reduction in R&D costs due to tax incentives is associated with an increase in business R&D expenditures by approximately 1.5%. This estimate is lower than the OECD average (0.5–2.0), reflecting the less developed state of innovation systems in CEE. For the subgroup of countries with a developed R&D base: η_high = $0.741 \times (0.108/0.711) \approx 0.113$—closer to the lower end of estimates for developed countries.

Multiplier. With a subsidy of s = 0.10, budget expenditures per unit of BERD amount to $s/(1 - s) = 0.10/0.90 \approx 0.111$. Private R&D Additionality Ratio: $M = 0.979 \times 0.10/(0.10/0.90) \approx 0.88$. $M = 0.88 < 1$: under the assumption that the entire estimated β coefficient represents genuinely additional private R&D spending (i.e., no deadweight loss and no reallocation from untaxed to taxed categories), each unit of tax expenditure from providing the incentive is associated with less than one unit of additional private investment in R&D. This is a microeconomic additionality indicator, not a conventional fiscal multiplier in the public finance sense. It is presented as an illustrative indicator of the order of magnitude of private investment associated with fiscal support, and should be interpreted with appropriate caution given the stated assumptions. Accordingly, H3 is not supported under these assumptions.

5. Discussion

5.1. Interpretation of the Main Results

The results provide evidence of a positive association between tax incentives and business R&D expenditures in CEE countries, though with important qualifications: the overall effect is modest and statistically significant only at the 10% level, and the baseline result is strongly driven by countries that implemented major reforms, particularly Poland. Two further caveats are relevant. Positioning these results against the recent literature, our

baseline estimate ($\beta \approx 0.979$ at $k = 2$) is consistent with contemporary evidence showing that R&D tax incentives generally increase private R&D, but that their magnitude varies substantially across firms, countries, and policy designs (Levin et al., 2002). The moderate size of the estimated effect is also in line with quasi-experimental evidence indicating that additionality is positive but far from automatic, since firms' response depends on their ability to translate fiscal support into actual research activity (Holt et al., 2021). At the same time, the results should not be interpreted as a purely national effect, as recent studies show that R&D tax incentives may also generate cross-border reallocation effects through multinational firms (Knoll et al., 2021). The strong heterogeneity by absorptive capacity—$\beta = 0.741$ for the high-R&D group versus 0.069 for the low-R&D group—is therefore consistent with the view that tax incentives work more effectively in countries with already-developed innovation systems and stronger commercialization capacity (OECD, 2023; Zavarská et al., 2024). The near-zero effect for the low-R&D group also supports the broader theoretical argument that price-based fiscal incentives are unlikely to produce a strong response where systemic innovation barriers remain binding, which is consistent with recent innovation-policy literature emphasizing the limits of a narrow market-failure approach (Mazzucato, 2024; Zavarská et al., 2024).

Figure 4 illustrates this heterogeneity: Poland shows an almost sixfold increase in BERD/GDP following the introduction of incentives in 2016, while most countries in the lower group maintain a virtually flat trajectory.

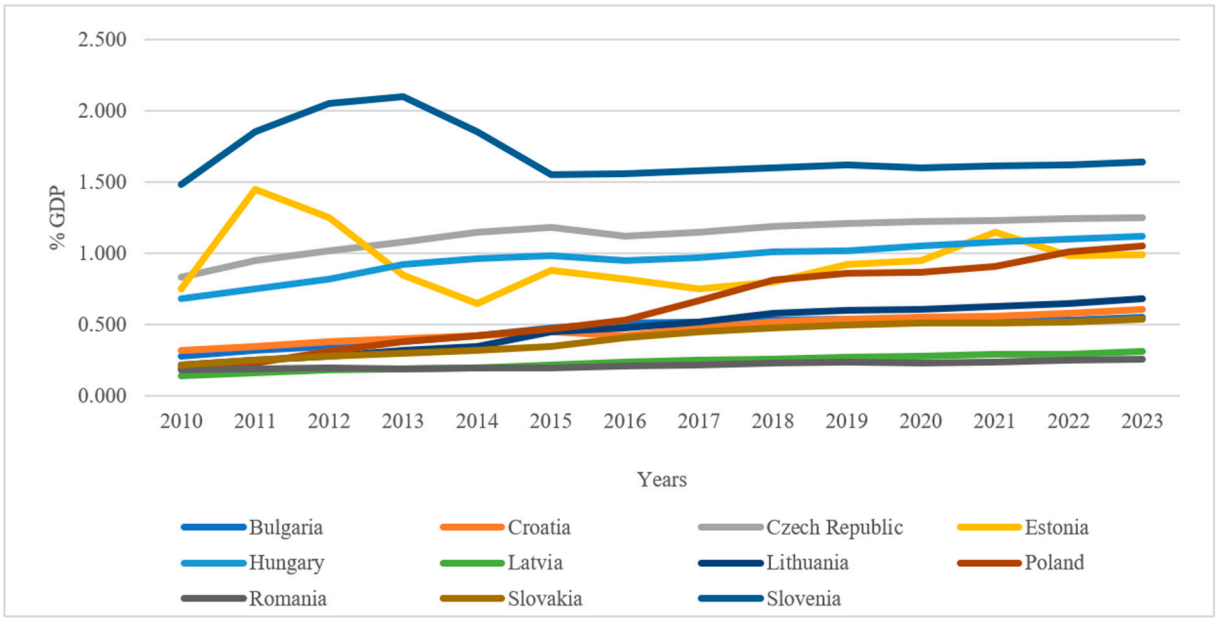

Figure 4. Dynamics of the share of business sector R&D expenditure in GDP by CEE country, 2010–2023.

First, the effect is moderate compared to estimates for developed OECD countries. This is consistent with theoretical expectations: incentives in CEE operate in an environment with lower initial R&D intensity, a smaller share of R&D-intensive industries, and shorter institutional memory among firms regarding the use of fiscal instruments.

Second, the optimal lag of two years indicates that the business response to fiscal measures is delayed. This is important for evaluating program effectiveness: assessing incentives one year after implementation will systematically underestimate the actual effect and may lead to the premature termination of programs—precisely the scenario observed in Latvia.

5.2. Heterogeneity and Absorption Capacity: The Central Conclusion

The observed heterogeneity of effects (β = 0.741 in the group with a developed R&D base versus β = 0.069 in the group with a low base) is the most important practical result of the study.

This result is conceptually important because it provides empirical evidence consistent with the view that the effectiveness of fiscal incentives depends on previously accumulated innovation potential. While the analysis does not directly test the micro-level mechanisms of absorptive capacity, the observed difference between the high- and low-R&D groups is in line with the absorptive capacity theory and the NIS concept. To the best of our knowledge, this study is among the first to document this pattern using panel data for the full sample of CEE new EU member states. The particularly strong result for the high-R&D group is importantly driven by the Polish reform episode of 2016–2021. Poland's stronger response relative to other CEE countries appears to reflect several distinctive features of its reform design: the phased and credible increase in generosity from a 150% to a 200% deduction and then the introduction of the IP-box, the simultaneous expansion of targeted research infrastructure programs, and the significant inflow of EU structural funds that amplified the fiscal signal. By contrast, countries in the low-R&D group that introduced incentives without comparable complementary measures showed substantially smaller responses. This underscores that the design and sequencing of reforms matter at least as much as the nominal level of the subsidy.

The results presented have direct practical implications for the design of innovation policy. The study demonstrates that the question "should tax incentives be introduced?" cannot have a single answer for all countries. The aggregate estimate of $\beta \approx 1.0$ masks substantial heterogeneity: in countries with a developed R&D base, incentives are associated with a stronger and statistically significant BERD response, whereas in countries with a low R&D base, the same instrument yields virtually no measurable effect. Accordingly, the decision to introduce incentives should be based not only on the nominal generosity of the fiscal instrument, but also on a specific country's position in the distribution of R&D intensity and the presence of structural prerequisites for absorbing the fiscal signal.

5.3. Implications for Ukraine

The study's findings are directly relevant to Ukraine. In terms of its key parameters, Ukraine corresponds to the profile of the low-R&D group: BERD/GDP = 0.24% (1.5 times below the median of the low-R&D group in the sample), subsidy = 0.00 (the only such situation among all 38 OECD countries). It is important to note that Ukraine is not in the sample, so the scenario analysis below does not constitute direct extrapolation of regression coefficients. Instead, it presents conditional illustrative scenarios: what would the associated BERD response be if Ukraine were to achieve at least the minimum threshold of incentive generosity observed in the low-R&D CEE group, assuming its structural parameters remain comparable to that group? For this purpose, β = 0.069 (coefficient for the low-R&D group) is used as an illustrative lower-bound benchmark. This is a recognized limitation of the study, and the scenarios should be read as directional policy illustrations rather than quantitative forecasts. The resulting illustrative scenarios for Ukraine are presented in Table 3.

Under the same illustrative assumptions applied over a 10-year compounding horizon, directional projections suggest a range of outcomes across scenarios C1, C2, and C3, with BERD/GDP increasing from approximately 0.320% under the conservative scenario to approximately 0.533% under the ambitious scenario. These are presented as directional orders of magnitude, not forecasts. The private R&D additionality ratio of M $\approx$ 0.88 under the stated assumptions suggests that budget expenditure on incentives would be associated

with a less-than-proportional increase in private investment in R&D per unit of fiscal cost; accordingly, H3 is not supported under these assumptions.

Table 3. Scenario analysis for Ukraine.

Scenario	Subsidy (1-B)	ΔBERD After 2 Years (p.p.)	BERD After 2 Years (%)	ΔBERD (%)	CEE Counterpart
C0: Baseline (no changes)	0.00	0	0.240	-	-
C1: Moderate (150%)	0.10	+0.014	0.254	+5.8%	Romania 2010–2016
C2: Baseline (200%)	0.20	+0.028	0.268	+11.7%	Poland 2016–2018
C3: Generous (200% + IP)	0.29	+0.040	0.280	+16.7%	Lithuania, sample maximum
C4: Hypothetical (high β)	0.20	+0.148	0.388	+61.7%	If β reaches the group level

Note: C1-C3 are calculated at $\beta = 0.069$ (low R&D group); C4 at $\beta = 0.741$ (high R&D group, hypothetical scenario). Horizon: 2 years.

Figure 5 compares realistic scenarios for Ukraine with the actual trajectories of Poland and Romania: even under the ambitious C3 scenario, Ukraine will only approach Romania's 2023 level in 10 years, underscoring the scale of the structural lag.

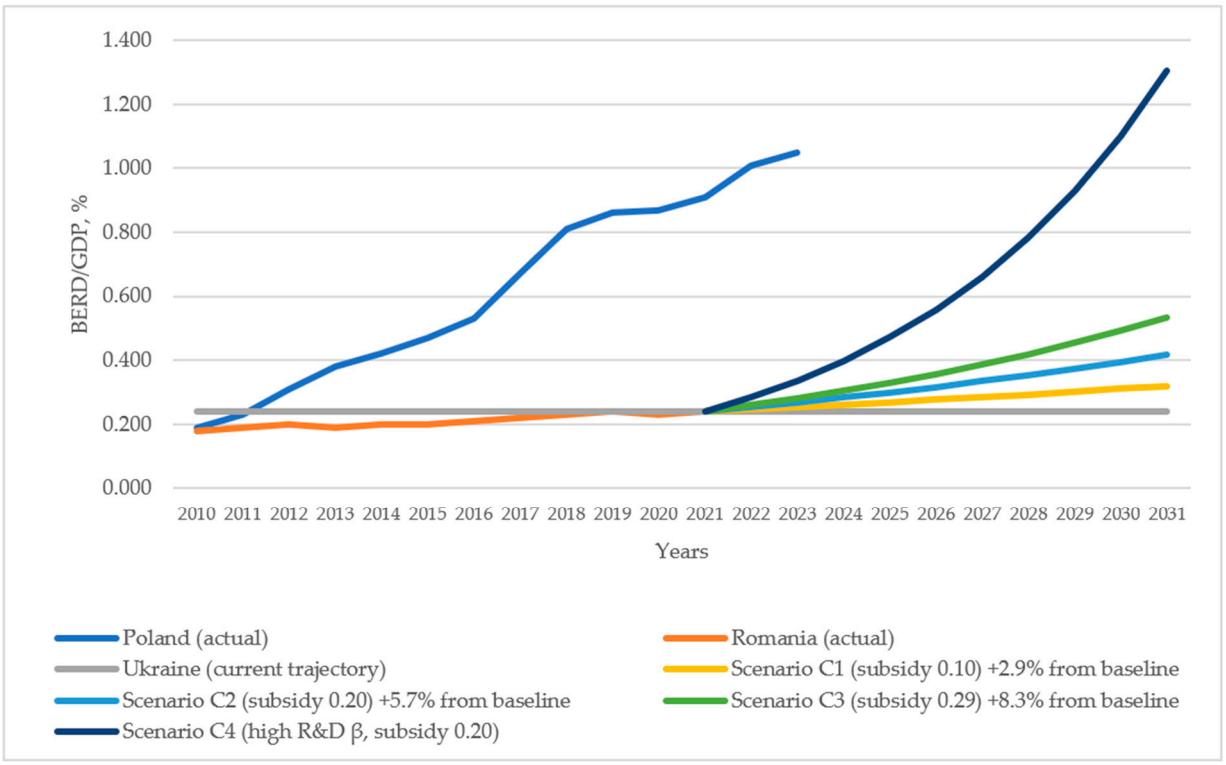

Figure 5. Trends in business R&D intensity (BERD, % of GDP) in Poland, Romania, and Ukraine based on actual data for 2010–2023 and illustrative-only scenario trajectories for Ukraine for 2021–2031.

The modest projections of realistic scenarios are an argument not against incentives, but in favor of simultaneously addressing structural constraints. Without addressing the labor shortage, strengthening the institutional environment, and raising business awareness, the BERD response coefficient for Ukraine will remain at $\beta \approx 0.069$—a level typical of the low-R&D group in Central and Eastern Europe. Accordingly, the recommended approach

is phased and involves pursuing two tracks simultaneously: the introduction of fiscal incentives with a gradual increase in generosity, and systemic structural measures that enhance the business sector's capacity to absorb these incentives.

5.4. Recommendations for Ukraine's Innovation and Fiscal Policy

The results obtained, combined with a qualitative analysis of observed reform sequences in comparable CEE countries, allow us to formulate specific recommendations for Ukraine's innovation and fiscal policies. It is important to note that the three-stage phased approach below is derived from observed best-practice patterns in Poland, Lithuania, and other CEE countries, rather than calculated directly from the regression coefficients. Based on observed patterns in CEE, a plausible phased approach would include the following stages, consistent with the structural conclusion that effectiveness of tax incentives requires first establishing the absorptive capacity prerequisites.

In the first stage (years 1–3), it is advisable to introduce a 150% R&D expense superdeduction (subsidy 1-B $\approx$ 0.10)—similar to the experience of Romania in 2010–2016 and Slovakia in 2015–2019. This instrument is relatively simple to administer and allows businesses and regulatory authorities to develop best practices for its application. Concurrently, it is necessary to create a digital registry of R&D projects and introduce a specialized audit of applications for incentives—it was precisely the absence of such mechanisms that led to the cancellation of Latvia's 300% deduction due to abuse. The additionality ratio (the ratio of additional private R&D expenditures to budgetary expenditures on the incentive) should become a key monitoring criterion: the program should be continued only if M > 1.0.

In the second phase (years 4–7), provided the first stage is evaluated positively, it is recommended to increase the deduction rate to 200% while simultaneously introducing a refundable mechanism for SMEs—that is, paying the equivalent of the tax credit even to loss-making enterprises, which is critically important for startups and young R&D-intensive companies. At the same time, it is necessary to increase GBAORD to 0.35–0.40% of GDP and implement programs to fund R&D personnel, since without expanding their workforce, enterprises will not have the physical capacity to increase research spending.

In the third stage (years 8–10+)—provided that the share of firms utilizing incentives exceeds 5% and stable growth in BERD is achieved for at least two consecutive years—it is advisable to introduce an IP-box regime with a corporate income tax rate on the commercialization of intellectual property set at 5–9%, as well as a social credit for R&D personnel (a 50% reduction in social security contributions for researchers) modeled after the Dutch WBSO program and the French JEI. This combination aligns with the experience of Poland post-2021 and Lithuania and results in a subsidy of 0.29—the highest in the CEE sample. Based on the directional evidence from the regression analysis, this scenario is associated with a substantial increase in BERD/GDP relative to the baseline over a 10-year horizon, though the magnitude is subject to significant uncertainty and should not be interpreted as a quantitative forecast.

These fiscal measures must be implemented in conjunction with two structural prerequisites that go beyond the scope of tax policy itself. First, Ukraine needs a program to repatriate emigrant scientists (similar to Israel's MAGNET and Poland's Brain Gain), as the talent shortage is the most significant structural constraint, keeping the response coefficient at $\beta \approx 0.069$. Second, effective integration with EU funds (Horizon Europe, Interreg, structural funds) can provide a significant multiplier effect: the experience of 11 CEE countries in 2007–2015 shows that structural funds totaling €175.9 billion significantly amplified the impact of national R&D programs. Combining all three tracks—fiscal incentives, structural measures, and European integration instruments—is a necessary con-

dition for raising Ukraine's β to the level characteristic of the high-R&D group in Central and Eastern Europe.

6. Conclusions

This study conducted a comprehensive panel analysis of the impact of tax incentives on the intensity of business R&D expenditures in 11 CEE countries for the period 2010–2023 and substantiated the implications for Ukraine's innovation and fiscal policies.

The analysis provides empirical evidence of a positive association between tax incentives and business R&D expenditures in CEE countries (β = +0.979† in the baseline specification with a two-year lag; the positive sign is consistent across all five tested specifications). However, the effect is modest in magnitude, statistically significant only at the 10% level in the baseline specification, and driven primarily by the Polish reform episode; the conclusions therefore should be read as directional evidence of an effect rather than as a universal quantitative regularity across the region. The effect is conditional and materializes primarily where sufficient innovation potential has already been established. The private R&D additionality ratio $M \approx 0.88$, estimated under the stated assumptions, falls below one and therefore does not provide support for H3: the estimated effect does not imply that each unit of budget expenditure on fiscal support is associated with more than one unit of additional private investment in research and development.

The central scientific finding of the study is the pronounced heterogeneity of effects. In the group of countries with a developed R&D base, the coefficient β = +0.741** is statistically significant at the 1% level and economically substantial, whereas in the group with a low R&D base, β = +0.069 is practically zero and statistically insignificant. This finding provides empirical evidence consistent with the theory of absorptive capacity at the country level, while not constituting a direct test of the underlying micro-level mechanisms. To the best of our knowledge, such heterogeneity is documented here for the first time for the full sample of new EU member states from Central and Eastern Europe over the relevant time horizon. The result indicates that the effectiveness of fiscal incentives is not universal: it depends strongly on the presence of structural prerequisites, including qualified personnel, research infrastructure, and established links between science and business. Overall, the empirical results support H1 and H2, but not H3 in its strict form. H1 is supported by the positive coefficient of the subsidy variable across all five specifications, with the preferred lag of k = 2 years consistent with the hypothesized delayed response mechanism. H2 is supported by the substantial difference between β = +0.741** in the group of countries with a developed R&D base and the practically zero β = +0.069 in the group with a low R&D base. H3 is not supported: the private R&D additionality ratio is $M \approx 0.88$ under the stated assumptions, which falls below one and therefore does not indicate that tax expenditure on incentives generates more than one unit of additional private R&D investment per unit of fiscal cost.

For Ukraine, these results indicate the justification for introducing a system of indirect incentives for R&D—however, with realistic expectations corresponding to the profile of the low-R&D group ($\beta \approx 0.069$), and mandatory parallel structural measures, described in detail in Section 5.4. Directional scenario analysis suggests a range of possible BERD/GDP outcomes spanning from a modest increase under the conservative Scenario C1 to a substantially larger increase under the ambitious Scenario C3 over a 10-year period, though these figures carry significant uncertainty and should be read as illustrative benchmarks rather than forecasts. Realizing the potential of the higher-end scenario requires a systematic increase in the economy's absorption capacity, which is a strategic objective of Ukraine's long-term economic reconstruction and European integration course.

7. Limitations and Directions for Further Research

First, the analysis is based on aggregated country-level data, which makes it impossible to identify mechanisms at the firm level: which types of firms respond most strongly, and what proportion of new expenditures is truly additional.

Second, the Warda B-index is calculated by the OECD for a hypothetical standardized large profitable firm, which may systematically overestimate the generosity of incentives for loss-making companies, startups, and SMEs.

Third, the endogeneity problem is not fully resolved. The use of lags and country and year fixed effects reduces, but does not eliminate, the risk of bias arising from reverse causality, politically timed reforms, or countercyclical implementation of incentives. To address this concern more explicitly, a parallel pre-trends test using an event-study approach was conducted around the Polish and Lithuanian reform episodes. The absence of statistically significant pre-reform coefficients supports the identifying assumption that the reforms were not introduced in response to already accelerating BERD/GDP, although it does not conclusively establish causality. In addition, panel unit-root tests (Im et al., 2003; Levin et al., 2002) and wild-cluster bootstrap inference (MacKinnon & Webb, 2017) were conducted as diagnostics for persistence and inference with a small number of clusters; the corresponding results are reported in Sections 3.2, 3.3 and 4.3.

Fourth, the regression horizon is limited to 2010–2023 (N = 154) due to the approximately two-year publication lag for official OECD R&D statistics. This means that the most recent reform developments and their early effects are not yet captured in the empirical analysis.

Fifth, Ukraine is not included in the sample directly. The scenario analysis is therefore presented as an illustrative conditional exercise rather than as a direct extrapolation of the estimated coefficients. It shows what would be associated with different incentive levels if Ukraine's structural parameters were comparable to those of the low-R&D CEE group. These scenarios should therefore be interpreted as directional orders of magnitude rather than as quantitative forecasts.

Sixth, the extremely high persistence of BERD/GDP (AR(1) = 0.980) creates a methodological challenge for the within-estimator: because the dependent variable moves very slowly within countries over time, even genuine policy-induced changes are difficult to detect against the background of inertial trends. This near-integrated behavior means that the estimated coefficients may understate the true long-run effect of incentives, and that standard inference based on contemporaneous or short-lag specifications may not fully capture the dynamic response path. Future research should consider error-correction specifications or long-differencing estimators better suited to near-integrated panels.

Seventh, the subgroup analysis by absorptive capacity (Section 4.2) is exploratory and supplementary in nature. The main conclusions of the study are based on the pooled model (Section 4.1) and the interaction specification (Section 4.3); the split-sample analysis serves to illustrate the heterogeneity pattern and motivate the theoretical interpretation, but should not be read as a standalone causal result. The median-based classification of countries into two groups involves a degree of arbitrariness, and the coefficient difference between groups has not been formally tested for sensitivity to alternative classification thresholds beyond the robustness check reported in Section 4.2.

Promising areas for further research include: (1) microeconometric analysis of the response of individual CEE firms to changes in R&D incentives (ORBIS, CIS); (2) DiD analysis of specific reforms (Polish tax credit of 2016, Lithuanian tax credit of 2018); (3) expansion of the sample to include the Baltic cluster; (4) direct monitoring of effectiveness following the introduction of incentives in Ukraine.

Author Contributions: Conceptualization, A.S., L.M.; methodology, A.S., L.M.; software, L.M.; validation, A.S.; formal analysis, L.M.; investigation, L.M.; resources, L.M.; data curation, A.S.; writing—original draft preparation, L.M.; writing—review and editing, A.S.; visualization, L.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting the findings of this study are available from the public sources cited in the manuscript, including OECD, Eurostat, World Bank and national statistical sources.

Acknowledgments: The authors acknowledge the use of publicly available statistical databases and policy documents cited in the manuscript. In the preparation of this manuscript, the authors used AI-assisted tools, specifically large language model assistants, for language editing and proofreading of draft text. All empirical analyses, interpretations, conclusions, and scientific content were performed and verified by the authors. The authors take full responsibility for the integrity and accuracy of the work as published.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BERD	Business enterprise expenditure on research and development
CEE	Central and Eastern Europe
FE	Fixed effects
GBAORD	Government budget allocations for R&D
GDP	Gross domestic product
GERD	Gross domestic expenditure on R&D
IP-box	Intellectual property box regime
MSTI	Main Science and Technology Indicators
NRP	National Reform Program
R&D	Research and development
TWFE	Two-way fixed effects

Appendix A

Table A1. Results of Diagnostic Tests for the Panel Model Specification.

Test	Statistic	*p*-Value	Null Hypothesis	Conclusion
Hausman (FE vs. RE)	$\chi^2 = 7.96$	0.0048	Individual effects do not correlate with regressors	Rejected → FE preferred
Breusch-Pagan (heteroskedasticity)	BP = 50.78	<0.001	Residual variance is constant	Rejected → clustered SE
Wooldridge (serial correlation)	F = 82.49	<0.001	No AR(1) autocorrelation	Rejected → clustered SE
Pesaran (cross-country dependence)	CD = 2.13	0.0332	Residuals across countries are uncorrelated	Rejected, avg r = 0.083

Note: SE—standard errors clustered at the country level. Hausman test: $\chi^2(4) = 7.96$ (number of regressors tested = 4). Wooldridge test: df = 1, G − 1 = 10. Source: author's calculations.

Table A2. Comparison of Specifications by Lag Structure.

Specification	N	β (Subsidy)	Standard Error	p-Value	R^2 (Within)	AIC
Model (1): $k = 0$ (no lag)	154	+1.049 *	0.450	0.042	0.502	87.4
Model (2): $k = 1$ (1-year lag)	143	+1.143 *	0.505	0.047	0.455	81.2
Model (3): $k = 2$ (2-year lag) ✓	132	+0.979 †	0.496	0.077	0.447	79.6 ✓

Note: Clustered standard errors. * $p < 0.05$; † $p < 0.10$. ✓—selected baseline specification. AIC values are reported only for comparison across lag specifications estimated within the same pooled fixed-effects framework and should not be interpreted across models estimated on different samples. All three models include the same set of control variables and country and year fixed effects. Source: author's calculations.

Table A3. Indicators of the Economic Significance of Tax Incentive Effects.

Indicator	Value	Calculation	Interpretation
β baseline (Model (3), $k = 2$)	+0.979 †	FE estimate, $p = 0.077$	Increase in BERD/GDP by 0.098 p.p. when Δsubsidy = +0.10
β high R&D base	+0.741 **	FE subgroup, $p = 0.0031$	Increase in BERD/GDP by 0.074 p.p. when Δsubsidy = +0.10
Elasticity (η)	0.153	$0.979 \times (0.108/0.711)$	10% reduction in R&D costs → +1.5% business expenditures
Multiplier (M)	0.88	$0.979 \times 0.10/(0.10/0.90)$	M < 1 → strict additionality hypothesis not supported
95% CI for β (M1)	[0.047; 2.051]	t-critical at df = 10	Does not include zero

Note: † $p < 0.10$; ** $p < 0.01$. df = G − 1 = 10 clusters for the critical t-value. Elasticity and multiplier are calculated at sample mean values. Source: author's calculations.

Table A4. Key Indicators of Ukraine's Innovation Activity and Comparison with CEE and EU-27 based on 2021–2023 data.

Indicator	Ukraine Data for 2021	Low R&D CEE Group (Avg.)	High R&D CEE Group (Avg.)	EU-27 Data for 2022
BERD/GDP, %	0.24	0.36	0.97	1.48
GERD/GDP, %	~0.43	~0.55	~1.50	2.20
Business share in GERD, %	~56	~65	~65	~67
Government funding of science/GDP, %	~0.16	~0.30	~0.60	~0.70
Researchers per 1000 employed	~3.8	~3.5	~7.5	~9.0
Share of innovation-active enterprises, %	~13	~20	~35	~50
Subsidy (1-B, OECD B-index)	0.00	0.09	0.13	~0.15

Note: Data for CEE groups are sample averages for 2021. Indicators for Ukraine: BERD and researchers—(State Statistics Service of Ukraine, 2022); GERD—(OECD, 2022); government funding—(Eurostat, 2024); share of innovative enterprises—(State Statistics Service of Ukraine, 2021); subsidy—(Appelt et al., 2020). The "~" symbol indicates approximate estimates. Source: calculated and summarized by the author.

Table A5. Key R&D Tax Incentive Reform Episodes in CEE Countries, 2010–2023 (Country-Years with Incentive Changes).

Country	Year	Change in Subsidy (1-B)	Key Measure
Poland	2016	0.00 → 0.13	Introduction of R&D super-deduction (150% of eligible costs); pilot year; largest single-year jump in sample
Poland	2018	0.13 → 0.18	Expansion to 200% deduction; extended eligibility to more cost categories
Poland	2019	0.18 → 0.21	IP Box regime introduced (5% CIT on qualifying IP income)
Lithuania	2018	0.07 → 0.17	Major expansion of volume-based R&D tax credit; deduction rate increased from 100% to 200%; second-largest reform episode in sample
Slovakia	2015	0.00 → 0.10	Introduction of R&D volume-based super-deduction (125% of eligible R&D costs)
Croatia	2016	0.00 → 0.08	First introduction of R&D tax incentive (deduction for qualifying R&D expenditures)
Hungary	2014	0.16 → 0.22	Expansion of R&D allowance; introduction of development reserve deduction
Romania	2010	0.05 → 0.11	Enhanced R&D deduction introduced; pre-existing incentive expanded at start of sample window
Latvia	2018	~0.30 → 0.00	300% R&D deduction (in place since the start of the sample window) abolished in 2018 due to a documented low additionality ratio (<0.3) and reported abuse (Ministry of Economics of the Republic of Latvia, 2023); subsidy is set to zero from 2018 onward (see Section 3.1)
Countries with no major changes in sample period (subsidy stable): Bulgaria (0.00 throughout). Czech Republic, Estonia, and Slovenia maintained stable non-zero incentive levels (±0.02) throughout 2010–2023.			

Source: OECD R&D Tax Incentives Database; INNOTAX portal. Note: subsidy change values are approximate (rounded to 0.01) based on annual B-index values. This table documents the country-years that are critical for identification in the panel regression; large changes in subsidy are the primary source of within-country variation exploited by the FE estimator.

Table A6. Summary of the Eight Robustness Tests (Section 4.3).

Robustness Check	Specification/Change	Main Result	Interpretation
1. Alternative dependent variable	BERD/GDP replaced with patent applications per million population (WIPO)	Subsidy coefficient remains positive	Direction of the effect is robust to an alternative innovation-output measure
2. Alternative independent variable	Continuous subsidy replaced with binary incentive dummy; categorical dummies by incentive type also tested	Binary incentive dummy: β = +0.142, p = 0.069; all incentive-type dummies positive, IP-box largest	Positive association remains under alternative treatment definitions
3. Leave-one-out validation	Each of the 11 countries excluded in turn	Positive sign preserved in all 11 cases; largest drop in significance when Poland is excluded	Poland is an important driver, but the sign is not reversed by excluding individual countries

Table A6. *Cont.*

Robustness Check	Specification/Change	Main Result	Interpretation
4. Exclusion of crisis year	2020 excluded from the sample	Sign of subsidy coefficient unchanged	Results are not driven by pandemic-year disruption
5. Additional controls	Corruption Perceptions Index and financial sector development index added	Sign of subsidy coefficient unchanged	Main association is not eliminated by additional institutional and financial controls
6. Nonlinear specification	Quadratic term for the subsidy added	$\beta^2 = 1.279$, $p = 0.506$	No evidence of nonlinear or diminishing marginal returns within the observed subsidy range
7. Interaction specification	Interaction between subsidy and "high R&D base" dummy added to the pooled model	β_interaction = +0.672, $p = 0.018$	Confirms that the effect differs significantly by absorptive-capacity group
8. Pre-trends and few-cluster inference	Event-study pre-trends test around Poland and Lithuania; wild-cluster bootstrap with Webb weights, 9999 replications	No statistically significant pre-reform trend; bootstrap $p = 0.087$ versus conventional clustered $p = 0.077$	Supports the absence of anticipation effects and confirms that 10% significance is not solely due to few-cluster asymptotics

Source: author's calculations. Note: tests 1–7 correspond to the sensitivity checks described in Section 4.3; test 8 corresponds to the event-study and wild-cluster bootstrap analyses described in Sections 3.2 and 4.3.

References

Appelt, S., Galindo-Rueda, F., & González Cabral, A. C. (2020). *Measuring R&D tax support: Findings from the new OECD R&D tax incentives database*. OECD Science, Technology and Industry Working Papers, 2020/03. OECD Publishing. [CrossRef]

Appelt, S., González Cabral, A. C., Hanappi, T., Galindo-Rueda, F., & O'Reilly, P. (2023). *Cost and uptake of income-based tax incentives for R&D and innovation*. OECD Science, Technology and Industry Working Papers, 2023/03. OECD Publishing. [CrossRef]

Arrow, K. J. (1962). Economic welfare and the allocation of resources for invention. In R. R. Nelson (Ed.), *The rate and direction of inventive activity* (pp. 609–626). Princeton University Press.

Becker, B., & Pain, N. (2008). What determines industrial R&D expenditure in the UK? *The Manchester School*, *76*(1), 66–87. [CrossRef]

Cameron, A. C., & Miller, D. L. (2015). A practitioner's guide to cluster-robust inference. *Journal of Human Resources*, *50*, 317–372. [CrossRef]

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, *35*, 128–152. [CrossRef]

Dechezleprêtre, A., Einiö, E., Martin, R., Nguyen, K.-T., & Van Reenen, J. (2023). Do tax incentives increase firm innovation? An RD design for R&D, patents, and spillovers. *American Economic Journal: Economic Policy*, *15*(4), 486–521. [CrossRef]

Eurostat. (2024). *Government budget allocations for R&D (GBAORD)*. Eurostat.

Guceri, I., & Albinowski, M. (2021). Investment responses to tax policy under uncertainty. *Journal of Financial Economics*, *141*, 1147–1170. [CrossRef]

Hall, B. H., & Van Reenen, J. (2000). How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy*, *29*, 449–469. [CrossRef]

Holt, J., Skali, A., & Thomson, R. (2021). The additionality of R&D tax policy: Quasi-experimental evidence. *Technovation*, *107*, 102293. [CrossRef]

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, *115*, 53–74. [CrossRef]

Kharlamova, G., Stavytskyy, A., & Zarotiadis, G. (2018). The impact of technological changes on income inequality: The EU states case study. *Journal of International Studies*, *11*, 76–94. [CrossRef]

Knoll, B., Riedel, N., Schwab, T., Todtenhaupt, M., & Voget, J. (2021). Cross-border effects of R&D tax incentives. *Research Policy*, *50*, 104326. [CrossRef]

Lenihan, H., Mulligan, K., Perez-Alaniz, M., & Rammer, C. (2024). R&D policy instrument mix sequencing: Evaluating the impact of receiving R&D grants and R&D tax credits over time on firm-level R&D. *Industry and Innovation*, *32*(5), 540–573. [CrossRef]

Levin, A., Lin, C.-F., & Chu, C.-S. J. (2002). Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, *108*, 1–24. [CrossRef]

Lundvall, B.-Å. (1992). *National systems of innovation: Toward a theory of innovation and interactive learning*. Pinter Publishers.

MacKinnon, J. G., & Webb, M. D. (2017). Wild bootstrap inference for wildly different cluster sizes. *Journal of Applied Econometrics*, *32*, 233–254.

Mazzucato, M. (2024). Governing the economics of the common good: From correcting market failures to shaping collective goals. *Journal of Economic Policy Reform*, *27*, 1–24. [CrossRef]

Ministry of Economics of the Republic of Latvia. (2023). *Background report on R&D tax incentives*. Ministry of Economics of the Republic of Latvia.

Montmartin, B., & Herrera, M. (2015). Internal and external effects of R&D subsidies and fiscal incentives. *Research Policy*, *44*, 1065–1079. [CrossRef]

Nelson, R. R. (1959). The simple economics of basic scientific research. *Journal of Political Economy*, *67*, 297–306. [CrossRef] [PubMed]

OECD. (2020). *The effects of R&D tax incentives and their role in the innovation policy mix: Findings from the OECD microBeRD project, 2016–19* (OECD Science, Technology and Industry Policy Papers No. 92). OECD Publishing. [CrossRef]

OECD. (2022). *Main science and technology indicators: Volume 2022 issue 2*. OECD Publishing.

OECD. (2023). *The impact of R&D tax incentives: Results from the OECD microBeRD+ project* (OECD Science, Technology and Industry Policy Papers No. 159). OECD Publishing. [CrossRef]

OECD. (2024a). *INNOTAX portal*. OECD Publishing.

OECD. (2024b). *Main Science and Technology Indicators (MSTI)* [Data set]. OECD Data Explorer.

OECD. (2025). *R&D tax incentives continue to outpace other forms of government support for R&D in most countries*. OECD Data Insights Statistical Release.

Schot, J., & Steinmueller, W. E. (2018). Three frames for innovation policy: R&D, systems of innovation and transformative change. *Research Policy*, *47*, 1554–1567. [CrossRef]

State Statistics Service of Ukraine. (2021). *Innovation activity of industrial enterprises in 2016–2020: Express release*. State Statistics Service of Ukraine.

State Statistics Service of Ukraine. (2022). *Scientific and innovation activity of Ukraine: Statistical yearbook 2021*. State Statistics Service of Ukraine.

Warda, J. (2002). Measuring the value of R&D tax treatment in OECD countries. *STI Review*, *27*, 185–211.

Zavarská, Z., Bykova, A., Grieveson, R., & Guadagno, F. (2024). *Toward innovation-driven growth: Innovation systems and policies in EU member states of Central Eastern Europe*. Research Report No. 476. The Vienna Institute for International Economic Studies.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.