"Environmental protection expenditure, digital government, and EU membership: Cross-country panel evidence"

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ENVIRONMENTAL PROTECTION EXPENDITURE, DIGITAL GOVERNMENT, AND EU MEMBERSHIP: CROSS-COUNTRY PANEL EVIDENCE

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Abstract

Environmental protection accounts for a small share of public budgets, which makes its determinants a practical policy question. Digital administration is expected to improve public resource allocation, and environmental protection is an information-intensive function where that expectation should be visible. This study measures the association between digital government development and the share of public expenditure allocated to environmental protection, compares it with the other nine budget functions, and describes Latvia, Ukraine, and Armenia as illustrations of divergent expenditure trajectories under broadly comparable digital government development. The analysis covers 592 country-year observations for 68 economies, including 13 post-Soviet economies, over 2004 to 2024, combining the United Nations E-Government Development Index with IMF Government Finance Statistics in a two-way fixed effects design with wild cluster bootstrap inference. Digital government development is not associated with the environmental share ($\beta = -0.002$, $p = 0.997$), and environmental protection records the smallest standardized effect among the ten functions, indistinguishable from zero, compared with 0.451 for social protection. European Union membership is associated with a higher environmental share ($\beta = 0.331$, $p = 0.004$), although the estimate is identified from four changes of membership status. A stronger association inside the post-Soviet subsample does not survive a specification that allows every coefficient to differ by group. The study therefore finds no evidence that higher digital government development alone is systematically associated with a larger environmental share of public budgets.

Keywords digital government, budget allocation, public policy, sustainable development, COFOG, post-Soviet, fixed effects, fiscal priorities

JEL Classification H50, H11, O33, Q58

INTRODUCTION

Environmental protection occupies one of the smallest functional categories of general government expenditure. In the European Union, general government spending on this function amounted to EUR 142 billion in 2023, which corresponds to 0.8 percent of GDP and 1.7 percent of total expenditure, and the ratio to GDP has remained between 0.7 and 0.8 percent since 1995 (Eurostat, 2025). For the post-Soviet region, the adequacy of these allocations carries direct policy weight. Official Ukrainian estimates put war-related environmental damage at UAH 6.01 trillion as of December 2025, equivalent to roughly USD 140 billion at the contemporaneous exchange rate (Ministry of Economy, Environment and Agriculture of Ukraine, 2025), while the 2025 joint assessment by the Government of Ukraine, the World Bank, the European

Commission, and the United Nations estimated the total recovery and reconstruction needs of the country at USD 524 billion over the following decade (World Bank Group et al., 2025).

Digital government has expanded over the same period. The global average of the United Nations E-Government Development Index rose from 0.6102 in 2022 to 0.6382 in 2024, 76 of 193 member states reached the very high group, and the share of the world population lagging in digital government development fell from 45 to 22.4 percent, while the post-Soviet region illustrates how wide the remaining differences are, with Estonia ranked second among the 193 member states and other successor economies placed considerably lower (United Nations, 2024b). A recurring expectation attached to this expansion is that stronger information systems, by narrowing information asymmetry between the state and its counterparts (Ivashchenko et al., 2017), improve the allocation of public resources. Whether the improvement extends to the environmental function of the budget, where monitoring, permitting, and enforcement are information-intensive, remains an open empirical question.

This study measures the association between the development of digital government and the priority that governments assign to environmental protection in their budgets. It combines the E-Government Development Index with expenditure data classified by function from the IMF Government Finance Statistics for 68 economies observed at the eleven survey waves between 2004 and 2024, and treats the 13 post-Soviet economies in the sample as the group of interest. Latvia, Ukraine, and Armenia serve as focus cases because they reached broadly comparable levels of digital government development while occupying three distinct positions in relation to the European Union. Latvia has been a member throughout the observation window, Ukraine opened accession negotiations in June 2024, with its first negotiating cluster in June 2026 (Council of the European Union, 2024, 2026), and Armenia brought into force a law launching an accession process in April 2025 without submitting a membership application (European Parliament, 2025). The three cases therefore provide an informative institutional contrast against a background of broadly similar digital government trajectories. The remainder of the paper reviews the related literature, describes the data and methods, reports the results, and discusses their implications.

1. LITERATURE REVIEW

Research on digital government has accumulated most of its evidence on administrative rather than fiscal outcomes. Cross-country and case-based studies associate the digitalization of public services with higher citizen trust and satisfaction, treating the digital environment as a channel of dialogue between the state and its users (Gharbaoui et al., 2024; Litovtseva et al., 2022). Related work links e-governance to better execution of organizational strategy in the ICT sector (Abou-Moghli & Shatem, 2024). Digitized financial management appears in the same strand as a catalyst for good governance in the public sector (Ntuli et al., 2025). Recent contributions unpack the human-centred mechanisms through which e-government development translates into quality of life (Vasylieva et al., 2026). A second strand concentrates on integrity. Automation of administrative services narrows the space for discretionary abuse, and estimates for Ukraine attribute a substantial share of variation in corruption control to technological determinants (Yefimenko, Boronos, et al., 2025; Yefimenko, Malaniuk, et al., 2025). The optimism is not unconditional. Panel evidence for Europe indicates that digital readiness restrains corruption and cyber threats only where institutional quality is already high (Yarovenko et al., 2025). The Georgian experience shows that digital instruments can coexist with accountability erosion and rent-seeking once ruling elites consolidate (Ugulava, 2026). Findings at the organizational level point in the same direction, since declared readiness for digital transformation does not by itself guarantee performance (Al-Smadi, 2025), and a survey of civil servants in Croatia documents a wide gap between regulatory mandates for artificial intelligence and the capacity of officials to apply them (Keser & Mudrić, 2026). Administrative capacity therefore appears necessary, but not sufficient, and institutional quality itself calls for explicit criteria of effectiveness (Masyk et al., 2023), which raises the question of what digitalization actually delivers in the environmental domain.

Where digitalization meets the environment, the evidence concentrates on outcomes rather than budgets. A panel of 51 countries links e-government construction to lower carbon emission intensity, and studies of digital government transformation reach the same direction for total CO2 emissions (Huang et al., 2024; Wen et al., 2025). Chinese evidence estimated with two-way fixed effects confirms the negative association with carbon intensity (Yi, 2025), although double machine learning suggests that the contribution holds in the short run and may reverse over longer horizons as energy-intensive digital infrastructure accumulates (Xu et al., 2025). A related result concerns the productivity of public money, since an evaluation of China's information-benefiting pilot policy finds higher fiscal expenditure efficiency in participating cities (Tong et al., 2026). Capacity does not always convert into output. Government readiness for artificial intelligence accelerates the expansion of installed renewable capacity yet shows no statistically significant association with actual generation (Lyeonov, Mielczarek, et al., 2025), and artificial intelligence also shapes the distributional side of the energy transition through energy equity (Kirichok et al., 2025). GIS-based monitoring of water resources in Bulgaria integrates large volumes of environmental data, while investment in wastewater disposal fell by 40 percent over 2016–2023 (Kostev, 2025). At the service level, where smart city experience accumulated earliest (Bashynska & Dyskina, 2018), artificial intelligence in municipal waste management cuts operating costs by roughly 30 percent and improves sorting through neural network classification (Kajda & Karwot, 2025; Kajda & Karwot, 2026), which illustrates how digital tools change the unit cost of an environmental function rather than its budget line. Sectoral studies extend the question to healthcare, asking whether digitalization relates to population longevity (Tossekbayev et al., 2025) and showing that the e-government index moderates the effectiveness of health expenditure in a non-linear way (Hrytsenko et al., 2026). The relationship can also run against green spending. Firm-level digital transformation in developing economies reduces green investment, even though enterprise digitalization supports sustainable development through market channels (Bashynska et al., 2023; Chahdi et al., 2025; Kozhakhmetova et al., 2025). Outcomes and efficiency thus dominate this agenda, and the allocation of public money across functions remains in the background.

There is a distinct body of literature explaining the level and composition of public expenditure with macroeconomic and institutional forces and, notably, without digital measures. In the Baltic states, output dynamics emerge as the dominant predictor of government spending (Filipova et al., 2025). The growth contribution of expenditure differs across functions, with social protection mattering most for Lithuania and health combined with social protection for Estonia (Dudzevičiūtė, 2023). Allocation is rarely optimal. A formal test finds that most governments fail to divide revenue between current and capital uses in a welfare-maximizing way (Abbasov, 2023), and panel evidence on the Abuja health target shows that internationally agreed functional benchmarks are met only where economic capacity and institutional quality allow (Megbowon & Zerihun, 2025). Subnational evidence adds that the own revenue of rural local governments translates only marginally into development expenditure (Mohapatra, 2026), while macro-level work treats the expenditure mix as a determinant of exchange rate stability (Ahmed, 2025). Comparative studies of a single function underline persistence, since social protection shares converge within the Visegrad group while diverging across Benelux welfare models (Piekut & Rybaltowicz, 2024). Functional shares therefore move slowly and respond to institutions and income rather than to administrative technology, which directs attention to the instruments through which environmental priorities enter the budget.

Environmental priorities reach the budget through an instrument mix that stretches well beyond a single expenditure line. Environmental tax reforms deliver measurable gains for economic and ecological security, yet the gains arrive with a lag and depend on digital skills among taxpayers (Samusevych et al., 2024), while feed-in tariffs de-risk renewable projects sufficiently to attract conservative institutional investors such as insur-

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ers (Lyeonov, Artyukhov, et al., 2025), although in Ukraine the state support schemes for renewables still require redesign (Prokopenko et al., 2021). Crisis conditions reshape the mix. Forecasts built during the European energy crisis connect emergency energy management with greenhouse gas trajectories (Kuzior et al., 2023), causality tests tie renewable deployment to energy security under geopolitical risk (Havrylenko & Myroshnychenko, 2025), and the transition itself faces economic and environmental limits (Prokopenko et al., 2024). At the European level, agricultural eco-schemes within the Common Agricultural Policy target the energy intensity of farming (Pimenow et al., 2026), and policy analysis of sustainable tourism shows how EU frameworks transmit environmental objectives into national governance (Taliouris & Trihas, 2026). Behavioral instruments such as green promotions and financial incentives complement regulation at the level of individual choices (Burrell et al., 2025), as do the financial mechanisms that govern household adoption of energy efficiency and renewables (Prokopenko et al., 2025). These instruments also presuppose an information base, and a growing accountability infrastructure now produces the environmental disclosures on which regulatory and budgetary decisions draw. Board-level governance improves carbon disclosure in banking (Mansour et al., 2026) and environmental disclosure in industrial companies (Yardımcı & Aslanertik, 2025), and the audit of sustainability reporting is being standardized across EU countries (Bezverkhyi et al., 2025). Sustainability reporting itself has matured into a core tool of corporate social responsibility (Shygun & Bezverkhyi, 2026), external assurance raises its quality (Pasko et al., 2021), and bibliometric mapping shows digital accounting emerging as the information infrastructure of sustainability (Asare, 2025). Both the instruments and their information base rest on administrative capacity, and the fiscal counterpart of that capacity differs sharply across European and post-Soviet contexts.

The heterogeneity of Eastern European countries is not background noise but a first-order feature of both digitalization and budgets. Structural disparities in digital readiness persist between core and catch-up EU economies (Obelovska et al., 2025; Valaskova et al., 2025), and fuzzy set assessments document a widening gap in cloud computing and artificial intelligence adoption (Kolupaieva & Tiesheva, 2023). Self-organizing maps qualify the pessimism by showing that every European country had left the weakest digital cluster by 2020 (Pakhnenko et al., 2025), and cluster analysis of inclusive growth reveals equally persistent socio-economic profiles across member states (Saher et al., 2025), which regional patterns of economic modernization reproduce (Ladonko et al., 2022). For transition economies, the regional dimension has long been framed as a problem of financial convergence for sustainable development (Vakhovych et al., 2015). Recent evidence from Ukraine and Kazakhstan shows banks combining digitalization with social responsibility to build institutional legitimacy (Zakharkina et al., 2025). War overlays these differences. The full-scale invasion destabilized Ukraine's external trade and macroeconomic security (Tsymbal & Demediuk, 2025), with evident consequences for every budget priority. Contexts that share Soviet administrative legacies therefore differ profoundly in their institutional commitments, and this variation motivates the comparison of European Union members with other successor states.

Methodologically, the field has moved from cross-sections toward panel designs, bringing greater care about identification. Surveys of two-way fixed effects warn that heterogeneous effects can contaminate conventional estimates (de Chaisemartin & D'Haultfœuille, 2023), guidance on cluster-robust inference stresses the risk of over-rejection when clusters are few (MacKinnon et al., 2023), and placebo tests have become a standard device for probing design assumptions (Eggers et al., 2024). Substantively, however, no study in this literature estimates the effect of digital government development on the functional composition of public expenditure. The closest contributions either take spending efficiency as the outcome (Tong et al., 2026) or use a functional expenditure share as a moderator of digital government rather than as the dependent variable (Hrytsenko et al., 2026). The environmental function has not been examined in this role, even though its day-to-day administration consists largely of the data work that digital government systems are built to carry. Nor has the post-Soviet region, where digital capacity and institutional commitments diverge most visibly, served as the testing ground. Therefore, this study aims to determine whether digital government development is associated with the environmental protection share of public expenditure, with particular attention to post-Soviet economies. The aim is pursued by relating the E-Government Development Index to that share within a two-way fixed effects design, comparing the environmental function against the other nine COFOG divisions under identical estimation conditions, and describing Latvia, Ukraine, and Armenia as illustrative trajectories. It thereby connects three strands that have developed largely in isolation, namely the digital government literature, the expenditure composition literature, and research on post-communist heterogeneity.

2. METHODS

2.1. Data and sample

The dependent variable is government spending on environmental protection from the IMF Government Finance Statistics, Expenditure by Function of Government. It corresponds to division 05 of the Classification of the Functions of Government, is reported for budgetary central government at annual frequency, and is normalized by total government expenditure and by GDP. The share of total expenditure is the main measure, since the question concerns the relative claim of the environmental function on the budget rather than fiscal size. Normalization by total expenditure reduces the dependence of the series on the absolute size of the budget, but it does not eliminate the influence of the denominator, and a movement in the share can originate in total expenditure as well as in environmental spending. The share also reflects the division of spending responsibilities across levels of government, the scale of environmental needs, and the accounting treatment of individual transactions. It is therefore read throughout as a measure of relative fiscal allocation, and the word priority is used in that restricted sense. On the 1,104 observations reporting all six subdivisions, their sum matches the division aggregate to within 0.113 percentage points, with two discrepancies above 0.01.

Digital government is measured by the United Nations E-Government Development Index and its Online Service, Telecommunication Infrastructure, and Human Capital components. The twelve available waves cover 2003, 2004, 2005, 2008, and every second year from 2010 to 2024. Controls come from the World Development Indicators and the Worldwide Governance Indicators, and EU membership equals one from the year of accession, with the United Kingdom reverting to zero in 2021.

Four exclusions were applied. Country aggregates under IMF group codes were removed. Fourteen country-year observations with negative values in any component of division 05 were dropped as inconsistent with the definition of expenditure. Nine of them fall in the Baltic states and the Czech Republic between 2006 and 2012 and match the recording of asset disposals, documented for Estonia where sales of Kyoto assigned amount units produced negative environmental expenditure in 2010 and 2011 (Pädam & Ehrlich, 2014); the remaining five are Iceland in 2011, Mauritius in 2020, New Zealand in 2004, Singapore in 2022, and Switzerland in 2023. In three of the fourteen, the division aggregate itself is negative, while in the others only a component is, and seven of the fourteen fall on survey wave years and are therefore candidates for the estimation sample. Fourteen observations with an environmental share below 0.01 percent were dropped as non-reporting coded as zero. The IMF extract carries no observation-status attribute that would distinguish a reported zero from a missing value, so the classification rests on the data pattern: thirteen of the fourteen record an exact zero for the division aggregate, for every component, and in national currency, in economies that report positive environmental spending at adjacent waves, and six of them belong to a single economy; the fourteenth records 0.005 percent. Because a genuine zero cannot be separated from non-reporting with certainty, the exclusion is treated as a modelling choice rather than a data correction. Two observations with a zero index value and single-observation economies were also dropped. Subsection 3.7 reports how the estimates change when the negative and the zero observations are retained. The estimation sample comprises 592 country-year observations for 68 economies over 2004 to 2024, of which 108 are for 13 post-Soviet economies. Appendix A lists the economies with their income groups, post-Soviet status, and number of obser-

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vations. Turkmenistan does not report functional expenditure to the IMF, and Tajikistan falls out as a singleton, so 13 of the 15 successor states remain.

Latvia, Ukraine, and Armenia are described as illustrative cases and are not used as a comparative design. Their index values rose by 0.27, 0.25, and 0.22 points over their respective observation windows, while their environmental shares moved in different directions. The three economies do not, however, identify an institutional contrast inside the estimation period. Latvia is a member of the European Union throughout its window and therefore contributes no within-country variation to the membership indicator, on which that coefficient is identified, while Ukraine and Armenia take the value zero at every wave at which they are observed, so the model does not separate them along the membership dimension. The institutional developments that distinguish the three, namely the opening of accession negotiations with Ukraine in June 2024 and the entry into force of the Armenian accession law in April 2025, postdate most or all of the budget outcomes observed here. The windows also differ in length and placement, with nine waves for Latvia and ten for Ukraine between 2004 and 2022 against four waves for Armenia between 2018 and 2024, and the Ukrainian series after 2022 reflects a wholesale restructuring of public expenditure under full-scale war. Subsection 3.5 therefore presents these trajectories as a description of divergent budgetary paths under broadly similar digital government development, without attributing the divergence to European Union anchoring.

2.2. Variables

Table 1 lists the variables, definitions, and sources. Appendix B reports their pairwise correlations on the estimation sample.

2.3. Model specification

The baseline in equation (1) is a two-way fixed effects panel regression estimated by ordinary least squares.

$$y_{it} = \beta EGDI_{i,t-1} + \gamma' X_{it} + \theta EU_{it} + \alpha_i + \delta_t + \varepsilon_{it}, \quad (1)$$

where y with subscripts i and t denotes environmental protection expenditure as a share of total expenditure in economy i in wave year t, $EGDI$ with the lag is the index at the preceding survey wave, X is the vector of controls listed in Table 1, EU is the membership indicator, alpha and delta capture country and wave fixed effects, and epsi-

Table 1. Variables, definitions, and sources

Variable	Definition	Source
Environmental protection expenditure	COFOG division 05, budgetary central government, as a share of total expenditure and of GDP	IMF Government Finance Statistics
E-Government Development Index	Composite index of online services, telecommunication infrastructure, and human capital, scaled from 0 to 1	UN E-Government Survey
Online Service Index	Component measuring the scope and quality of government online services	UN E-Government Survey
Telecommunication Infrastructure Index	Component measuring connectivity infrastructure	UN E-Government Survey
Human Capital Index	Component measuring literacy and school enrollment	UN E-Government Survey
GDP per capita	Constant 2015 US dollars, in logarithm	WDI, NY.GDP.PCAP.KD
GDP growth	Annual percentage change of real GDP	WDI, NY.GDP.MKTP.KD.ZG
Population	Total population, in logarithm	WDI, SP.POP.TOTL
Trade openness	Exports plus imports as a share of GDP	WDI, NE.TRD.GNFS.ZS
CO2 emissions per capita	Tonnes of CO2 equivalent per person	WDI, EN.GHG.CO2.PC.CE.AR5
Urban population	Share of total population living in urban areas	WDI, SP.URB.TOTL.IN.ZS
Industry value added	Industry including construction, as a share of GDP	WDI, NV.IND.TOTL.ZS
Government effectiveness	Estimate in standard normal units	Worldwide Governance Indicators
EU membership	Binary indicator, one from the year of accession	Constructed
Post-Soviet	Binary indicator, one for successor states of the Soviet Union	Constructed

Note: All variables enter at the years of the United Nations survey waves. The index and its components enter with a one-wave lag.

lon is the idiosyncratic error. Beta is the parameter of interest, gamma is the vector of coefficients on the controls, and theta is the coefficient on membership. The one-wave lag establishes temporal ordering between the index and the outcome; it does not represent a uniform fiscal-year lag. Because the survey waves are unequally spaced, being annual between 2003 and 2005 and biennial from 2010 onward with a three-year interval in between, a lag of one wave corresponds to one year for 93 observations in the estimation sample, two years for 446, and three years for 53. Subsection 3.7 reports the contemporaneous index as an alternative ordering.

Group heterogeneity is assessed in equations (2) and (3).

$$y_{it} = \beta_1 EGDI_{i,t-1} + \beta_2 EGDI_{i,t-1} \cdot PS_i + \gamma' X_{it} + \theta EU_{it} + \alpha_i + \delta_t + \varepsilon_{it}, \tag{2}$$

$$y_{it} = \beta_1 EGDI_{i,t-1} + \beta_2 EGDI_{i,t-1} \cdot PS_i + \gamma' X_{it} + \lambda' X_{it} \cdot PS_i + \theta EU_{it} + \alpha_i + \delta_t + \varepsilon_{it}, \tag{3}$$

where PS is a binary indicator equal to one for post-Soviet economies, beta with subscript 1 is the slope of the index in the comparison group, beta with subscript 2 is the difference in that slope, and lambda collects the coefficients on the interactions of the controls with the indicator. Equation (2) lets only the index slope differ, whereas equation (3) lets every control differ as well, since a subsample estimate permits all slopes to vary and a difference attributed to the index may originate in the controls. PS is time-invariant and absorbed by the country fixed effects.

To establish whether an association is specific to environmental protection, equation (4) re-estimates the baseline for each of the ten divisions.

$$y_{it}^k = \beta^k EGDI_{i,t-1} + \gamma^k X_{it} + \theta^k EU_{it} + \alpha_i^k + \delta_t^k + \varepsilon_{it}^k, \tag{4}$$

where the superscript k indexes the division and y with superscript k is that division's share of total expenditure. Because the ten shares sum to one hundred percent, the coefficients beta with superscript k should approximately offset one another, an internal consistency check. Divisions differ in scale by up to two orders of magnitude, so equation (5) standardizes the coefficients.

$$\tilde{\beta}^k = \frac{\hat{\beta}^k s_w^{EGDI}}{s_w^{y^k}}, \; s_w^z = \mathrm{sd}\left(z_{it} - \bar{z}_i\right), \tag{5}$$

where s with subscript w is the within-country standard deviation of a variable, z with a bar is the country mean, *sd* is the sample standard deviation, and beta with a hat is the estimated coefficient; the standardized beta with a tilde gives the change in division k expenditure, in its own within-country standard deviations, per one within-country standard deviation of the index. Equation (6) adds a specification-free measure.

$$r_i = corr_t\left(EGDI_{i,t-1}, \, y_{it}\right), \; T_i \geq 5, \tag{6}$$

where r is the correlation between the lagged index and environmental protection expenditure computed within economy i across its own observations, and T is the number of observations for that economy. The distribution of these correlations indicates whether a null average reflects an absence of co-movement or the cancellation of opposing country patterns.

2.4. Estimation and inference

All models are estimated by ordinary least squares with country and wave fixed effects absorbed and standard errors clustered by country. Because the post-Soviet subsample contains thirteen clusters, inference is supplemented by the wild cluster bootstrap with Rademacher weights and the null imposed, using 9,999 replications (Cameron et al., 2008; MacKinnon et al., 2023); with thirteen clusters, the 8,192 weight combinations are enumerated in full, so those p-values are exact (Roodman et al., 2019). Since the membership indicator changes status in only four economies, its bootstrap p-value is read with the caution recommended for few treated clusters (MacKinnon & Webb, 2018).

Multicollinearity was assessed on within-transformed data. Variance inflation factors on the country-demeaned regressors range from 1.2 to 2.3, and government effectiveness is retained because its correlation with log GDP per capita falls from 0.89 in levels to 0.49 after country and wave

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demeaning. The re-estimation across the ten divisions in equation (4) is a cross-function comparative analysis rather than a placebo outcome test in the sense of Eggers et al. (2024). The remaining nine functions are not outcomes for which the absence of a digital government mechanism can be assumed, so they do not serve as null outcomes, and the ten shares form a compositional system that sums to one hundred percent, so an increase in one share mechanically implies a decrease in one or more of the others, and the coefficients across functions are not independent of each other. The comparison therefore establishes whether the environmental function is distinctive in magnitude relative to the rest of the budget under identical estimation conditions, and not whether a design assumption survives. Because ten outcomes are evaluated simultaneously, the bootstrap p-values are reported alongside Holm and Benjamini-Hochberg adjustments, and any result for a function other than environmental protection is treated as exploratory. The compositional structure is addressed directly in subsection 3.7, which reports an additive log-ratio specification for the environmental share against the remainder of the budget and a centered log-ratio specification computed over all ten divisions; separate fixed effects regressions remain the descriptive backbone of the comparison. Estimates close to zero are reported as bounds in within-country standard deviations rather than as an absence of effect (Rainey, 2014). Internet penetration and tertiary enrollment are excluded wherever the composite index is the regressor, because two of its three components are built from the same underlying data and would absorb the variation of interest; they enter only alongside the Online Service Index (Cinelli et al., 2024).

2.5. Limitations

Six limitations qualify the results. First, the series covers budgetary central government rather than general government and therefore omits municipal environmental spending, notably waste and wastewater. Subnational governments account for roughly 40 percent of public expenditure and well over half of public investment across OECD countries (OECD & UCLG, 2022), so the omission is material and likely largest where cohesion funding supports municipal environmental infrastructure. Second, the sample is uneven, with 407 of 592 observations in Europe and Central Asia and 394 in high-income economies, so the estimates describe economies reporting disaggregated functional expenditure to the IMF. Third, the waves are unequally spaced, so a lag of one wave is not a fixed length of calendar time, and the index is a relative measure whose component weights have been questioned on construct validity grounds (Whitmore, 2012), which is one reason the components are reported separately. Fourth, the data are observational; fixed effects absorb time-invariant characteristics and common shocks, but time-varying unobserved factors remain, so the estimates are associations rather than causal effects. Fifth, the membership indicator is identified from four status changes, namely Bulgaria and Romania in 2007, Croatia in 2013, and the United Kingdom in 2021, so its coefficient rests on few events and, under staggered accession, averages potentially heterogeneous membership effects (de Chaisemartin & D'Haultfœuille, 2023). Sixth, the post-Soviet subsample contains 13 clusters, with nine observations for Latvia, ten for Ukraine, and four for Armenia; inference relies on the exact bootstrap, and the focus economies are described rather than estimated separately.

3. RESULTS

3.1. Descriptive statistics

The estimation sample covers 592 country-year observations for 68 economies across the eleven United Nations survey waves between 2004 and 2024. Environmental protection expenditure averages 0.856 percent of total government expenditure (SD = 0.784), with individual values ranging from 0.015 to 6.524 percent. Measured against GDP, the same variable averages 0.253 percent (SD = 0.281). The lagged E-Government Development Index averages 0.670 (SD = 0.153), with a minimum of 0.238 and a maximum of 0.976. Table 2 reports the full set of summary statistics.

Since every specification absorbs country fixed effects, the variance decomposition determines what the estimates identify. For environmental protection expenditure, the between-country standard deviation is 0.785, and the within-country standard deviation is 0.384, so the within-country

Table 2. Descriptive statistics, estimation sample

Variable	N	Mean	SD	Min	Max	Between SD	Within SD
Environmental protection expenditure (% of total expenditure)	592	0.856	0.784	0.015	6.524	0.785	0.384
Environmental protection expenditure (% of GDP)	590	0.253	0.281	0.003	2.112	0.294	0.124
E–Government Development Index (t–1)	592	0.670	0.153	0.238	0.976	0.144	0.084
Online Service Index (t–1)	592	0.620	0.212	0.035	1.000	0.175	0.150
Telecommunication Infrastructure Index (t–1)	592	0.524	0.240	0.047	0.998	0.203	0.152
Human Capital Index (t–1)	592	0.867	0.095	0.521	1.000	0.093	0.046
GDP per capita (log, constant 2015 US$)	592	9.637	1.053	6.993	11.609	1.086	0.137
GDP growth (annual %)	592	2.395	3.974	–28.759	15.842	1.652	3.644
Population (log)	592	16.153	1.798	9.282	21.068	1.975	0.056
Trade openness (% of GDP)	592	100.512	57.237	22.772	412.177	58.171	14.819
CO2 emissions per capita (t CO2e)	592	6.770	4.564	0.000	34.529	4.808	1.287
Urban population (% of total)	592	70.679	15.312	34.700	100.000	15.922	2.493
Industry value added (% of GDP)	586	25.588	8.428	9.114	74.812	9.452	2.406
Government effectiveness (WGI)	592	0.707	0.873	–1.288	2.280	0.879	0.181
EU membership (dummy)	592	0.470	0.499	0.000	1.000	0.482	0.111

Note: Estimation sample of 592 country-year observations for 68 economies, 2004-2024. Between SD is the standard deviation of country means; Within SD is the standard deviation of country-demeaned values.

standard deviation amounts to 49.0 percent of the total. Among the digital government measures, the Online Service Index shows the highest within-country share at 70.5 percent, followed by the Telecommunication Infrastructure Index at 63.4 percent and the composite index at 55.2 percent. Government effectiveness varies considerably less within countries (20.8 percent), as do log GDP per capita (13.0 percent), urbanization (16.3 percent), and log population (3.1 percent).

The sample concentrates in Europe and Central Asia (407 observations) and in high-income economies (394 observations), while the remaining regions contribute between 30 and 62 observations each. Post-Soviet economies account for 108 observations across 13 of the 15 successor states, with contributions per economy ranging from four waves for Armenia to eleven for Belarus. Mean environmental protection expenditure is 0.785 percent in post-Soviet economies and 0.872 percent elsewhere, 0.973 percent in EU member states and 0.754 percent in non-members.

3.2. Baseline estimates

Table 3 reports two-way fixed effects estimates with standard errors clustered by country. The coefficient on the lagged E-Government Development Index is −0.136 (SE = 0.431) without controls, 0.047 (SE = 0.481) with macroeconomic controls, and −0.002 (SE = 0.500) once government effectiveness enters the specification (p = 0.997, wild cluster bootstrap p = 0.997). The 95 percent confidence interval for the last estimate spans −0.981 to +0.977 percentage points. Scaled to a one within-country standard deviation change in the index (0.084), the interval narrows to −0.083 to +0.083 percentage points, which corresponds to −0.216 to +0.215 within-country standard deviations of the dependent variable.

Government effectiveness carries a coefficient of 0.099 (SE = 0.134, p = 0.459). EU membership carries a coefficient of 0.331 (SE = 0.112, cluster-robust p = 0.004, wild cluster bootstrap p = 0.042) and is identified from four economies that change status inside the observation window, namely Bulgaria and Romania in 2007, Croatia in 2013, and the United Kingdom in 2021, so the estimate is read with the few-switcher caution set out in subsection 2.4. Dropping the United Kingdom yields 0.362 (SE = 0.146, p = 0.016). Replacing the dependent variable with expenditure as a share of GDP yields −0.002 (SE = 0.175, p = 0.992) on the index.

Estimating the same specification separately for each subindex yields 0.033 (SE = 0.187) for the Online Service Index, 0.069 (SE = 0.337) for the Telecommunication Infrastructure Index, and −1.002 (SE = 0.918) for the Human Capital Index. Adding internet penetration and tertiary enrollment to the Online Service Index specification yields 0.048 (SE = 0.212) on 510 observations.

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Table 3. Digital government and environmental protection expenditure, two-way fixed effects

Variables	(1)	(2)	(3)	(4)
E–Government Development Index (t–1)	−0.136 (0.431)	0.047 (0.481)	−0.002 (0.500)	−0.002 (0.175)
GDP per capita (log)		−0.477 (0.324)	−0.542 (0.308)	−0.277* (0.113)
GDP growth (annual %)		0.008 (0.007)	0.009 (0.007)	0.000 (0.003)
Population (log)		0.491 (0.409)	0.563 (0.446)	0.079 (0.156)
Trade openness (% of GDP)		(0.002)	0.000 (0.002)	−0.000 (0.001)
CO2 emissions per capita		0.018 (0.030)	0.021 (0.030)	0.012 (0.010)
EU membership		0.329** (0.111)	0.331** (0.112)	0.090** (0.032)
Government effectiveness			0.099 (0.134)	0.038 (0.050)
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	592	592	592	590
R–squared	0.764	0.770	0.770	0.818

Note: The dependent variable is environmental protection expenditure as a share of total government expenditure in columns (1) to (3) and as a share of GDP in column (4). Standard errors clustered by country in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.3. Comparison across expenditure functions

The specification of column (3) of Table 3 was estimated for each of the ten COFOG divisions using the same controls, sample, and inference procedure. Figure 1 plots the resulting standardized effects with 95 percent confidence intervals for the global sample in Panel A and for the post-Soviet subsample in Panel B, and Table 4 reports them with bootstrap p-values and with adjustments for the ten simultaneous tests. In the global sample, the effects range from −0.305 to +0.451. Social protection records +0.451 and recreation and culture records −0.305, with bootstrap p-values of 0.004 and 0.007; under the Holm adjustment these become 0.040 and 0.063, and under the Benjamini-Hochberg adjustment 0.035 each, so only social protection remains significant at the five percent level once multiplicity is taken into account. Both are reported as exploratory, since the analysis is designed to locate environmental protection among the divisions and not to test the other nine. Environmental protection records −0.000 (bootstrap $p = 0.997$), the smallest absolute value among the ten divisions, and the next smallest is education at +0.065. The environmental row of Table 4 is the baseline of column (3) of Table 3 itself, estimated on the same 592 observations with the same controls, so the two values coincide by construction. Because the ten shares sum to one hundred percent, the coefficients should approximately offset one another, an internal consistency check: they sum to +2.16 while individual coefficients reach 18.6 in absolute value, and the small residual from the zero implied by the additive constraint reflects slightly different estimation samples across divisions. Panel B is examined in the next subsection.

3.4. Post-Soviet economies

Within the post-Soviet subsample (108 observations, 13 clusters), the coefficient on the lagged index is 2.308 (SE = 0.999, cluster-robust $p = 0.039$, wild cluster bootstrap $p = 0.023$ based on full enumeration of 8,192 weight combinations), corresponding to a standardized effect of +0.695. Panel B of Figure 1 places this estimate among the other divisions. Economic affairs records +0.765 (bootstrap $p = 0.145$) and general public services records −0.694 (bootstrap $p = 0.093$), so the movement of the environmental share is part of a broader reallocation from general public services toward several functions rather than a shift specific to environmental protection. Within that comparison, where ten divisions are tested simul-

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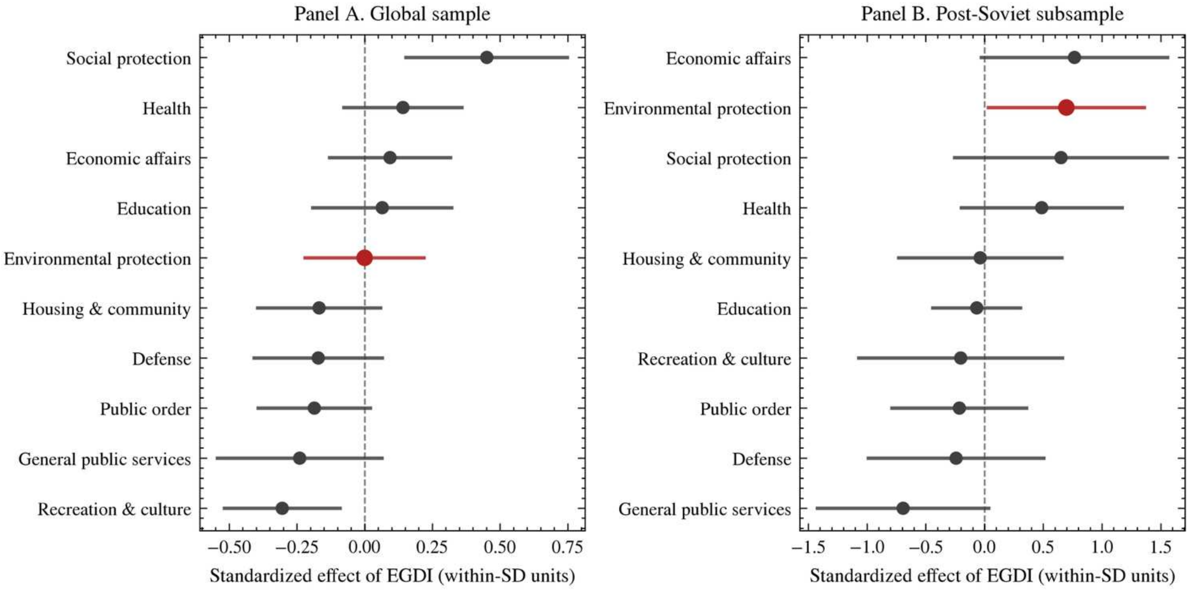

Note: Each marker is a separate two-way fixed effects regression with the controls of column (3) of Table 3. Effects are expressed in within-country standard deviations of the respective dependent variable for a one within-country standard deviation change in the index. Horizontal lines are 95 percent confidence intervals. Panel A covers the global sample; Panel B covers the post-Soviet subsample and omits the European Union membership indicator, which is collinear within that subsample.

Figure 1. Standardized effect of the E-Government Development Index across COFOG divisions

Table 4. Digital government across the ten COFOG divisions

COFOG function	Coef.	SE	Std. effect	p (boot)	p (Holm)	p (BH)	N
Panel A. Global sample							
Social protection	18.602	6.164	+0.451	0.004	0.040	0.035	591
Recreation and culture	–1.690	0.594	–0.305	0.007	0.063	0.035	592
General public services	–15.019	9.524	–0.240	0.166	1.000	0.300	591
Public order	–2.667	1.490	–0.186	0.089	0.712	0.297	584
Defense	–4.111	2.842	–0.172	0.180	1.000	0.300	584
Housing and community	–1.726	1.166	–0.168	0.147	1.000	0.300	591
Health	3.114	2.413	+0.141	0.223	1.000	0.319	592
Economic affairs	4.232	5.064	+0.093	0.421	1.000	0.526	591
Education	1.431	2.842	+0.065	0.660	1.000	0.733	592
Environmental protection	–0.002	0.500	–0.000	0.997	1.000	0.997	592
Panel B. Post–Soviet subsample							
Economic affairs	31.226	14.856	+0.765	0.145	1.000	0.368	107
Environmental protection	2.308	1.010	+0.695	0.026	0.260	0.260	108
General public services	–54.249	26.156	–0.694	0.093	0.837	0.368	108
Social protection	28.709	18.325	+0.650	0.243	1.000	0.486	108
Health	8.590	5.549	+0.486	0.147	1.000	0.368	108
Defense	–9.846	13.743	–0.243	0.564	1.000	0.747	100
Public order	–3.469	4.199	–0.215	0.490	1.000	0.747	100
Recreation and culture	–0.961	1.879	–0.204	0.672	1.000	0.747	108
Education	–1.818	4.619	–0.067	0.641	1.000	0.747	108
Housing and community	–0.188	1.598	–0.038	0.919	1.000	0.919	108

Note: Each row is a separate two-way fixed effects regression with the controls of column (3) of Table 3. Panel B omits the European Union membership indicator, which is collinear within the subsample because no post-Soviet economy changes membership status between 2004 and 2024. Std. effect is expressed in within-country standard deviations of the respective dependent variable for a one within-country standard deviation change in the index. p (boot) is the wild cluster bootstrap p-value with 9,999 replications; p (Holm) and p (BH) adjust it for the ten simultaneous tests.

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taneously, the environmental estimate does not survive the adjustment for multiplicity (Holm $p = 0.260$); the subsample estimate reported above is a single pre-specified test and is not adjusted, but the comparison reinforces the reading of a fragile regional tendency rather than an established effect. Excluding the three Baltic states reduces the coefficient on the index to 1.194 (SE = 0.640, $p = 0.095$) on 80 observations.

Two interaction specifications were estimated on the full sample. When only the slope of the index is allowed to differ by group, the interaction term is 0.254 (SE = 0.686, bootstrap $p = 0.727$). When every control is additionally interacted with the post-Soviet indicator, the interaction on the index is 0.491 (SE = 0.725, bootstrap $p = 0.532$), while the interactions on CO_2 emissions per capita and log population are 0.135 (SE = 0.035, $p < 0.001$) and 2.218 (SE = 0.880, $p = 0.014$). The EU indicator is not separately identified within the post-Soviet subsample because no post-Soviet economy changes membership status between 2004 and 2024.

3.5. Latvia, Ukraine, and Armenia

The three focus economies recorded increases in the lagged index of 0.27, 0.25, and 0.22 points respectively, while differing in their position relative to the European Union throughout the observation window. Table 5 summarizes their trajectories and Figure 2 plots them. As set out in subsection 2.1, the three economies are described here as illustrations of divergent budgetary paths and not as a comparative design: the institutional differences to which their labels refer either lie outside the estimation period or do not enter the model, and the observation windows are of unequal length and placement.

Between 2004 and 2022, Latvia's lagged index rose from 0.506 to 0.780 while environmental protection expenditure moved from 1.623 to 1.894 percent of total expenditure, reaching a maximum of 2.95 percent in 2008. Over the same period, the index in Ukraine rose from 0.462 to 0.712 while expenditure fell from 0.672 to 0.175 percent. Armenia, observed between 2018 and 2024, records an increase in the index from 0.518 to 0.736 and a decline in expenditure from 0.623 to 0.386 percent. Averaged over the observed years, Latvia and Armenia record almost identical values of the index (0.642 and 0.641) alongside mean expenditure of 2.249 and 0.398 percent, a ratio of 5.65. The within-country correlation between the two series is −0.238 for Latvia and −0.687 for Ukraine. Armenia is not included in that calculation, which is restricted to economies observed in at least five waves. The Ukrainian series is observed through 2022, and its later part coincides with a wholesale restructuring of public expenditure under full-scale war, which is a sufficient explanation for the decline in the environmental share on its own, so the comparison with Latvia and Armenia is descriptive.

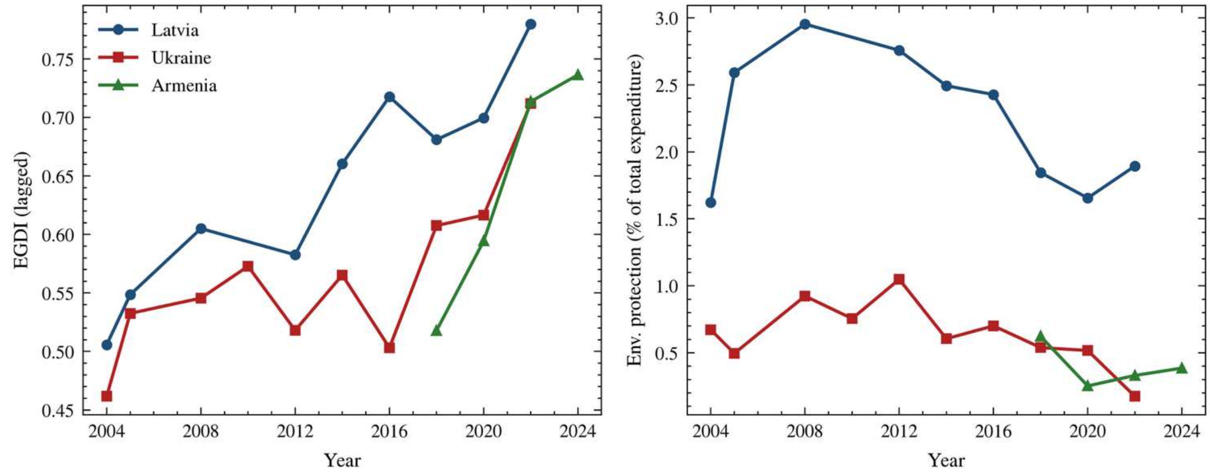
3.6. Within-country co-movement

For the 61 economies observed in at least five waves, the correlation between the lagged index and environmental protection expenditure was computed separately within each country. The median is +0.022, and the mean is +0.028. Thirty of the 61 correlations are negative (49.2 percent), and the values span −0.88 to +0.93. Figure 3 shows the distribution. Estonia records −0.87, Ukraine −0.687, and Latvia −0.238, while Cyprus records +0.93 and Georgia +0.85.

Table 5. Three focus economies

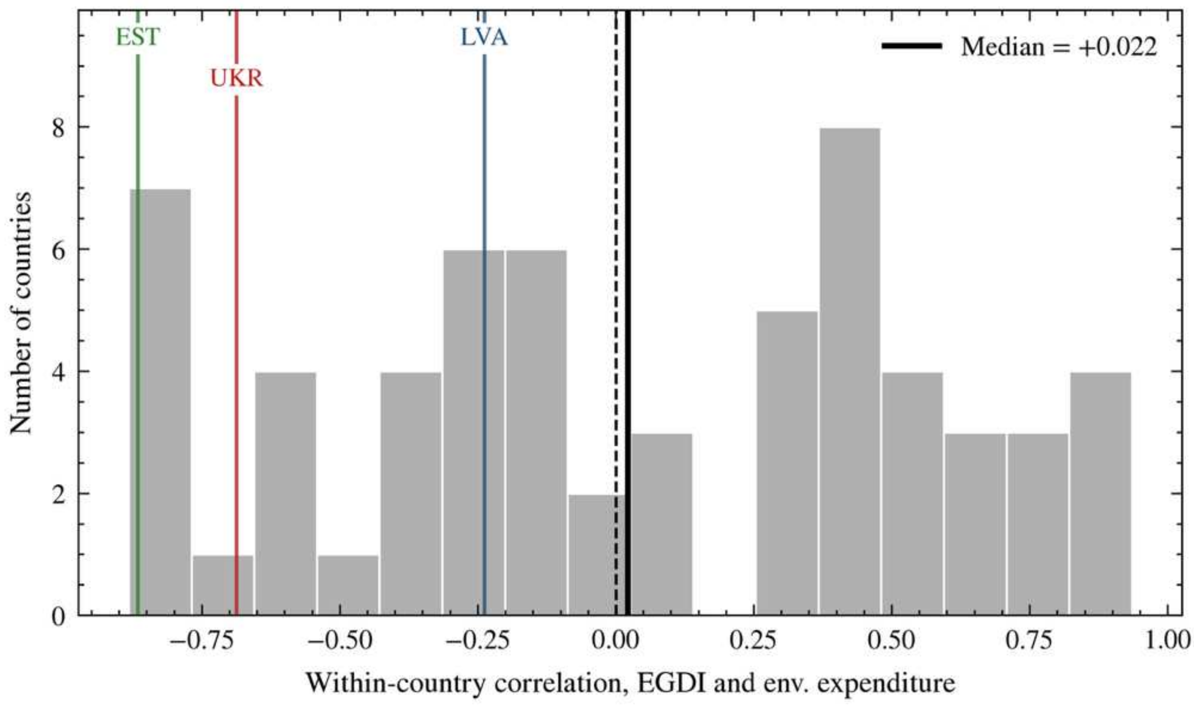
Economy	Waves	EGDI (t – 1)	Env. share	Change in EGDI	EU status
Latvia	9 (2004–2022)	0.506 to 0.780	1.623 to 1.894	+0.274	Member
Ukraine	10 (2004–2022)	0.462 to 0.712	0.672 to 0.175	+0.250	Non-member
Armenia	4 (2018–2024)	0.518 to 0.736	0.623 to 0.386	+0.218	Non-member

Note. Change is measured between the first and last observed wave. EU status refers to the observation window. Latvia acceded in 2004; Ukraine opened accession negotiations in June 2024; Armenia brought a law launching an accession process into force in April 2025 without submitting a membership application. Neither Ukraine nor Armenia takes the value one on the membership indicator at any point in the sample.



Note: Left panel plots the lagged E-Government Development Index; right panel plots environmental protection expenditure as a share of total government expenditure. Observations correspond to United Nations survey waves

Figure 2. E-government development and environmental protection expenditure in Latvia, Ukraine, and Armenia



Note: One correlation per economy, computed across that economy's own observations; 61 economies with at least five observations.

Figure 3. Distribution of within-country correlations between the index and environmental protection expenditure

3.7. Robustness

Table 6 reports seventeen alternative specifications. Standardized effects range from −0.054 to +0.130, and no bootstrap p-value falls below 0.372. Two further checks not reported in the table, truncating the sample at 2022 and excluding Ukraine, yield 0.211 (SE = 0.534, p = 0.694) and 0.174 (SE = 0.501, p = 0.729).

Two specifications address the compositional structure of budget shares. The additive log-ratio

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Table 6. Robustness checks, global sample

Specification	Coef.	SE	p (boot)	Std. effect	N	Countries
Baseline	–0.002	0.500	0.997	–0.000	592	68
Plus urbanization	–0.011	0.496	0.984	–0.002	592	68
Plus industry value added	0.204	0.508	0.704	0.045	586	67
Plus urbanization and industry	0.188	0.502	0.720	0.042	586	67
Plus total expense (% of GDP)	0.264	0.562	0.659	0.056	530	67
Dependent variable as % of GDP (with urbanization and industry)	0.080	0.162	0.666	0.058	584	67
Excluding microstates	0.512	0.515	0.372	0.130	542	61
Economies with five or more waves	0.417	0.506	0.442	0.101	565	61
Excluding Baltic states	0.160	0.499	0.772	0.036	558	64
Contemporaneous index	–0.231	0.459	0.630	–0.054	586	67
Waves from 2008 onward	–0.198	0.539	0.723	–0.045	494	66
Additive log-ratio against the rest of the budget	0.224	0.654	0.740	0.041	592	68
Centered log-ratio, ten divisions	0.439	0.565	0.480	0.089	552	64
Negatives with non-negative aggregate retained	0.083	0.489	0.875	0.018	596	68
All negative observations retained	0.068	0.495	0.899	0.014	600	69
Zero observations retained	0.014	0.511	0.980	0.003	607	70
Negatives and zeros retained	0.036	0.506	0.947	0.007	615	71

Note: Each row is a separate two-way fixed effects regression; the reported coefficient is that on the lagged E-Government Development Index. Std. effect is expressed in within-country standard deviations of the dependent variable for a one within-country standard deviation change in the index. p (boot) is the wild cluster bootstrap p-value with 9,999 replications. The rows from Excluding microstates to Waves from 2008 onward are estimated with urbanization and industry value added among the controls. The log-ratio rows transform the dependent variable; the last four rows re-estimate the baseline on the panel before the corresponding exclusion.

of the environmental share against the remainder of the budget yields 0.224 (SE = 0.654, bootstrap p = 0.740) on the same 592 observations. A centered log-ratio computed over all ten divisions yields 0.439 (SE = 0.565, bootstrap p = 0.480) on the 552 observations for which every share is strictly positive. The centered log-ratio measures the movement of a function relative to the average of the ten, and its coefficients sum to zero by construction, so it answers a different question from the share specification: not whether the environmental share moves with the index, but whether it moves differently from the budget as a whole. Neither transformation changes the conclusion. Across the ten divisions, only recreation and culture reaches conventional significance in the log-ratio metric (-0.799, p = 0.006), and that result does not survive the Holm adjustment (p = 0.059). The coefficient on European Union membership keeps its sign and order of magnitude in both transformations, 0.410 with p = 0.062 in the additive log-ratio and 0.415 with p = 0.044 in the centered log-ratio, but is estimated less precisely than in the share specification.

Four alternative treatments of the excluded observations were estimated on the panel before exclusion. Retaining the seven wave-year observations whose division aggregate is non-negative yields 0.083 (SE = 0.489, bootstrap p = 0.875) on 596 observations, and retaining all of them, including the three with a negative aggregate, yields 0.068 (SE = 0.495, bootstrap p = 0.899) on 600 observations. Retaining the zero-expenditure observations yields 0.014 (SE = 0.511, bootstrap p = 0.980) on 607 observations, and retaining both groups yields 0.036 (SE = 0.506, bootstrap p = 0.947) on 615 observations. The coefficient on European Union membership stays between 0.328 and 0.369 with p at or below 0.006 across all four.

4. DISCUSSION

At first sight, the estimated null contradicts the digital-environmental literature, in which e-government construction lowers carbon emissions (Huang et al., 2024) and digital governance raises fiscal expenditure efficiency (Tong et al., 2026). The contradiction dissolves once the outcome variables are kept apart. Those studies measure environmental performance or budget productivity, whereas the present estimates measure the claim of the environmental function on the budget. Digitalization that lowers the unit cost of environmental services, as artificial intelligence does in municipal waste management (Kajda & Karwot, 2025), can improve outcomes without enlarging the expenditure share, and a similar capacity-operation gap appears where government AI readiness expands renewable capacity without moving generation (Lyeonov, Mielczarek, et al., 2025). The null is therefore consistent with an efficiency channel and contradicts only a re-prioritization claim that the literature has not actually tested.

The pattern of estimates aligns more closely with the composition literature. Functional shares in Europe move slowly along welfare-model lines (Piekut & Rybaltowicz, 2024), and compliance with functional spending benchmarks depends on economic capacity and institutional quality rather than on administrative technology (Megbowon & Zerihun, 2025). Against this background, the positive association of European Union membership and the flat association of the digital index fit an interpretation in which the environmental priority responds to institutional commitments rather than to informational capacity, which is consistent with evidence that compliance with European integration requirements drives sustainable development (Ivanenko & Muraviov, 2026). That reading is kept deliberately narrow. The membership coefficient is identified from four changes of status within the observation window, membership bundles regulatory, fiscal, and investment changes that the design cannot separate, and institutional anchoring is not itself measured in the model. The coefficient also keeps its sign and order of magnitude under the log-ratio transformations reported in subsection 3.7 but is estimated less precisely there, so the result is reported as a cautious association between European Union membership and a higher environmental share, not as evidence on the mechanism through which anchoring would operate. The conditional digital effects reported for health expenditure point the same way (Hrytsenko et al., 2026), as does firm-level evidence that digital transformation competes with green investment (Kozhakhmetova et al., 2025), which makes a flat budgetary counterpart of digital progress unsurprising for a resource-constrained government.

The post-Soviet contrast deserves the same discipline. The subsample association does not survive the fully interacted specification, forms part of a broader reallocation away from general public services, and weakens without the Baltic states, so it indicates a fragile regional tendency rather than a digital dividend. The illustrative cases are consistent with that reading without testing it. Latvia, Ukraine, and Armenia followed broadly similar digital trajectories while assigning persistently different shares to the environmental function, and the Ukrainian combination of a rising index with a falling share cautions against reading digital capacity as a fiscal commitment device. Since the institutional events that distinguish the three lie outside or at the very edge of their observation windows, and since the Ukrainian series is shaped by the fiscal consequences of full-scale war, these trajectories illustrate the dispersion of budgetary outcomes rather than the effect of European Union anchoring. These associational readings refer to central government budgets, yet their message is consistent, with digital government among the enabling conditions and the budgetary priority answering to institutional commitments.

CONCLUSION

This study asked whether the development of digital government shifts the priority that governments assign to environmental protection within their budgets, with post-Soviet economies as the group of interest. The question was examined on 592 country-year observations for 68 economies across the eleven United Nations survey waves of 2004 to 2024, combining the lagged E-Government Development Index with IMF functional expenditure data in a two-way fixed effects design with wild cluster bootstrap inference. Digital government development shows no association with the environmental share of expenditure ($\beta = -0.002$, $p = 0.997$), and the environmental function records the smallest standardized effect among the ten budget divisions, indistinguishable from zero compared with 0.451 for social protection. European Union membership is associated with a higher environmental share ($\beta = 0.331$, $p = 0.004$), whereas government effectiveness is not. The larger coefficient

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inside the post-Soviet subsample (2.308) does not survive the fully interacted specification (0.491, p = 0.532), and the three focus economies raised the index by 0.22 to 0.27 points, while the environmental share rose only in Latvia, the member state.

For governments of the region, the immediate implication is that programs of digital government development should be justified by service quality, transparency, and administrative efficiency rather than presented as a lever for greening the budget. Where a higher environmental priority is the objective, the results point instead to institutional commitments: membership of the European Union is associated with a higher environmental share, on the cautious reading set out in section 4. Instruments that would reproduce that logic, such as legally fixed expenditure floors for the environmental function, environmental conditionality in accession frameworks, or environmental benchmarks in recovery and cohesion financing, are not evaluated by the models estimated here. They follow from the membership association as hypotheses about the kind of commitment that moves budget shares, and their effectiveness is a question for future evaluation rather than a result of this study.

For Ukraine and Armenia, this combination matters most. For both, the study finds no evidence that higher digital government development alone is systematically associated with a larger environmental expenditure share, while both face environmental liabilities far beyond the current scale of the environmental budget line. Whether embedding environmental expenditure benchmarks into accession frameworks and recovery programming would change budgetary outcomes is an open question that the present design cannot answer, and it is the natural object of a subsequent evaluation. For statistical authorities, the priority is extending functional reporting to general government, so that the municipal component of environmental spending becomes visible to analysis and policy.

AUTHOR CONTRIBUTIONS

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Supervision: Liudmyla Zakharkina.
Validation: Liudmyla Zakharkina, Alina Danileviča, Alina Brychko, Valentina Djakona.
Visualization: Nora Ayvazyan, Alina Brychko, Deniss Djakons, Valentina Djakona, Olga Niemi.
Writing – original draft: Nora Ayvazyan, Liudmyla Zakharkina, Alina Danileviča, Alina Brychko, Deniss Djakons, Valentina Djakona, Olga Niemi.
Writing – review & editing: Liudmyla Zakharkina, Valentina Djakona, Olga Niemi.

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DATA AVAILABILITY STATEMENT

The study uses openly available data. Environmental protection expenditure and the other functional expenditure series come from the IMF Government Finance Statistics, Expenditure by Function of Government dataset (International Monetary Fund, 2026). The E-Government Development Index and its Online Service, Telecommunication Infrastructure, and Human Capital components come from the United Nations E-Government Knowledge Base (United Nations, 2024a). Macroeconomic and structural controls come from the World Development Indicators (World Bank, 2026a), and government effectiveness comes from the Worldwide Governance Indicators (World Bank, 2026b). All series were accessed in May 2026. The European Union membership and post-Soviet indicators were constructed by the authors as described in Table 1.

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APPENDIX A

Table A1. Economies in the estimation sample

Economy	Income group	PS	N	Economy	Income group	PS	N
Albania	Upper middle	No	7	Ireland	High	No	10
Argentina	Upper middle	No	7	Israel	High	No	11
Armenia	Upper middle	Yes	4	Italy	High	No	11
Australia	High	No	10	Japan	High	No	10
Austria	High	No	11	Kazakhstan	Upper middle	Yes	7
Azerbaijan	Upper middle	Yes	9	Kiribati	Lower middle	No	5
Belarus	Upper middle	Yes	11	Kuwait	High	No	6
Belgium	High	No	11	Kyrgyzstan	Lower middle	Yes	6
Bolivia	Lower middle	No	2	Latvia	High	Yes	9
Brazil	Upper middle	No	8	Lithuania	High	Yes	10
Bulgaria	High	No	10	Luxembourg	High	No	11
Cabo Verde	Upper middle	No	5	Malta	High	No	10
Chile	High	No	10	Mauritius	Upper middle	No	10
China	Upper middle	No	10	Moldova	Upper middle	Yes	10
Costa Rica	High	No	6	Nauru	High	No	3
Croatia	High	No	10	Netherlands	High	No	10
Cyprus	High	No	10	Norway	High	No	11
Czechia	High	No	10	Poland	High	No	10
Denmark	High	No	11	Portugal	High	No	11
Dominican Republic	Upper middle	No	5	Romania	High	No	10
Ecuador	Upper middle	No	5	Russia	High	Yes	9
Egypt	Lower middle	No	4	Seychelles	High	No	4
El Salvador	Upper middle	No	10	Singapore	High	No	4
Estonia	High	Yes	9	Slovakia	High	No	10
Finland	High	No	10	Slovenia	High	No	11
France	High	No	10	South Africa	Upper middle	No	11
Georgia	Upper middle	Yes	9	Spain	High	No	11
Germany	High	No	11	Sweden	High	No	11
Greece	High	No	10	Switzerland	High	No	11
Guatemala	Upper middle	No	6	Thailand	Upper middle	No	11
Hungary	High	No	10	Turkiye	Upper middle	No	9
Iceland	High	No	10	Ukraine	Upper middle	Yes	10
Indonesia	Upper middle	No	9	United Kingdom	High	No	11
Iran	Upper middle	No	3	Uzbekistan	Lower middle	Yes	5

Note: Income group follows the World Bank classification (high, upper middle, and lower middle income) as recorded in the estimation sample. N is the number of survey-wave observations per economy; PS marks post-Soviet successor states. In total, the sample comprises 68 economies and 592 observations; the 13 post-Soviet economies contribute 108 observations. EU membership changes status within the window for Bulgaria and Romania in 2007, Croatia in 2013, and the United Kingdom in 2021.

APPENDIX B

Table B1. Pairwise correlations, estimation sample

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Env. expenditure, % of total	1.00														
(2) Env. expenditure, % of GDP	.91	1.00													
(3) EGDI (t–1)	–.04	–.07	1.00												
(4) OSI (t–1)	–.10	–.12	.89	1.00											
(5) TII (t–1)	.02	–.01	.93	.73	1.00										
(6) HCI (t–1)	–.01	–.04	.49	.23	.34	1.00									
(7) GDP per capita (log)	.05	.02	.75	.52	.74	.57	1.00								
(8) GDP growth	.01	–.03	–.26	–.28	–.24	–.05	–.14	1.00							
(9) Population (log)	–.47	–.56	.08	.21	–.05	.02	–.11	–.04	1.00						
(10) Trade openness	.38	.37	.14	.00	.23	.09	.27	.07	–.56	1.00					
(11) CO2 per capita	–.03	–.04	.25	.10	.22	.42	.53	.03	–.05	.21	1.00				
(12) Urban population	–.10	–.04	.52	.40	.51	.31	.64	–.15	–.02	.07	.39	1.00			
(13) Industry value added	–.25	–.31	–.24	–.15	–.30	–.06	–.23	.19	.38	–.22	.11	–.23	1.00		
(14) Government effectiveness	.11	.08	.73	.54	.71	.52	.89	–.14	–.15	.27	.37	.52	–.30	1.00	
(15) EU membership	.14	.17	.40	.23	.38	.44	.49	–.15	–.13	.36	.18	.13	–.31	.47	1.00

Note: Pearson correlations on the estimation sample of 592 country-year observations (586 to 592 pairwise, as industry value added and the GDP share of environmental expenditure have minor gaps). Variables and their order follow Table 2. Correlations above 0.8 in absolute value link the two measures of the dependent variable (0.91), the composite index with its online service (0.89) and telecommunication infrastructure (0.93) components, and government effectiveness with GDP per capita (0.89).

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