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Economic Growth in the Digital Era: Innovation, Cultural Dimensions, and Environmental Policy Challenges

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This research provides an analysis of the effects of innovation, digitalization, and environmental taxation on economic growth, as well as the moderating effect of national cultural traits within the context of the European Union's member states. It addresses a need that arises as the significance of technological transformation has increased within the context of multiple nations with diverse cultures. The study analyzed a balanced panel dataset covering a time period of 2013 to 2022 for 27 EU member states, with a total of 270 observations. We employed a mixture of econometric analyses, including ordinary least squares (OLS) estimates, fixed-effects panel regressions, and a form of lagged variable modeling. Environmental tax revenues are found to have a negative effect on GDP per capita in the short run. Scientific output from research and digitalization engagement levels (with a measurement variable based on online purchasing) both show positive impacts on the rate of economic growth. To account for the potential effects of culture on the outcomes, countries are grouped into 3 clusters based upon Hofstede's cultural dimensions. Results show that cultural differences play an important role in determining the effect of innovation, environmental policy, and environmental taxation on economic outcomes. In short, EU member state countries with improved rates of growth were observed in the context of low levels of uncertainty avoidance and high levels of individualism. The findings of this study, as discussed in the empirical section of this paper, provide several contributions to research and future policy considerations. For theoretical contributions, the study expanded upon macroeconomic models of empirical strategies by adding cultural elements, following the work of Hofstede. As for future policies, the results suggest that customizing innovation and environmental policy to the context of the national culture may leverage better performance of these outcomes.

Keywords: *Digital Economy; Economic Growth; Hofstede; Innovation.*

Introduction

Paul Romer, an economist and Nobel laureate in economic sciences, demonstrates in his work (Nobel Prize, 2018) how knowledge can drive long-term economic growth. Romer's work highlights innovation as a key element in a country's economic development. The integration of new technologies and optimization of economic processes contribute to increased efficiency and productivity. Optimizing economic processes involves not only introducing new technologies but also rethinking these processes from different perspectives, which may be influenced by cultural factors. Steve Jobs, one of the people who revolutionized the digital era through innovation, highlighted: "Innovation is the ability to see change as an opportunity , not a threat." (Baker, 2024; A. Jones *et al.*, 2016)

The progress of an economy can be influenced by aspects related to cultural diversity, even if, from a technological standpoint, all prerequisites for its realization exist. Cultural diversity can sometimes hinder economic development, even though, from a strictly technological perspective, an increase in efficiency and productivity should occur (Hall, 2023). Certain studies (Nettle *et al.*, 2007) indicate that even the linguistic diversity of a country can lead to reduced economic performance. Moreover, the study (G. Jones et al., 2020) highlighted the link between innovation and the cultural dimensions of a nation. Uncertainty avoidance and masculinity are negatively correlated with innovation, while individualism is positively correlated with innovation.

Some countries have widely adopted technological advancements due to the lack of alternatives in society. For example, Kenya has significantly expanded its mobile payment system due to limited access to traditional banking services (OpenMind, 2016).

Research and innovation share a causal relationship, as any study has the potential to drive innovation, making investments in research crucial for any national economy. The result of research activity is scientific output published in specialized journals, which fuels innovation. Therefore, investments in research and the dissemination of findings through academic journals are essential for innovation and economic growth.

While many studies have examined the role of innovation, environmental taxation, or digitalization in economic performance, few have done so in an integrated manner within an empirical framework. Even fewer studies have investigated the moderating role of culture, in which cultural traits were measured using Hofstede's dimensions. Most studies isolate these factors or examine them while dealing with a specific region or institutional context, and they do not consider culture as cultural heterogeneity in the EU. This study fills the gap by integrating economic, digital, environmental, and cultural variables into a robust econometric analysis using data from the EU member states

and a panel dataset. Furthermore, the study contributes to the understanding of national characteristics that might shape the influence of innovation and policy on economic growth.

To address policies and strategies for the sustainable growth of national economies, it is necessary to fully understand the influences of factors such as innovation, the environment, and digitalization. This study explores the interactions between these factors, focusing on how economic growth is influenced by innovation through research efforts, digitalization, the growing prevalence of environmental taxes, and e-commerce.

RQ1: To what extent do investments in research and development, environmental policies (as reflected by environmental taxes), and digitalization (measured through e-commerce activity) influence economic growth across European Union member states during the period of 2013 to 2022?

Cultural diversity can influence the progress of an economy; therefore, understanding how culture affects innovation, digital technologies, and environmental factors leads us to the second research question.

RQ2: How do national cultural traits, based on Hofstede's dimensions, moderate the relationship between innovation, digitalization, environmental policies, and economic growth in the context of cultural diversity within the European Union?

This study's distinctive feature is its analysis of the contribution of environmental factors and digital technologies to economic growth, while also integrating cultural traits, thus offering a unique perspective on their impact. To test the formulated hypotheses, we employed a set of econometric models, ranging from robust linear regressions to fixed-effects panel analyses. These methods allowed us to explore the links between innovation, digitalization, and environmental policies, while also accounting for the unique cultural influences of the studied countries.

Continuing this work, we analyzed the existing context through a literature review and presented the research methodology. We then obtained results from data analysis and discussions that highlight their implications. The conclusions summarize the findings and offer perspectives for future research in this field.

Literature Review

In this section, the existing literature related to innovation, environmental policies, digital transformation, and economic development, particularly regarding the intersection with national cultural characteristics, is reviewed. The review synthesizes and connects the theoretical contributions, empirical findings, and methodological approaches from a range of academic viewpoints that speak to this multifaceted area of inquiry. The review pays particular attention to the episode of the European Union, characterized by common economic frameworks and considerable cultural diversity.

Overview of Thematic Domains and Gaps

Recent studies have increasingly explored the individual effects of innovation, environmental policy, and digitalization on economic development, particularly in the context of advancing sustainability. Innovation and R&D are widely recognized for their potential to improve productivity over the long term; environmental taxation is viewed as a mechanism to internalize ecological costs; and digitalization is considered a key driver of structural transformation in modern economies.

However, this growing body of research remains fragmented. The vast majority of empirical studies continue to treat these factors in isolation, failing to integrate them into a cohesive analytical framework. Furthermore, while Hofstede's cultural dimensions are well established in management and behavioral sciences, their application in macroeconomic models remains limited. The majority of research overlooks the moderating role culture may play when examining the effectiveness of innovation systems, digital transitions, or environmental policies.

This oversight is particularly salient in the case of the European Union, where countries operate under shared policy architectures but vary along cultural dimensions. The study we report on addresses this gap by providing a multidimensional econometric model that combines economic, environmental, digital, and cultural dimensions. In doing so, it seeks to establish a more holistic explanation for differences in economic performance across European Union member states.

The following sections examine each thematic pillar in greater detail, beginning with the role of innovation and research and development in fostering economic growth.

Environmental Policies

Environmental protection is the goal of modern society. The influence of environmental policies on economic growth has been analyzed from many perspectives. One point of view is that environmental taxes hurt economic growth (Abdullah & Morley, 2014; Rakpho et al., 2023). However, in the long term, they can increase GDP through how these taxes are used, for example, as investments in innovation. Counteracting the adverse effects of environmental taxes on economic growth is achieved by reinvesting in revenue (Mashhadi Rajabi, 2023).

Although a number of studies (Charfeddine et al., 2020; Ojha et al., 2020; Hassan et al., 2020) argue that environmental taxes raise production costs and slow economic growth, others have highlighted the long-term benefits of environmental taxes by investing tax revenues into innovation and green technologies (Mashhadi Rajabi, 2023; Karmaker et al., 2021). This discrepancy in thinking reflects a broader debate in the literature on the short- or long-term effects of environmental taxation. This study contributes to this debate by introducing cultural moderating factors to explain national variation in environmental policy outcomes.

The contrasts in the literature emerge from whether environmental taxes create economic constraints or stimulate development, which is largely a function of policy design and fiscal reinvestment strategies. Some studies indicate that environmental policies are effective when part of broader strategies designed to transition sectors of the economy towards less polluting alternatives. Others argue that environmental taxes simply internalize costs to final product prices, thereby dampening consumption and

slowing growth. Evidence from empirical studies in countries such as China (Wen et al., 2021; Zhao et al., 2023; Y. Wang & Yu, 2021) suggests that, although financial burdens may arise in the short term, policy initiatives have stimulated innovation and green investment growth.

There are also studies by (Mashhadi Rajabi, 2023) suggesting that, in the long run, environmental taxes, when used to fund R&D projects in green technologies, boost innovation and support sustainable economic growth. (Charfeddine *et al.*, 2020; Hassan *et al.*, 2020) show that environmental policies are effective when they are part of broader strategies for transforming economic sectors into less polluting ones. The study (Ojha *et al.*, 2020) argues that any environmental tax ultimately appears in the final price of goods and services, which can reduce demand and have a negative impact on economic growth.

A report by the (World Bank, 2023b) underlines that the effect of introducing environmental taxes depends fundamentally on how governments manage the revenues. Report (McKinsey & Company, 2023a) indicates that transitioning toward a green economy creates jobs, especially in the energy sector, and can even lead to the emergence of new markets.

Polluting industries still represent a significant share of GDP in many countries. Increasing environmental taxes may impose extra costs on these industries. However, by strategically reinvesting tax revenues, such policies could support innovation and the shift toward a more sustainable economy, thereby mitigating long-term negative effects. Research shows that, although environmental protection taxes initially harm the financial performance of polluting companies, over time they spur investments in innovation and energy efficiency (Duan & Rahbarimanesh, 2024; Lei & Zhao, 2024; Zhao *et al.*, 2023; Qi *et al.*, 2023; X. Xu & Huang, 2024). Studies that evaluated the impact of an environmental tax in China (Wen *et al.*, 2021; Zhao *et al.*, 2023; Y. Wang & Yu, 2021) showed that, while the tax reduced bank lending to highly polluting firms, it also fostered investments in green innovation. Another study examined how environmental taxes affect economic performance and innovation investments in China's polluting industries. Findings revealed a positive effect on technological innovation, even though some companies experienced additional financial pressure (Karmaker *et al.*, 2021; Z. Wang *et al.*, 2022; C. Zhang *et al.*, 2022; Zhao *et al.*, 2023; Y. Wang & Yu, 2021).

These observations support the following research hypothesis:

H1: Environmental tax revenues negatively impact short-term economic growth by increasing costs for polluting industries.

This research operationalizes environmental policies through the use of environmental tax revenues (ETX), a tax-based fiscal component of the set of environmental policy instruments. We recognize that environmental policies include regulatory measures, subsidies, and other non-fiscal instruments; however, in the absence of data, ETX is the most well-defined and comparable metric across EU countries.

Innovation and R&D

The literature on this subject varies significantly in assessing the influencing factors related to innovation, with opinions not being unanimous, even though the general importance of innovation in the economy is recognized by all authors (Barreto et al., 2022).

The significance of R&D expenditures on innovation is particularly noted in OECD countries (Ciaffi *et al.*, 2024; Ding *et al.*, 2024; Dritsaki & Dritsaki, 2023). The study (Meo *et al.*, 2013) analyzed research and development spending and the number of scientific publications and their influence on the Gross Domestic Product (GDP) of 40 Asian countries, identifying a correlation between research spending and the number of scientific journals. However, researchers found no association between per capita GDP and the number of scientific publications. Conversely, the study (Al-Marzouqi & Arabi, 2022) analyzes scientific production correlating with gross domestic product to indicate a country's economic growth level. In contrast, (Jiang et al., 2022; Ma *et al.*, 2022; Pinto & Teixeira, 2020) identified an adverse effect of scientific research on economic growth.

This divergence points to a fundamental tension in the literature: while R&D is often championed as a cornerstone of innovation-led growth, the economic return on such investments varies significantly. In emerging economies, excessive or misaligned funding may delay economic benefits due to low absorption capacity or weak innovation systems. Questions remain about the optimal scale, focus, and timing of R&D investments, especially in cross-country contexts.

This occurs when allocated financial resources are excessive and fail to generate immediate benefits. A recent World Bank report (World Bank, 2023c) indicates that R&D investments support emerging economies. These investments help transfer technology and adapt global innovations to local needs. Report (McKinsey & Company, 2024) also notes that economies allocating substantial resources to R&D are better equipped to tackle global market challenges, especially in advanced-technology sectors.

Another key aspect is the link between innovation and digitalization. (J. Zhang *et al.*, 2022) found that digital economies fuel innovation by facilitating quick access to information, reducing barriers to market entry, and boosting the efficiency of economic processes. Moreover, (Appiah-Otoo & Song, 2021) demonstrated that information technologies can accelerate innovation, particularly in countries with well-developed digital infrastructure. In the short term, scientific research is costly. However, R&D investments foster technological progress, which benefits the economy over time.

Although R&D investments are generally regarded as drivers of long-term growth and innovation (Ciaffi *et al.*, 2024; Soete *et al.*, 2022), their short-term economic benefits are more contentious. Some studies (Jiang *et al.*, 2022; Pinto & Teixeira, 2020) suggest that excessive or misaligned R&D spending may delay economic returns, particularly in emerging economies with weak absorption capacity. This raises questions about the optimal timing and targeting of

research expenditures, issues that remain insufficiently addressed in cross-country empirical work.

The studies (Badulescu *et al.*, 2024; Castelli *et al.*, 2024; Neagu *et al.*, 2022; Soete *et al.*, 2022) showed that in Central and Eastern European countries, R&D outcomes take longer to materialize in the economy, as transforming ideas into practical solutions requires time. Similarly, (Shah *et al.*, 2024; Vijayaraghavan *et al.*, 2022; Zakaria *et al.*, 2021) highlighted that limited infrastructure and the lack of a coherent strategy in emerging economies delay the positive impact of research. The research studies (Ke, 2023; Ma *et al.*, 2022; Pinto & Teixeira, 2020) demonstrated that fundamental research paves the way for major technological breakthroughs, with a profound effect on the global economy. The studies (Alston *et al.*, 2023; Betarelli Junior *et al.*, 2020; Soete *et al.*, 2020, 2022) emphasized that R&D investments improve productivity, but these benefits become apparent only after a maturation period, when new technologies are adopted and integrated into the economy.
These observations support the following research hypotheses:

H2: Investments in R&D affect economic growth, though the direction and timing of effects may differ across models.

H3: Scientific publications have a positive impact on economic growth, reflecting the role of research outputs in supporting innovation and productivity gains.

Digital Economy

Digital transformation has become a central pillar of modern economic systems. The following review summarizes both macro- and firm-level findings on how digitalization affects economic performance.

Innovation and digital transformation serve as the underpinnings of technology and are evidence of changing business processes, resulting in numerous economic efficiencies or sustainable growth. However, within the context of technological progress, the impact on the economy does not occur in a vacuum. The significance of technology from an economic perspective is that, by its nature, it is dependent on environmental policies, which often stimulate and inhibit growth, depending on how they are structured and implemented. Therefore, consideration of the interaction between innovation and regulation is warranted when examining sustainability.

Recent studies show a positive correlation between the use of digital technologies and improvements in sustainable development indicators, such as DESI, SDG, and Green Growth (Bocean, 2025; Mazza *et al.*, 2024; Nosratabadi *et al.*, 2023; Consilium Europa, 2020). Research by (Pérez-Martínez et al., 2023) highlights that digitalization significantly contributes to economic and social development, yet it may negatively impact environmental sustainability. In ASEAN countries, (Nurdiana et al., 2023) find that better access to information lowers unemployment and enhances quality of life. In the corporate sector, (Zhu, 2024) notes that digitalization stimulates eco-innovation and boosts green economic efficiency, although adoption rates vary. (Bahl *et al.*, 2023) show that adequate workforce training improves bank performance and supports the achievement of SDG goals 1, 5, and 8. (Yan *et al.*, 2023) emphasize the importance of combining eco-digitalization with green finance to foster sustainability, underlining the need for suitable policies. In Romania, (Stan *et al.*, 2020) explored how digitalization affects sustainable development using DESI and SDG indicators. At the European Union level, (Stoliarov & Sinkovskiy, 2024) found that digital transformation enhances economic performance and strengthens sustainability. The pandemic accelerated the adoption of digital technologies, confirming their crucial role in building resilient and energy-efficient economies. However, digitalization poses challenges such as cybersecurity risks, the loss of traditional jobs, and economic polarization. Embracing new technologies depends on cultural context and workforce readiness, prompting the need for tailored policies in each country. Investing in digitalization can support economic growth and ecological transition, but balancing innovation, regulation, and adaptability is essential.

Digital technology helps optimize decision-making processes, boosting market demand and lowering production costs (Bratta *et al.*, 2023; Hagberg & Kjellberg, 2020; Peng & Li, 2023). According to studies (Dallocchio et al., 2024; Sharabati et al., 2024; Zou & Cheshmehzangi, 2022), the use of digital technologies is reshaping the economic structure by promoting e-commerce and expanding access to online markets. A report of (World Bank, 2023a) reveals that expanding the digital economy lowers trade barriers and fosters global economic integration, thus contributing to sustainable economic growth. At the same time, (Chen *et al.*, 2024; Q. Wang & Wei, 2023; J. Xu & Li, 2022) note that the effects of digital research can be delayed because research-based innovations need time to translate into tangible economic benefits. Recent report (McKinsey & Company, 2023b) findings confirm that economies making substantial R&D investments in digital technology become more resilient and competitive in the long run.

Broader access to online markets is a key driver of economic growth. The articles (Chui *et al.*, 2023; Hoyer *et al.*, 2020; Meng & Gong, 2024) show that adopting digital commerce technologies sparks innovation, cuts transaction costs, and improves the consumer experience. Integrating digital solutions, such as artificial intelligence and automation, speeds up economic processes and creates new market opportunities. The study (Yasmeen *et al.*, 2024) examines how the digital economy, green technologies, and economic activities influence growth and environmental sustainability in G7 countries. Their study shows that digitalization and technological innovations both stimulate economic expansion and help reduce carbon emissions. The research (B. Wang & Wang, 2025) highlights that digitalization significantly boosts green economic growth in China by advancing technological innovation and modernizing industrial structures. Their findings indicate that, while foreign direct investments can dampen this effect, intensive R&D spending strengthens it. Additionally, papers (Behera *et al.*, 2024; Soete *et al.*, 2022; J. Zhang *et al.*, 2022) find that regions running pilot programs for digital currencies attract more businesses and spur fixed-asset investments, thereby contributing to economic growth.
These observations support the following research hypothesis:

H4: The growth of online purchasing activity positively impacts economic growth by enhancing digital market integration.

While the literature largely supports the positive effects of digitalization on economic performance, its interaction with institutional and cultural contexts remains understudied. Furthermore, few empirical models assess how digital adoption impacts economic growth differently across countries with varying socio-cultural characteristics, a gap that this study aims to address.

Cultural Diversity and Economic Development

National culture influences the adoption of technologies, environmental regulation, and innovation outcomes by shaping societal values and behaviors (Hofstede, 1984; Baudier et al., 2022). While the overall importance of innovation is widely acknowledged (Barreto et al., 2022), the literature remains divided on how specific cultural traits, such as individualism, uncertainty avoidance, or power distance, enhance or inhibit economic performance (Kaasa & Vadi, 2010; Gyedu et al., 2021).

Other dimensions, such as high uncertainty avoidance, may suppress entrepreneurial activity and slow down the diffusion of new technologies. There is no agreement in the literature regarding whether culture is a catalyst or a constraint, particularly in comparisons of multiple countries. Our research addresses this discussion by empirically testing the differentiated effects of cultural clusters on economic outcomes.

Recently, the field of cultural economics has turned its attention to the idea that culture benefits economic performance through several mechanisms: institutional quality, trust and cooperation, entrepreneurial mindset, and consumer preferences (Gorodnichenko & Roland, 2017; Tabellini, 2010; Hu & Qi, 2022; Kara & Dheer, 2023). The cultural traits of firms can be reflected through their willingness to innovate, consumers' willingness to adopt new technologies, and regulators' openness to regulatory design. These mechanisms allow us to discern how cultural context interacts with innovation systems, digitalization, and environmental policies, which in turn may inform growth paths.

The research also assesses how cultural context influences the effectiveness of digital adoption, R&D intensity, and environmental policy on economic policy while providing an integrated view across EU member states.

Recent research underscores the crucial role of national culture in shaping economic behavior and spurring innovation. The GLOBE project, led by (House *et al.*, 2004) and lately by (Alipour, 2021; Posthuma e*t al.*, 2022; Urbach *et al.*, 2021), extends Hofstede's cultural dimensions analysis and illustrates how future orientation and collectivism positively influence economic development. Likewise, papers (Czupryna & Schaff, 2024; Kostis, 2021; Song *et al.*, 2022) demonstrated that core values affect the priorities of national economic strategies and provide a strong foundation for understanding cultural diversity.

In the context of digitalization, cultures with a higher tolerance for uncertainty more readily adopt emerging technologies, thus encouraging innovation and promoting economic growth (Venkatesh *et al.*, 2016).

In addition, culture influences corporate strategic choices, especially in sectors where innovation and technology change requires risk-taking and long-term investment (Henrich, 2020). Corporate innovation may be promoted by cultures that demonstrate high trust and an orientation toward the future, while risk-averse cultures may dissuade technology adoption or even delay technology adoption.

The study (Welzel *et al.*, 2022) notes that societies characterized by secular-rational values and self-expression orientations integrate digital technologies swiftly, thereby speeding economic progress. The research by (Trompenaars & Hampden-Turner, 2020) reveals that nations with a universalist outlook and a proactive stance toward economic shifts are better positioned to develop resilient, innovative economies. Meanwhile, research (Chui *et al.*, 2023) emphasizes that aligning cultural values with investments in digitalization makes a significant contribution to economic growth, especially in emerging economies.

These findings highlight the significance of learning about the interaction between culture, innovation, and policy instruments, and underscore the need for culturally responsive economic approaches. Therefore, policies must be sensitive to the cultural context to achieve the maximum possible effect on sustainable development (Benito *et al.*, 2024; Kashima, 2020; Serra *et al.*, 2022; Zheng *et al.*, 2021). Although there is rising theoretical interest, there is a lack of empirical studies that consider cultural variables within econometric models that include innovation, digitalization, and environmental taxes. This research will fill that gap.

Although Hofstede's framework offers a valuable comparative basis for the analysis, it may be insufficient to capture the cultural complexity that drives economic behavior. It is more recent models (Gorodnichenko & Roland, 2017; Henrich, 2020) that show the integration of more factors such as generalized trust, civic capital, and historical institutional legacies, may further enrich our understanding of how culture shapes the channels through which innovation, digitalization, and environmental policies impact economic growth.

These observations support the following research hypothesis:

H5: Cultural traits fostering innovation and adaptability accelerate digital adoption and economic growth.

Concluding Observations and Justification for the Current Study

The reviewed literature confirms the relevance of innovation, digitalization, and environmental policies as key drivers of economic performance. It also reveals significant complexity and, in many cases, conflicting findings regarding their short- and long-term effects. R&D investments are widely viewed as related to productivity growth, although the economic benefits will vary over time and differ by geography. Environmental taxes have a dual nature, in that they constrain economic activity in the short-run, but allow for innovation and sustainability in the long-run. The digital transformation of businesses is also a

consistent growth driver, but it creates inequities and it has a great potential to produce structural changes to labor markets. Recently, an academic interest in these subjects has emerged and increased, while research has considered these factors in isolation, and the national culture has never been taken into account as a context. There is a notable lack of integrated empirical studies that examine how cultural dimensions moderate the relationship between technological and policy-driven factors and economic outcomes, especially in a geographically and culturally diverse region like the European Union.

This research advances the state of the art by developing a thorough econometric framework that takes into account cultural clusters, R&D intensity, environmentally-leveraged taxation, and indicators of digital engagement. The need to shed light on differences in influence due to structural and contextual factors helps to inform a more nuanced understanding of the nature of economic growth as not only an output of innovation and regulation, but also of deeper cultural dynamics.

Conceptual Framework

An integration conceptual framework is presented, based on the literature reviewed, that links the three principal drivers of economic growth as innovation (as proxied by R&D expenditure and scientific publications), environmental (as assessed using environmental tax revenues), digitalization (as measured by e-commerce activities), and national culture (as a measure using Hofstede's dimensions variables).

All of these factors are presumed to have a direct impact on GDP per capita, showing the complexity of economic development in today's society; furthermore, culture is considered an intrinsic factor describing national economic performance, and not merely an external moderating factor.

This conceptual framework serves as a basis for the econometric models examined in the research and allows for investigation of heterogeneity economic outcomes across distinct cultural contexts.

The conceptual framework represents the structure through which these variables interact with each other, with figure 1 providing a reference for the influence of technological, policy, and cultural variables on economic growth.

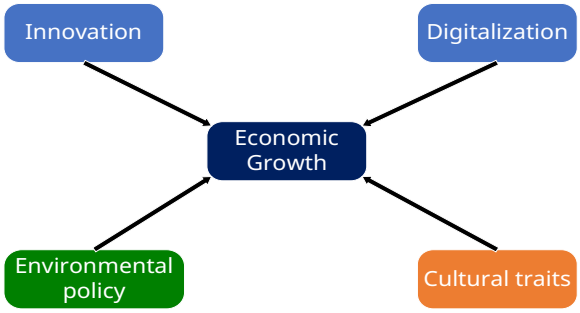

Figure 1. Conceptual Framework: the Influence of Innovation, Digitalization, Environmental Policy, and Cultural Traits on Economic Growth

Research Methodology

Regression Models

Empirical regression models are fit to data to test the effect of environmental policies, digital technologies, investment in research, and GDP growth. The dependent variable is GNP per capita, while the independent variables are environmental tax; R&D expenditure; scientific publications; and internet purchases. The control variable for unemployment comes in to identify its effect, and Hofstede's cultural clusters serve as dummy variables to account for culture. Based on previous studies (Appiah-Otoo & Song, 2021), an econometric model was developed in order to estimate the impact of environmental policies, R&D expenditures, scientific publications, and digitalization on gross domestic product (GDP).

$$\text{GDP} = \alpha + \beta_1 \text{ETX} + \beta_2 \text{RDE} + \beta_3 \text{SPU} + \beta_4 \text{INP} + \beta_5 UNEMP + \beta_6 HOF + \varepsilon \ (0)$$

where GDP is GDP per capita, ETX is the environmental taxes, RDE is research and development expenditures, SPU is the number of fractional scientific publications, and INP is the share of individuals who made online purchases. UNE is the unemployment rate in relation to the labor force. HOF is a dummy variable representing Hofstede's cultural clusters, which classify countries based on six cultural dimensions and allow for the assessment of cultural influences on economic growth and technological adoption. A logarithmic transformation was applied to GDP (GDPLN), unemployment rate (UNELN), and scientific publications (SPULN) to reduce skewness and improve the normality of their distributions, consequently ensuring more reliable and interpretable regression coefficients (Table 3).

For a more comprehensive understanding of the relationship between environmental policies, digitalization, and economic growth, we used the OLS regression and panel data regression models. The OLS approach enabled to capture the static nature of the relationships between variables in a cross-sectional framework, thus showing the aggregate effects of explanatory factors at one point in time. The approach based on panel data models, which focus on dynamic aspects over time effects, controlling for country-specific effects and thus mitigating the risk of omitting relevant variables.

By using both of these methods, we were able to ensure a thorough investigation of the same by drawing a comparison between cross-sectional and longitudinal views. Such a duet also acted as a robustness check confirming the conformity of the results across the multitude of estimation techniques. The panel data models also enabled us to measure the individual impact of each variable on per capita GDP, while taking into account cross-country and temporal variation.

Model 1: OLS Regression without control variable

A first linear regression model was developed without using the control variable:

$$GDPLN = \alpha + \beta_1 ETX + \beta_2 RDE + \beta_3 SPULN + \beta_4 INP + \varepsilon \quad (1)$$

Model 2: OLS regression with control variable (Unemployment)

The second model is a linear regression model with the control variable:

$$GDPLN = \alpha + \beta_1 ETX + \beta_2 RDE + \beta_3 SPULN + \beta_4 INP + \beta_5 UNELN + \varepsilon \quad (2)$$

Model 3: Panel regression without control variable

The third model is a panel regression model without the control variable:

$$GDPLN_{ij} = \alpha + \beta_1 ETX_{ij} + \beta_2 RDE_{ij} + \beta_3 SPULN_{ij} + \beta_4 INP_{ij} + \varepsilon_{ij} \quad (3)$$

where i *denotes the country and* j *denotes the year*.

Model 4: Panel regression with control variable

The fourth model is a panel regression model with the control variable:

$$GDPLN_{ij} = \alpha + \beta_1 ETX_{ij} + \beta_2 RDE_{ij} + \beta_3 SPULN_{ij} + \beta_4 INP_{ij} + \beta_5 UNELN_{ij} + \varepsilon_{ij} \quad (4)$$

where i *denotes the country and* j *denotes the year*

Model 5: OLS regression with Hofstede cluster 2 and 3 as dummy variable

Model 5 is an OLS linear regression model without the control variable but with the dummy variable Hofstede cluster 2 and 3:

$$GDPLN = \alpha + \beta_1 ETX + \beta_2 RDE + \beta_3 SPULN + \beta_4 INP + \beta_5 HOF2 + \beta_6 HOF3 + \varepsilon \quad (5)$$

Model 6: OLS regression with control variable and Hofstede cluster 2 and 3 as dummy variable

Model 6 is an OLS linear regression model with the control variable and the dummy variable Hofstede cluster 2 and 3:

$$GDPLN = \alpha + \beta_1 ETX + \beta_2 RDE + \beta_3 SPULN + \beta_4 INP + \beta_5 HOF2 + \beta_6 HOF3 + \beta_7 UNELN + \varepsilon \quad (6)$$

Model 7: Panel Regression with Lagged Explanatory Variables

To mitigate anticipated endogeneity issues and to more accurately depict the delayed economic effects of innovation and policy, we estimated a panel regression model using one-period lagged values of our primary explanatory variables. The model specification is as follows:

$$GDPLN_{it} = \alpha + \beta_1 ETX_{it-1} + \beta_2 RDE_{it-1} + \beta_3 SPULN_{it-1} + \beta_4 INP_{it-1} + \beta_5 UNELN_{it-1} + \varepsilon_{it}$$

Where:

t−1 represents the value of the variable in the previous year;

i denotes the country and t the time period;

All explanatory variables were lagged by one year to minimize reverse causality and capture delayed effects. This model was estimated using fixed effects with robust standard errors clustered at the country level, consistent with previous specifications.

This model assumes that the errors have a mean of zero and that their variances are constant (homoscedasticity) and not serially correlated, and also that they are normally distributed. Variance estimates reported are robust standard errors. The implication of these robust esteem is that it addresses the problems of heteroscedasticity of the errors. In the case of panel data models, we conducted a Hausman test to choose between fixed-effects and random-effects estimation and opined for a Wooldridge test for serial autocorrelation. The panel data models incorporated control variables within the robust standard errors. Because the control variable (unemployment rate) was correlated with the other independent variables, especially the internet use for purchasing goods and services, the panel models with the control variable included used standard errors clustered at the country level. For all the models, the Hausman test revealed that the fixed-effects model is the most acceptable one. The modified Wald test (xttest3) was conducted to check for the presence of heteroscedasticity, which evaluates whether the errors can be considered as having a constant variance (homoscedasticity) or whether the heteroscedasticity assumed to be at the panel unit level. To detect possible multicollinearity, we computed the Variance Inflation Factor (VIF) for all independent variables. The results showed that all VIFs were below the conventional threshold of 5, indicating that multicollinearity problem was not a serious one.

Endogeneity Considerations

One of the potential limitations of our econometric models is endogeneity, particularly in the relationship between GDP per capita and innovation or digitalization variables, such as R&D expenditure and internet purchases. Endogeneity may arise from reverse causality or omitted variables that influence both the independent and dependent variables. While fixed-effects models partially mitigate these concerns by controlling for time-invariant unobserved heterogeneity, we acknowledge that they do not fully eliminate the risk of simultaneity bias.

Due to limitations in our sample size (27 countries over 10 years) and the risk of instrument proliferation, we did not employ the Generalized Method of Moments (GMM). Nonetheless, as a robustness check, we estimated alternative models using lagged values of the main predictors, and the coefficients were in the same direction and statistically significant. This suggests a relatively stable finding in the presence of endogeneity.

To further mitigate endogeneity risks, Model 7 incorporates lagged explanatory variables, which reduces the possibility of reverse causality between economic growth and predictors such as R&D or digitalization.

Justification of Control Variables

The selection of control variables was informed by empirical precedent and economic rationale. Unemployment was included as a predictor since it has a direct effect on household consumption and labor market flows, both of which are closely linked to gross domestic product (GDP) variation. Other standard economic controls, such as trade openness or education levels, were not included due to constraints in terms of data availability and correlated predictors. Future studies may look to expand the control list to include these variables.

Robustness of Clustering Results

The K-means algorithm, utilizing Hofstede's six cultural dimensions, was employed to group the EU countries into cultural clusters. To test the stability of the clustering results, we tried several k values (i.e., numbers of

clusters) and multiple initialization seeds. The silhouette score and the Calinski-Harabasz index indicated that three clusters generated the best results. Consistent results across the multiple attempts and k values support the stability of the cultural typology captured by the clustering in the regression model.

Model Diagnostics

A series of diagnostic tests were performed to check the validity of our regression estimates:

Heteroscedasticity: White's test and the Breusch–Pagan test indicated no significant heteroscedasticity in Models 1 and 2 ($p > 0.05$). However, to ensure robustness across all models, we computed robust standard errors using the vce(robust) and vce(cluster id) options where appropriate.

Autocorrelation: For panel regressions, we assessed potential serial correlation in the residual structure by analyzing the dependence between successive residual terms. Given the strong persistence detected, we employed cluster-robust standard errors (vce(cluster id)) at the country level to ensure consistent and unbiased inference..

Multicollinearity: We computed the Variance Inflation Factors (VIF) for all independent variables. All VIFs were below 5, which is an acceptable threshold for measuring multicollinearity.

Model Specification: We implemented the Hausman test for the fixed or random effects models and found support for the use of fixed effects.

The Hausman test was employed to assess the correct specification between fixed-effects and random-effects models. The test results ($\chi^2(5) = 46.37$, $p = 0.0000$) strongly reject the null hypothesis that the differences in coefficients are not systematic. Simply put, the Hausman test indicates the fixed-effects model is more appropriate since it provides consistent estimates if regressors are correlated with unobserved country-specific effects. For the fixed-effects specification without control variables (Model 3), a Hausman test was performed to assess the consistency of the random-effects estimator. The result ($\chi^2(4) = 34.17$, $p = 0.0000$) led to the rejection of the null hypothesis, indicating that the fixed-effects model remains the preferred specification even in the reduced form, as it accounts for unobserved heterogeneity correlated with the regressors.

A Hausman test was also conducted for the lagged panel specification (Model 7) to assess whether a random-effects model would be appropriate. The test returned a chi-squared statistic of 42.93 ($p = 0.0000$), strongly rejecting the null hypothesis. Therefore, the fixed-effects model with lagged predictors remains the consistent and preferred estimation strategy, even when accounting for temporal dynamics.

The Breusch–Pagan test on Model 1 produced a chi-squared value of 1.68 ($p = 0.1943$), suggesting that there was no evidence of heteroskedasticity. Nevertheless, the standard errors are estimated using the robust approach in this paper, to ensure consistency and reliability across model specifications.

The Breusch-Pagan test on Model 2 for heteroscedasticity produced a p-value of 0.1866, indicating that we cannot reject the null hypothesis of constant variance. As a result, we did not observe any meaningful heteroscedasticity in the OLS model 2. However, we calculated robust standard errors in all models to ensure valid inference.

Table 1

Results of Model Diagnostic Tests

Diagnostic Test	Model Tested	Test Statistic	p-value	Conclusion
Hausman Test (FE vs RE)	Model 3	$\chi^2 = 34.17$	0.0000	Fixed effects preferred
Hausman Test (FE vs RE)	Model 4	$\chi^2 = 46.37$	0.0000	Fixed effects preferred
Hausman Test (FE vs RE)	Model 7	$\chi^2 = 42.93$	0.0000	Fixed effects preferred
Breusch–Pagan Test	Model 1 (OLS)	$\chi^2 = 1.68$	0.1943	No heteroscedasticity detected
Breusch–Pagan Test	Model 2 (OLS)	$\chi^2 = 1.74$	0.1866	No heteroscedasticity detected
Residual–Lag Correlation	Panel Models (3,4,7)	0.9985		Strong autocorrelation; cluster-robust SEs used
Mean VIF	All models	All VIF < 2.5		No multicollinearity

(Source: Data processed by the authors using SPSS).

Description of Variables

The details of the explanatory and control variables used in the model are provided in Table 2. The data were taken from the OECD, Eurostat, and World Bank databases.

The dependent variable GDP is one of the broadest and most evaluative indicators of income of a country over a certain time period that starts with a zero or is greater than it, measured in thousand U.S. dollars.

ETX, an abbreviation for environmental tax, refers to taxes imposed for environmental protection purposes. The environmental issues are being reflected in tax rate variations for goods and services. R&D expenditure refers to expenditure on research and development as a percentage of GDP.

Scientific publications refer to all peer-reviewed research papers indexed in international databases.

Internet purchases refer to all transactions conducted online by individuals, measured as the percentage of individuals purchasing goods or services online.

Internet purchases (INP) were chosen as the primary measure of digital economy participation because they reflect both consumer adoption of digital technology and the economy's integration with online platforms. Although broader composite indices like DESI include many dimensions (and are, therefore, less focused and subject to collinearity, internet purchases serve as a more focused, comparable, and consistently available measure across all EU member states and for the full analysis period (2013-

2022). Other potential indicators, such as business-level ICT adoption or broadband penetration, were either incomplete across the dataset timeframe or less directly linked to the consumer-market dynamics that influence GDP through demand-side digital integration.

Unemployment (UNE) is controlled as a variable to isolate its effect on GDP from those of the other independent variables. This should decrease consumption and private investment, both of which support economic growth.

Inclusion of the unemployment rate as a control variable was deemed appropriate for labor market conditions, which transmit multiple effects on GDP per capita through aggregate demand, consumer spending, or labor productivity. Unemployment may also encompass cyclical effects that the other variables in the model do not capture. Variance Inflation Factor (VIF) tests were performed and no evidence of significant multicollinearity existed.

Having employed Hofstede's six cultural dimensions where two or more countries were grouped into three distinct clusters (Table 5), clustering using k-means clustering was applied in IBM SPSS Statistics version 29 (IBM Corp, 2024). The silhouette score and Calinski-Harabasz index were required to determine the optimal number of clusters. In the regression analysis, these clusters are represented as a dummy variable HOF.

Although Hofstede's cultural dimensions are one of the most commonly used measures in cross-national studies, culture itself is a complex, multidimensional construct that is influenced by other factors such as history, religion, and social structure. While the use of Hofstede's dimensions provides an effective approach to operationalizing culture using a parsimonious approach, additional work is warranted using a more extensive framework to account for the greater dimensionality of culture.

Table 2

Variables

Indicators	Description	Unit of measurement	Source
Dependent variable			
GDP	GDP per capita	thousand USD	(World Bank, n.d.-a)
Independent variables			
ETX	Environmental tax	Percentage of GDP	(Organisation for Economic Co-operation and Development (OECD), n.d.-b)
RDE	Research and development expenditure	Percentage of GDP	(World Bank, n.d.-b)
SPU	Scientific publications, fractional counting	fractional counts	(Organisation for Economic Co-operation and Development (OECD), n.d.-a)
INP	Internet purchases - goods or services	Percentage of individuals	(Eurostat, n.d.-b) (Eurostat, n.d.-a)
HOF	Hofstede cluster	1 or 2 or 3	Base on authors grouping
HOF2	Dummy variable Hofstede cluster 2	1 if HOF is 2 and 0 else	
HOF3	Dummy variable Hofstede cluster 3	1 if HOF is 3 and 0 else	
Control variable			
UNE	Unemployment rate	Percentage of population in the labor force	(Eurostat, n.d.-c)

Results and Discussion

Descriptive Statistics and Data Transformations

For each country in the European Union (Appendix 1), observations for twelve years (2011-2022) were analyzed, resulting in a total of 324 observations.

Table 3 provides an overview of the variables used in the analysis. The GDP variable shows an asymmetric distribution with extreme values (as indicated by high kurtosis), potentially distorting the regression estimate. Applying a logarithmic transformation significantly reduced the skewness (0.03) and the kurtosis (2.46), approximating a normal distribution.

Scientific publications (SPU) display a considerable variation, with high skewness and kurtosis. Applying a logarithmic transformation to this variable reduced its skewness and kurtosis.

The environmental tax revenue (ETX) and the R&D expenditure (RDE) have moderate variability. Their distributions are relatively close to normal, so no additional transformation was required.

Online purchases (INP) have a moderate standard deviation and are sufficiently symmetric to be included directly in the analysis without any transformation.

The unemployment rate (UNE) has high skewness and kurtosis, and a logarithmic transformation brings it closer to a normal distribution. Logarithmic transformations were applied to GDP (GDPLN), the unemployment rate (UNELN), and scientific publications (SPULN) to reduce skewness and approximate a normal distribution, ensuring the robustness of the regression analysis. These adjustments enhanced the robustness and validity of the regression models.

Table 3

Descriptive Statistics

Variable	Mean	SD	Min	Max	Skewness	Kurtosis
GDP	26277.25	17163.92	5320.00	86540.00	1.52	5.66
ETX	2.61	0.73	0.87	5.60	0.74	3.54
SPU	4907.64	3612.85	1555.14	17346.04	1.90	5.72
RDE	1.64	0.89	0.38	3.62	0.57	2.08
INP	40.64	19.31	2.99	83.26	0.07	2.00

Variable	Mean	SD	Min	Max	Skewness	Kurtosis
UNE	8.61	4.63	2.00	27.80	1.67	6.18
GDPLN	9.98	0.62	8.58	11.37	0.03	2.46
SPULN	8.31	0.57	7.35	9.76	0.97	3.13
UNELN	2.03	0.48	0.69	3.32	0.23	3.11
HOF	2.48	0.74	1	3	-1.03	2.58

(Source: Data processed by the authors using Stata 14.2).

Table 4 presents the correlation analysis between the variables. GDP per capita (GDP) is moderately and positively correlated with R&D expenditure (RDE) and online purchases (INP), suggesting that more developed economies tend to invest more in research and more readily embrace online commerce. By contrast, GDP showed a slightly negative correlation with environmental tax revenue (ETX) and the unemployment rate (UNE), indicating potential economic costs tied to these taxes or the negative effects of unemployment.

R&D expenditure (RDE) shows a strong positive correlation with online purchases, indicating a link between investment in innovation and the expansion of digital commerce. Scientific publications (SPU) exhibit weaker ties to the other variables but are moderately and positively correlated with RDE, reflecting the direct impact of research on scientific output.

Meanwhile, the unemployment rate (UNE) is negatively correlated with online purchases, implying that higher unemployment might restrict people's access to or interest in online shopping. On the other hand, UNE shows a slight positive correlation with environmental tax revenue, possibly hinting at an indirect relationship between fiscal policy and economic conditions.

Table 4

Pearson Correlation Matrix

No	Variables	1	2	3	4	5
1	GDP	1.000				
2	ETX	-0.277	1.000			
3	SPU	0.196	-0.167	1.000		
4	RDE	0.452	-0.043	0.356	1.000	
5	INP	0.689	-0.212	0.247	0.622	1.000
6	UNE	-0.245	0.259	0.173	-0.303	-0.487

(Source: Data processing by authors using Stata 14.2)

Cultural Clustering of EU Countries

To analyze the influence of cultural factors, EU countries in the European Union were grouped into three groups of countries with similar cultural traits based on cultural characteristics using Hofstede's indicators. Countries were grouped into three clusters using the K-means algorithm in SPSS. The optimal number of clusters was determined based on the silhouette score and the Calinski-Harabasz index. Table 5 presents the features of the six Hofstede indicators for each country group, representing different cultural profiles based on the average values of these dimensions.

The first cluster includes countries with high scores in individualism, masculinity, and long-term orientation, indicating a tendency towards pragmatism and future-oriented vision. A low indulgence score indicates social restrictions, and a high score for power distance indicates a trend towards hierarchical inequalities.

A high level of indulgence characterizes the second cluster, which, combined with low levels of masculinity and power distance, indicates a culture that emphasizes equality and personal freedom.

The characteristics of the third cluster, such as the low level of indulgence, individualism, and masculinity, indicate greater interdependence among society members with an orientation towards consensus. The increased level of uncertainty avoidance suggests resistance to change.

In figure 2, the countries of the European Union are represented and grouped according to their cultural characteristics.

Table 5

Central Values of Hofstede's Cultural Clusters

	Cluster 1	Cluster 2	Cluster 3
Individualism	69	69	50
Power Distance	59	27	60
Uncertainty Avoidance	68	45	84
Long Term Orientation	69.773	46.305	59.130
Indulgence	32.477	66.778	35.784
Masculinity	84	35	40
Country	Germany Hungary Italy Slovakia	Austria Denmark Finland Ireland Netherlands Sweden	Belgium Bulgaria Croatia Cyprus Czechia Estonia

	Cluster 1	Cluster 2	Cluster 3
			France Greece Latvia Lithuania Luxembourg Malta Poland Portugal Romania Slovenia Spain

(Source: Data processed by the authors using SPSS)

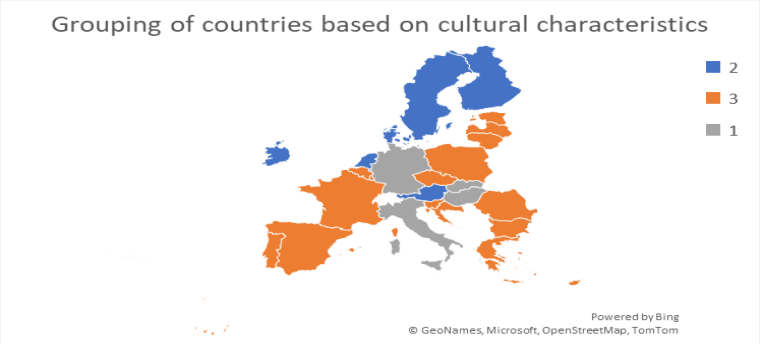

Figure 2. Classification of European Countries Based on Hofstede's Cultural Dimensions (source: authors' processing using Microsoft Excel)

The grouping of the European Union member states into three clusters based on Hofstede's six indicators highlighted the cultural effects of innovation, digitalization, and environmental policies on economic growth.

Regression Models

Table 5 presents the regression findings from seven model specifications, including a standard OLS regression model specified to account for fixed effects, or panel effects. In particular, this table shows the contribution of innovation, environmental policy, and digitalization to GDP per capita, which was specified in all models.

The estimated Variance Inflation Factor (VIF) values are low under the models selected and suggest the absence of multicollinearity among regressors in the linear models. Robust regressions and fixed-effects panel models were used to deal with heteroscedasticity.

The first regression model estimates the relationship between GDP (GDPLN) and environmental tax revenue (ETX), scientific publications (SPULN), R&D expenditure (RDE), and online purchases (INP).

Robust standard errors are used (the 'vce(robust)' option in Stata) to ensure valid inference when the observations in sample exhibit heteroscedasticity. ETXs exert a negative effect on GDP, indicating the economic costs associated with the taxes. The VIF test results consider the absence of multicollinearity after the test.

The second model shows OLS regression with control variables and robust standard errors and manages to affirm negative significant impact ETX has on GDP. While scientific publications have a marginally positive impact, R&D expenditure contributes significantly to GDP growth. Online purchases also showed a significant positive effect. The values of the R-squared yield greater insights on the explanation levels of the mean GDP levels. Within R-squared indicates 62.07 % of changes over time in GDPLN can respectively be explained by the model within countries controlled for country effects. Motivated by this, the between R-squared explains that 59.64 % of changes in GDPLN among countries are captured. Finally, the overall R-squared shows that selected variables explain respectively 48.97 % of total change in GDPLN.

To better understand the relative importance of each independent variable, we estimated standardized coefficients (Beta) for Models 1 and 2. The results indicate that online purchases (INP) have the strongest positive influence on GDP per capita ($\beta \approx 0.70$), followed by the unemployment rate (UNELN) ($\beta \approx 0.23$), and R&D expenditure ($\beta \approx 0.18$). Environmental tax (ETX) showed a negative effect, with a Beta coefficient of approximately -0.12. These results confirm that digital engagement and labor market dynamics are among the most influential drivers of economic performance in the European Union.

The fixed-effects panel regression with robust standard errors examined the nature and extent of the relationship at the country level and took control of each country's peculiar characteristics. The environmental tax revenue showed a significant negative relation to GDP. Scientific publications had a strong positive impact, indicating knowledge as part and parcel of economic growth. R&D expenditure shows a significant negative effect, indicating that these developments take time to pay off. Online purchases had a positively small but significant outcome.

A fixed-effects panel regression model with clustered errors was elected as the final regression model since, in this case, autocorrelation existed between the control variable

and the other independent variables. This method is useful in that it allows controlling for unobserved, time-invariant characteristics of each country. In addition, the standard errors were clustered at the country level to address both grouped heteroscedasticity and serial autocorrelation concerns. The results show that scientific publications exert a positive impact on GDP, while R&D spending again exhibits a significantly negative impact, suggesting that, although these investments yield benefits over the long term, they potentially incur short-run costs. Online purchases had a small but significant positive effect in contrast to the logged unemployment rate, whereby the latter negatively influenced GDP, indicating that high unemployment may hinder the economic growth. The within R-squared has indicated that, on average, the fixed-effects model explains 62.07% of the variation in GDPLN within each country over time, after ruling out any fixed effects specific to the country. The between R-squared measures the proportion of variation in GDPLN across countries explained by the independent variables, which is 59.64%. Finally, the overall R-squared indicates that 48.97% of the total variation in GDPLN is explained by the model, which combines both the within-country and the between-country differences.

Model five is an OLS regression model estimated via robust computation of standard errors with dummy variables included for cultural clusters (HOF2, HOF3). This model tests the hypothesis that the respective membership in a Hoffman cluster affects GDP independent of the economic variables. The results show that cultural clusters significantly affect economic growth. Cluster 2 has a 0.51 unit increase in GDPLN when compared with Cluster 1, whereas Cluster 3 presents a more marginally distinguished increase of 0.95. Moreover, the ETX is significantly reducing the GDPLN, while SPU and INP positively influence it. The model accounted for 66.25 % of the variance in the GDPLN. The models do show significant distinctness with an F-test between Clusters 2 and 3 giving an F-statistic value of 41.42 and a p-value of 0.0000. This difference is statistically significant. The economic effect of cultural variables in Cluster 2 is considerably stronger than that of in Cluster 3. An F-test carried out between Cluster 1 and Cluster 3 produced an F-statistic of 3.74 with a p-value of 0.0541; thus, the conclusion could be drawn that GDPLN in Cluster 3 was only marginally higher compared to Cluster 1 again not reaching statistical significance at the 5% level. White's test gives evidence of heteroskedasticity (χ^2 = 151.06, p = 0.0000). The drawback is, however, that because the regression was estimated using robust-Heteroskedasticity standard errors ('vce(robust)'), the problem has already been accounted for and valid statistical inference is allowed.

Model six is an OLS regression model estimated with robust errors and includes UNPLN as a control variable and dummy variables for cultural clusters (HOF2, HOF3). The results confirm that ETX had a significant negative effect on GDPLN, while SPULN, INP, and UNELN all exercised a positive influence on GDPLN. RDE has no statistically significant effect. Cultural clusters also showed differential effects; Cluster 2 refers to a significantly larger GDPLN than Cluster 1; and there is no difference of significance between Cluster 1 and Cluster 3. The result implies that cultural attributes are important in economic performance. The result from White's test supports the existence of heteroskedasticity (χ^2 = 161.56, p = 0.0000). However, since the regression had been estimated using heteroskedasticity-robust standard errors ('vce(robust)'), this issue has already been taken care of, rendering valid statistical inference.

Table 6

Regression Results

Variables	Model 1 OLS (no controls)	Model 1 OLS (no controls) beta	Model 2 (OLS + Unemployment)	Model 2 (OLS + Unemployment) beta	Model 3 (Panel FE (no controls))	Model 4 (Panel FE + Unemployment)	Model 5 (OLS + Cultural Clusters)	Model 6 (OLS + Unemployment + Cultural Clusters)	Model 7 (Panel FE + Lagged Predictors (Robust))	Hypothesis
(Constant)	7.67*** (0.35)		7.69*** (0.38)		8.91*** (0.44)	9.92*** (0.20)	7.05*** (0.33)	7.23*** (0.37)	9.60*** (0.40)	
ETX	-0.06** (0.03)	-0.074	-0.10*** (0.03)	-0.121	-0.03 (0.01)	-0.03 (0.03)	-0.08*** (0.02)	-0.11*** (0.02)	–0.03 (0.03)	**H1**
RDE	0.11*** (0.03)	0.152	0.13*** (0.03)	0.183	-0.06* (0.03)	-0.06** (0.03)	-0.007 (0.03)	0.02 (0.03)	–0.07** (0.03)	**H2**
SPULN	0.19*** (0.04)	0.169	0.10* (0.05)	0.090	0.12* (0.46)	0.12** (0.05)	0.28*** (0.04)	0.20*** (0.05)	0.09** (0.04)	**H3**
INP	0.02*** (0.002)	0.579	0.02*** (0.002)	0.697	0.0063*** (0.0004)	0.006*** (0.0008)	0.02*** (0.002)	0.02*** (0.002)	0.004*** (0.001)	**H4**
UNELN			0.30*** (0.05)	0.229		-0.20*** (0.02)		0.20*** (0.05)	–0.14*** (0.02)	
HOF (Cluster 2)							0.51*** (0.06)	0.41*** (0.07)		**H5**
HOF (Cluster 3)							0.10 (0.05)	0.06 (0.05)		
R Square	0.62		0.65		0.62	0.62	0.66	0.69	0.75	

****p < 0.01, ** p < 0.05, * p < 0.1 Robust standard errors are in parentheses*

FE = Fixed Effects. Robust standard errors used throughout. Model 7 includes lagged values (t–1) of predictors to address potential endogeneity. Variable names are retained for consistency. Standardized coefficients (Beta) are reported only for OLS models using beta option in Stata.

(Source: Data processing by authors using Stata 14.2)

Environmental taxes increase the final price of goods and services, which may constrain economic growth. The same conclusion has been documented in other studies (Rakpho *et al.,* 2023; Abdullah & Morley, 2014; Mashhadi Rajabi, 2023; Hassan *et al.,* 2020). although the immediate effect of investments in R&D may not be that visible in economic growth. The time required for implementing results guarantees that this is still enhancing economic growth, as demonstrated in prior studies (Gyedu *et al.,* 2021, 2021; Meo *et al.,* 2013).

These results provide support for Hypothesis H1: Environmental taxes negatively influence economic growth. The final price of goods and services reflects their cost, which justifies ample investment in environmental protection activities. The work of (Abdullah & Morley, 2014; Hassan *et al.,* 2020; Rakpho et al., 2023) put forward the same results. Increases in price can reduce both final consumption and production, which will slow down growth in the economy (Charfeddine *et al.,* 2020; Ojha *et al.,* 2020).

This provides evidence to support Hypothesis H2: R&D contributes positively to economic growth. Although its impact on economic growth may not be directly observed, due to the time required to translate results into action, R&D does have a positive influence when it comes to boosting economic growth. This is evident from previous studies (Ciaffi *et al.,* 2024; Ding *et al.,* 2024; Dritsaki & Dritsaki, 2023; Meo *et al.,* 2013).

Publications do not necessarily change the economic development right away; instead, there is often a time lag (Barrett *et* al., 2021; Chen *et al.,* 2024; Meo *et al.,* 2013; Q. Wang & Wei, 2023; J. Xu & Li, 2022). A part of the scientific output, especially in academia, may prioritize the rankings at the international level in which it operates, or it may materialize much later into the innovations that lead to economic growth (Jiang *et al.,* 2022; Ma *et al.,* 2022; Pinto & Teixeira, 2020). It is also worthy of mention that certain research activities could stimulate innovations without immediate results. Aligning research investments with sustainable development strategies is key to fostering innovation and long-term economic growth. Online purchasing exemplifies the expansion of the digital economy, which positively impacts economic growth, as demonstrated by several studies (J. Zhang *et al.,* 2022). The regression findings indicate that scientific publications (SPULN) have a positive and statistically significant effect on GDP per capita across all models. This is in alignment with the proposition that scholarly outputs produce an economic benefit through stimulating innovative activities. The models depict an average yearly effect; however, longitudinal analysis would be needed to disentangle short-term from long-term dynamics with greater precision.

Hypothesis H3 is validated: Scientific research remains crucial for long-term innovation, though its short-term impact on economic growth is less clear. This corroborates other studies showing that economic aspects from research tend to have a long-term horizon. Scientific publications do not always refer to items that guarantee economic growth. Some of the scientific output, especially in the field of academic disciplines, aims merely at positioning itself in global rankings or can turn into technological innovations that spur economic development after a long span of time (Jiang *et al.,* 2022; Ma *et al.,* 2022; Pinto & Teixeira, 2020).

Hypothesis H4 stands confirmed: The digital economy exerts a positive influence on economic growth. The emergence of online purchases adds weight to the development of the digital zone, which propels economic activity, as found in previously performed scholarly works (J. Zhang *et al.,* 2022).

The regression findings consistently indicate that Internet purchases have a positive and substantial effect on GDP per capita. While that indicator does not directly reflect productivity or innovation mechanisms, it indicates the level of consumer adoption of digital services and integration into the digital marketplace that contributes to economic activity.

Culture and traditions have influences on economic processes, hence need to be included in economic studies. In Cluster 2 countries, the study states that the cultural dimension is highly influential in environmental policies and consumer behavior in the digital space; it correlates better with economic growth than other countries. According to the study (Barreto e*t al.,* 2022), economic growth is positively related to strict avoidance of uncertainty and encouragement of individualist values. For countries that have an equally relaxed approach to avoidance of uncertainty, environmental policies have proved to be more influential in economic development. Evidence suggests that not only can one consider cultural attributes positively affecting economic development in support of Hypothesis H5 but also that countries where strict avoidance of uncertainty and individualist values tends to prevail more consistently correlate economic growth based on technological innovations (Barreto *et al.,* 2022). Where the approach to the avoidance of uncertainty is very soft, environmental policies bring a stronger influence on economic growth.

Model seven incorporates a pertinent methodological advancement by using one-period lagged values (t-1) for all the explanatory variables. This is intended to decrease possible endogeneity, especially in the association of GDP to one of the predictors such as digitalization and R&D investment. The model was estimated using fixed effects with standard errors clustered by country to accommodate for unobserved heterogeneity and possible autocorrelation. The results show that the lagged explanatory variables maintain their directional relationships from prior models. Scientific publications (SPULN) and digital commerce (INP) have positive and statistically significant estimates on GDP per capita, which support the transformative nature of knowledge and technology within EU economies. At the same time, R&D expenditure (RDE) has a statistically significant negative effect, which may suggest that there is a lag between investment in R&D by firms and the resulting economic payoff. The lagged unemployment rate (UNELN) also has a strong negative effect, underscoring the constraining aspect of labour market instability as a component of GDP per capita performance. This specification builds upon the robustness of the main findings and is additional validation of organizational capital hypotheses H2 through H4, with clarification on the

directional causality between explanatory factors and economic growth.

Our results support previous research that environmental taxation has a negative short-term effect on economic growth (Rakpho *et al.,* 2023; Abdullah & Morley, 2014); however, we also show that these effects differ across cultural clusters, providing substantive evidence in support of the notion that cultural traits may play a role in the effectiveness of policy.

Additionally, the positive effect of online purchases strengthens the case for digital integration to act as a modern driver of growth (Zhang *et al.,* 2022), and builds upon previous models by estimating that effect in a cross-cultural context within the European Union.

Environmental taxation influences both short-run and long-run economic growth through several channels. The direct increase in the final price of goods and services will diminish demand, especially for energy-intense and resource-intense goods. This deterioration in demand will impact several sectors of the overall economy, including manufacturing, transport, and construction, where input costs increase substantially. The firm will respond by scaling back production, delaying investment or shifting resources to less productive uses, where growth in output is depressed. Disruption in the supply chain may occur when key intermediate goods increase in price, generating an even more substantial negative growth impact on the economy. These channels help characterize how short-run costs associated with environmental taxation persist beyond a price increase.

Regression Analyses for Cultural Clusters

To examine how national culture moderates the impacts of innovation, environmental policies, and digitalization on economic growth, we performed regressions separately for each of the three cultural clusters in Section 4.2. The estimated standardized coefficients (Beta) for each cultural cluster are reported in Table 7.

The results provide evidence of important cross-cluster differences. For Cluster 1, it appears that digitalization (SPU_LN and INP) has a very strong positive relationship to GDP per capita, which suggests that digital integration is a predominant driver of economic growth in this cultural cluster. The total effects of environmental taxes (ETX) and R&D (RDE) were much weaker and not statistically significant.

For Cluster 2, environmental taxes (ETX) and R&D (RDE) had a substantially greater negative relationship to GDP than it did in Cluster 1, and digitalization still had a reliably positive contribution. This supports the notion that regulatory burdens and innovation costs may have a stronger impact on short-run economic performance in Cluster 2 economies.

In Cluster 3, digitalization (INP) again had a strong positive impact on GDP per capita, but environmental taxes had a very strongly negative impact. Interestingly, R&D investment had a positive contribution in Cluster 3, which may suggest higher absorptive capacity for innovation in these cultural contexts with regard to GDP growth. The unemployment variable (UNE_LN) was positively correlated to GDP per capita in Cluster 3 which may reflect structural labor market dynamics.

Overall, our findings support the conclusion that culture is a significant moderator of how innovation, environmental, and digital drivers translate into economic growth. Leaving the cultural context out of consideration would lead to mischaracterizations of the data and ultimately poor economic and regulatory decision-making.

Moreover, observable differences in GDP per capita across cultural clusters may capture a number of possible causal mechanisms, including attitudes toward innovation, divergences in consumer preferences, and institutional responsiveness. For example, clusters characterized by lower uncertainty avoidance and more individualism may exhibit an entrepreneurial spirit, which leads to greater digital technology uptake and quicker responses to incentives created by environmental policies. Although we do not directly test these causal mechanisms in this analysis, our results are generally compatible with theoretical expectations derived from cultural economics and institutional theory.

Table 7

Standardized Coefficients (Beta) by Cultural Cluster

Variables	Cluster 1 (Beta)	Cluster 2 (Beta)	Cluster 3 (Beta)
ETX	-0.0127	-0.1813	-0.2095
RDE	0.0585	-0.4546	0.1561
SPU_LN	0.9056	-0.3315	-0.0519
INP	0.0915	0.7896	0.7702
UNE_LN	-0.0297	0.0218	0.3218
R-squared	0.9806	0.7204	0.6303

Note: Standardized coefficients are reported. Separate OLS regressions with standardized coefficients were estimated for each cultural cluster (HOF = 1, 2, 3). (Source: Data processing by authors using Stata 14.2)

Conclusion

The presented study examines the general factors that influence per capita GDP, including cultural dimensions. Findings suggest that investments in R&D positively affect economic growth by supporting technological progress and innovation. Online shopping has gained growing popularity and has promoted the digital economy as a force that engages market forces and affects consumer behavior, a development that bears a positive impact on economic growth. The study presents a negative relationship between environmental taxes and GDP because the increment in these taxes results in the increment of the final prices of goods and services, leading to a decrease in consumption and production. This scenario poses a fundamental challenge; hence, environmental policies must strike a balance between ecological objectives and economic interests for both consumers and businesses. Cultural

dimensions play an important part in explaining variations in economic growth across countries. Cultural analyses indicate that national values and traditions have shaped environmental policies along with economic behavior. The countries which strongly avoid uncertainty and give more importance to individualistic values reflect a higher prospect of economic growth.

These findings enrich the literature by underscoring the moderating role of national culture in the relationship among innovation, environmental policy, and economic outcomes. By introducing Hofstede's cultural dimensions into the macroeconomic spanning analysis of the model, the study presents a new empirical lens through which to analyze the interplay between structural drivers of growth and sociocultural dimensions. This multi-level approach adds to existing models of endogenous growth and institutional economics.

To strengthen the robustness of the results and address potential endogeneity issues, an additional model was introduced that used one-year lagged values of the main explanatory variables. The findings of this lagged panel fixed-effects model confirmed and refined the previous conclusions. In particular, R&D investment displayed a negative short-term impact on GDP per capita, reinforcing the notion that such efforts generate benefits only in the longer term. Scientific publications and digitalization continued to show a positive and significant contribution to economic performance, even when considering delayed effects. Furthermore, the unemployment rate, when lagged, maintained a significant negative influence, highlighting the inertia of labor market imbalances and their persistent impact on economic outcomes.

The evaluation of externally standardized coefficients indicates that online market access has the largest relative effect on GDP per capita of all the variables examined, underscoring the importance of digitization in contemporary growth approaches.

From a policy perspective, these findings underscore the necessity for a policy-led and definitive commitment towards targeted long-term investment, research and development, and policy support that outlines cultural readiness and institutional capability. It would be essential for digital strategies to align with social structures, paired with educational efforts, to alleviate adaptation stress and improve productivity efforts. Policymakers should also consider aligned environmental tax schemes to avoid unintended short-term contractionary changes and effectively recycle revenues towards innovation or support for vulnerable groups. For businesses, on the other hand, additional cultural studies of the national character could be used to build coherent market strategies in particular areas around their digital expansion and R&D capability.

One limitation of this study is its focus on EU countries. Expanding the analysis to include different regions and additional variables would render a more sophisticated vision of the interactions of innovation, technology, culture, and environmental policies.

Furthermore, there is another limitation pertaining to the measurement of cultural factors. Hofstede's six dimensions do present a useful set of tools for comparative purposes, but the nature of culture may not be adequately conceptualized across all socio-historical contexts. To further this analysis, future research may build upon the findings described here by including additional models of culture in order to test and elaborate upon them.

Although the model controls for unemployment, as with any macroeconomic model, there remains the potential for omitted variable bias due to unobserved factors not included in the specification.

Future studies may examine non-linear effects and mediating mechanisms (e.g., institutional quality or governance effectiveness) when analyzing the link between policy tools and economic performance. Comparative studies between EU countries and non-EU countries would shed light on how policy and culture co-influence development trajectories in disparate socio-economic systems.

The work highlights the importance of R&D investments, digitalization, and cultural considerations in the promotion of economic growth. The study highlights the challenge that environmental taxes pose to economic performance, as higher taxation can increase the final prices of goods and services, potentially leading to reduced consumption and production. This underlines the need for policies that balance ecological objectives with economic sustainability for both consumers and businesses. These present findings, therefore, might hold significant implications for the formation of economic and environmental policies and an understanding of economic processes.

From a policy-making viewpoint, the implications of these findings indicate the need for careful construction of environmental taxation schemes to balance the costs for businesses in the short-run with the benefits to the environment in the long-run. One useful option may be to recycle the tax back into the economy to stimulate green innovation, which can in turn offset some of the impacts of such a tax on production and consumption. Environmental taxation can be structured to have a more positive impact on the behavior of firms through targeted subsidies or incentives for firms moving towards sustainable technologies, which could be used to bolster business competitiveness within the early implementation stages of an environmental tax. As environmental taxation can be unpopular, consistent and clear messaging on long-term policy objectives should facilitate public support for environmental taxation. Policymakers should also consider culturally relevant factors, as the less uncertain one is in business, the less pragmatic their society is, and more open to changes in regulation.

It is recommended that policy-makers adopt a phased or differentiated implementation of environmental taxes that includes a reinvestment system directed towards sectors and regions that suffer the greatest extent from the tax. Additionally, because of the differences among cultures observed above, it is also essential that the design of the policy will be culturally sensitive. For example, in countries with high uncertainty avoidance, stronger communication and potentially compensatory incentives will need to be employed to obtain greater acceptance and incentivize policies that could be effective.

From a scholarly perspective, this research contributes to the corpus of knowledge by introducing cultural dimensions into the econometric investigation of

innovation, environmental policy, and digitalization impacts on economic growth. While many prior studies have examined the above-mentioned influence factors in isolation, our multidimensional model builds a more comprehensive understanding of how these elements interact within the European context. Furthermore, the empirical application of cultural clusters based on Hofstede's framework provides a new way to understand the heterogeneous implications of policy, as well as technological factors, in distinctly different cultural environments. These contributions will assist with future comparative studies and stimulate future investigations that explore the application of cultural variables as a way to elucidate economic growth models.

Cultural determinants affect economic growth through a few specific pathways. First, they affect national values toward innovation and risk taking. Societies with a low uncertainty avoidance and high individualism often promote innovation and take risks to develop new technologies through entrepreneurial behavior. Second, consumer preferences are subject to cultural norms, affecting demand for more innovative or sustainable products. Third, cultural values largely condition corporations to be open to corporate decisions and organizational change, the adoption of digital technologies and policy responses. Lastly, cultural traits dictate public willingness or acceptance of policy tools, such as environmental taxes. When societies have citizens that are open to regulatory changes, the policy toolkit is more likely to be effective. Understanding the pathways above will allow policy makers and business leaders to better tailor their organizations strategic practices to the cultural context.

In real terms, the results imply that policy actors should keep cultural contexts in mind when developing and implementing environmental and innovation policy. For example, the negative short-term impact of environmental taxes, in relation to GDP, suggests that complementary measures, including specific green innovation investments, could alleviate, at least temporarily, negative economic consequences. Furthermore, it is clear that creating digital literacy and opportunities for potential local firms to participate in an online marketplace could significantly improve economic performance; thus, the net effect of the Internet helped to support and sustain greater GDP per capita. Adapting policy to cultural attitudes towards uncertainty and individualism could also enhance potential effectiveness in achieving sustainable growth.

Appendix 1

Country List

No.	Country	No.	Country	No.	Country
1	Austria	10	France	19	Malta
2	Belgium	11	Germany	20	Netherlands
3	Bulgaria	12	Greece	21	Poland
4	Croatia	13	Hungary	22	Portugal
5	Cyprus	14	Ireland	23	Romania
6	Czechia	15	Italy	24	Slovakia
7	Denmark	16	Latvia	25	Slovenia
8	Estonia	17	Lithuania	26	Spain
9	Finland	18	Luxembourg	27	Sweden

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