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Regulatory Quality and Economic Performance: Evidence from European Countries

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Abstract: This study investigates the relationship between regulatory quality and economic growth across 11 European countries over the period 2010–2023 using a comprehensive panel data framework. Employing pooled OLS, fixed effects, two-way fixed effects, and System GMM estimators, the analysis examines the robustness, heterogeneity, and dynamic properties of the regulatory quality–growth nexus. The results indicate that regulatory quality does not have a statistically significant or robust effect on economic growth once country-specific and time-specific heterogeneity are controlled for. Additional analyses reveal no significant differences across Western, Central, and Eastern European countries, nor evidence of dynamic or non-linear effects. The findings suggest that in mature and highly regulated European economies, regulatory quality may act more as a background institutional condition rather than a direct driver of short-term growth, highlighting the importance of complementary macroeconomic factors.

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1. Introduction

The relationship between regulatory quality and economic growth has attracted significant attention in economic literature; however, its empirical relevance remains uncertain, particularly across European economies with varying institutional structures and levels of development. Regulatory quality is widely recognized as a critical driver of economic performance, as effective policy frameworks enhance private-sector activity, attract investment, and support sustainable economic growth (Udemba et al., 2025). Similarly, strong governance structures improve economic outcomes by increasing efficiency, promoting responsible practices, and supporting long-term value creation (Filfilan & Shawdari, 2025). From a broader perspective, regulatory efficiency fosters predictable economic environments that facilitate business activity and investment (Valdiglesias & Quintana, 2026). Empirical evidence largely supports this view; for instance, panel regression analyses show that improved regulatory

quality enhances growth outcomes (Lee et al., 2021), while further studies demonstrate that it can moderate the relationship between financial development and economic growth, particularly in developed economies (Ullah et al., 2024). Additionally, regulatory quality interacts with financial and environmental dynamics, influencing both economic growth and environmental sustainability through asymmetric channels (Islam et al., 2024; Sikic et al., 2025).

Despite these contributions, the literature presents mixed and context-dependent findings, particularly in highly regulated and mature economies such as Europe, where the marginal impact of regulatory quality may be limited or heterogeneous. Existing studies often focus on single countries, specific regions, or particular economic channels (e.g., finance, environment), with limited attention to comprehensive panel frameworks that jointly examine robustness, heterogeneity, and dynamic effects. This creates a critical research gap in understanding whether regulatory quality consistently influences economic growth when controlling for macroeconomic factors, cross-country differences, and temporal dynamics.

Addressing this gap, the present study provides a comprehensive panel analysis of 11 European countries over the period 2010-2023, integrating static, dynamic, and robustness-based econometric approaches. The novelty of this study lies in its unified framework that combines two-way fixed effects, heterogeneity analysis between Western, Central, and Eastern European economies, dynamic and non-linear specifications, and endogeneity correction through System GMM. This approach allows for a more rigorous and multidimensional evaluation of the regulatory quality-growth nexus.

Accordingly, the study is guided by the following research questions:

RQ1: How does regulatory quality affect economic growth across selected European countries during 2010-2023?

RQ2: Does regulatory quality remain significant after controlling for macroeconomic factors, and does its effect vary by country group or timing?

2. Materials and Methods

2.1 Data and Variable Construction

This study employs a balanced panel dataset of 11 European countries over the period 2010–2023, ($N = 11, T = 14$) yielding 154 country-year observations. The sample includes both Western European economies (Austria, France, Germany) and Central and Eastern European (CEE) countries (Czechia, Slovakia, Poland, Hungary, Slovenia, Croatia, Romania, and Bulgaria), enabling comparative institutional analysis across different stages of economic development. GDP growth (NY.GDP.MKTP.KD.ZG) is used as the dependent variable, representing the standard measure of short- to medium-run macroeconomic performance; using growth rates rather than levels removes country-specific trends and aligns with fixed-effects estimation based on within-country variation. The key explanatory variable is regulatory quality (RQ.ES) from the World Bank's Worldwide Governance Indicators, which captures the ability of governments to design and implement policies that support private-sector development. In line with the institutions-for-growth hypothesis, stronger regulatory frameworks reduce

transaction costs, enhance investment incentives, and improve resource allocation, thereby fostering economic performance. The index is standardized, ranging approximately from -2.5 to $+2.5$, where a one-unit increase reflects a substantial improvement in institutional quality. To isolate this effect, the model incorporates key macroeconomic controls: inflation, which reflects macroeconomic stability and influences investment efficiency; trade openness, which captures economic integration and productivity gains through international trade; and foreign direct investment (FDI), which represents external capital inflows and technological transfer. Including FDI also enables the separation of the direct effect of regulatory quality on growth from its indirect impact through investment attraction.

Table 1. Variable Definitions and Theoretical Justification

Variable Type	Variable	Description	Theoretical Justification
Dependent	GDP Growth (%)	Annual percentage growth rate of GDP	Standard indicator of macroeconomic performance; growth rates remove country-specific trends and suit fixed-effects estimation
Key Explanatory	Regulatory Quality	Measures government ability to design and implement policies supporting private-sector development	Core to institutions-for-growth hypothesis; improves investment climate and resource allocation (Acemoglu & Johnson, 2005; Kaufmann et al., 2010)
Control	Inflation (%)	Annual inflation rate	Captures macroeconomic stability; high inflation distorts investment and growth (Barro, 1995)
Control	Trade Openness (% GDP)	Total trade as a share of GDP	Reflects economic integration and productivity gains (Frankel & Romer, 1999)
Control	FDI (% GDP)	Net foreign direct investment inflows	Captures capital inflows and technology transfer; separates direct and indirect institutional effects (Bevan & Estrin, 2004)

Source: Own Research.

2.2 Empirical Specification

The baseline empirical model is specified as:

$$GDP_Growth_{it} = \beta_0 + \beta_1 RQ_{it} + \beta_2 Inflation_{it} + \beta_3 Trade_{it} + \beta_4 FDI_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where i indexes countries and t denotes time. The term α_i captures unobserved country-specific effects (e.g., geography, legal origin), while λ_t controls for common time shocks (e.g., financial crises, COVID-19).

2.3 Estimation Strategy and Diagnostic Tests

To ensure robustness and reliability of the empirical findings, a sequence of panel data estimators and diagnostic procedures is employed. The analysis begins with a pooled Ordinary Least Squares (OLS) model, which serves as a baseline specification without accounting for unobserved heterogeneity. This is followed by Fixed Effects (FE) models that control for time-invariant country-specific characteristics, and Two-Way Fixed Effects (TWFE) models that

additionally incorporate time effects to capture common macroeconomic shocks, forming the primary specification of the study. Random Effects (RE) models are also estimated for comparison, with the Hausman test used to determine the consistency and suitability of the RE estimator relative to FE. All regressions are estimated using country-clustered standard errors to account for within-country serial correlation. In cases where cross-sectional dependence is detected, Driscoll–Kraay standard errors are applied to ensure robustness to both cross-sectional and temporal dependence.

Before estimation, standard panel diagnostics are conducted to validate the properties of the data. Panel unit root tests (Fisher-ADF, Maddala & Wu, 1999) are used to assess stationarity, as the presence of non-stationary variables may lead to spurious regression results. Additionally, panel Granger causality tests (Hurlin & Venet, 2001) are employed to examine the temporal direction of relationships, providing preliminary evidence on whether regulatory quality can be considered a driver of economic growth. Following estimation, further diagnostic tests are performed to verify model assumptions. The Pesaran (2004) cross-sectional dependence test is used to detect contemporaneous correlation across countries, while the Wooldridge (2002) test evaluates the presence of serial correlation in panel residuals. Finally, Variance Inflation Factors (VIF) are calculated to assess potential multicollinearity among explanatory variables. Together, these estimation strategies and diagnostic procedures ensure that the empirical results are robust, reliable, and consistent with econometric best practices.

2.4 Robustness, Extensions, and Endogeneity

To strengthen the validity of the empirical findings, several robustness checks and model extensions are implemented. First, a COVID-19 shock adjustment is introduced through a binary dummy variable for the years 2020 – 2021 to capture the impact of the global pandemic on economic activity. Second, heterogeneity analysis is conducted by splitting the sample into Western European and Central and Eastern European (CEE) countries, complemented by interaction models to test whether the effect of regulatory quality differs across these groups. Third, dynamic and non-linear specifications are considered to capture more complex relationships. A lagged regulatory quality term (RQ_{t-1}) is included to test for delayed effects. In contrast, a quadratic term (RQ^2) is introduced to examine potential diminishing returns and non-linearities in the relationship between regulatory quality and economic growth.

To address potential endogeneity arising from reverse causality and omitted variable bias, the study employs the System Generalized Method of Moments (System GMM) estimator (Blundell & Bond, 1998). This approach removes fixed effects through first differencing, uses lagged endogenous variables as internal instruments, and improves efficiency by combining moment conditions in both levels and differences. Model validity is assessed using the Hansen test for overidentifying restrictions and the Arellano–Bond tests for serial correlation in first-differenced errors (AR(1) and AR(2)). Overall, the study integrates static panel models, robustness diagnostics, heterogeneity analysis, and dynamic estimation techniques within a unified empirical framework. This comprehensive approach ensures that the relationship between regulatory quality and economic growth is examined rigorously, addressing key econometric concerns including heterogeneity, cross-sectional dependence, and endogeneity.

3. Results

GDP growth averages 2.13% with moderate volatility, while regulatory quality shows relatively low dispersion across countries. Inflation remains generally stable but exhibits occasional spikes. Trade openness is high, indicating strong global integration, particularly in smaller economies. FDI is highly volatile, driven by extreme inflow and outflow episodes. Country-level averages reveal higher growth in emerging economies (e.g., Poland, Romania) and stronger institutional quality in developed countries (e.g., Germany, Austria), highlighting structural heterogeneity within the sample.

Table 2. Descriptive Statistics (2010–2023)

Variable	N	Mean	Std. Dev.	Min	Q25	Median	Q75	Max
GDP Growth(%)	154	2.12900	2.9980	-8.311	0.7510	2.29800	3.9180	12.6320
Regulatory Quality	154	0.83300	0.4380	0.119	0.4390	0.76500	1.2070	1.69500
Inflation (%)	154	3.04500	3.6090	-1.545	0.9660	1.99900	3.5230	17.1250
Trade (% of GDP)	154	116.871	37.610	56.588	83.412	108.293	147.70	204.056
FDI (% of GDP)	154	3.25700	11.734	-40.108	1.5320	2.64500	3.8780	105.636

Source: Own Research.

Table 3. Country-Level Averages

Country	GDP Growth	Reg. Quality	Inflation	Trade	FDI
Austria	1.354	1.455	2.793	106.949	-0.629
Bulgaria	2.183	0.388	3.279	123.478	3.527
Croatia	1.863	0.273	2.283	92.9040	3.558
Czechia	1.903	1.074	3.547	141.899	3.688
France	1.263	1.205	1.671	64.1120	1.707
Germany	1.461	1.573	2.095	78.5070	2.322
Hungary	2.510	0.538	4.642	164.259	11.157
Poland	3.456	0.792	3.599	98.3800	3.450
Romania	2.778	0.379	4.271	82.7800	2.526
Slovakia	2.600	0.774	3.132	179.654	2.265
Slovenia	2.047	0.708	2.181	152.657	2.262

Source: Own Research.

The correlation results indicate generally weak linear relationships among variables. GDP growth shows a small positive association with trade openness (0.151) and inflation (0.072), while its relationship with regulatory quality (−0.099) and FDI (−0.037) is negligible. Regulatory quality is moderately negatively correlated with trade (−0.250), suggesting structural differences between more regulated and more open economies. Inflation is weakly positively related to trade (0.189), while FDI exhibits very low correlations with all variables. Overall, the absence of high correlations ($|r| < 0.3$) suggests that multicollinearity is not a concern, supporting the reliability of subsequent regression analysis.

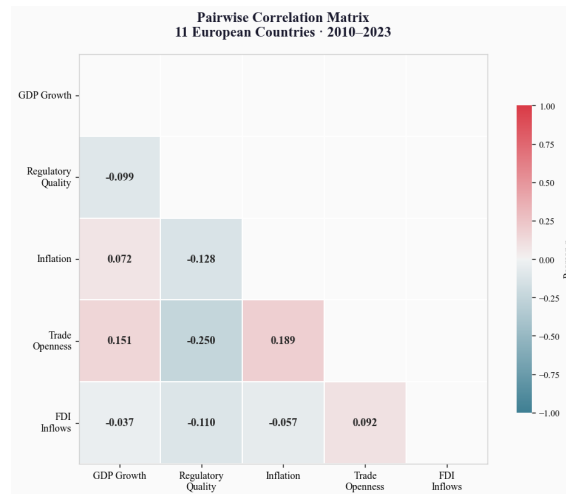


Figure 1. Variable Correlation Matrix

Figure 2 presents the temporal evolution of key variables across 11 European countries over the period 2010–2023. GDP growth exhibits relatively stable patterns until 2019, followed by a sharp contraction in 2020 across all countries, reflecting a common external shock, and a strong rebound in 2021. Regulatory quality remains comparatively stable over time, with only gradual improvements or minor fluctuations, indicating institutional persistence. Inflation shows moderate levels before 2020 but rises sharply in the post-2021 period, highlighting increasing macroeconomic pressures across the sample. Trade openness demonstrates a generally upward trend for most countries, with temporary declines around 2020, followed by recovery, suggesting resilience in international trade integration. In contrast, FDI inflows are highly volatile, with significant spikes and drops in specific years, indicating sensitivity to external economic conditions and country-specific investment dynamics. Overall, the trends reveal synchronized shocks in GDP and trade during crisis periods, stable institutional structures, and increasing inflationary pressures in recent years, while FDI remains the most unstable component.

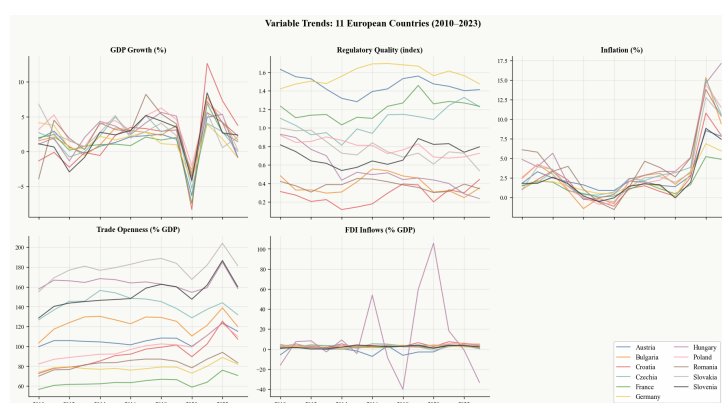


Figure 2. Variable Trends (2010–2023)

Source: Own Research.

The panel unit root results indicate mixed stationarity across variables. Regulatory quality and trade openness are stationary at levels, while GDP growth, inflation, and FDI are non-stationary. This suggests the need for appropriate transformations (e.g., first differencing) or model specifications that account for non-stationarity to ensure robust econometric estimation.

Table 4. Panel Unit Root Test (Fisher-ADF, Maddala & Wu, 1999)

Variable	Chi-square	p-value	N	Stationary I(0)
GDP Growth	23.951	0.350	11	No
Regulatory Quality	36.631	0.026	11	Yes
Inflation	0.391	1.000	11	No
Trade	39.113	0.014	11	Yes
FDI	18.635	0.668	11	No

Source: Own Research.

The Granger causality results show no statistically significant causal relationship between regulatory quality and GDP growth in either direction. This suggests that, within the sample period, neither variable provides predictive power for the other in a dynamic panel context.

Table 5. Panel Granger Causality Test (Fisher Combination, Lag = 2)

Direction	Chi-square	p-value	N	Significance
Regulatory Quality → GDP Growth	23.604	0.368	11	No
GDP Growth → Regulatory Quality	21.780	0.473	11	No

Source: Own Research.

The results indicate that regulatory quality does not have a robust or statistically significant effect on GDP growth once country and time heterogeneity are controlled for. While the pooled OLS model suggests a negative and significant relationship, this effect disappears after introducing fixed effects, indicating that the initial result is driven by cross-country differences rather than within-country dynamics. In the fully specified TWFE model (M4), regulatory quality remains statistically insignificant, suggesting that improvements in institutional quality do not translate into short-term economic growth within countries over time. Among control variables, only inflation shows a weak negative effect, indicating that higher inflation may slightly reduce growth. Overall, the findings imply that regulatory quality alone is not a strong short-run driver of economic growth in the selected European countries during the study period.

Table 6. Panel Regression Results: Effect of Regulatory Quality on GDP Growth

Variables	M1 Pooled OLS	M2 Entity FE	M3 Two-way FE	M4 TWFE + Controls
Regulatory Quality	-0.676** (0.330)	2.029 (1.976)	0.065 (1.758)	-0.520 (1.733)
Inflation	—	—	—	-0.252* (0.140)
Trade Openness	—	—	—	0.042 (0.053)
FDI Inflows	—	—	—	0.003 (0.005)
Constant	2.692*** (0.353)	—	—	—
Observations	154	154	154	154
R ² (within)	-0.005	0.006	0.000	-0.006
Entity FE	No	Yes	Yes	Yes
Time FE	No	No	Yes	Yes
Controls	No	No	No	Yes
SE (clustered)	Country	Country	Country	Country

Source: Own Research.

Notes: Clustered standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

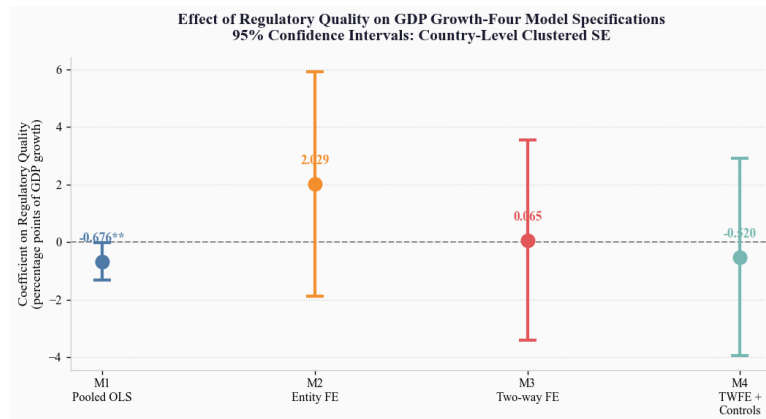


Figure 3. Effect of Regulatory Quality on GDP Growth
Source: Own Research.

Table 7. Robustness and Model Validation Results

Test / Model	Statistic / Coefficient	p-value	Interpretation
Random Effects (β RQ)	-0.460	0.455	Not significant
Hausman Test	2.033	0.154	RE consistent (fail to reject H_0)
VIF (RQ)	1.085	—	No multicollinearity
VIF (Controls)	~1.02–1.10	—	No multicollinearity

Source: Own Research.

Figure 4 illustrates the estimated coefficients of regulatory quality across alternative model specifications with 95% confidence intervals. The random effects model confirms that regulatory quality remains statistically insignificant when macroeconomic controls are included. The Hausman test indicates no systematic difference between fixed and random effects estimators, suggesting that the RE specification is consistent. Variance Inflation Factor (VIF) results show no evidence of multicollinearity among explanatory variables, supporting the reliability of coefficient estimates. The coefficient stability plot further demonstrates that estimates of regulatory quality vary across specifications but remain statistically insignificant in most cases, with confidence intervals consistently overlapping zero.

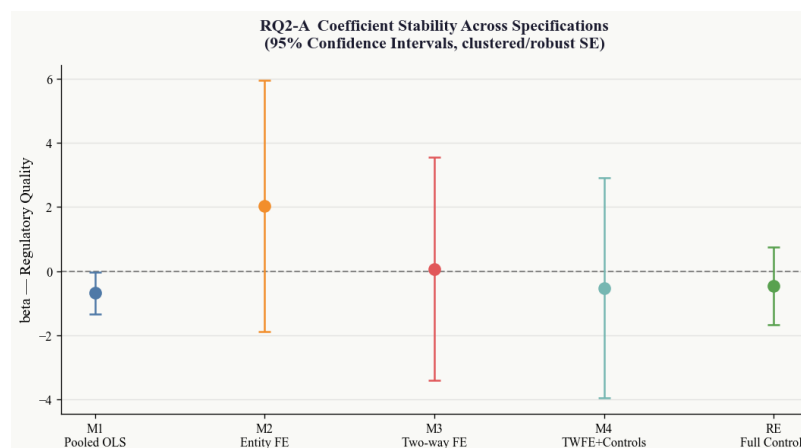


Figure 4. Coefficient Stability Across Specifications
Source: Own Research.

Table 8. Heterogeneity of Regulatory Quality Effect by Country Group

Model / Group	Coefficient (RQ)	Std. Error	p-value	Interpretation
Western Europe (n=3)	-0.075	1.853	0.968	Not significant
CEE (n=8)	0.440	1.155	0.704	Not significant
Interaction (Western)	-2.795	—	0.215	Baseline effect (Western)
Interaction (RQ × CEE)	2.782	—	0.291	No differential effect
Total Effect (CEE)	-0.013	—	—	No net effect

Source: Own Research.

Figure 5 presents coefficient estimates with 95% confidence intervals for the full sample, Western Europe, and CEE countries. The results show no statistically significant effect of regulatory quality on GDP growth in either Western Europe or CEE countries (Tab. 9). The estimated coefficients differ in sign. Still, both are insignificant and associated with wide confidence intervals. The interaction model confirms that the difference in the effect of regulatory quality between Western and CEE countries is not statistically significant. The total marginal effect for CEE economies is close to zero, further supporting the absence of a meaningful relationship.

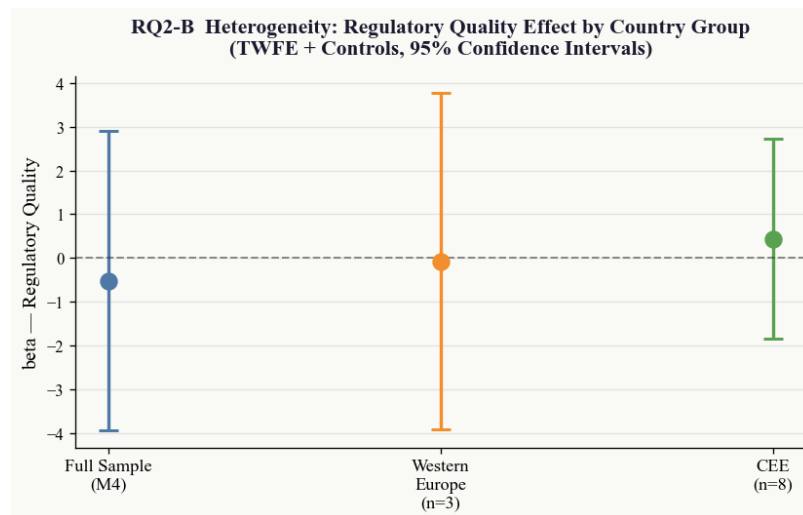


Figure 5. Regulatory Quality Effect by Country Group

Source: Own Research.

Table 9. Dynamic and Non-linear Effects of Regulatory Quality

Model	Coefficient	p-value	Interpretation
Lagged RQ (t-1)	-1.571	0.108	Weak, not significant
RQ (linear term)	1.541	0.697	Not significant
RQ ² (quadratic term)	-1.233	0.477	Not significant
Turning Point (RQ*)	0.625	—	Within sample range

Source: Own Research.

The left panel compares contemporaneous and lagged effects of regulatory quality, while the right panel illustrates the marginal effect of regulatory quality across its distribution Figure 6). The lagged regulatory quality coefficient is negative and weakly insignificant, suggesting no strong evidence of delayed effects on economic growth. The quadratic specification indicates a potential inverted-U relationship; however, both the linear and squared terms are statistically insignificant. Although the estimated turning point lies within the observed range, the lack of statistical significance implies that the non-linear relationship is not robust. Overall, there is no empirical support for either dynamic or non-linear effects of regulatory quality on GDP growth

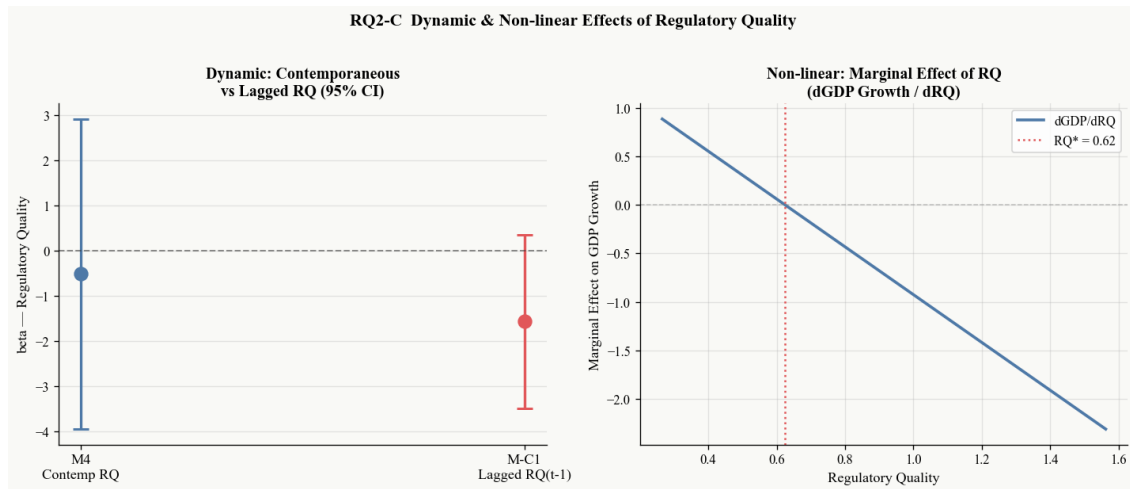


Figure 6. Regulatory Quality Effect by Country Group
Source: Own Research.

The System GMM results show that regulatory quality is not statistically significant after controlling for endogeneity, with a large standard error indicating imprecise estimation (Tab. 10). The coefficient differs substantially from the TWFE estimate, suggesting sensitivity to estimation method. The Hansen test indicates instrument validity; however, the significant AR(2) test raises concerns about instrument reliability and potential model misspecification (Tab. 11). Additionally, the relatively high number of instruments compared to the sample size may weaken inference.

Table 10. System GMM Estimation Results (Arellano–Bond / Blundell–Bond)

Variable	Coefficient	Std. Error	p-value	Interpretation
Lagged GDP (t–1)	-0.324	0.186	0.082	Weak persistence
Regulatory Quality	3.718	8.466	0.661	Not significant
Inflation	0.149	0.162	0.358	Not significant
Trade	0.048	0.081	0.556	Not significant
FDI	-0.010	0.037	0.781	Not significant
Constant	-6.631	16.452	0.687	Not significant

Source: Own Research.

Table 11. : Model Diagnostics

Test	Statistic	p-value	Interpretation
Hansen Test (Overidentification)	9.566	1.000	Instruments valid
AR(1) Test	-1.80	0.072	Expected first-order correlation
AR(2) Test	-2.34	0.019	Potential second-order correlation

Source: Own Research.

4. Discussion

The results of this study indicate that regulatory quality does not have a statistically significant and robust effect on economic growth once country and time heterogeneity are controlled for. While the pooled OLS model initially suggests a significant relationship, this effect disappears in fixed-effects specifications, implying that cross-country differences rather than within-country dynamics drive the observed association. This finding suggests that in mature and highly regulated European economies, the marginal impact of regulatory improvements on growth may be limited. Robustness checks support this conclusion. The random effects model

confirms the insignificance of regulatory quality, and diagnostic tests indicate that the results are not driven by multicollinearity or model instability. However, the sensitivity of the estimates to the inclusion of COVID-19 controls highlights the influence of external shocks, suggesting that institutional factors may interact with global conditions rather than exerting a direct effect on growth. The heterogeneity analysis shows no significant differences between Western, Central, and Eastern European countries, indicating that the effect of regulatory quality does not vary systematically across these groups. Similarly, the dynamic and non-linear specifications provide no evidence of delayed or diminishing-return effects. The System GMM results further confirm the lack of robustness, with insignificant and unstable coefficients. Overall, the findings suggest that regulatory quality acts more as a background institutional condition rather than a direct driver of short-term economic growth in the European context.

5. Conclusion

This study examined the impact of regulatory quality on economic growth across 11 European countries over the period 2010–2023 using a comprehensive panel econometric framework. The findings consistently show that regulatory quality does not exert a statistically significant or robust effect on economic growth once country-specific and time-specific factors are controlled for, and this result remains stable across multiple specifications, robustness checks, and endogeneity corrections. Furthermore, no evidence is found for heterogeneity across country groups or for dynamic and non-linear effects, suggesting that the influence of regulatory quality is limited in the short run within mature European economies. These results imply that while maintaining strong regulatory frameworks is essential for economic stability, incremental improvements in regulatory quality alone may not be sufficient to drive growth, and policymakers should instead focus on complementary factors such as productivity, innovation, and macroeconomic stability. Overall, the study highlights that the regulatory quality–growth relationship is context-dependent and underscores the need for more nuanced approaches in institutional and macroeconomic policy design.

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Efficiency versus inequality: a computational and bibliometric analysis of law and political economy scholarship

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Abstract: This study provides a large-scale empirical comparison between Law & Economics (LE) and Law & Political Economy (LPE) scholarship using computational text analysis techniques. Drawing on 405 publications indexed in the Web of Science Core Collection between 2010 and 2025, the study investigates whether LE and LPE represent conceptually distinct intellectual traditions characterized by different discourse orientations and thematic structures. The research integrates bibliometric analysis, Natural Language Processing (NLP), TF-IDF analysis, topic modeling, econometric modeling, and machine learning classification techniques to evaluate the divergence between the two scholarly frameworks. The findings reveal that LE scholarship remains strongly associated with efficiency-oriented discourse emphasizing markets, incentives, liability systems, and institutional optimization, whereas LPE scholarship demonstrates significantly stronger politically oriented discourse centered on governance, institutional power, social structures, and distributive concerns. Topic modeling results further confirm substantial thematic divergence between the two traditions. The econometric analysis demonstrates that LPE scholarship is significantly associated with higher politically oriented discourse and lower efficiency-oriented discourse. Robustness tests and logistic classification models additionally confirm the stability and computational distinguishability of the two intellectual traditions. Overall, the study contributes new empirical evidence to ongoing debates concerning the evolving relationship between law, economics, governance, and political power within contemporary legal scholarship.

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1. Introduction

Law & Economics (LE) has remained one of the most influential intellectual traditions within modern legal scholarship for several decades. Emerging primarily from the Chicago School tradition, LE applies economic reasoning to legal institutions and evaluates legal systems through concepts such as efficiency, incentives, transaction costs, liability structures, and market optimization. Foundational contributions by Ronald Coase, Guido Calabresi, and Richard Posner significantly shaped the development of the field and established economic analysis as a central methodology within legal studies. However, important distinctions have long existed within the broader LE tradition itself. Hylton, (2019) argues that the broad categories of “law and economics” and “economic analysis of law” often obscure significant

methodological differences between positive and normative economic analysis as well as positivist and non-positivist legal reasoning. Similarly, Marciano & Ramello, (2019) emphasize that Calabresi's conception of law and economics differs substantially from Posner's narrower efficiency-oriented economic analysis of law.

The evolution of LE scholarship has therefore never been entirely methodologically uniform. Several scholars have argued that the field extends beyond simple market-efficiency analysis and includes broader institutional and interdisciplinary considerations. For example, Bix, (2019) highlights Calabresi's criticism that economic analysis of law often dismisses aspects of legal and social life that do not fit narrow efficiency-based models. Similarly, Leon Quiroga, (2021) argues that "law and economics" should be viewed as a genuinely interdisciplinary framework combining legal and economic analysis rather than merely applying economics to law. Other studies have demonstrated the expansion of LE into areas such as criminal law, environmental governance, labor regulation, and institutional analysis (Castro Linares, 2019; Cruz Cunha Peixoto, 2013; Kaufman, 2012).

Despite its intellectual influence, LE scholarship has increasingly faced criticism for prioritizing efficiency while downplaying broader distributive, institutional, and political concerns. These criticisms intensified after the global financial crisis, rising inequality debates, labor precarity, and growing concerns regarding corporate and institutional power. In response, the Law & Political Economy (LPE) movement emerged as a rapidly expanding intellectual framework seeking to challenge the dominance of efficiency-oriented legal reasoning. Since its formal development around 2019, LPE has gained substantial visibility within major academic institutions, including Harvard, Yale, and Stanford. LPE scholars argue that legal systems actively construct markets, institutional hierarchies, and socio-economic power relations rather than merely regulating pre-existing market structures.

From the LPE perspective, law cannot be understood solely through the lens of market efficiency because legal institutions fundamentally shape inequality, governance structures, labor relations, and democratic participation. Contemporary LPE scholarship, therefore, places significantly greater emphasis on political authority, institutional power, social rights, governance systems, neoliberalism, labor structures, and distributive justice. Recent scholarship has applied LPE perspectives to issues such as constitutional political economy, labor power, financialization, global governance, attention capitalism, and social rights erosion (Alemparte, 2025; Gregorut, 2025; Newman, 2026; Velazquez, 2026).

At the same time, critics of LPE argue that the movement often misunderstands or misrepresents the methodological foundations and analytical strengths of traditional Law & Economics scholarship. Chilton et al., (2026) argue that contemporary LE scholarship has become significantly broader and more empirically sophisticated than many LPE critiques acknowledge. Similarly, several scholars contend that economic reasoning continues to provide valuable analytical tools for understanding institutional incentives, legal behavior, and policy effectiveness (Chen, 2025; Depoorter & Demot, 2011; Leeson, 2012). Other critics suggest that LPE sometimes overstates the extent to which markets are entirely products of legal construction or fails to adequately distinguish between coercive and voluntary institutional arrangements (Zwolinski, 2026).

Consequently, contemporary debates surrounding LE and LPE increasingly concern not only legal doctrine but also broader questions regarding governance, institutional design, political authority, and the relationship between law and economic systems. However, despite the growing influence of these debates, the existing literature remains heavily dominated by theoretical, doctrinal, and normative discussions. Very limited empirical evidence currently exists regarding whether LE and LPE scholarship actually demonstrate systematically different discourse structures, thematic priorities, and conceptual orientations on a large scale.

This study addresses this research gap by conducting a large-scale computational and empirical analysis of LE and LPE scholarship using publication data collected from the Web of Science Core Collection database. The study integrates bibliometric analysis, Natural Language Processing (NLP), TF-IDF analysis, topic modeling, statistical testing, econometric modeling, and machine learning classification techniques to evaluate the intellectual divergence between the two scholarly traditions.

More specifically, the study aims to answer the following research questions:

RQ1: Do Law & Economics and Law & Political Economy scholarship exhibit different discourse orientations?

RQ2: What thematic structures dominate LE and LPE scholarship?

RQ3: To what extent can computational methods distinguish LE from LPE discourse?

The study contributes to the literature in several important ways. First, it provides one of the first large-scale empirical computational comparisons between LE and LPE scholarship. Second, it demonstrates the usefulness of NLP, bibliometric analysis, topic modeling, and econometric methods for examining intellectual transformations within legal scholarship. Third, the study contributes directly to ongoing debates surrounding the rise of the LPE movement by providing systematic empirical evidence regarding its conceptual orientation relative to traditional Law & Economics scholarship.

Overall, the findings suggest that LE and LPE scholarship represent conceptually distinct intellectual traditions characterized by different thematic priorities, discourse structures, and analytical orientations. While LE scholarship remains strongly associated with efficiency-oriented legal-economic reasoning, LPE scholarship demonstrates significantly greater emphasis on governance, institutional power, social structures, and political authority. The study, therefore, highlights the growing transformation of contemporary legal-economic scholarship and demonstrates the increasing importance of computational methods within interdisciplinary legal research.

2. Literature Review and Theoretical Background

2.1 Evolution of Law & Economics Scholarship

Law & Economics (LE) emerged as one of the most influential interdisciplinary approaches within modern legal scholarship during the second half of the twentieth century. The field primarily developed through the contributions of Ronald Coase, Guido Calabresi, Richard

Posner, and other scholars associated with the Chicago School tradition. The central objective of LE scholarship has traditionally been to apply economic reasoning to legal institutions and evaluate legal systems according to efficiency, incentives, transaction costs, and welfare optimization. Coase's seminal work on social cost and transaction costs fundamentally transformed legal-economic analysis by emphasizing the role of institutions and bargaining structures in shaping economic outcomes. Posner later expanded the field by systematically applying neoclassical economic theory to legal doctrine, arguing that many legal rules could be understood as mechanisms for maximizing economic efficiency. According to Marciano, (2012), however, important methodological distinctions existed even among the foundational scholars of LE, particularly regarding the relationship between efficiency and institutional analysis. Similarly, Hylton, (2019) argues that the broad categories of "law and economics" and "economic analysis of law" conceal important differences between positive and normative approaches within the field.

Several scholars have emphasized that LE scholarship evolved beyond narrow efficiency-based reasoning and increasingly incorporated institutional, empirical, and interdisciplinary perspectives. Bix, (2019) notes that Calabresi criticized purely efficiency-oriented analysis for failing to adequately capture broader aspects of legal and social life. Likewise, Leon Quiroga, (2021) argues that "law and economics" should be understood as a genuinely interdisciplinary framework combining legal and institutional analysis rather than merely applying economics to legal doctrine. Over time, LE scholarship expanded into numerous legal domains, including criminal law, environmental regulation, labor law, constitutional law, and corporate governance. Studies by Castro Linares, (2019), Kaufman, (2012), and Cruz Cunha Peixoto, (2013) demonstrate the growing application of economic reasoning across increasingly diverse legal contexts. At the same time, empirical legal analysis became progressively more sophisticated, incorporating quantitative methods, experiments, econometrics, and computational approaches (Kim et al., 2026). Despite these developments, LE scholarship has continued to face criticism for its strong emphasis on market efficiency and its limited engagement with broader distributive, political, and governance-related concerns. These criticisms created the intellectual conditions that contributed to the emergence of the Law & Political Economy movement.

2.2 Emergence of the Law & Political Economy Movement

The Law & Political Economy (LPE) movement emerged as a direct critique of the perceived dominance of efficiency-oriented legal reasoning within modern legal scholarship. Formally gaining visibility after 2019, LPE rapidly developed into a prominent interdisciplinary movement within major academic institutions, including Harvard, Yale, and Stanford. LPE scholars argue that legal systems cannot be analyzed solely as neutral mechanisms for improving market efficiency because law itself actively constructs markets, institutional hierarchies, labor relations, and socio-economic power structures. According to Immermann, (2026), LPE seeks to challenge the intellectual dominance of the "Chicago approach" by reclaiming earlier institutionalist traditions emphasizing the relationship between economic and political power. Similarly, Valenzuela & Guiloff, (2026) argue that LPE scholarship focuses on historically situated and institutionally grounded approaches to understanding legal-economic orders. Contemporary LPE scholarship places strong emphasis on governance systems, social inequality, constitutional political economy, labor structures, financialization, and institutional power. Recent studies have applied LPE frameworks to topics such as pension privatization

(Alemparte, 2025), constitutional design (Lucherini, 2026), global governance (Yamin, 2026), labor power and bankruptcy law (Velazquez, 2026), and attention capitalism (Newman, 2026). These studies collectively demonstrate the growing expansion of LPE into multiple legal and political-economic domains.

2.3 Critiques and Debates Surrounding LPE

Despite its growing influence, the LPE movement has also faced substantial criticism from both legal and economic scholars. Critics argue that LPE often underestimates the analytical value of economic reasoning and misrepresents the methodological sophistication of contemporary Law & Economics scholarship. Chilton et al., (2026) argue that modern LE scholarship has evolved significantly beyond simplistic efficiency models and now incorporates empirical methods, institutional analysis, and broader social-scientific inquiry. Similarly, Depoorter & Demot, (2011) contend that LE scholarship has developed extensive interdisciplinary applications across different legal systems despite institutional differences across countries. Other scholars challenge some of the foundational assumptions of LPE. Zwolinski, (2026), for example, critiques the claim that markets are inherently coercive, arguing that broad definitions of coercion may reduce analytical precision. Likewise, Klick, (2026) argues that some LPE-inspired policy approaches may generate unintended negative consequences for marginalized communities despite their distributive intentions.

2.4 Hypothesis Development

Based on the theoretical distinctions between Law & Economics (LE) and Law & Political Economy (LPE) scholarship, substantial differences are expected in discourse orientation and thematic emphasis. Traditional LE scholarship primarily emphasizes efficiency, incentives, market coordination, and institutional optimization, whereas LPE scholarship focuses more heavily on governance structures, institutional power, inequality, and political authority. Accordingly, the following hypotheses are proposed:

H1: Law & Economics scholarship demonstrates significantly higher efficiency-oriented discourse compared to Law & Political Economy scholarship.

H2: Law & Political Economy scholarship demonstrates significantly higher politically oriented discourse compared to Law & Economics scholarship.

H3: Law & Economics and Law & Political Economy scholarship exhibit significantly different thematic structures identifiable through computational text analysis.

3. Materials and Methods

3.1 Research Design

This study employs a quantitative computational text analysis approach to examine the conceptual and thematic differences between Law & Economics (LE) and Law & Political Economy (LPE) scholarship. The research combines bibliometric analysis, Natural Language Processing (NLP), topic modeling, statistical testing, and econometric modeling to evaluate whether the two scholarly traditions demonstrate systematically different discourse

orientations. The study follows an empirical comparative design by constructing two separate datasets representing LE and LPE scholarship and analyzing their language patterns, thematic structures, and conceptual emphasis.

3.2 Data Source and Collection

The dataset was collected from the Web of Science (WoS) Core Collection, selected for its high-quality indexing standards and broad coverage of peer-reviewed academic publications. Two separate search queries were used to construct the dataset: “Law and Economics” and “Law and Political Economy.” The searches were conducted within the Web of Science Core Collection using article titles, abstracts, author keywords, and indexed keywords. The dataset included peer-reviewed journal articles published between 2010 and 2025. After removing duplicates, incomplete records, and non-relevant entries, the final dataset consisted of 340 publications related to Law & Economics (LE) and 65 publications related to Law & Political Economy (LPE). For each publication, the following variables were collected: publication title, abstract, author keywords, publication year, citation counts, journal source, and document type. The data were exported from Web of Science in CSV format for further computational analysis in Python.

3.3 Data Preprocessing

The textual data were preprocessed before conducting the computational analyses. The preprocessing stage was designed to improve textual consistency and reduce noise within the dataset. The following preprocessing steps were applied: Conversion of all text into lowercase format, Removal of punctuation marks, numbers, and special characters, Elimination of common stopwords using the Natural Language Toolkit (NLTK) stopword dictionary, Tokenization of textual data into individual words, Removal of extremely short and non-informative tokens, and Construction of cleaned abstract variables for further analysis. The preprocessing procedures were performed using Python libraries, including pandas, re, nltk, scikit-learn, and NumPy. The cleaned textual corpus was subsequently used for keyword analysis, TF-IDF analysis, topic modeling, and discourse orientation measurement. The preprocessing procedure can be formally represented as:

$$T_{clean} = f(T_{raw} - S - P - N) \quad (1)$$

Where T_{clean} represents the cleaned textual corpus obtained after applying the preprocessing transformation function $f(\cdot)$ to the original raw text T_{raw} . The preprocessing procedure involves the removal of stopwords (S), punctuation marks and special characters (P), as well as numerical values and noise terms (N).

3.4 Keyword and TF-IDF Analysis

To identify the dominant terminology and conceptual orientation of the two scholarly traditions, keyword frequency analysis and Term Frequency–Inverse Document Frequency (TF-IDF) analysis were conducted. Keyword frequency analysis was used to identify the most frequently occurring author-provided keywords within LE and LPE scholarship. TF-IDF analysis was subsequently employed to identify terms that were particularly distinctive and influential within each dataset. The TF-IDF weighting scheme is mathematically defined as:

$$TFIDF(t, d) = TF(t, d) \times \log\left(\frac{N}{DF(t)}\right) \quad (2)$$

Where $TF(t, d)$ is the frequency of term t in a document, d , N is the total number of documents, and $DF(t)$ is the number of documents containing term t . The TF-IDF analysis was implemented using the `TfidfVectorizer` function from the `scikit-learn` library.

Topic Modeling: To uncover hidden thematic structures within the dataset, Latent Dirichlet Allocation (LDA) topic modeling was applied. Topic modeling enables the identification of latent conceptual clusters within large textual corpora by grouping frequently co-occurring words into thematic topics. The cleaned abstract corpus was transformed into a document-term matrix, and the LDA algorithm was estimated using the `scikit-learn` implementation. The probabilistic structure of LDA can be expressed as:

$$P(w) = \sum_{k=1}^K P(w | z_k) P(z_k) \quad (3)$$

Where $P(w)$ is the probability of observing word w , z_k is the latent topic, k , $P(w | z_k)$ is the probability of word w given topic k , and $P(z_k)$ is the probability of the topic k . Five topics were extracted based on interpretability and thematic coherence. The resulting topics were manually interpreted and labeled according to their dominant terms and conceptual meaning.

3.5 Discourse Orientation Measurement

To measure conceptual orientation, two separate discourse indices were constructed: first, the Efficiency-Oriented Discourse Score, and then the Political-Oriented Discourse Score. The efficiency-oriented dictionary included terms associated with: market efficiency, incentives, transaction costs, liability, regulation, and economic optimization. The political-oriented dictionary included terms associated with governance, institutional power, inequality, social structures, democracy, and political authority. The discourse scores were calculated as:

$$Score_i = \sum_{j=1}^n f(w_j) \quad (4)$$

Where $Score_i$ is the discourse score for the document i , $f(w_j)$ is the frequency of the keyword w_j , and n is the total number of keywords in the dictionary. Higher scores indicate stronger conceptual emphasis within the corresponding discourse category. To improve reliability, alternative keyword dictionaries and normalized scores were also constructed as part of the robustness analysis.

3.6 Statistical and Econometric Analysis

Several statistical and econometric methods were employed to evaluate the conceptual differences between LE and LPE scholarship. First, descriptive statistics were used to summarize citation patterns, publication characteristics, and discourse orientation scores. Second, independent sample t-tests were conducted to determine whether the differences

between LE and LPE discourse scores were statistically significant. Third, Ordinary Least Squares (OLS) regression models were estimated to examine the effect of LPE membership on discourse orientation while controlling for citation counts and publication year. The general regression model is specified as:

$$Y_i = \beta_0 + \beta_1 LPE_i + \beta_2 Citations_i + \beta_3 Year_i + \varepsilon_i \quad (5)$$

Where, Y_i is the discourse orientation score, LPE_i is the dummy variable for LPE scholarship, $Citations_i$ is the citation count, $Year_i$ is the publication year, and ε_i is the error term. Two separate regression models were estimated: first, the Political Orientation Model, and then the Efficiency Orientation Model. To address potential heteroskedasticity, HC3 robust standard errors were additionally applied during robustness testing. Finally, logistic classification analysis was conducted to evaluate whether discourse variables could successfully distinguish between LE and LPE scholarship. The logistic regression probability function is expressed as:

$$P(Y = 1) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n)}} \quad (6)$$

Where, $P(Y = 1)$ is the probability that a publication belongs to the LPE category, X_n is the explanatory variables, and β_n is the estimated coefficients.

3.7 Robustness Analysis

To evaluate the stability and reliability of the empirical findings, several robustness tests were conducted. First, alternative keyword dictionaries were constructed for both efficiency-oriented and political-oriented discourse to examine whether the results remained consistent under different term selection strategies. Second, normalized discourse scores were calculated by adjusting for abstract length differences across publications. Third, heteroskedasticity-robust HC3 standard errors were applied within the regression models to address potential variance inconsistencies in the residuals. Finally, logistic classification analysis was performed to assess whether the identified discourse variables could accurately distinguish between Law & Economics (LE) and Law & Political Economy (LPE) scholarship. The robustness results consistently confirmed the main findings of the study, indicating that the conceptual divergence between LE and LPE scholarship remains stable across multiple analytical specifications and measurement approaches.

All analyses were conducted in Python using Jupyter Notebook. The primary libraries used in the study included: pandas, NumPy, scikit-learn, matplotlib, seaborn, nltk, statsmodels, and NetworkX. The visualizations, statistical analyses, topic modeling procedures, and regression estimations were fully implemented within the Python computational environment to ensure reproducibility and methodological transparency.

4. Results

4.1 Bibliometric Overview of the Dataset

Table 1 presents the descriptive statistics of the collected Web of Science dataset, consisting of 340 publications related to traditional Law & Economics (LE) scholarship and 65 publications

associated with the Law & Political Economy (LPE) movement. The descriptive results reveal notable differences in citation dynamics and discourse orientation between the two scholarly traditions. First, LE publications demonstrate substantially higher average citation counts (Mean = 21.54) compared to LPE publications (Mean = 9.28). This difference likely reflects the longer historical development and broader institutional establishment of Law & Economics scholarship within legal and economic academia. The relatively lower citation levels observed in LPE publications may be associated with the recent emergence of the movement, particularly after 2019, as identified in the publication trend analysis. Second, the discourse orientation scores indicate a clear conceptual divergence between the two schools of thought. LE scholarship exhibits a higher mean efficiency score (Mean = 1.99) relative to LPE scholarship (Mean = 1.14), suggesting a stronger emphasis on market coordination, incentives, liability structures, and efficiency-oriented legal reasoning. In contrast, LPE publications display a substantially higher political orientation score (Mean = 4.58) compared to LE scholarship (Mean = 1.44). This finding indicates that LPE discourse places significantly greater emphasis on political governance, institutional power, social structures, democratic concerns, and redistribution-oriented narratives. The standard deviations further suggest considerable thematic heterogeneity within both traditions, particularly in citation performance and political discourse orientation. In general, the descriptive statistics provide preliminary empirical evidence that Law & Economics and Law & Political Economy represent conceptually distinct scholarly frameworks characterized by different intellectual priorities and discourse structures.

Table 1. Descriptive Statistics of Law & Economics and Law & Political Economy Scholarship

Variable	LE	LPE
Number of publications	340	65
Mean citations	21.54	9.28
Citation standard deviation	31.94	31.76
Minimum citations	6	0
Maximum citations	364	249
Mean efficiency score	1.99	1.14
Efficiency score SD	2.90	1.95
Mean political score	1.44	4.58
Political score SD	2.08	3.54

Figure 1 illustrates the publication trends of Law & Economics (LE) and Law & Political Economy (LPE) scholarship between 2010 and 2025. The results show that LE scholarship consistently dominated the academic landscape throughout most of the observed period. Between 2010 and 2019, LE publications remained relatively stable at a high level, reflecting the long-established position of economic reasoning, market analysis, and efficiency-oriented approaches within legal scholarship. In contrast, LPE scholarship remained very limited before 2019, with only a small number of publications appearing annually. However, a clear structural shift emerges after 2019, where LPE publications begin to increase rapidly. This growth becomes particularly visible from 2020 onward, with publication counts steadily rising and reaching their highest level around 2025. The trend suggests that LPE has evolved into an increasingly influential and recognizable research movement within contemporary legal and economic scholarship. At the same time, the decline in LE publications after 2022 may indicate a relative transition in scholarly attention toward broader political, social, and institutional concerns that are strongly emphasized within LPE literature. In general, the figure demonstrates the emergence of LPE as a rapidly growing intellectual movement while confirming the historically dominant role of traditional Law & Economics scholarship.

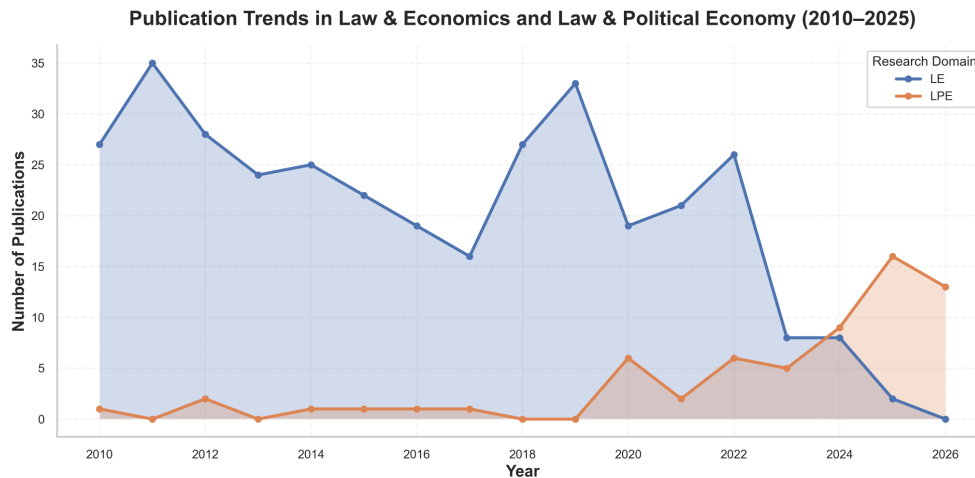


Figure 1. Publication Trends in Law & Economics and Law & Political Economy Scholarship

4.2 Keyword and TF-IDF Analysis

Table 2 presents the most frequently occurring keywords within Law & Economics (LE) and Law & Political Economy (LPE) scholarship. The results reveal a substantial conceptual divergence between the two research traditions. The LE dataset is dominated by keywords such as “corporate governance,” “competition law,” “transaction costs,” “liability,” “property rights,” “efficiency,” and “economic analysis of law.” These terms strongly reflect the traditional foundations of Law & Economics scholarship, which emphasize market coordination, incentives, institutional efficiency, liability structures, and economic optimization within legal systems. The appearance of terms such as “deterrence” and “regulation” further highlights the analytical and efficiency-oriented character of LE discourse. In contrast, the LPE dataset demonstrates a substantially different thematic orientation. Keywords such as “neoliberalism,” “social rights,” “human rights,” “social reproduction,” “domestic work,” “care,” and “institutionalism” indicate a stronger focus on social inequality, institutional power structures, labor relations, governance, and socio-political critiques of legal systems. The presence of terms associated with human rights and social structures suggests that LPE scholarship places considerably greater emphasis on redistribution, democratic governance, and structural inequalities than traditional LE scholarship. In general, the keyword analysis provides strong empirical evidence that LE and LPE scholarship represent conceptually distinct intellectual traditions characterized by different theoretical priorities and normative orientations.

Table 2. Most Frequent Keywords in Law & Economics and Law & Political Economy Scholarship

Rank	LE Keywords	Frequency	LPE Keywords	Frequency
1	law and economics	40	law and political economy	8
2	law	9	neoliberalism	4
3	corporate governance	8	legal realism	2
4	artificial intelligence	6	social rights	2
5	behavioural law and economics	5	human rights	2
6	competition law	5	business and human rights	2
7	regulation	5	social reproduction	2
8	deterrence	4	domestic work	2

9	transaction costs	4	care	2
10	liability	4	political economy	2
11	innovation	4	institutionalism	2
12	intellectual property	4	blockchain	2
13	efficiency	4	legal infrastructure	1
14	economic analysis of law	4	Latin America	1
15	property rights	4	constitutional regulations	1

Table 3 presents the TF-IDF analysis results for Law & Economics (LE) and Law & Political Economy (LPE) scholarship. Unlike simple keyword frequency analysis, TF-IDF identifies terms that are particularly important and distinctive within each scholarly domain. The findings reveal a substantial conceptual divergence between LE and LPE scholarship. The LE dataset is characterized by a stronger emphasis on terms such as “market,” “rule,” “theory,” “cost,” “policy,” “model,” and “effect.” These terms reflect the analytical and efficiency-oriented foundations of traditional Law & Economics scholarship, which typically focuses on market coordination, institutional efficiency, incentives, transaction costs, and formal legal-economic modeling. The prominence of “cost” and “market” particularly reinforces the role of efficiency and optimization within LE discourse. In contrast, the LPE dataset demonstrates a significantly different conceptual orientation. Terms such as “political,” “social,” “state,” “political economy,” “right,” and “power” appear with substantially higher importance scores. These results indicate that LPE scholarship places considerably greater emphasis on governance structures, institutional authority, political power relations, social inequality, and rights-based discourse. The presence of terms such as “international” and “work” further suggests broader engagement with labor relations, global governance, and structural critiques of legal-economic systems. The TF-IDF findings, therefore, provide strong computational evidence that LE and LPE scholarship differ not only in terminology but also in their underlying intellectual priorities and theoretical orientation. While LE scholarship remains closely associated with efficiency-driven and market-centered legal analysis, LPE scholarship demonstrates a substantially stronger focus on political governance, institutional power, and social structures.

Table 3. Top TF-IDF Terms Across Law & Economics and Law & Political Economy Scholarship

Rank	LE TF-IDF Terms	Score	LPE TF-IDF Terms	Score
1	law	0.171	law	0.179
2	economics	0.103	legal	0.133
3	legal	0.103	political	0.128
4	economic	0.098	economy	0.103
5	law economics	0.081	social	0.096
6	market	0.068	state	0.091
7	rule	0.067	political economy	0.087
8	theory	0.060	economic	0.085
9	cost	0.058	right	0.084
10	approach	0.056	market	0.080
11	policy	0.054	policy	0.070
12	case	0.052	power	0.060
13	effect	0.052	work	0.060
14	model	0.051	international	0.056
15	social	0.050	economics	0.056

Figure 2 presents the dominant vocabulary within Law & Economics (LE) scholarship through a word cloud visualization generated from the cleaned abstract dataset. The figure highlights several recurring terms, including “market,” “cost,” “rule,” “theory,” “policy,” “firm,”

“liability,” and “regulation.” The prominence of these terms reflects the traditional foundations of LE scholarship, which emphasize market coordination, institutional efficiency, incentives, liability structures, and economic optimization within legal systems. The frequent appearance of terms such as “market,” “cost,” and “efficiency” further demonstrates the central role of economic reasoning in LE discourse. Similarly, the visibility of terms related to “corporate,” “consumer,” “litigation,” and “governance” suggests that LE scholarship often focuses on regulatory structures, firm behavior, contractual relationships, and legal mechanisms that influence economic outcomes. At the same time, the figure also reveals the presence of broader institutional and policy-oriented terminology, including “public,” “state,” “international,” and “social.” This indicates that contemporary LE scholarship is not exclusively limited to narrow market analysis but increasingly engages with governance, regulation, and public policy concerns within legal-economic systems. In general, the visualization supports the earlier keyword and TF-IDF findings by demonstrating that LE scholarship remains strongly associated with analytical, market-oriented, and efficiency-based legal reasoning.

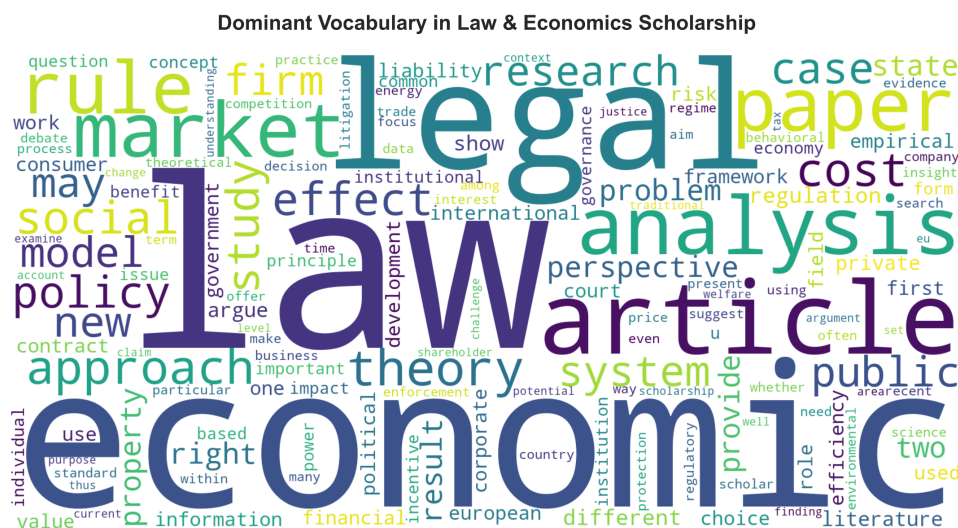


Figure 2. Word Cloud of Law & Economics Scholarship

Figure 3 presents the dominant vocabulary within Law & Political Economy (LPE) scholarship through a word cloud generated from the cleaned abstract dataset. In contrast to the Law & Economics visualization, the LPE word cloud is dominated by terms such as “political,” “social,” “state,” “power,” “rights,” “institutional,” “global,” “framework,” and “international.” These findings indicate that LPE scholarship places substantially greater emphasis on governance structures, institutional authority, social relations, and political power within legal and economic systems. The prominence of terms such as “state,” “rights,” “power,” and “institutional” suggests a strong focus on democratic governance, inequality, structural critiques, and the role of legal institutions in shaping economic and political outcomes. Similarly, the appearance of terms including “labour,” “health,” “global,” “capitalism,” and “neoliberal” reflects broader engagement with social justice, labour relations, globalization, and critiques of market-centered legal frameworks. Compared to LE scholarship, the LPE vocabulary demonstrates a clearer orientation toward political and social discourse rather than efficiency-oriented economic reasoning. While market-related terminology remains visible, it appears alongside broader discussions of governance, institutional structures, and collective social concerns. In general, the figure visually reinforces the earlier keyword and TF-IDF

analyses by demonstrating that LPE scholarship is conceptually centered on political governance, institutional power, and socio-economic critique.

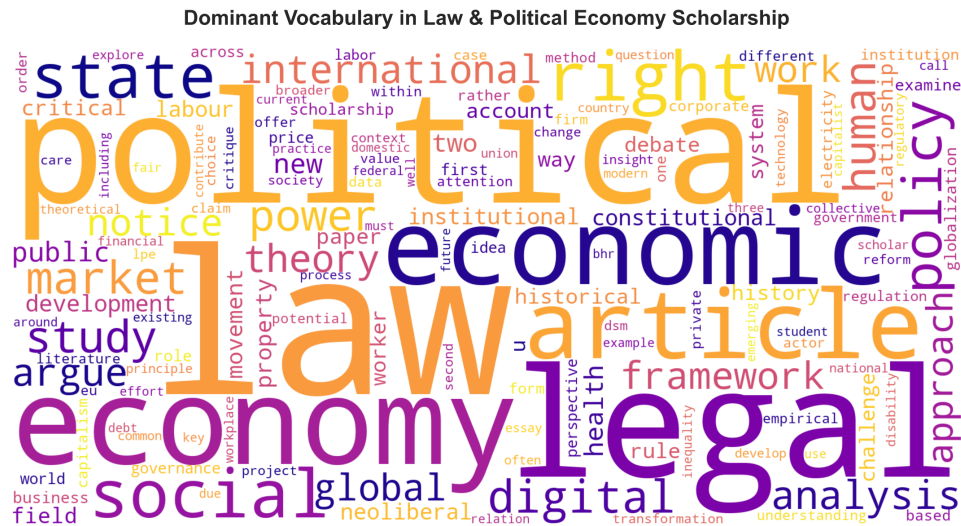


Figure 3. Word Cloud of Law & Political Economy Scholarship

4.3 Topic Modeling Results

Table 4 presents the thematic structures identified through Latent Dirichlet Allocation (LDA) topic modeling. The analysis reveals several distinct conceptual clusters within the combined Law & Economics (LE) and Law & Political Economy (LPE) dataset, demonstrating the coexistence of efficiency-oriented legal-economic discourse and politically oriented institutional critique. Topic 1 primarily focuses on markets, liability systems, institutional regulation, and cost structures. The presence of terms such as “market,” “cost,” “liability,” and “rule” strongly reflects the traditional foundations of Law & Economics scholarship, particularly its emphasis on efficiency, legal coordination, and institutional optimization. Topic 2 centers around judicial institutions, governance structures, and political authority. Keywords including “judicial,” “court,” “state,” and “political” indicate a stronger engagement with public governance and institutional authority, which aligns more closely with Law & Political Economy discourse. Topic 3 highlights the intersection of political economy, international governance, firms, and market structures. The appearance of terms such as “political,” “state,” “firm,” and “international” suggests a broader interdisciplinary discussion surrounding globalization, institutional power, and the relationship between markets and governance systems.

Topic 4 emphasizes institutions, social structures, property relations, and governance regimes. The prominence of terms such as “institution,” “social,” “property,” and “regime” indicates substantial attention toward institutional arrangements, labor structures, and broader socioeconomic governance mechanisms. Finally, Topic 5 captures themes associated with litigation, trade, deterrence, enforcement, and institutional power. Terms such as “litigation,” “trade,” “deterrence,” and “power” suggest a thematic focus on legal enforcement mechanisms, regulatory systems, and strategic institutional behavior within legal-economic frameworks. In general, the topic modeling analysis provides strong computational evidence that LE and LPE scholarship are organized around substantially different thematic priorities and intellectual orientations. While LE scholarship remains closely associated with markets, efficiency,

liability, and institutional coordination, LPE scholarship demonstrates a stronger orientation toward governance, political authority, social structures, and institutional power relations.

Table 4. Topic Modeling Results and Thematic Interpretation

Topic	Main Terms	Interpretation
Topic 1	public, private, system, social, price, cost, market, liability, rule	Markets, Liability, and Institutional Regulation
Topic 2	judicial, principle, case, public, state, theory, court, political	Courts, Governance, and Political Authority
Topic 3	model, political, right, market, state, firm, international	Political Economy and Global Market Structures
Topic 4	institution, state, regime, work, social, property, empirical	Institutional Structures and Social Governance
Topic 5	litigation, market, trade, deterrence, rule, power	Trade, Enforcement, and Legal Power Dynamics

Figure 4 shows the main thematic areas identified in the combined Law & Economics (LE) and Law & Political Economy (LPE) scholarship. The largest topic is “Markets & Liability,” indicating that many publications still focus on markets, legal rules, costs, regulation, and liability systems. This reflects the traditional influence of Law & Economics scholarship, which mainly emphasizes efficiency and market-related legal analysis. The second largest topic is “Political Economy,” followed by “Courts & Governance.” These topics highlight the increasing importance of political, institutional, and governance-related discussions within legal-economic research. The results suggest that newer scholarship, especially LPE-related studies, is placing greater attention on political power, institutions, public governance, and social issues. The figure also shows that themes such as institutions, property relations, trade, deterrence, and enforcement continue to play an important role in legal-economic scholarship. In general, the results indicate that modern legal-economic research is no longer focused only on efficiency and markets, but increasingly includes broader political and social concerns as well.

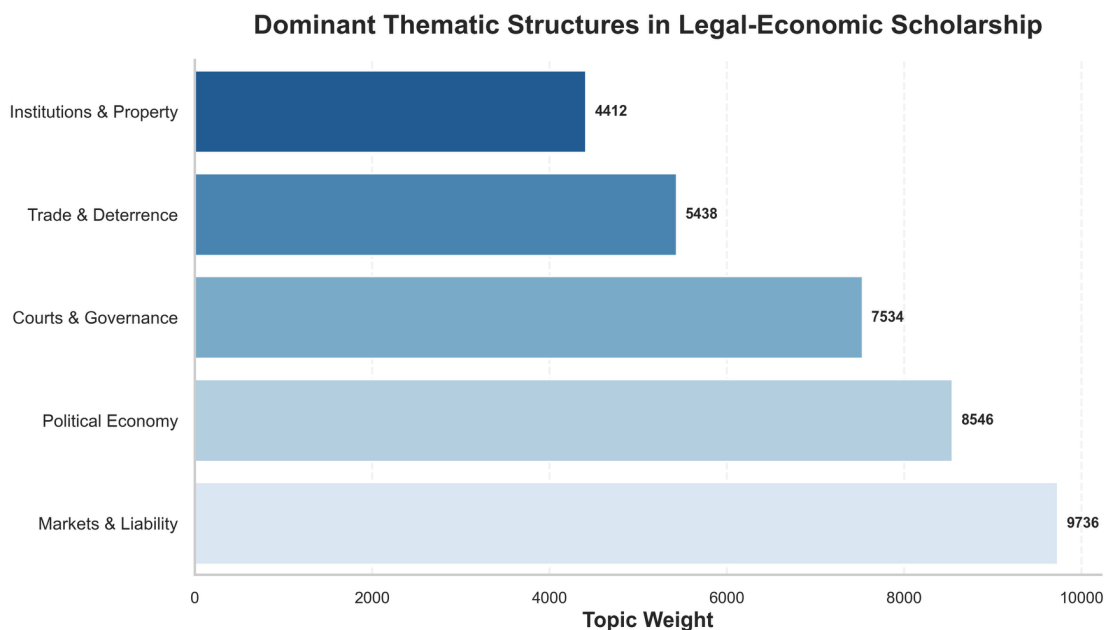


Figure 4. Dominant Thematic Structures in Legal-Economic Scholarship

4.4 Discourse Orientation Analysis

Figure 5 compares the average discourse orientation scores between Law & Economics (LE) and Law & Political Economy (LPE) scholarship. The figure clearly demonstrates a substantial conceptual divergence between the two scholarly traditions. LE scholarship exhibits a higher efficiency-oriented discourse score, reflecting a stronger focus on market coordination, incentives, liability systems, and efficiency-based legal reasoning. In contrast, LPE scholarship demonstrates a significantly higher politically oriented discourse score, indicating a stronger emphasis on governance structures, institutional power, political authority, and social concerns. The difference is particularly visible in the political orientation scores, where LPE publications substantially exceed LE publications. These findings suggest that LPE scholarship is conceptually centered around political and institutional critique, whereas LE scholarship remains more strongly associated with efficiency-oriented legal-economic analysis. In general, the figure provides clear visual evidence that LE and LPE scholarship represent distinct intellectual frameworks characterized by different thematic and conceptual priorities.

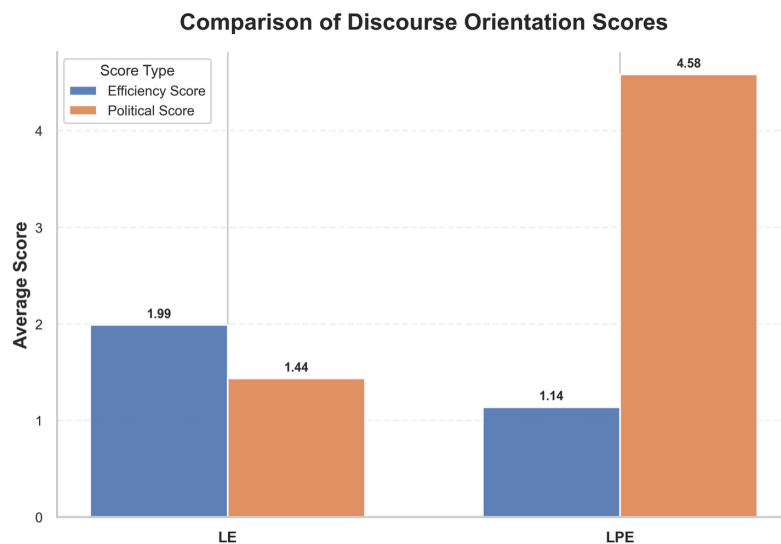


Figure 5. Comparison of Discourse Orientation Scores

Table 5 presents the independent sample t-test results comparing discourse orientation scores between LE and LPE scholarship. The results indicate that both the efficiency-oriented and political-oriented score differences are statistically significant. The efficiency score difference is significant at the 5% level ($p = 0.023$), suggesting that LE scholarship places significantly greater emphasis on efficiency-oriented discourse compared to LPE scholarship. More importantly, the political score difference is highly significant ($p < 0.001$), demonstrating that LPE scholarship is substantially more focused on political governance, institutional authority, and social structures. These findings provide strong statistical evidence that LE and LPE scholarship differ considerably in their underlying intellectual orientation and discourse priorities.

Table 5. Independent Sample t-Test Results

Variable	t-statistic	p-value
Efficiency Score	2.27	0.023
Political Score	-9.81	<0.001

4.5 Econometric Analysis

Table 6 presents the Ordinary Least Squares (OLS) regression results for the political orientation model. The analysis examines whether Law & Political Economy (LPE) scholarship is associated with stronger politically oriented discourse compared to traditional Law & Economics (LE) scholarship. The results show that the LPE dummy variable has a strong positive and highly significant effect on political discourse orientation ($\beta = 2.856$, $p < 0.001$). This indicates that LPE publications place substantially greater emphasis on governance structures, institutional authority, political power, social relations, and rights-based discussions compared to LE scholarship. The magnitude of the coefficient further suggests that politically oriented discourse represents a defining characteristic of LPE scholarship. The citation variable is not statistically significant ($p = 0.389$), indicating that politically oriented discourse is not primarily influenced by citation popularity or scholarly impact. Similarly, the publication year variable is only marginally significant ($p = 0.068$), suggesting a modest increase in politically oriented discourse over time. The model explains approximately 20% of the variation in political discourse orientation ($R^2 = 0.200$), which is relatively strong for text-based and discourse-oriented empirical analysis. In addition, the highly significant F-statistic confirms the overall explanatory power of the regression model. In general, the results provide strong econometric evidence that LPE scholarship differs systematically from traditional LE scholarship by demonstrating a substantially stronger political and governance-oriented discourse structure.

Table 6. OLS Regression Results: Political Orientation Model

Variable	Coefficient	Standard Error	t-statistic	p-value
Constant	1.419	0.152	9.352	<0.001
LPE Dummy	2.856	0.367	7.778	<0.001
Citations	0.003	0.004	0.863	0.389
Year Centered	0.052	0.029	1.827	0.068

Model Statistics

Statistic	Value
Observations	405
R ²	0.200
Adjusted R ²	0.194
F-statistic	33.44
Prob (F-statistic)	2.62e-19
Durbin-Watson	2.117

Table 7 presents the OLS regression results for the efficiency orientation model. The analysis examines whether Law & Political Economy (LPE) scholarship differs from traditional Law & Economics (LE) scholarship in terms of efficiency-oriented discourse. The results show that the LPE dummy variable has a negative and statistically significant effect on efficiency-oriented discourse ($\beta = -1.119$, $p = 0.010$). This indicates that LPE publications place significantly less emphasis on market efficiency, incentives, institutional optimization, and traditional economic reasoning compared to LE scholarship. The citation variable is not statistically significant ($p = 0.769$), suggesting that efficiency-oriented discourse is not strongly related to citation popularity or scholarly impact. Similarly, the publication year variable is not statistically significant ($p = 0.186$), indicating that efficiency-oriented discourse has remained relatively stable over time within the dataset. Although the explanatory power of the model is relatively modest ($R^2 = 0.017$), this is common in textual and discourse-based analyses where conceptual

orientation is influenced by multiple latent factors. Importantly, the statistically significant coefficient for the LPE variable confirms that LPE scholarship systematically differs from LE scholarship by exhibiting substantially lower efficiency-oriented discourse. In general, the findings support the broader argument of the study that LE and LPE represent distinct intellectual traditions characterized by different conceptual priorities and analytical orientations.

Table 7. OLS Regression Results: Efficiency Orientation Model

Variable	Coefficient	Standard Error	t-statistic	p-value
Constant	2.009	0.178	11.304	<0.001
LPE Dummy	-1.119	0.430	-2.602	0.010
Citations	0.001	0.004	0.294	0.769
Year Centered	0.044	0.033	1.325	0.186

Model Statistics	
Statistic	Value
Observations	405
R ²	0.017
Adjusted R ²	0.010
F-statistic	2.309
Prob (F-statistic)	0.0759
Durbin-Watson	1.933

Figure 6 presents the regression coefficients measuring the effect of Law & Political Economy (LPE) membership on discourse orientation. The figure clearly shows two opposite relationships between LPE scholarship and the two discourse models. The positive coefficient in the political model ($\beta = 2.86$) indicates that LPE scholarship is strongly associated with politically oriented discourse. This suggests that LPE publications place greater emphasis on governance structures, institutional power, political authority, social relations, and rights-based discussions. In contrast, the negative coefficient in the efficiency model ($\beta = -1.12$) indicates that LPE scholarship is associated with lower efficiency-oriented discourse compared to traditional Law & Economics scholarship. This finding suggests that LPE publications place less emphasis on market efficiency, incentives, and economic optimization. The figure provides a clear visual summary of the conceptual divergence between LE and LPE scholarship. While LE scholarship remains more closely connected to efficiency-oriented legal-economic reasoning, LPE scholarship demonstrates a significantly stronger political and institutional orientation.

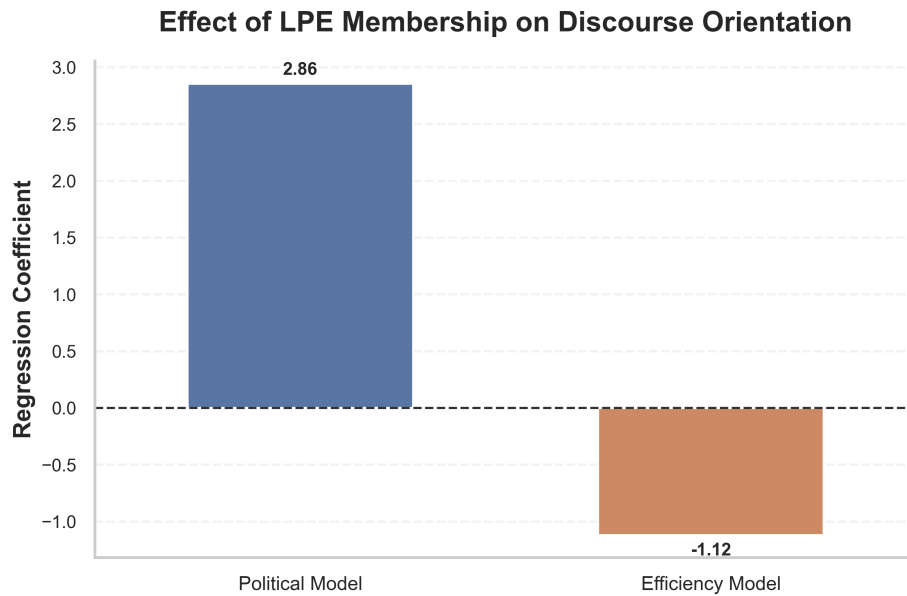


Figure 6. Effect of LPE Membership on Discourse Orientation

4.6 Robustness Analysis

This section evaluates the stability and reliability of the empirical findings using several robustness tests. The objective is to determine whether the observed conceptual differences between Law & Economics (LE) and Law & Political Economy (LPE) scholarship remain consistent under alternative model specifications, alternative dictionaries, normalized scores, and predictive classification methods. Table 8 presents the robustness test results using alternative keyword dictionaries for both efficiency-oriented and political-oriented discourse. The findings remain highly consistent with the main analysis. LE scholarship continues to demonstrate substantially higher efficiency-oriented discourse scores, while LPE scholarship maintains significantly higher political-oriented discourse scores. The persistence of these differences under alternative dictionary specifications indicates that the main findings are not dependent on a single keyword selection strategy. In general, the results confirm the conceptual divergence between LE and LPE scholarship and strengthen the reliability of the discourse orientation analysis.

Table 8. Robustness Tests Using Alternative Dictionaries		
Group	Alternative Efficiency Score	Alternative Political Score
LE	2.70	1.84
LPE	1.51	5.78

Table 9 reports the robustness test results using both alternative dictionaries and normalized discourse scores. The normalized scores control for differences in abstract length across publications. The results remain statistically significant across all model specifications. LE scholarship consistently demonstrates higher efficiency-oriented discourse, while LPE scholarship exhibits substantially higher politically oriented discourse. Importantly, the significance of the normalized score analysis indicates that the findings are not driven by differences in document length or writing style. These results provide strong evidence that the conceptual differences identified between LE and LPE scholarship are stable and robust across multiple measurement approaches.

Table 9. Independent Sample t-Test Results for Alternative and Normalized Scores

Test	t-statistic	p-value
Alternative Efficiency Score	2.67	0.008
Alternative Political Score	-10.49	<0.001
Normalized Efficiency Score	2.63	0.009
Normalized Political Score	-8.71	<0.001

Table 10 presents the heteroskedasticity-robust (HC3) regression results. The findings remain highly consistent with the primary regression models. The positive and statistically significant coefficient in the political orientation model confirms that LPE scholarship is strongly associated with politically oriented discourse. Similarly, the negative and significant coefficient in the efficiency model indicates that LPE scholarship is systematically less efficiency-oriented than traditional LE scholarship. The consistency of the coefficients after applying robust standard errors demonstrates that the main findings are not sensitive to heteroskedasticity or model specification issues. This substantially strengthens the reliability and validity of the econometric analysis.

Table 10. HC3 Robust Regression Results

Model	LPE Coefficient	p-value
Political Orientation Model	2.856	<0.001
Efficiency Orientation Model	-1.119	0.006

Table 11 presents the logistic classification results used to evaluate whether the identified discourse characteristics can successfully distinguish between Law & Economics (LE) and Law & Political Economy (LPE) scholarship. The model achieves an overall classification accuracy of 91.36%, indicating a very strong ability to differentiate between the two scholarly traditions based on their discourse structure and thematic orientation. The classification performance is particularly strong for LE scholarship, with precision, recall, and F1-scores all exceeding 0.90. This suggests that efficiency-oriented discourse patterns associated with traditional LE scholarship are highly consistent and computationally identifiable. The model also performs reasonably well in identifying LPE scholarship, achieving a precision score of 0.80 and an F1-score of 0.70. Although the recall value for LPE publications is comparatively lower, the overall results still demonstrate substantial predictive distinction between the two intellectual traditions. The high weighted average F1-score (0.91) further confirms the overall robustness and predictive reliability of the classification model. These findings suggest that LE and LPE scholarship are not only theoretically different but also computationally distinguishable through their language patterns, thematic structures, and discourse orientation. In general, the classification analysis provides strong additional evidence supporting the broader argument of the study that LE and LPE represent conceptually distinct scholarly frameworks with systematically different intellectual priorities.

Table 11. Logistic Classification Performance

Metric	Value
Accuracy	91.36%
Precision (LE)	0.93
Recall (LE)	0.97
F1-score (LE)	0.95
Precision (LPE)	0.80
Recall (LPE)	0.62
F1-score (LPE)	0.70

Macro Average F1-score	0.82
Weighted Average F1-score	0.91

5. Discussion

5.1 Discourse Differences Between LE and LPE

The results demonstrate clear differences between Law & Economics (LE) and Law & Political Economy (LPE) scholarship. LE is predominantly characterized by efficiency-oriented discourse, emphasizing market coordination, incentives, transaction costs, and institutional optimization. In contrast, LPE places significantly greater emphasis on governance, political authority, inequality, and institutional power. Econometric results confirm these distinctions, with the LPE indicator positively associated with political discourse and negatively associated with efficiency-oriented discourse. Overall, the findings indicate that LE and LPE represent distinct intellectual traditions with different analytical priorities.

5.2 Thematic Differences Between LE and LPE

The thematic analyses reveal substantial divergence between the two research traditions. LE primarily focuses on market efficiency, liability, competition, transaction costs, and corporate governance, whereas LPE emphasizes political economy, governance, labor, human rights, and institutional power. Publication trends indicate growing interest in politically oriented legal scholarship after 2019, reflecting increased attention to inequality and governance issues. These findings suggest that contemporary legal scholarship increasingly incorporates both efficiency-based and governance-centered perspectives.

5.3 Computational Identification of LE and LPE

The computational analyses effectively distinguish between LE and LPE scholarship. Combining NLP, TF-IDF, topic modeling, discourse scoring, econometric analysis, and machine learning achieved over 91% classification accuracy, demonstrating robust differences in language and thematic structures. Robustness tests confirmed the consistency of these findings across alternative specifications. The results highlight the value of computational methods for empirically examining legal scholarship and demonstrate their potential for advancing interdisciplinary legal and political economy research.

6. Conclusion

This study provides one of the first large-scale computational comparisons of Law & Economics (LE) and Law & Political Economy (LPE) scholarship. Using bibliometric analysis, natural language processing (NLP), topic modeling, econometric analysis, and machine learning, the findings demonstrate that the two traditions represent distinct intellectual frameworks. LE is primarily characterized by efficiency-oriented discourse centered on markets, incentives, and institutional optimization, whereas LPE places greater emphasis on governance, political authority, inequality, and institutional power. These differences are consistently supported by statistical, econometric, and computational analyses, with the classification model achieving over 91% accuracy. The results suggest that legal scholarship is becoming increasingly pluralistic. While efficiency-based analysis remains central to LE,

governance- and distribution-oriented perspectives associated with LPE have gained significant prominence, reflecting a broader shift toward interdisciplinary approaches in legal research. The study also demonstrates the value of computational methods for systematically examining intellectual developments within legal scholarship. The findings indicate that legal scholarship is increasingly addressing governance, inequality, and institutional power alongside traditional concerns of efficiency and market performance. Consequently, policymakers and legal institutions may benefit from integrating both efficiency- and governance-oriented perspectives when designing legal and regulatory frameworks. The study also highlights the growing relevance of computational methods, such as NLP and machine learning, for monitoring legal discourse, identifying emerging policy trends, and supporting evidence-based legal research.

6.1 Limitations and Future Research

This study has several limitations. First, the analysis is restricted to publications indexed in the Web of Science Core Collection and may not capture relevant scholarship from other databases such as Scopus, SSRN, or HeinOnline. Second, the discourse measures rely on dictionary-based methods, which, despite robustness checks, involve some degree of subjectivity. Third, the dataset includes only English-language publications from 2010–2025, limiting cross-cultural and multilingual perspectives. Finally, the study examines academic discourse rather than its direct influence on legal institutions or policymaking. Future research should incorporate multiple databases, multilingual datasets, and advanced language models such as BERT and large language models to improve semantic analysis. Further studies could also investigate how LE and LPE scholarship shapes judicial decisions, regulatory frameworks, legal education, and public policy over time.

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The impact of digitalization and automation on accounting practices and the accounting profession in the Czech Republic

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Abstract: The rapid development of the implementation of digitization and automation of processes in both government organizations and private companies brings new knowledge about their applicability in this sector. This article analyzes the impact of digitalization and automation on accounting practice in the Czech Republic, focusing on key technology trends and their impact on professional requirements. The research was conducted through a questionnaire among accounting professionals in the Czech Republic, which analyzed their attitudes towards digitalization and the degree of use of digital tools. Statistical methods identified relationships between variables, while content analysis provided deeper insights into respondents' experiences. The results show that digitalization is perceived positively, especially in terms of efficiency and accuracy of accounting operations; However, its implementation requires the development of analytical and technical skills. At the same time, fears of job losses have been identified. The research provides a comprehensive overview of the digitization of accounting and offers recommendations on how to adapt to technological changes.

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1. Introduction

At a time when digitization and automation are rapidly evolving phenomena, accounting is becoming a key focus not only in the business world but also in academic circles. Now, more emphasis is placed on the efficiency and productivity of companies. Accounting processes and strategies that have been in place for many years and are considered standard are increasingly influenced by technological changes and the need to adapt to rapid changes. In the field of accounting, digitization and automation are widely recognized as essential tools for improving an organization's performance. Thanks to these innovations, companies can not only simplify and speed up their processes, but also respond more effectively to market demands and competition. Especially in the Czech Republic, this change is perceived as an opportunity to increase competitiveness, which has great potential for business growth and efficiency. With the growing demands on the accounting profession, the role of accountants themselves is also

changing; They are now facing new challenges and need new skills to keep up with technological advancements.

The topic of the article was chosen based on current social and economic trends that emphasize understanding and optimization of accounting processes in the context of digital technologies. Companies across various industries are increasingly turning to automating and digitizing their accounting operations. These steps allow them to increase efficiency while reducing costs. Manual processes, which carry a higher risk of errors, are gradually being replaced by technologies that deliver more reliable and accurate results. In this context, the topic of this thesis is very topical and topical. Research suggests that both digitalization and automation have the potential to dramatically change the work of accountants, requiring new skills and adaptation to new technologies (Brynjolfsson & McAfee, 2017).

Further justification for the choice of this thesis topic can be found in recent studies in the field of economics and management, which emphasize the importance of digitalization and automation for modernizing accounting processes and improving the competitiveness of companies (Mistry, 2019). At the same time, more and more studies are investigating ethical and labor issues related to the use of AI technologies in accounting (Sweeney, 2020). This article aims to conduct a comprehensive analysis of the current state of digitalization and automation in the field of accounting, with a focus on evaluating the impact of these technological changes on the work processes and professional development of accountants.

The research identifies the key skills that accounting professionals will need in the near future to best adapt to the new demands of the labor market. Based on the data obtained as part of the questionnaire, recommendations will be proposed on how accounting professionals can prepare for these changes and effectively respond to the growing requirements associated with digitization and automation. The questionnaire-based data collection method will allow us to gather the opinions and attitudes of a wide range of accounting professionals, providing a comprehensive overview of their perception of current technological trends and their readiness to face changes in their professional environment. This article aims to provide a comprehensive approach so that the results provide a comprehensive view of the impact of digitalization and automation on accounting, including practical recommendations for accounting professionals looking for ways to best adapt to this rapidly evolving environment. To this end, the following research questions were formulated:

RQ1: What role do digitization and automation play in accounting practice and the accounting profession in the Czech Republic?

RQ2: How do digitization and automation contribute to accounting practice in the Czech Republic?

RQ3: What is the attitude of accountants to the automation of accounting processes?

2. Literature Review and Theoretical Background

Thanks to ERP systems, accounting has shifted from manual processing to automation, and today's technologies, such as RPA, AI, and cloud computing, further expand the possibilities of data analysis and processing. Chyzhevskaya et al. (2021) point out that digitization brings

fundamental structural changes in accounting systems; it introduces modern tools (e.g., Big Data, blockchain), creates new forms of assets, and increases the demands on the digital maturity of companies. According to the authors, the modernization of information systems is the key to competitiveness and effective management in the digital economy.

According to Willcocks and Lacity (2016), RPA can significantly reduce the time it takes to complete accounting tasks while reducing the error rate, leading to better reporting and faster decision-making processes. Furthermore, artificial intelligence is able to autonomously analyze accounting transactions and identify discrepancies that may signal fraudulent activities, thereby increasing the security of accounting systems. Cloud technologies then enable real-time data sharing, promote transparency, and improve cash flow management (Kevin and Strauss, 2018). In addition to greater efficiency, the digitization of accounting has positive impacts on audit, regulation, and financial management. Abhishek et al. (2024), based on a survey of 482 experts, demonstrated that digital systems increase accuracy and transparency while reducing error rates and the risk of sanctions. The authors emphasize the need to develop new methods and incorporate them into educational curricula, thus contributing to both practice and academic research on digital accounting.

Although technologies such as RPA, AI, and the cloud are changing accounting processes, their impact on managerial decision-making depends primarily on the quality of the information provided. Al-Okaily et al. (2023), based on data from the Jordanian banking sector, found that decision-making efficiency is more influenced by the quality of the data than by the technical sophistication of the systems. The analytical culture of the organization is also a key factor, indicating that the successful use of digital tools requires not only technology, but also quality data interpretation and a suitable organizational environment. Digitalization significantly improves the comparability of accounting data between companies, which increases the transparency and quality of decision-making. Yang et al. (2024) found that this effect is more pronounced in non-state enterprises and firms with lower quality of management, where digitalization acts as a tool for harmonization. The study highlights the need for strategic management of digitalisation and recommends that regulators take its impact into account when developing accounting standards.

With the advent of new technologies, the requirements for the accounting profession are changing; technical knowledge is changing, and analytical skills and knowledge of digital tools have replaced manual skills. Richins et al. (2017) describe this shift as a "transformation in accounting", with accountants transitioning into the roles of advisors and analysts for strategic decision-making. Digitalization is also changing managerial accounting and control, as he states (Moeller et al., 2020). These changes affect not only technology and business models, but also accounting practices themselves, thus redefining the role of the controller. Coman et al. (2022) confirm that digitalization is changing the working style and role of accountants, who become strategic advisors. The success of this transformation requires a change in mindset and organizational culture, and the COVID-19 pandemic has accelerated the need for technological flexibility. The study by Magopets et al. (2022) builds on this way of thinking and highlights the need for a paradigm shift in strategic accounting. The authors propose a transition from a classical to a neoclassical approach that integrates digital platforms and cognitive technologies, and presents a methodology reflecting the requirements of the digital business environment.

Digitalization increases the efficiency of companies and strengthens their competitiveness, but at the same time raises concerns about the loss of traditional jobs in accounting (Brynjolfsson and McAfee, 2014). Chen et al. (2024) described the so-called substitution effect, where digitization replaces accounting staff, especially in technologically advanced private firms. This trend is hitting low-skilled workers the hardest, while new opportunities are opening up for tech-savvy professionals. Changes in accounting are also evident from the point of view of theoretical research. Spilnyk et al. (2022) analyze the concept of "digital accounting" and highlight the transformation of its methodological and conceptual principles. According to the authors, the current phase of accounting development represents a qualitatively new stage that requires a transition to a digital paradigm corresponding to the needs of the digital economy. On a practical level, these changes are reflected in the transformation of job roles. Rautiainen et al. (2024), in their case study of Finnish banks, show how digitalization is changing the identity of managerial accountants, whose roles are becoming more flexible, include IT specializations, and enable collaboration in agile interdisciplinary teams.

At the same time, digitalisation promotes more efficient management, especially in small and medium-sized enterprises. Ratmono and Zuhrohtun (2023) show that DIMAS improves information accuracy and reduces costs, thereby promoting better decision-making and competitiveness of businesses in developing economies. As the importance of digital technologies grows, so does the interest in specific tools such as blockchain. Pflueger et al. (2024) critically analyze its potential as a new accounting technology and highlight the structural changes it brings in the areas of trust, governance, and organization of accounting processes. Kolisnyk et al. (2023) focus on the practical aspects of blockchain implementation and show that this technology can significantly reduce the likelihood of accounting errors, increase the security of financial information, and minimize the risk of loss or misuse. The results of their risk-oriented modeling show that the introduction of blockchain into accounting and auditing systems reduces the risk of accounting errors by up to 3.1 times and increases information security by almost 100 times compared to traditional methods. However, the authors also emphasize the need for more research and a methodological basis for implementing blockchain in accounting systems.

In the context of Industry 4.0, financial reporting itself is also changing. Petcu et al. (2024) emphasize the importance of digitalization in improving business transparency and sustainability, with cloud computing and data security playing a key role. Klymenko et al. (2021) also focus on the issue of sustainability in the context of digitalization; They analyzed the use of digital technologies in sustainability accounting in four manufacturing companies. The findings of the study show that while economic aspects are well covered, environmental and social aspects often remain neglected. Although companies are implementing Industry 4.0 technologies and automation, digital data from these systems is not linked to sustainability accounting. The authors highlight the potential of this data to significantly improve the tracking of sustainable practices, especially when integrated with accounting tools and product lifecycle management strategies.

Technological changes also affect educational requirements. Pargmann et al. (2023) point to the growing need for digital competences and the ability to handle non-routine tasks, which requires the reform of educational programs in accounting. According to Chyzhevska et al. (2021), digitalization is changing the labor market, increasing the demand for digital skills, working with data, and expertise with digital assets. The new profile of accountants requires the active

involvement of schools, employers, and professional organisations. Ionescu-Feleaga et al., (2022) analysed the development of accounting and financial services in Europe based on data from 337 professional associations in 40 countries. They identified digitalisation as a key factor in professional development and national competitiveness, noting that differences between countries are related to economic conditions and the number of professional organisations. The study provides recommendations for education and regulatory policy. Based on these findings, a study by Brabete et al. (2024) examined the impact of disruptive technologies such as artificial intelligence on accounting education. The authors suggest revising curricula and strengthening cooperation with universities as necessary steps to remain competitive in the digital economy.

Educating accounting professionals in the digital age requires a systematic and analytical approach that reflects the needs of the digital economy. Wu (2022) identified the development of the digital economy as a key factor in the competitiveness of businesses and highlighted the growing importance of educating so-called "hybrid accounting professionals", that is, professionals with a combination of accounting, digital and cross-border competencies. Using the entropy method, the main factors influencing the development of these talents were evaluated and weighed. The results show that education systems should be flexibly adapted to the requirements of the digital economy and should promote international orientation, technological adaptability and analytical skills. The study highlights that an innovative approach to education is not only an academic challenge, but also a strategic necessity for companies striving for sustainable growth and competitiveness in the digital environment.

Successfully managing the digital transformation does not depend only on the availability of modern technologies; The organisational and institutional environment also plays a key role. AlNasrallah and Saleem (2022) investigated the factors influencing the adoption of digital accounting tools in Saudi Arabia using TAM, ELM, and SET models. They found that organizational support is key, which has a greater impact than user experience or individual job relevance. In doing so, they emphasized the importance of leadership, training, and internal communication, seeing the digitization of accounting as a social and cultural process, not just a technological change. Fulop et al. (2022) analyzed the variability in the adoption of fintech accounting among professionals using the TAM model. The main factors for adoption were trust in technology and its perceived usefulness, while the risk was not significant. The authors also highlighted the increasing automation and the role of technology in financial policy decision-making in the era of Industry 4.0. Fulop et al. (2024) used a combination of TAM and TOE models in their follow-up study and confirmed that the adoption of digital tools is a complex process. Organizational support and external pressures play a key role. The study also noted that Romania lags behind the EU average in this area, which poses a challenge. The authors emphasize the need for deeper research on digitization in the context of changing conditions.

The quality of information systems is also an important factor in successful digitization. Papiórek and Hiebl (2024), based on an analysis of German companies, show that it is the quality of the systems, together with the degree of automation, that significantly increases the effectiveness of managerial controls. Finally, it is worth mentioning a study by Nadiia et al. (2022), which summarizes the current trends, benefits, and threats of digitalization and proposes four main directions for its further development. The results of this study can serve as a practical framework for the development of corporate digital strategies and for future research in this area.

3. Materials and Methods

The data needed for the analysis were collected through a questionnaire that was electronically distributed to accountants in various companies throughout the Czech Republic. The questionnaire was designed based on research questions and a literature review to ensure that the questions are relevant, clear, and in line with the research objectives. The research will focus on the collection of qualitative and quantitative data. Quantitative data will then be subjected to statistical analysis aimed at answering the formulated research questions. The questionnaire included both closed and open-ended questions, designed to reflect various aspects of digitalization and automation in accounting processes. Closed-ended questions provide quantitative data such as demographics, the extent of the use of digital tools in accounting processes, the perception of the benefits and risks associated with digitalization, the readiness of organizations to adopt digital technologies, and changes in the work activities of accountants. For example, respondents provided their rating by choosing from several options.

The collected data enables statistical analyses that identify relationships between individual variables, compare responses between groups of respondents, and thus reveal key trends in digitization and automation of accounting. For example, respondents provided their ratings by choosing from several options. The collected data allows statistical analysis to identify relationships between individual variables, compare responses between groups of respondents, and thus reveal key trends in digitization and automation of accounting. Open-ended questions provide qualitative data focused on respondents' specific experiences with digitization and automation. Participants in the research had the opportunity to express their views on future opportunities, describe what changes they expect in education, and explain how these changes will affect their organizations. This data is analyzed using content analysis and thematic coding to identify key patterns, topics, and differences in each respondent's responses.

To achieve the set goals, it was necessary to use a quantitative approach supplemented by qualitative knowledge, which enabled a comprehensive view of the examined issue. Data analysis was carried out using statistical methods and software tools suitable for quantitative data processing. The collected data were processed and presented in the form of tables, graphs, and results of analyses of relationships between variables. The results are interpreted with regard to the context and theoretical framework of the study. Each research study has certain limitations that are taken into consideration when analyzing and interpreting the results. The main limitation was the size and composition of the sample of respondents, which, although designed representatively, may affect the results. The time frame of data collection was also taken into account, as data collected in a certain period may be affected by current economic or technological conditions. Despite all these limitations, the methodological approach chosen should provide relevant and valuable insights into the impact of digitalisation and automation on accounting practice and the accounting profession. The findings will contribute to the expert debate on the digitalisation of accounting and may serve as a starting point for further research in this area. The data needed for the analysis were collected through a questionnaire that yielded 104 responses between September 2024 and March 2025.

The answer to the RQ1 question was obtained from a quantitative questionnaire, specifically from closed-ended questions related to the extent of use of digital tools, readiness of the organization, and demographic data.

The above-mentioned method of data collection was used to answer the research question 2 specifically; part of the answers suitable for statistical analysis of closed questions was used to evaluate benefits such as increased efficiency and accuracy and reduced error rate. For the qualitative analysis of the open-ended responses, thematic coding was performed, and recurring patterns in the responses were identified. The data were obtained from questionnaires and from respondents' own interpretations of the benefits of digitization in their practice.

The answer to the RQ3 question (What are the attitudes of accountants towards the automation of accounting processes?) was found mainly in open-ended questions focused on opinions and concerns. The content analysis of qualitative data consisted of categorizing opinions and identifying problems and opportunities (loss of employment, need for new skills, increased efficiency, loss of routine). Data sources were open responses from respondents, analyzed using thematic coding.

4. Results

A total of 104 responses were collected from participants, focusing mainly on their demographic characteristics, professional experience, and level of familiarity with digital tools used in accounting practice. The data collected provides a comprehensive overview of the age composition of the respondent sample, allowing for a better understanding of how different age groups are adapting to technological changes in accounting. An analysis of the age distribution of respondents showed that the largest group is made up of professionals aged 25-34 (43.3%) who already have work experience and demonstrate a high degree of adaptability to new technologies. The second largest group is made up of respondents aged 35-44 (36.5%), who often hold managerial or specialized positions. Another important category is accountants aged 45-55 (17.3%), whose many years of experience are particularly valuable in implementing new systems. Younger professionals under the age of 25 make up only 1% of the sample, indicating a lower influx of graduates into the profession. The oldest group, people over 55 years of age, makes up only 1.9%. Overall, the accounting profession is predominantly carried out by workers aged 25-44, who are most open to digital change.

Women dominate the answers, accounting for 69.2% of respondents, while men make up 30.8%. Its distribution confirms the long-standing gender imbalance in female-dominated accounting, probably due to the historical perception of accounting as a detail-oriented and administrative activity. In terms of education, respondents with higher education predominate, 36.5% have a bachelor's degree and 45.2% have a master's degree, reflecting the growing demand for qualifications, analytical thinking and digital competences. 15.4% of respondents have secondary education, mainly in operational positions. Only 2.9% said they had a doctorate, confirming that the highest level of academic education is not common or necessary in accounting, the emphasis is primarily on practical experience and practical skills. The distribution of the respondents' years of experience shows considerable diversity. The largest groups are professionals with 4-10 years and 11-20 years of experience (both 35.6%) who already have extensive experience and are well versed in legislative and technological changes. Employees with up to 3 years of experience make up 20.2% of the sample and are in the early stages of their professional development. More experienced professionals with more than 21 years of experience make up 8.7% and often hold leadership positions or participate in strategic decision-making.

As regards the sectoral breakdown, the majority of respondents (88.5%) work in the private sector, confirming the dominant role of accounting in the business environment. 6.7% of respondents work in the public sector, where accounting is subject to specific regulations and stricter supervision. The non-profit sector accounts for 4.8% of respondents, with accounting primarily used to ensure transparent management of grants and contributions. Respondents practice their profession in organizations of different sizes. The largest share is made up of small enterprises (43.3%), which make up the main segment of the accounting services market. 33.7% of respondents work in medium-sized companies, which reflects the importance of these organizations as stable employers with their own accounting departments. Micro-enterprises employ 12.5% of respondents, often with limited accounting functions or those that are outsourced. 10.6% of professionals work in large companies, where it is typical to use specialized teams and advanced digital tools. This confirms the diversity of the working environment of the accounting profession across company sizes.

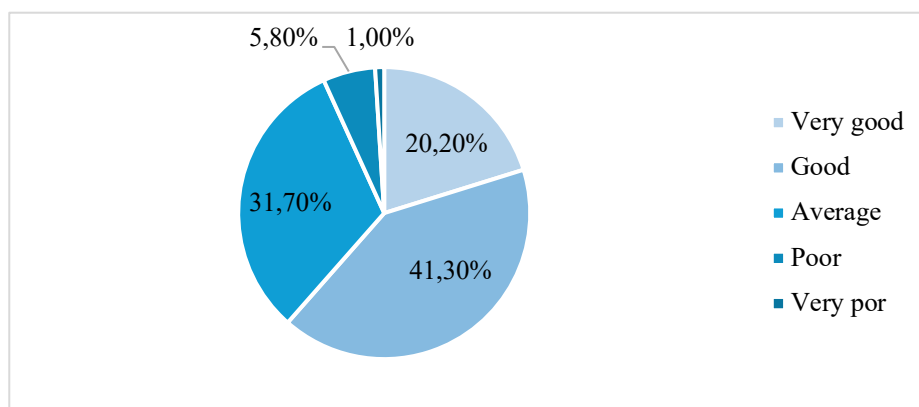


Figure. 1: Self-assessment of knowledge and experience with digital tools in accounting
Source: Author's own analysis based on data obtained from a questionnaire survey

Figure 1 shows that the use of digital tools in accounting was assessed on the basis of respondents' self-assessments. The largest proportion (41.3%) reported good knowledge, indicating regular use of accounting software and the ability to adapt to technological innovations. An average level was reported by 31.7% of respondents who have basic digital skills but may have room for improvement in more advanced features. 20.2% of respondents reported a very good understanding. By contrast, 5.8% feel that they are not very familiar with digital technologies, which may be related to a more traditional work environment, and only 1% of respondents said they have very limited experience with digital tools.

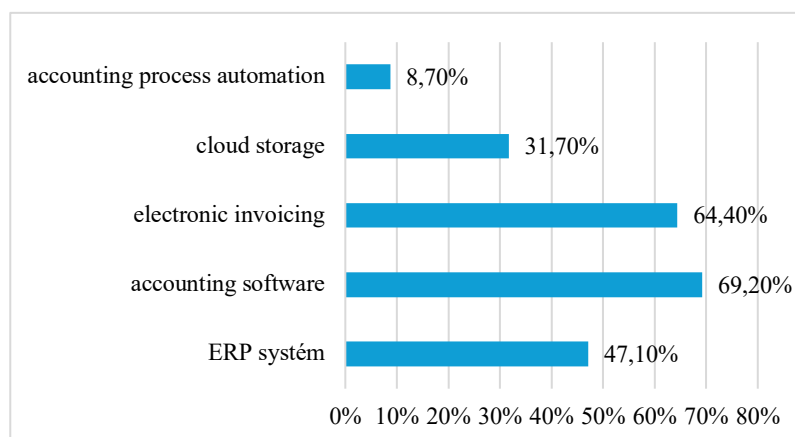


Figure 2: How digital tools are used in practice
Source: Author's own analysis based on questionnaire data

Figure 2 clearly shows that accounting software is the most commonly used digital tool, which is used by 69.2% (72) of respondents, confirming its role as the standard in accounting practice. Electronic invoicing is used by 64.4% (67) of respondents, indicating a trend towards paperless processing. ERP systems are used by 47.1% (49) of respondents to integrate accounting with other business functions. Cloud storage was cited by 31.7% (33) of respondents, reflecting an emphasis on data availability and security. Only 8.7% (9) of respondents indicated limited adoption, likely due to the complexity of implementation and low awareness of its benefits. The quantitative analysis revealed diverse attitudes of respondents towards the automation of accounting processes. For 24%, automation is of little importance, likely due to the absence of digital transformation or concerns about costs and technical barriers. The largest share of respondents (51.9%) consider it to be of medium importance; Although they already use modern tools to some extent, they still face obstacles to wider implementation, such as the need for training or incompatibility with existing processes. On the contrary, 24% of respondents consider automation to be very important; this group is already using modern technology to achieve greater efficiency and accuracy, and to free up capacity for analytical tasks.

The results showed that 20.2% of respondents have had a very good experience with digital accounting tools and 41.3% rate them as good, which shows a high level of digital competence for most participants. The average level was reported by 31.7% of respondents who work with digital tools but lack advanced skills or access to more modern technologies. 6.8% of respondents reported a bad or very bad experience; they may face technological barriers or a lack of education in this area. Overall, therefore, the adoption of digitalization in accounting remains uneven, highlighting the need for targeted support and further training for accounting professionals.

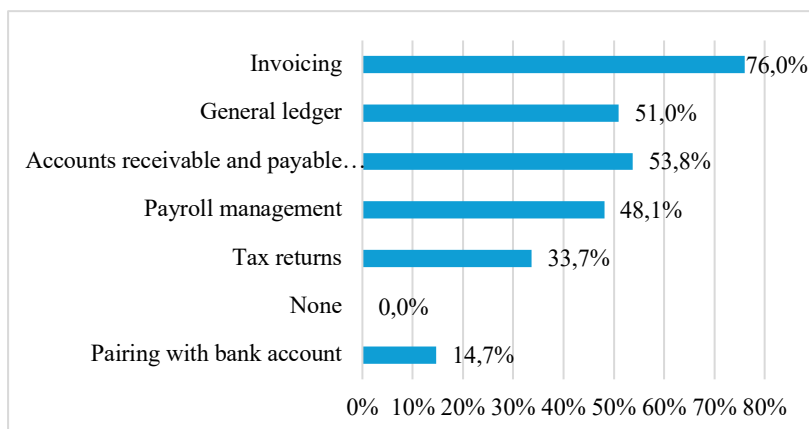


Figure. 3: Automated accounting transactions
Source: Author's own analysis based on questionnaire survey data

Figure 3 shows that the most commonly automated accounting operation is invoicing, which was cited by 76% of respondents. Automation in this area reduces administrative burden and the risk of errors, and improves cash flow management. 53.8% of respondents have automated management of accounts receivable and payable, which provides more effective control over due dates, reminders, and payment flows. Ledger management is automated for 51% of survey participants, making it easier to record transactions and contributing to the accuracy of accounting records. Payroll accounting is digitized for 48.1% of respondents, leading to automatic calculation of wages, taxes, and contributions, and simplifying compliance with regulatory requirements. Only 33.7% of respondents have their tax returns automated, indicating room for improvement in this area, even though digital tools for generating and filing tax returns are already available. The lowest level of automation is in bank reconciliation (14.7%), which, however, offers the potential to speed up and improve the accuracy of accounting operations. The degree of automation varies by area; when routine operations are digitized, more complex or less frequent tasks require manual intervention. Therefore, the implementation of technologies varies according to the needs and capabilities of specific organizations.

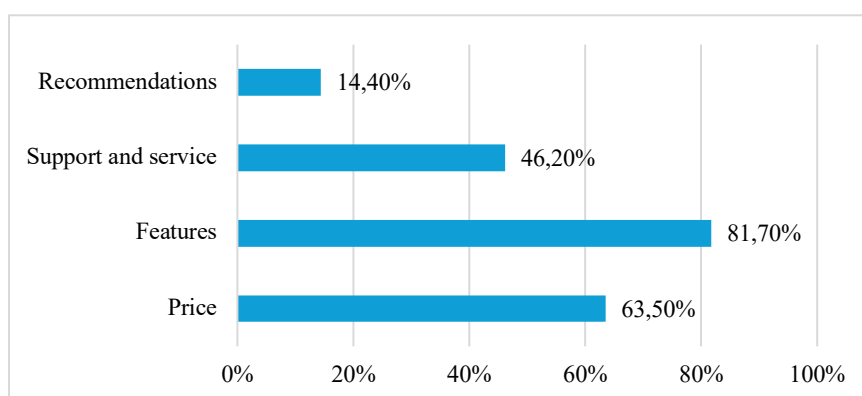


Figure 4: Key criteria for choosing accounting software
Source: Author's own analysis based on questionnaire survey data

The choice of accounting software is a key decision that affects the efficiency of accounting processes, as shown in Figure 4. The main selection criterion is functionality, which was stated

by 81.7% of respondents. Organizations emphasize a wide coverage of accounting operations, accuracy of records, and the possibilities of automation, analytics, and integration with other systems. The second most common factor is price (63.5%), which reflects the efforts of companies to optimize costs. Not only the purchase price is taken into account, but also the costs of implementation, training and maintenance. Support and service are important to 46.2% of respondents; quality technical support and regular updates ensure reliable system operation. On the other hand, only 14.4% of respondents cited recommendations from colleagues or partners as a key criterion. Therefore, most accounting professionals rely on rational evaluations of software features rather than subjective references.

The frequency of use of digital tools varies between respondents. 22.1% of respondents use them daily, indicating a high degree of integration of technology into their work activities. The largest group (42.3%) work with digital tools several times a week, while 33.7% use them only a few times a month, probably in an environment with partial digitization. Only 1.9% of respondents said that they rarely use digital technologies, confirming that digitalisation is becoming a common part of accounting practice.

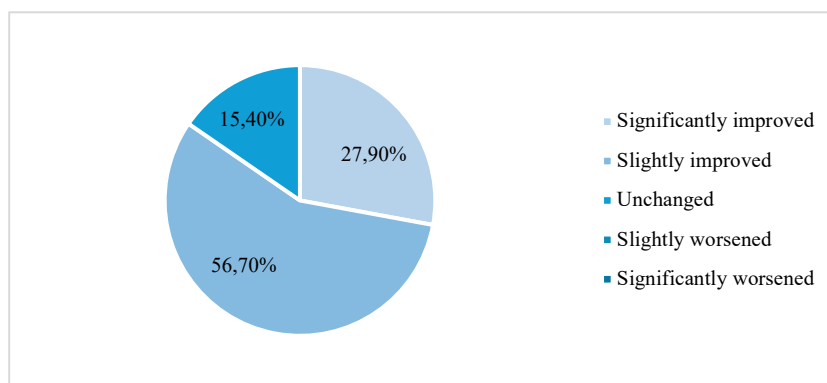


Figure 5: Impact of digitization and automation on work efficiency
Source: Author's own analysis based on questionnaire survey data

In Figure 5, let's look at the self-assessment of efficiency related to digitization. A significant improvement was noted by 27.9% of respondents who are likely to work with advanced systems and automation. However, the largest share of responses (56.7%) report only a slight improvement, which may be the result of partial implementation or a transitional adaptation period. On the other hand, 15.4% of respondents reported no change, which may be related to a low level of digitalisation, technical barriers, or perceived ineffectiveness of change.

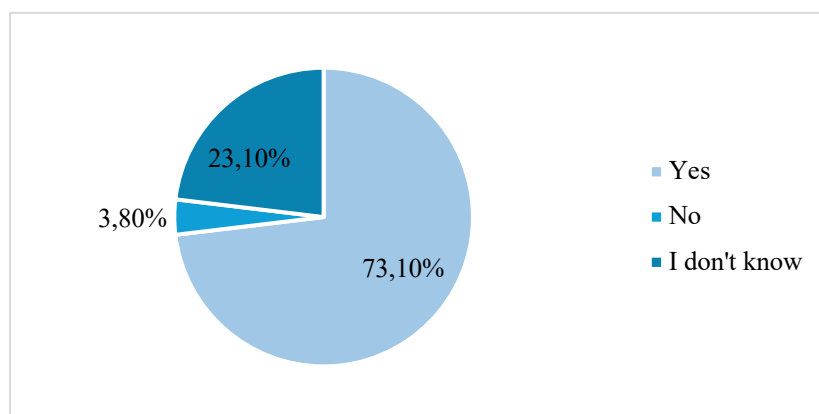


Figure 6: A view of data security through digitization and automation
Source: Author's own analysis based on questionnaire survey data

The results of the questionnaire shown in Figure 6 show that digitization and automation have a positive effect on the perceived accuracy of accounting data. A total of 73.1% of respondents said that digital tools make data more accurate. Automation helps reduce error rates, ensures data consistency, and eliminates the risks associated with manual data entry. At the same time, modern systems offer control mechanisms that help detect errors in real time. By contrast, 3.8% of respondents do not feel more secure due to digitalisation, which may reflect concerns about cyber threats, loss of control over data, or uncertainty about liability. Another 23.1% are unsure whether digitalisation has actually improved data accuracy, likely due to lack of experience, incomplete implementation, or lack of metrics to evaluate its benefits.

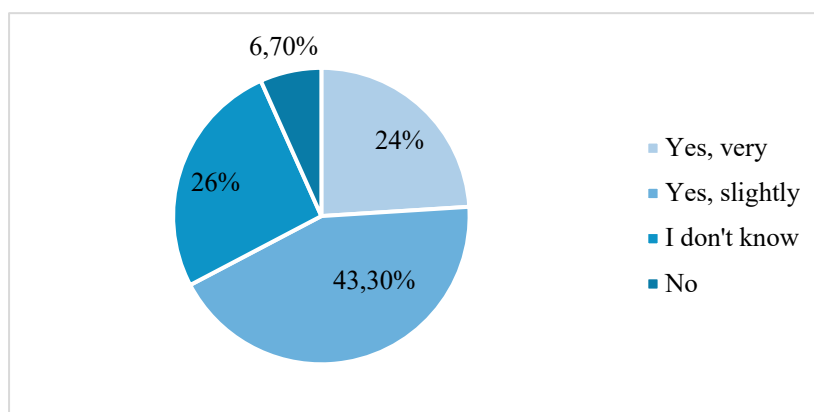


Figure 7: Self-reflection on feelings about the accuracy and quality of financial statements
Source: Author's own analysis based on questionnaire survey data

Figure 7 shows that a total of 24% of respondents perceive a significant improvement in the accuracy and quality of accounting data, confirming the positive impact of digitalisation on the accuracy and standardisation of financial reporting. This advantage is attributed to the automated processing and validation mechanisms of modern accounting systems that minimize human error. Another 43.3% perceive the changes as mild. This may reflect different levels of digital integration across organizations or differences in their use. Some respondents (26%) express uncertainty about the changes that may be related to the incomplete implementation of digitalisation, the transition period, or limited experience with new tools.

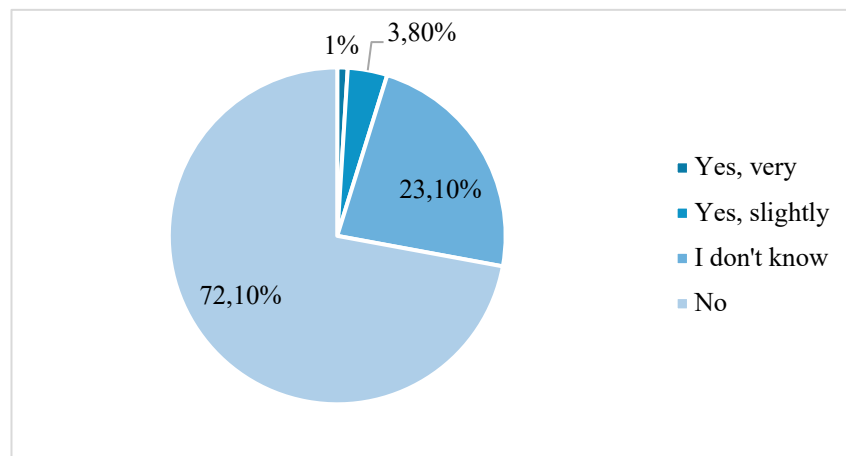


Figure. 8: Self-reflection of the workload and stress associated with the implementation of digitization and automation

Source: Author's own analysis based on questionnaire survey data

Figure 8 shows that the majority of respondents (72.1%) do not experience increased workload or stress related to the digitalisation and automation of accounting processes. Digitalisation is therefore seen as a means of simplifying work rather than as a source of pressure. It probably contributes to the reduction of routine tasks and allows accountants to focus on analytical activities. It can be assumed that these respondents have already successfully gone through the adaptation process. 23.1% of respondents expressed uncertainty in this area, which may be related to the recent introduction of technology or different levels of support in the organization. A slight increase in workload was reported by 3.8% of respondents, probably due to the initial phase of adaptation to new systems. Only 1% of respondents perceive a high workload and stress, which may reflect concerns about technological change, lack of support, or uncertainty about future job prospects.

According to 92.3% of respondents, automation can lead to layoffs in accounting, especially in routine tasks such as invoicing or ledger management. However, most expect a change in the nature of work rather than a massive loss of jobs, a shift to analytical and strategic roles. This view is not shared by 7.7% of respondents, who believe that the human factor will remain indispensable, especially in decision-making processes and professional advice. Although digitalization may seem like a disruptive trend, 89.4% of respondents did not express any concerns about its future development. Only 10.6% have concerns such as the need to adapt, technological pressure, or job loss. However, the vast majority (100%) expect the level of automation in accounting to continue to grow over the next five years.

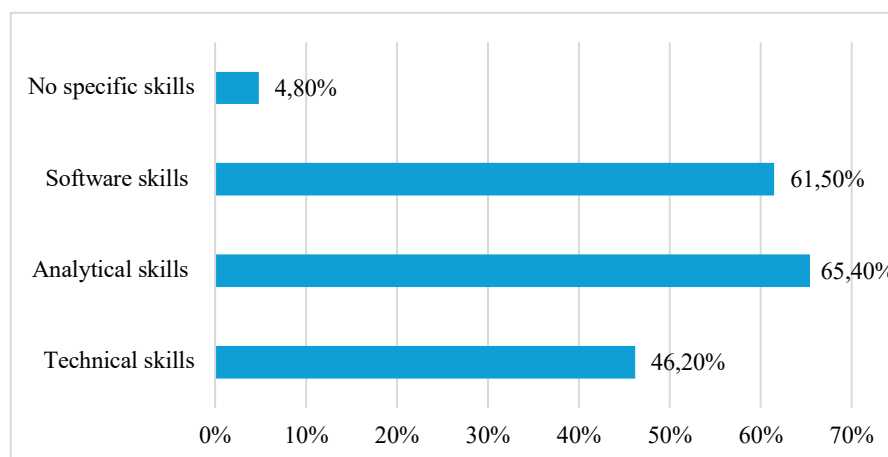


Figure 9: List of skills considered essential in view of the increasing digitalisation of accounting
Source: Author's own analysis based on questionnaire survey data

Figure 9 shows that respondents consider analytical skills (65.4%), i.e., the ability to interpret data and draw conclusions, to be the most important key skills for accountants in the age of digitalisation. This is followed by software skills (61.5%), which confirm the importance of knowledge of accounting systems, ERP tools, and cloud solutions. Technical knowledge (e.g. understanding databases or automation principles) is considered important by 46.2% of respondents. Interestingly, 4.8% of respondents do not consider any digital skills to be essential, which may reflect either working in a less digitised environment or a high degree of personal adaptability. According to 45.2% of respondents, it was expected that the upcoming new accounting law would affect their work, while 54.8% stated the opposite. The results were influenced by the postponement of the law; many respondents were unsure about the possible impacts. Nevertheless, it is expected that the new legislative requirements will bring a review of internal guidelines and accounting procedures, the need to train employees in legislation and digital tools, and an increased emphasis on compatibility with modern accounting systems.

According to respondents, the digitization of accounting is perceived as an inevitable and generally well-received process. Respondents highlighted the following benefits: increased efficiency and accuracy of accounting operations, reduced error rates and administrative burdens, greater transparency and simplified audit supervision. Despite fears of job losses, the majority of respondents see digitalisation as an opportunity for professional growth and a change in job responsibilities. Respondents believe that digitalisation is changing the nature of the accounting profession in the following ways: automation of routine tasks frees up time for analytical and consulting work, accountants are increasingly involved in strategic decision-making and data analysis, and there is a growing demand for skills in ERP systems, AI, and digital reporting. According to respondents, the increased demand for digital competencies leads to the following trends in education: emphasis on practical skills, working with software and simulation of real situations, integration of technology into teaching, ERP systems, automation and artificial intelligence, the need for IT literacy: cybersecurity, working in the cloud and working with data.

5. Discussion

5.1 The Role of Digitization and Automation in Accounting Practice

Based on the research carried out, it was found that digitization and automation already play an important role in accounting practice in the Czech Republic. Accounting software, electronic invoicing, and ERP systems are widely implemented, with respondents describing their use as a common part of their work. This confirms the trend cited by Varzaru et al. (2022), for example, who highlight the increasing integration of digitalization into management and accounting information systems. Nevertheless, advanced technologies such as robotic process automation (RPA) and artificial intelligence in accounting still appear to be used to a relatively limited extent, which corresponds to the findings of Rautiainen et al. (2024) on the slow transition of accounting professionals to advanced digital tools. Unlike international studies such as the work of Ionescu-Feleagy et al. (2022), which show a higher level of digitalization in the developed economies of the European Union, Czech accounting still faces some obstacles in implementing the latest technological solutions. These differences can be attributed to different regulatory frameworks and approaches to investment in digitisation technologies. At the same time, the adoption of digitalisation has been found to be uneven across different sectors, with the private sector showing a higher degree of automation than the public and non-profit sectors, which corresponds to the findings of Petchenko et al. (2023), who identified similar trends in Ukraine.

5.2 Contribution of Digitization and Automation to Accounting Practices in the Czech Republic

The results of the questionnaire show that digitalization has a positive impact on the efficiency and accuracy of accounting processes. Around 67.3% of respondents said that digitalisation has led to an increase in the accuracy of financial statements. In their analysis, Petcu et al. (2024) emphasize that the digitalization of accounting systems contributes to greater transparency and better decision-making in management. However, it has also been found that while digitalization increases efficiency, it does not always lead to a reduction in workload. Only 27.9% of respondents said that digitalization has significantly improved work efficiency, while 15.4% of respondents did not notice any change. These results suggest that the transition to digital accounting may not always be seamless and may require further adjustments to work processes. This conclusion is in line with the conclusions of Fulop et al. (2024), who found that accountants still face challenges in adapting to digital technologies and that the full benefits often only become apparent after a longer period of time.

5.3 Accountants' Attitudes Toward the Automation of Accounting Processes

The results of the research indicate that most accountants consider digitization and automation to be an inevitable trend that brings practical benefits, especially in the area of streamlining routine tasks and improving accuracy. However, the attitudes of individuals vary, the key factors are age, level of digital competence, and the type of organization in which the accountant works. The younger generation shows greater openness to new technologies, while older professionals are often more cautious, mainly due to concerns about job security or the complexity of new systems. Authors Chen et al. (2024) and Brynjolfsson & McAfee (2014) came to similar conclusions in their research. However, even more skeptical accountants recognize that digitalization allows for a shift from routine tasks to analytical and consulting work.

Organizational culture, availability of training, and technical support play a significant role in the positive adoption of technology; these findings were also reported by Fulopem et al. (2024) and AlNasrallah & Saleem (2022). At the same time, these changes in attitude also reflect the new requirements for accountant education in the digital age.

6. Conclusion

The aim of this article was to systematically evaluate the current state of digitization and automation in the field of accounting, focusing on their impact on work processes and professional development of accountants in the Czech Republic. The aim of the article was to conduct a comprehensive analysis of the current level of digitalization, to evaluate the impact of technology on accounting processes themselves, and to find out how accounting professionals perceive and evaluate these changes. Three research questions were asked within the study: the role of digitization and automation in the accounting profession, the extent of the benefits of these technological changes, and the attitudes of accountants towards the automation of accounting processes. This objective was achieved by analysing secondary sources and conducting an original questionnaire among accounting professionals, accounting department employees, and independent accountants. A synthesis of theoretical knowledge and empirically observed facts was carried out, on the basis of which it was possible to formulate answers to research questions. The survey confirmed that digitization and automation are playing an increasingly important role in domestic accounting practice, which is in line with the conclusions of foreign authors. It found that accounting professionals generally perceive this technological shift positively, although there are still some barriers and concerns about the potential impacts on jobs and the need for reskilling. These findings highlight the need to develop new competencies – especially analytical and technical skills – for the successful integration of automation into accounting processes.

The main advantage is a deeper understanding of the specific factors that affect the implementation of digital tools in accounting and the identification of their impacts on the professional requirements of accountants. The survey also revealed areas where digitalization contributes to increasing the efficiency and accuracy of accounting processes, while also describing the limitations associated with adapting to advanced technologies. The findings can be applied in practice, especially in the implementation of accounting systems and in the support of targeted professional development of accountants. This knowledge can thus benefit both organizations deciding on the scope and method of digitization, as well as accountants themselves, who are looking for ways to use modern technologies more effectively. It should be noted that several limiting factors arose during the conduct of the research. First of all, it was a limited number of respondents, which may affect the representativeness of the findings. Furthermore, it is worth noting that the pace of technological progress and the different levels of preparedness of individual companies can cause the results to quickly become obsolete if the research is not repeated or expanded with a longitudinal approach. Nevertheless, it can be concluded that the societal demand for understanding the impacts of digitization and automation on accounting has been met, as a comprehensive view of the current situation in the Czech Republic has been created and practical implications have been formulated that are useful for both accountants and company management.

Based on the analysis performed, it can therefore be concluded that the declared goal has been met, as a comprehensive analysis of the digitization and automation of accounting processes

has been carried out, including an assessment of the practical impacts for accounting professionals and recommendations on how accounting experts can best adapt to the constantly evolving technological requirements. This thesis thus contributes to the development of theoretical knowledge and practical guidance in the field of modern accounting and offers a starting point for further research into the use of advanced technologies in accounting practice. We can conclude that the goal of the article has been met, which is confirmed by the results of the applied part, which show a similar trend in market sentiment and copper prices in all the years reviewed.

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Climate disasters and annual inflation: International evidence from OECD countries

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Abstract: Climate-related disasters have become increasingly frequent and severe, raising concerns regarding their potential macroeconomic consequences, particularly their influence on inflation dynamics. This study investigates whether climate disasters significantly affect annual consumer price inflation across OECD countries during the period 2000–2024. Using an unbalanced panel dataset comprising 941 country-year observations from 38 OECD economies, the analysis employs a comprehensive panel-data framework, including pooled ordinary least squares, fixed-effects, random-effects, and two-way fixed-effects models with country-clustered robust standard errors. Climate disasters are measured using both occurrence indicators (floods, storms, droughts, extreme temperature events, and wildfires) and disaster severity, represented by the logarithm of reported economic damage. The Hausman specification test supports the use of the fixed-effects estimator, indicating the presence of unobserved country-specific heterogeneity. Across all model specifications, neither aggregate disaster severity nor individual disaster categories exhibit statistically significant effects on annual inflation after controlling for country and year fixed effects. These findings suggest that advanced OECD economies possess sufficient institutional resilience, effective policy responses, and diversified economic structures to mitigate the inflationary consequences of climate-related shocks. The study contributes to the growing literature on climate economics by providing cross-country evidence that the macroeconomic impact of climate disasters on aggregate annual inflation is limited within developed economies. Future research should investigate higher-frequency data, sector-specific price dynamics, and additional macroeconomic controls to further examine the transmission mechanisms linking climate disasters and inflation.

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1. Introduction

Climate change has become one of the most pressing global challenges of the twenty-first century, with the increasing frequency and intensity of climate-related disasters posing substantial risks to economic stability. Extreme weather events such as floods, storms, droughts, wildfires, and heatwaves disrupt agricultural production, damage infrastructure, interrupt supply chains, and reduce industrial output, thereby generating significant macroeconomic consequences. Beyond their direct economic losses, these disasters have increasingly been

recognized as important drivers of inflation through supply-side disruptions, higher production costs, food shortages, and increased reconstruction demand (Cevik & Gwon, 2024; Chavleishvili & Moench, 2025; Jackson, 2024).

Recent empirical evidence suggests that climate-related disasters can create upward pressure on consumer prices, although the magnitude and persistence of these effects vary across countries and disaster types. Beirne et al., (2024), using data for the Euro Area, found that weather-related disasters increase inflation in the short run, primarily through supply-side channels, while disproportionately affecting expenditure categories that account for a larger share of low-income households' consumption. Similarly, Qi et al., (2025) demonstrated that climate risk significantly increases inflation in the short term through higher food prices and monetary policy responses, whereas Li et al., (2023) identified rising energy demand as an important mechanism linking climate change to inflation. Country-specific studies also support these findings. For example, Narayan et al., (2026) reported that cyclones, droughts, and heavy rainfall substantially increase inflation in Fiji, while Romero and Naranjo-Saldrriaga (2024) showed that weather-related shocks significantly influence both realized inflation and inflation expectations in Colombia.

The inflationary consequences of climate-related disasters have important implications for monetary policy and macroeconomic management. Climate-induced supply shocks challenge conventional inflation-targeting frameworks because central banks have limited ability to offset inflation generated by disruptions to production and distribution networks (Cantelmo et al., 2024; Kabundi et al., 2026). Furthermore, increasing disaster frequency may amplify inflation volatility, complicate inflation expectations, and reduce the effectiveness of traditional monetary policy instruments (Chavleishvili & Moench, 2025; Yalçinkaya et al., 2026). These challenges are expected to become increasingly important as climate change intensifies over the coming decades. Despite the growing literature, several research gaps remain. Existing studies primarily focus on individual countries, specific regions such as the Euro Area, or particular climate indicators including temperature anomalies, droughts, or rainfall. Comparatively little evidence is available on whether observed climate-related disasters systematically influence annual consumer price inflation across OECD countries using internationally comparable disaster data. Given that OECD economies differ substantially in their economic structures, institutional resilience, and exposure to climate risks, cross-country evidence is essential for understanding the broader macroeconomic consequences of climate disasters and informing effective policy responses.

Accordingly, this study investigates the relationship between climate-related disasters and annual consumer price inflation across OECD countries using panel data analysis. By providing international evidence from advanced economies, this research contributes to the emerging literature on climate-induced inflation and offers insights for policymakers seeking to maintain price stability under increasing climate uncertainty. This will lead to our first research question:

RQ1: Do climate-related disasters significantly influence annual consumer price inflation in OECD countries?

2. Literature Review and Theoretical Background

2.1 Climate Disasters as a Source of Inflationary Pressure

Climate-related disasters have increasingly been recognized as important drivers of macroeconomic instability, particularly through their influence on consumer prices. Economic theory suggests that disasters such as floods, storms, droughts, and extreme temperature events reduce productive capacity, disrupt transportation and supply chains, lower agricultural output, and increase reconstruction demand. These simultaneous supply- and demand-side shocks create upward pressure on inflation, especially in the short run. Consequently, climate change is no longer viewed solely as an environmental challenge but also as a significant macroeconomic risk affecting price stability and monetary policy (Chavleishvili & Moench, 2025; Jackson, 2024). Recent empirical evidence largely supports this theoretical mechanism. Using a panel structural vector autoregression model for the Euro Area, Beirne et al., (2024) found that weather-related disasters significantly increase inflation, although the effects are temporary. Their findings indicate that supply-side disruptions dominate the inflationary response and disproportionately affect expenditure categories representing larger shares of low-income households' budgets. Similarly, Qi et al., (2025) reported that climate risk increases inflation primarily through rising food prices and monetary policy adjustments, while Li et al., (2023) identified higher energy demand as another important transmission mechanism linking climate change and inflation.

2.2 Evidence from Country-Specific and Regional Studies

A growing number of country-level studies further demonstrate that climate-related disasters generate inflationary pressures, although the magnitude varies across economies and disaster types. Narayan et al., (2026) found that cyclones, droughts, and excessive rainfall substantially increase monthly inflation in Fiji while having relatively limited effects on output, suggesting that climate disasters primarily operate as supply-side shocks. Likewise, Romero & Naranjo-Saldrriaga, (2024) showed that weather-related shocks significantly influence both realized inflation and inflation expectations in Colombia, highlighting the importance of climate risks for monetary policy decisions. Cross-country evidence also supports these findings. Zhang, (2023) reported that climate risks significantly affect inflation dynamics across BRICS economies, although the effects differ by country. Similarly, Kabundi et al., (2026) showed that adverse climate shocks increase inflation in both advanced and developing economies, with droughts exerting the strongest inflationary effects through higher food prices. These findings collectively suggest that climate-related disasters are becoming increasingly important determinants of inflation across diverse economic environments.

2.3 Climate Disasters, Supply Chains, and Food Price Inflation

One of the primary mechanisms through which climate-related disasters affect inflation is the disruption of production and distribution systems. Extreme weather events interrupt agricultural production, transportation infrastructure, logistics networks, and manufacturing activities, leading to shortages of essential goods and rising production costs. Cevik & Gwon, (2024) demonstrated that weather anomalies disrupt global supply chains across major economies, generating inflationary pressures that differ according to countries' exposure to supply-chain

vulnerabilities. Similarly, Kunawotor et al., (2022) found that droughts and floods increase both headline inflation and food price inflation in African economies through reduced agricultural production. Marwa et al., (2025) further showed that climate change negatively affects food security by increasing food price inflation and reducing agricultural productivity. These studies suggest that food markets represent one of the principal transmission channels through which climate-related disasters influence overall inflation.

2.4 Climate Risks and Monetary Policy

The growing importance of climate-induced inflation has attracted increasing attention from central banks and monetary authorities. Unlike conventional demand-driven inflation, climate-related inflation often originates from supply-side shocks that monetary policy cannot easily offset. Consequently, central banks face difficult trade-offs between maintaining price stability and supporting economic activity following climate disasters. Cantelmo et al., (2024) argue that inflation targeting remains the welfare-optimal monetary policy framework despite increasing climate risks, although central banks should avoid accommodating disaster-induced inflation. Conversely, Chavleishvili & Moench, (2025) show that climate disasters significantly increase inflation volatility and upside inflation risk, suggesting that standard macroeconomic models underestimate the uncertainty generated by climate shocks. Yalçinkaya et al., (2026) further demonstrate that temperature shocks have persistent effects on both realized and expected inflation in the United States, emphasizing the need for climate risks to be incorporated into monetary policy frameworks.

2.5 Research Gap

Although the literature increasingly recognizes the relationship between climate-related disasters and inflation, several important limitations remain. First, many studies focus on individual countries or specific regions, limiting the generalizability of their findings. Second, previous research often examines monthly inflation, inflation expectations, temperature anomalies, or climate risk indices rather than observed climate-related disaster occurrences. Third, relatively few studies investigate annual consumer price inflation across OECD countries using internationally comparable disaster databases over extended periods. Therefore, evidence on whether climate-related disasters systematically influence annual consumer price inflation across OECD economies remains limited. This study addresses this gap by employing panel data for OECD countries and internationally comparable disaster records from the EM-DAT database to examine the macroeconomic relationship between climate-related disasters and annual inflation. By focusing on advanced economies and multiple disaster types, this research contributes to the growing literature on climate economics and provides evidence relevant for monetary authorities and policymakers facing increasing climate uncertainty.

3. Materials and Methods

3.1 Data

This study employs an unbalanced panel dataset comprising 38 OECD countries over the period 2000–2024, resulting in 941 country-year observations. The sample includes all OECD member countries for which complete information on annual inflation and climate disaster indicators is available. The use of OECD countries provides a relatively homogeneous institutional and

economic environment while allowing substantial variation in climate-related disasters across countries and over time. The dependent variable is annual consumer price inflation (CPI), measured as the annual percentage change in the Consumer Price Index. Inflation data capture realized price dynamics and serve as an indicator of macroeconomic price stability. Climate disaster information is obtained from the Emergency Events Database (EM-DAT) maintained by the Centre for Research on the Epidemiology of Disasters (CRED). The database provides internationally harmonized information on the occurrence and impacts of natural disasters. Five major climate-related disaster categories are considered: floods, storms, droughts, extreme temperature events, and wildfires. Binary indicators equal one if at least one event of the corresponding disaster type occurred within a country during a given year and zero otherwise.

To capture disaster severity, two continuous measures are constructed. The first is the total reported economic damage associated with climate disasters, while the second measures the total affected population. Because both variables exhibit highly right-skewed distributions, they are transformed using the natural logarithm as follows:

$$\begin{aligned} \text{Log_Damage} &= \ln(1 + \text{Total_Damage}) \\ \text{Log_Affected} &= \ln(1 + \text{Total_Affected}) \end{aligned} \quad (1)$$

The logarithmic transformation reduces the influence of extreme observations while preserving country-year observations with zero reported disaster losses.

3.2 Variables

Table 1 summarizes the variables used in the empirical analysis.

Table 1. Variables and definitions.

Variable	Definition	Measurement
Inflation	Annual consumer price inflation	Annual CPI growth (%)
Log_Damage	Disaster severity	$\ln(1 + \text{total economic damage})$
Log_Affected	Disaster severity	$\ln(1 + \text{affected population})$
Flood	Flood occurrence	Dummy (1 = event occurred)
Storm	Storm occurrence	Dummy (1 = event occurred)
Drought	Drought occurrence	Dummy (1 = event occurred)
Extreme Temperature	Extreme temperature occurrence	Dummy (1 = event occurred)
Wildfire	Wildfire occurrence	Dummy (1 = event occurred)

3.3 Econometric Methodology

The empirical analysis proceeds in several stages to examine whether climate disasters influence annual inflation in OECD countries. First, descriptive statistics are reported to summarize the distribution of the variables. Pearson and Spearman correlation coefficients are subsequently calculated to evaluate pairwise relationships among the variables. Potential multicollinearity is assessed using the Variance Inflation Factor (VIF), where values below five indicate the absence of serious multicollinearity. The baseline empirical model is specified as

$$\text{Inflation}_{it} = \alpha + \beta \text{Disaster}_{it} + \varepsilon_{it}$$

where $Inflation_{it}$ denotes annual inflation in country i during year t , $Disaster_{it}$ represents the climate disaster variable of interest, and ε_{it} is the stochastic error term.

The analysis begins with pooled ordinary least squares (OLS) estimation to provide a benchmark comparison. However, because pooled estimation ignores country-specific heterogeneity, panel estimators are subsequently employed. The one-way fixed-effects model is estimated as

$$Inflation_{it} = \alpha_i + \beta Disaster_{it} + \varepsilon_{it} \quad (2)$$

where α_i captures all time-invariant country-specific characteristics that may influence inflation, such as institutional quality, monetary policy frameworks, and structural economic differences. A random-effects specification is also estimated for comparison,

$$Inflation_{it} = \alpha + \beta Disaster_{it} + u_i + \varepsilon_{it}, \quad (3)$$

where u_i denotes the country-specific random effect assumed to be uncorrelated with the explanatory variables. The choice between the fixed-effects and random-effects estimators is determined using the Hausman specification test. The null hypothesis states that the random-effects estimator is consistent and efficient. Rejection of the null hypothesis indicates that the country-specific effects are correlated with the explanatory variables, thereby supporting the use of the fixed-effects estimator. Following the Hausman test, the preferred specification is a two-way fixed-effects model, which simultaneously controls for both country-specific and year-specific effects:

$$Inflation_{it} = \alpha_i + \lambda_t + \beta Disaster_{it} + \varepsilon_{it} \quad (4)$$

where λ_t represents year fixed effects that capture global shocks common to all OECD countries, including international commodity price fluctuations, financial crises, and pandemic-related disruptions. Several model specifications are estimated. The first examines aggregate disaster severity using logged disaster damage. The second replaces disaster severity with individual disaster-type indicators (floods, storms, droughts, extreme temperature events, and wildfires). The final specification simultaneously includes disaster occurrence indicators and logged disaster damage to distinguish between the occurrence and severity of climate disasters. To account for heteroskedasticity and serial correlation within countries, country-clustered robust standard errors are employed in all two-way fixed-effects regressions.

3.4 Model Specifications

Five econometric models are estimated sequentially:

Model 1: Fixed Effects

$$Inflation_{it} = \alpha_i + \beta_1 LogDamage_{it} + \varepsilon_{it} \quad (5)$$

Model 2: Random Effects

$$Inflation_{it} = \alpha + \beta_1 LogDamage_{it} + u_i + \varepsilon_{it} \quad (6)$$

Model 3: Two-Way Fixed Effects

$$Inflation_{it} = \alpha_i + \lambda_t + \beta_1 LogDamage_{it} + \varepsilon_{it} \quad (7)$$

Model 4: Two-Way Fixed Effects with Disaster Types

$$Inflation_{it} = \alpha_i + \lambda_t + \beta_1 Flood_{it} + \beta_2 Storm_{it} + \beta_3 Drought_{it} + \beta_4 ExtremeTemperature_{it} + \beta_5 Wildfire_{it} + \varepsilon_{it} \quad (8)$$

Model 5: Two-Way Fixed Effects with Disaster Severity

$$Inflation_{it} = \alpha_i + \lambda_t + \beta_1 LogDamage_{it} + \beta_2 Flood_{it} + \beta_3 Storm_{it} + \beta_4 Drought_{it} + \beta_5 ExtremeTemperature_{it} + \beta_6 Wildfire_{it} + \varepsilon_{it} \quad (9)$$

This section should provide sufficient detail to enable the study to be replicated. Authors should clearly describe the research design, data sources, variables, sampling procedures, analytical methods, software used, and any assumptions or limitations relevant to the methodology.

4. Results

4.1 Descriptive Statistics

Table 2 presents the descriptive statistics for the variables used in the analysis based on 941 country-year observations from 38 OECD countries between 2000 and 2024. The average annual inflation rate is 3.37%, with a median of 2.37%, indicating that inflation remained relatively moderate across most OECD economies during the sample period. However, the maximum inflation rate of 72.31% and the high values of skewness (7.42) and kurtosis (75.08) reveal the presence of several extreme inflationary episodes, primarily driven by a small number of country-year observations. The climate disaster variables also exhibit considerable variation. Floods (40.6%) and storms (39.3%) are the most frequently recorded disasters, followed by extreme temperature events (27.4%), while droughts are relatively rare, occurring in only 4.3% of the observations. The logged measures of disaster damage and affected population have median values of zero, indicating that many country-year observations experienced either no reported disaster losses or no affected population, while the logarithmic transformation reduces the influence of exceptionally large disaster events. Overall, the descriptive statistics indicate substantial variation in both inflation and climate disaster indicators across countries and over time, providing an appropriate basis for the subsequent panel data analysis.

Table 2. Descriptive Statistics of the Variables (OECD Countries, 2000–2024)

Variable	Obs	Mean	Std. Dev.	Min	25th P	Median	75th P	Max	Skewness	Kurtosis
Inflation	941	3.365	5.261	-4.448	1.264	2.370	3.754	72.309	7.415	75.078
Log_Damage	941	5.173	6.660	0.000	0.000	0.000	12.565	19.385	0.606	-1.454
Log_Affected	941	4.258	4.754	0.000	0.000	0.000	8.459	18.260	0.507	-1.233
Flood	941	0.406	0.491	0.000	0.000	0.000	1.000	1.000	0.384	-1.857

Storm	941	0.393	0.489	0.000	0.000	0.000	1.000	1.000	0.438	-1.812
Drought	941	0.043	0.202	0.000	0.000	0.000	0.000	1.000	4.543	18.675
Extreme Temperature	941	0.274	0.446	0.000	0.000	0.000	1.000	1.000	1.014	-0.974

Notes: Inflation represents annual consumer price inflation (CPI). Log_Damage and Log_Affected are natural logarithmic transformations of total disaster-related economic damage and affected population, respectively. Flood, Storm, Drought, and Extreme Temperature are binary indicators equal to one if at least one event occurred in a given country-year.

4.2 Correlation Analysis and Multicollinearity

Figure 1 provides a visual representation of the Pearson correlation matrix among annual inflation, climate disaster indicators, and disaster severity measures. Overall, the heatmap reveals relatively weak correlations between annual inflation and the climate-related variables. The largest positive correlation involving inflation is observed for floods (0.088), whereas storms exhibit a weak negative association (−0.065). These low coefficients suggest that simple pairwise relationships between climate disasters and inflation are limited, highlighting the need for panel regression models that account for country-specific heterogeneity and common time effects.

Among the explanatory variables, the strongest relationship is observed between logged disaster damage and logged affected population (0.631), indicating that disasters generating greater economic losses typically affect larger populations. Flood occurrence is also moderately associated with both logged disaster damage (0.544) and logged affected population (0.739), reflecting the substantial economic and social consequences commonly associated with flood events. Correlations among the remaining disaster indicators are generally weak to moderate, suggesting that each disaster type captures a distinct dimension of climate risk.

Taken together, the correlation matrix indicates that pairwise relationships among the explanatory variables remain well below levels that would typically raise concerns regarding multicollinearity. This visual evidence is consistent with the subsequent Variance Inflation Factor analysis, which confirms that multicollinearity is not a significant issue in the regression models.

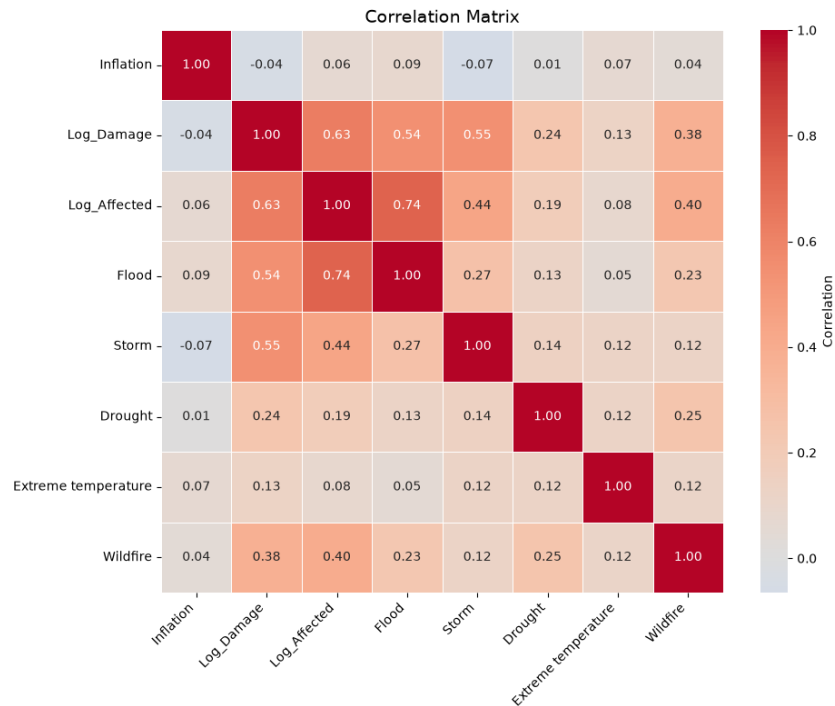


Figure 1. Pearson Correlation Matrix of Inflation and Climate Disaster Variables

Note: The heatmap presents Pearson correlation coefficients among annual inflation, disaster severity measures, and climate disaster indicators for the OECD sample covering 2000–2024. Darker shades indicate stronger positive correlations, while lighter shades represent weaker associations.

Table 3 reports the Variance Inflation Factor (VIF) statistics used to evaluate potential multicollinearity among the explanatory variables. All VIF values are substantially below the commonly accepted threshold of 5, with the highest value observed for logged affected population ($VIF = 3.026$). Logged disaster damage ($VIF = 2.194$) and flood occurrence ($VIF = 2.385$) also exhibit relatively low values, while the remaining variables have VIF statistics close to one. These results indicate that multicollinearity is not a concern in the estimated models. Although logged disaster damage and logged affected population are conceptually related measures of disaster severity, their correlation is insufficient to create instability in the coefficient estimates. Therefore, the explanatory variables can be included in the regression models without compromising the reliability or precision of the estimated parameters.

Table 3. Variance Inflation Factors

Variable	VIF
Log_Damage	2.194
Log_Affected	3.026
Flood	2.385
Storm	1.556
Drought	1.101
Extreme temperature	1.035
Wildfire	1.336

Note: The constant term is omitted because its VIF is not used for assessing multicollinearity.

4.3 Panel Regression Results

Table 4 presents the panel regression estimates examining the relationship between climate disasters and annual inflation across OECD countries. The analysis begins with one-way fixed-effects and random-effects specifications before proceeding to the preferred two-way fixed-effects models that control for both country-specific and year-specific heterogeneity. The fixed-effects model indicates that logged disaster damage has a positive but statistically insignificant effect on annual inflation ($\beta = 0.008$, $p = 0.771$). Similarly, the random-effects estimator produces a positive coefficient ($\beta = 0.031$, $p = 0.227$), although the effect likewise fails to reach conventional significance levels. The Hausman specification test strongly rejects the null hypothesis that the random-effects estimator is consistent ($\chi^2 = 6.326$, $p = 0.012$), indicating that country-specific effects are correlated with the explanatory variables. Consequently, the fixed-effects estimator is selected as the preferred modelling framework for the remainder of the analysis.

To account for global macroeconomic shocks affecting all OECD countries simultaneously, a two-way fixed-effects model incorporating both country and year effects is estimated. After controlling for these unobserved effects, logged disaster damage remains positively associated with annual inflation ($\beta = 0.035$), but the relationship remains statistically insignificant ($p = 0.139$). This finding suggests that aggregate disaster severity does not independently explain cross-country variation in annual inflation once persistent country characteristics and common time effects are removed. The analysis is subsequently extended by replacing the aggregate damage measure with individual climate disaster indicators. None of the disaster categories exhibits a statistically significant relationship with annual inflation. Floods display a positive coefficient ($\beta = 0.727$, $p = 0.334$), indicating that flood years are associated with higher inflation on average, although the effect is not statistically distinguishable from zero. Storms produce a small negative coefficient ($\beta = -0.116$, $p = 0.382$), while extreme temperature events similarly show no measurable impact ($\beta = -0.144$, $p = 0.696$). Wildfires exhibit a positive but statistically insignificant coefficient ($\beta = 0.927$, $p = 0.234$). Among all disaster types, droughts consistently generate the largest negative coefficient ($\beta = -0.727$, $p = 0.151$), although this estimate remains statistically insignificant. The relatively small number of drought observations within the sample likely limits statistical power and contributes to the wider confidence intervals observed for this variable.

The final specification simultaneously incorporates disaster occurrence indicators and logged disaster damage to distinguish between the occurrence and severity of climate events. The estimated coefficient for logged disaster damage decreases to 0.020 ($p = 0.208$), while the coefficients for the disaster-type indicators remain broadly unchanged. None of the explanatory variables achieves statistical significance, suggesting that neither the occurrence nor the economic severity of climate disasters exerts an independent influence on annual inflation in OECD countries over the study period. Overall, the regression evidence is remarkably consistent across alternative specifications. Although the estimated coefficients vary modestly in magnitude, the direction and statistical significance of the results remain stable. The findings therefore suggest that annual inflation in OECD economies is primarily driven by broader macroeconomic conditions rather than by direct climate-disaster shocks. This result is consistent with the institutional resilience of advanced economies, where effective monetary policy, insurance mechanisms, fiscal interventions, and diversified supply chains may mitigate the inflationary pressures associated with climate-related disasters.

Table 4. Panel Regression Results: Climate Disasters and Annual Inflation in OECD Countries

Variables	(1) FE	(2) RE	(3) TWFE	(4) TWFE: Disaster Types	(5) TWFE: Full Model
Log Damage	0.0080 (0.0276)	0.0314 (0.0260)	0.0347 (0.0234)	–	0.0195 (0.0155)
Flood	–	–	–	0.7270 (0.7528)	0.6459 (0.7702)
Storm	–	–	–	-0.1157 (0.1322)	-0.1995 (0.1609)
Drought	–	–	–	-0.7273 (0.5055)	-0.7735 (0.5103)
Extreme Temperature	–	–	–	-0.1435 (0.3669)	-0.1505 (0.3661)
Wildfire	–	–	–	0.9268 (0.7776)	0.8589 (0.7929)
Country Fixed Effects	Yes	No	Yes	Yes	Yes
Year Fixed Effects	No	No	Yes	Yes	Yes
Clustered SE	No	No	Yes	Yes	Yes
Observations	941	941	941	941	941
Within R ²	0.0001	-0.0007	-0.0010	0.0011	-0.0008

Notes: Robust standard errors are reported in parentheses. Models (3)–(5) employ two-way fixed effects with country-clustered standard errors. The Hausman specification test ($\chi^2 = 6.326$, $p = 0.012$) supports the use of the Fixed Effects estimator over the Random Effects estimator.

5. Discussion

The present study examined whether climate-related disasters significantly influence annual consumer price inflation across 38 OECD countries during the period 2000–2024. Using a sequence of panel-data estimators, including fixed effects, random effects, and two-way fixed-effects models, the empirical analysis consistently found no statistically significant relationship between climate disaster indicators and annual inflation. This finding remained robust regardless of whether disasters were measured by aggregate economic damage, individual disaster categories, or a combination of occurrence and severity measures.

The absence of statistically significant effects should not be interpreted as evidence that climate disasters are economically irrelevant. Instead, the results suggest that climate-related shocks may not generate persistent annual inflationary pressures in advanced OECD economies once country-specific characteristics and common macroeconomic shocks are appropriately controlled for. Advanced economies generally possess well-developed institutional frameworks, diversified production systems, comprehensive insurance markets, and effective fiscal and monetary policy mechanisms that help absorb temporary supply disruptions caused by natural disasters. Consequently, although climate disasters may temporarily increase prices in specific sectors, these effects may dissipate before becoming reflected in annual aggregate inflation.

The comparison of alternative panel estimators provides additional methodological insights. While pooled ordinary least squares produced a negative but statistically insignificant coefficient for disaster damage, both fixed-effects and random-effects estimators generated positive coefficients. The Hausman specification test demonstrated that country-specific effects are correlated with the explanatory variables, supporting the use of the fixed-effects estimator.

This result highlights the importance of controlling for unobserved heterogeneity when analysing macroeconomic relationships across countries. Ignoring permanent institutional and structural differences may produce biased estimates and misleading conclusions.

Among the individual climate disaster categories, droughts consistently exhibited the largest negative coefficient, although statistical significance was not achieved. One possible explanation is that drought events are relatively uncommon within the OECD sample, limiting the available within-country variation and reducing statistical power. Furthermore, the agricultural sectors of many OECD economies represent a relatively small share of total economic output, while food imports and international trade may mitigate domestic supply shortages arising from drought conditions. Consequently, drought-induced production losses may have only limited effects on aggregate consumer prices. Floods and wildfires produced positive coefficients throughout the estimated models, whereas storms and extreme temperature events generated negative coefficients. Nevertheless, none of these relationships reached conventional significance levels. These findings suggest that different types of climate disasters may affect economic sectors differently, but their aggregate influence on national inflation remains limited within developed economies. Public infrastructure investment, disaster-response policies, and efficient supply-chain management may substantially reduce the transmission of localized disaster shocks into nationwide inflationary pressures.

The results also indicate that disaster severity, measured by logged economic damage, does not independently explain annual inflation once disaster occurrence and fixed effects are considered simultaneously. Although larger disasters naturally generate greater economic losses, these losses do not necessarily translate into sustained inflation. In many OECD countries, reconstruction spending, insurance compensation, fiscal transfers, and credible monetary policy may prevent temporary supply disruptions from evolving into broader inflationary episodes. Overall, the findings contribute to the growing literature on climate economics by suggesting that the macroeconomic consequences of climate disasters may differ substantially between developed and developing economies. While previous studies frequently report inflationary effects of climate shocks in countries characterized by weaker institutions and greater dependence on agriculture, the present results imply that OECD countries possess sufficient economic resilience to absorb many climate-related disturbances without generating persistent increases in annual consumer price inflation.

Nevertheless, several limitations should be acknowledged. First, annual data may mask short-term inflationary responses that occur immediately following major disaster events. Second, the analysis focuses exclusively on OECD countries and therefore may not be generalizable to emerging or developing economies where climate disasters often have more severe macroeconomic consequences. Third, inflation is influenced by numerous macroeconomic factors, including monetary policy, energy prices, exchange rates, and aggregate demand conditions, which were not explicitly incorporated into the present specifications. Future research could extend the analysis by introducing additional macroeconomic control variables, higher-frequency data, and dynamic panel estimators to investigate both the short-run and long-run transmission mechanisms through which climate disasters influence inflation.

6. Conclusion

This study investigated the relationship between climate disasters and annual consumer price inflation across 38 OECD countries over the period 2000–2024 using panel-data econometric techniques. A comprehensive empirical framework was implemented, including descriptive statistics, correlation analysis, multicollinearity diagnostics, pooled ordinary least squares estimation, fixed-effects and random-effects models, the Hausman specification test, and two-way fixed-effects estimators with country-clustered standard errors. The empirical findings consistently indicate that neither aggregate disaster severity nor individual climate disaster types exert a statistically significant effect on annual inflation within the OECD sample. The Hausman specification test confirmed that fixed-effects estimation is the appropriate modelling framework, emphasizing the importance of accounting for unobserved country-specific heterogeneity. Furthermore, the inclusion of both country and year fixed effects demonstrates that the estimated relationships remain robust after controlling for common macroeconomic shocks affecting all OECD countries.

From a policy perspective, the results suggest that advanced economies possess sufficient institutional resilience, fiscal capacity, and monetary policy credibility to prevent climate-related disasters from generating persistent annual inflationary pressures. While natural disasters undoubtedly impose substantial human and economic costs, their effects on aggregate price dynamics appear to be effectively mitigated through existing economic and policy mechanisms within OECD countries. The study contributes to the literature by providing one of the few cross-country panel analyses examining the relationship between multiple climate disaster categories and annual inflation across developed economies over a twenty-five-year period. Unlike studies focusing on individual countries or single disaster events, the present analysis simultaneously evaluates disaster occurrence and disaster severity within a unified panel-data framework while accounting for both country-specific and time-specific heterogeneity.

Although no statistically significant relationship was identified, this finding is itself an important contribution. It suggests that the macroeconomic effects of climate disasters cannot be generalized across countries and that institutional quality, disaster preparedness, and policy responses likely play critical roles in moderating inflationary pressures following extreme climate events. Future research should investigate whether climate disasters exert stronger effects on sector-specific prices, food inflation, producer prices, or inflation persistence rather than aggregate annual consumer price inflation. Additionally, incorporating macroeconomic control variables, dynamic panel estimators, and higher-frequency monthly or quarterly data would provide a more comprehensive understanding of the channels through which climate-related shocks influence inflation dynamics.

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Dynamic interdependence between gold and oil markets: Evidence from multivariate time-series analysis (2007–2026)

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Abstract: Commodity markets play a central role in global financial systems, with gold and crude oil representing strategic assets characterized by distinct economic functions and responses to market uncertainty. This study examines the dynamic interdependence between gold and oil markets using daily observations from 2007 to 2026. Gold is represented by SPDR Gold Shares, while West Texas Intermediate (WTI) and Brent crude oil are considered as major oil benchmarks. Daily logarithmic returns are analyzed using descriptive statistics, correlation analysis, Augmented Dickey–Fuller tests, Vector Autoregression (VAR), Impulse Response Functions (IRFs), and Forecast Error Variance Decomposition (FEVD). The findings reveal heterogeneous and asymmetric relationships across the commodity markets. While significant short-run transmission effects emerge between gold and WTI returns, cross-market shocks generally dissipate rapidly, indicating limited persistence. Gold remains comparatively insulated from energy-market disturbances, whereas WTI exhibits greater responsiveness to gold-market shocks. Overall, the evidence suggests that gold–oil interdependence is predominantly short-term and asymmetric rather than persistent. These findings contribute to understanding commodity-market transmission mechanisms and provide implications for portfolio diversification, risk management, and investment decision-making.

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1. Introduction

Commodity markets play a fundamental role in the global financial system by influencing investment decisions, inflation expectations, industrial production, and portfolio risk management. Among internationally traded commodities, crude oil and gold occupy particularly important positions because they perform distinct yet complementary economic functions. Crude oil serves as a primary input for industrial production, transportation, and economic growth, making its price highly sensitive to changes in global demand, geopolitical developments, and supply disruptions. Gold, in contrast, is widely regarded as a safe-haven asset and store of value that attracts investors during periods of financial uncertainty, inflationary pressure, and heightened market volatility. Consequently, understanding the interactions between these two strategic commodities has become increasingly important for

investors, policymakers, and researchers seeking to evaluate market integration, risk transmission, and diversification opportunities.

Growing financial integration and repeated episodes of global economic disruption have substantially increased interest in the dynamic relationships between commodity markets. Previous studies demonstrate that the strength and direction of interactions between gold and oil are not constant over time but vary across investment horizons, market conditions, and major economic events. Stronger interdependence is frequently observed during periods of financial crises, geopolitical conflicts, and elevated market uncertainty, suggesting that commodity markets respond differently under normal and turbulent conditions (Bonato et al., 2020; Cevik et al., 2018; Raggad & Bouri, 2023; Tran et al., 2026).

Recent research has increasingly adopted advanced econometric techniques to capture the complexity of commodity market interactions. Wavelet analysis, Dynamic Conditional Correlation GARCH (DCC-GARCH), BEKK-GARCH, quantile connectedness, transfer entropy, and time-varying Granger causality have revealed that relationships among commodity prices exhibit considerable nonlinearities, asymmetries, and frequency-dependent characteristics. These studies consistently report that spillovers intensify during extreme market conditions, while connectedness generally weakens during relatively stable economic periods. Furthermore, evidence suggests that crude oil frequently acts as a major transmitter of shocks, whereas gold alternates between transmitting and absorbing market disturbances depending on the prevailing economic environment and investment horizon (Lee et al., 2023; Shang & Hamori, 2024; Torun, 2025; Uddin et al., 2018; Yang et al., 2025).

Despite this growing body of literature, empirical evidence remains mixed regarding the magnitude, persistence, and direction of interactions between gold and oil markets. Some studies report substantial return and volatility spillovers, particularly during periods of global financial stress and geopolitical crises, whereas others find relatively weak or highly time-dependent relationships. These inconsistent findings suggest that the interdependence between the two markets remains sensitive to the choice of methodology, sample period, benchmark oil price, and frequency of analysis (Bonato et al., 2020; Raggad & Bouri, 2023; Sahadudheen & Kumar, 2025).

Most existing studies primarily emphasize volatility spillovers, nonlinear dependence, or multiscale connectedness using sophisticated econometric frameworks. While these approaches provide valuable insights into evolving market dynamics, relatively fewer studies offer a comprehensive assessment of the short-run transmission mechanisms between gold and oil returns using a conventional multivariate time-series framework that combines descriptive analysis, stationarity testing, Vector Autoregression (VAR), Impulse Response Functions (IRFs), and Forecast Error Variance Decomposition (FEVD). Such an integrated framework remains valuable because it provides transparent evidence regarding lagged transmission effects, dynamic shock propagation, and the relative importance of internal and external sources of market variability.

Accordingly, this study investigates the dynamic relationship between gold and oil markets using daily observations covering the period from 2007 to 2026. Specifically, the analysis examines historical price behaviour, return characteristics, statistical dependence, stationarity, dynamic interactions, shock transmission, and forecast error variance decomposition between

gold and two major international crude oil benchmarks. By combining descriptive analysis with multivariate time-series techniques, this study seeks to determine whether the observed co-movements between gold and oil represent persistent market interdependence or merely temporary short-run adjustments driven by changing economic conditions. The findings contribute to the literature by providing updated evidence spanning multiple episodes of global financial instability, including the Global Financial Crisis, the COVID-19 pandemic, and recent geopolitical disruptions, thereby offering useful implications for investors, portfolio managers, and policymakers concerned with commodity market integration and risk management.

2. Materials and Methods

2.1 Data

This study examines the dynamic relationship between gold and crude oil markets using daily financial market data covering the period from January 2007 to 2026. Gold prices are represented by the SPDR Gold Shares (GLD), while crude oil markets are represented by the West Texas Intermediate (WTI) and Brent Crude Oil Futures, which together capture the two principal international oil benchmarks. The sample period encompasses several major episodes of global economic and geopolitical uncertainty, including the Global Financial Crisis, the European sovereign debt crisis, the COVID-19 pandemic, and recent geopolitical conflicts, thereby providing a comprehensive environment for evaluating commodity market interactions. Daily closing prices were obtained from publicly available financial market databases. To ensure comparability across assets with different price levels, all analyses were conducted using continuously compounded logarithmic returns rather than raw price levels. Daily log returns were calculated as:

$$r_t = \ln \left(\frac{P_t}{P_{t-1}} \right) \times 100 \quad (1)$$

where P_t denotes the closing price on trading day t . Logarithmic returns are widely used in financial econometrics because they stabilize the variance, facilitate statistical inference, and reduce non-stationarity commonly observed in asset price series.

2.2 Descriptive Analysis

The empirical analysis begins with descriptive statistics to summarize the principal characteristics of the return distributions. Measures including the mean, standard deviation, minimum, maximum, quartiles, skewness, kurtosis, and the Jarque–Bera statistic are reported to evaluate central tendency, dispersion, distributional asymmetry, tail behaviour, and deviations from normality. Historical price series and daily return plots are also presented to provide an initial visual assessment of market behaviour, volatility clustering, and potential co-movement between gold and crude oil prices over the sample period (Table 1).

2.3 Correlation Analysis

To provide preliminary evidence regarding the association between commodity markets, Pearson correlation coefficients were computed using daily logarithmic returns. Scatter plots were additionally employed to visualize the strength and direction of the linear relationship between gold and oil prices. Although correlation provides an initial measure of contemporaneous association, it does not establish dynamic dependence or predictive

relationships. Consequently, further multivariate time-series analysis is required to investigate the transmission of shocks between markets.

2.4 Stationarity Testing

Before estimating the multivariate time-series model, the stationarity properties of each return series were evaluated using the Augmented Dickey–Fuller (ADF) unit root test. The ADF test examines whether a series contains a stochastic trend by testing the null hypothesis of a unit root against the alternative hypothesis of stationarity. Since Vector Autoregressive (VAR) models require stationary variables to avoid spurious estimation, the ADF procedure serves as an essential diagnostic before model estimation. Rejection of the null hypothesis indicates that the return series fluctuate around a stable mean and variance, satisfying the assumptions necessary for subsequent dynamic modelling.

2.5 Vector Autoregressive Model

Dynamic interactions between gold and crude oil returns were examined using a Vector Autoregressive (VAR) model. The VAR framework treats each variable as endogenous, allowing current returns to depend on their own past values as well as the lagged values of the other variables within the system. This approach captures feedback effects and dynamic interdependence without imposing strong theoretical restrictions regarding causal direction. The general VAR(p) specification is expressed as:

$$Y_t = c + \sum_{i=1}^p A_i Y_{t-i} + \varepsilon_t \quad (2)$$

where Y_t represents the vector of return series, c is a vector of constants, A_i denotes coefficient matrices associated with lag i , and ε_t is the vector of innovation terms. The optimal lag length was determined using standard information criteria, including the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Hannan–Quinn Information Criterion (HQIC), and Final Prediction Error (FPE). Based on these criteria, the selected lag order was subsequently used for all dynamic analyses.

2.6 Impulse Response Analysis

Following VAR estimation, Impulse Response Functions (IRFs) were employed to evaluate how unexpected shocks originating in one commodity market propagate through the system over subsequent periods. IRFs trace the temporal adjustment path following a one-standard-deviation innovation while holding the remaining structural relationships constant. This analysis enables the identification of both the magnitude and persistence of cross-market transmission effects and illustrates whether market disturbances dissipate rapidly or generate prolonged responses across commodities.

2.7 Forecast Error Variance Decomposition

To complement the impulse response analysis, Forecast Error Variance Decomposition (FEVD) was conducted to quantify the proportion of forecast uncertainty attributable to own-market shocks and shocks originating from other markets within the VAR system. Variance

decomposition provides additional insight into the relative importance of internal and external sources of market variability over different forecast horizons. High own-market variance contributions indicate relatively independent market dynamics, whereas larger cross-market contributions suggest stronger interdependence and information transmission between commodity markets.

All statistical analyses were conducted using Python. Data preprocessing, descriptive statistics, econometric estimation, and graphical visualizations were implemented using widely adopted scientific computing libraries for financial time-series analysis, ensuring the reproducibility and transparency of the empirical results.

3. Results

3.1 Historical Price Behavior

Figure 1 presents the historical evolution of Gold and oil prices across the primary volatile sub-period of 2016 to 2026 for visual clarity, while the broader econometric analysis utilizes the full 2007 to 2026 sample framework. Because the assets differ substantially in price magnitude, separate vertical axes are used to improve interpretability and avoid visual compression of lower-valued series. The figure demonstrates that gold and oil exhibit notably different long-term price dynamics, suggesting that their underlying economic drivers are not identical. Oil prices display stronger cyclical behavior and greater short-term volatility, while gold follows a comparatively smoother long-term appreciation path. From 2016 to 2019, oil experienced sustained upward momentum, reflecting stronger economic conditions and increased energy demand. During the same period, gold remained relatively stable with modest appreciation, suggesting limited contemporaneous integration between the markets.

A substantial structural disruption emerges in 2020. Oil prices experienced an abrupt decline followed by recovery, whereas gold moved upward during the same interval. This divergence reflects the differing economic roles of the commodities: oil is closely linked to industrial activity and demand expectations, while gold frequently functions as a defensive asset during periods of uncertainty. Between 2021 and 2022, both markets entered a temporary recovery phase and demonstrated periods of positive co-movement. However, this relationship weakened again after 2023 as oil experienced renewed instability while gold entered a stronger upward trend. Overall, historical price movements indicate that although periods of co-movement exist, a stable long-run relationship is not visually apparent. Consequently, further econometric analysis is required to determine whether statistical interdependence exists beyond descriptive observation.

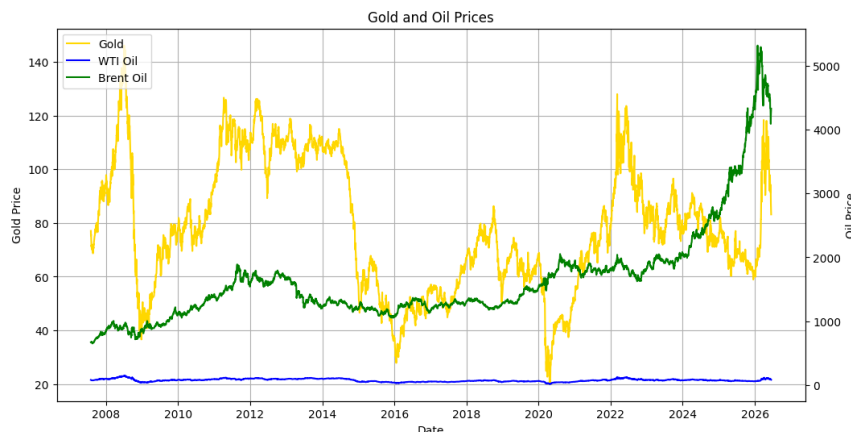


Figure 1. Historical Prices

Note. Daily closing prices are shown in USD. Gold prices are represented by SPDR Gold Shares and oil prices by Brent Oil Futures. Separate y-axes are used due to differences in scale and should not be interpreted as indicating comparable rates of change. The figure focuses on the 2016–2026 timeline for visual clarity and is intended for descriptive analysis only and does not establish causality or predictive relationships between variables.

3.2 Return Dynamics and Distribution Characteristics

To evaluate short-run market behavior independent of long-term price trends, price levels were transformed into daily logarithmic returns. All return series fluctuate around zero, providing preliminary evidence of stationarity and enabling comparison of short-run market volatility across commodities. Most observations remain concentrated around their average values; however, periods of elevated volatility are visible throughout the sample. These visual variations are robustly supported by the descriptive statistics presented in Table 1. Average daily returns remain relatively close to zero across all markets, a pattern standard in financial return time series. However, the standard deviations reveal distinctly different levels of underlying risk exposure. West Texas Intermediate (WTI) exhibits the highest short-run variability ($SD = 2.740$), followed closely by Gold ($SD = 2.381$), while Brent crude demonstrates a substantially lower overall dispersion ($SD = 1.156$). Furthermore, WTI records an exceptionally high kurtosis (17.464), signaling significant fat-tail risk and a higher probability of extreme market corrections compared to the other assets.

Distributional measures indicate departures from normality. Negative skewness observed in gold and Brent suggests a greater frequency of downside movements, while elevated kurtosis across all series indicates heavier tails and a higher likelihood of extreme outcomes than expected under a normal distribution. Jarque–Bera statistics strongly reject normality assumptions across all return series. These findings support the use of econometric methods designed to accommodate financial data characteristics including volatility clustering and non-normal distributions.

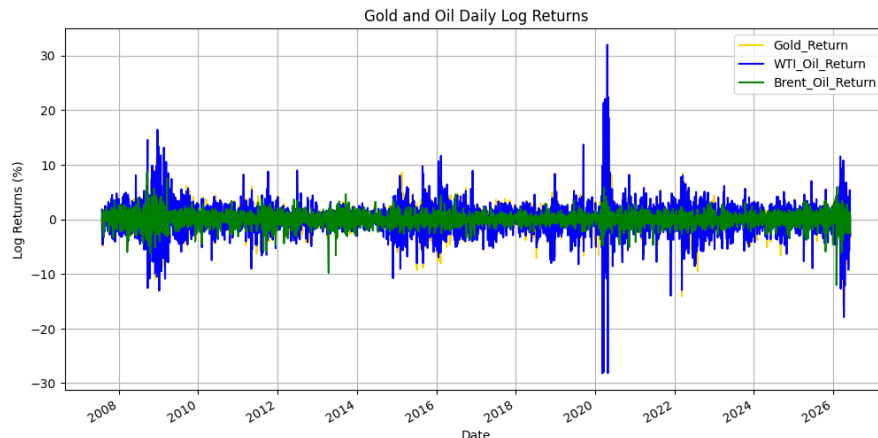


Figure 2. Daily Log Returns

Note. The figure displays daily logarithmic returns calculated from commodity closing prices. Log returns are expressed as percentages and computed as the first difference of the natural logarithm of consecutive price observations. Positive values indicate price increases relative to the previous trading period, while negative values indicate price declines. Values centered around zero indicate that the transformed series fluctuate around a stable mean over time.

Table 1. Descriptive Statistics

Statistic	Gold Return (%)	WTI Oil Return (%)	Brent Oil Return (%)
Observations	4,687	4,687	4,687
Mean	0.012	0.016	0.040
Standard Deviation	2.381	2.740	1.156
Minimum	-27.575	-28.221	-12.066
25th Percentile	-1.041	-1.247	-0.490
Median	0.074	0.089	0.048
75th Percentile	1.166	1.315	0.632
Maximum	19.077	31.963	8.643
Skewness	-0.496	0.005	-0.534
Kurtosis	8.988	17.464	7.487
Jarque–Bera Statistic	15,929.98	59,429.72	11,142.30
Jarque–Bera p-value	<0.001	<0.001	<0.001

Note. Returns are calculated as daily logarithmic percentage changes. The Jarque–Bera (JB) test evaluates departure from normality; p-values below 0.05 indicate rejection of the null hypothesis of normally distributed returns.

3.3 Preliminary Dependence Analysis

Initial examination of market relationships was conducted using scatter plots and correlation analysis. The scatter plot of price levels suggests a weak positive association with considerable dispersion around the fitted trend line. In contrast, return-based correlation analysis reveals a highly benchmark-specific structure; a substantially stronger contemporaneous relationship is observed exclusively between Gold and WTI returns ($r = 0.88$), suggesting intense short-run co-movement between precious metals and US domestic crude benchmarks. Conversely, the contemporaneous association between Gold and Brent returns remains notably weak ($r = 0.16$). These findings imply that levels of market integration differ across commodity groups. However, correlation measures contemporaneous association only and cannot determine predictive influence or causal transmission.

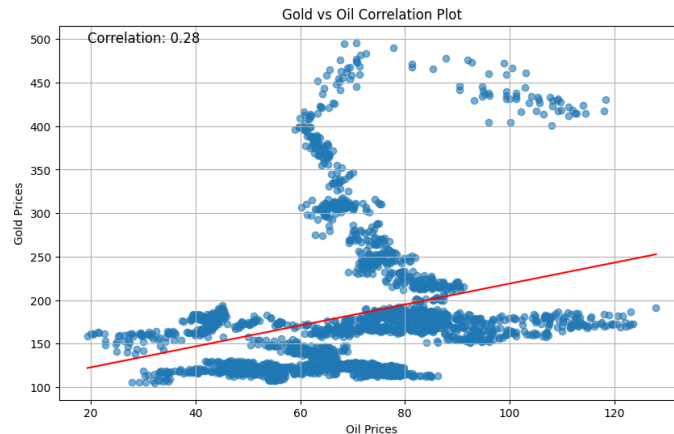
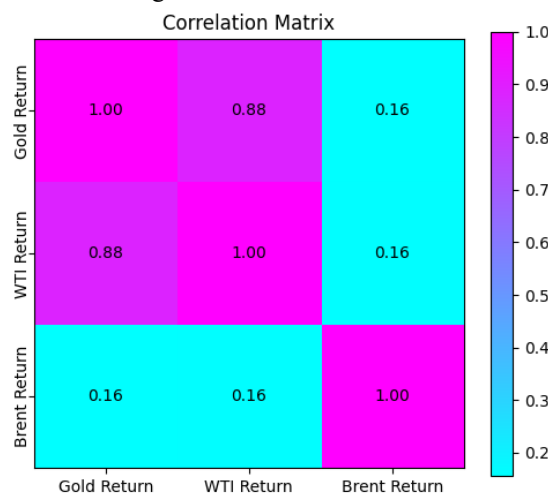


Figure 3. Scatter Plot

Note. The figure displays a scatter plot of daily gold and oil price observations with a fitted linear trend line. The reported correlation coefficient measures the strength and direction of the linear association between variables. Correlation values closer to +1 indicate stronger positive relationships, values closer to -1 indicate stronger negative relationships, and values near zero indicate weak linear association. The observed relationship should not be interpreted as evidence of causality.

Figure 4. Correlation Matrix



Note. Values represent Pearson correlation coefficients calculated using daily logarithmic returns. Correlation coefficients range from -1 to +1, where values closer to ± 1 indicate stronger linear relationships.

3.4 Stationarity and Model Specification

Before estimating dynamic relationships, stationarity testing was performed using the Augmented Dickey–Fuller (ADF) procedure. All return series rejected the null hypothesis of a unit root at conventional significance levels, indicating stationarity. This confirms that transformed returns fluctuate around a stable mean and variance and therefore satisfy a key assumption required for multivariate time-series modelling. Because all asset series are stationary in their first-differenced log return formats, as confirmed by the highly significant ADF test statistics exceeding critical thresholds, the subsequent lag selection criteria are evaluated directly on daily returns to avoid spurious regression. Lag-order selection criteria produced mixed recommendations. Although AIC and FPE suggested longer lag structures, BIC and HQIC selected a more parsimonious specification. To balance explanatory power and

model simplicity, a VAR(3) specification was selected for subsequent analysis. Although lower information criterion values were observed at higher lag lengths, the VAR(3) specification was selected to preserve model parsimony while adequately capturing short-run market dynamics.

Table 2. ADF Results

Test Statistic	Gold Return	WTI Oil Return	Brent Oil Return
ADF Statistic	-15.009	-12.053	-69.302
p-value	<0.001	<0.001	<0.001
Stationarity Decision	Stationary	Stationary	Stationary

Note. The Augmented Dickey–Fuller (ADF) test was conducted to assess stationarity of the return series. The null hypothesis assumes the presence of a unit root (non-stationarity). Rejection of the null hypothesis at conventional significance levels indicates that the series is stationary.

Table 3. Lag Selection

Lag	AIC	BIC	FPE	HQIC
0	2.247	2.249	9.456	2.248
1	2.242	2.250	9.408	2.244
2	2.231	2.245	9.312	2.236
3	2.219	2.238	9.194	2.225
4	2.219	2.244	9.200	2.228
5	2.219	2.249	9.198	2.230
6	2.216	2.252	9.175	2.229
7	2.216	2.257	9.166	2.230
8	2.214	2.260	9.149	2.230
9	2.212	2.264	9.132	2.230
10	2.209	2.267	9.103	2.229

Note. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; FPE = Final Prediction Error; HQIC = Hannan–Quinn Information Criterion. Lower values indicate preferred model specifications.

3.5 Dynamic Market Interactions: VAR Estimation

The VAR(3) estimation provides strong empirical evidence of short-run interactions and lag transmission dynamics between commodity markets. Looking at the Gold Return equation, first-lagged WTI crude returns exert a statistically significant positive effect ($\beta = 0.095$, $p < 0.001$), demonstrating an immediate, short-run transmission running from energy markets into precious metals. Conversely, the transmission from precious metals back to energy markets operates with an asymmetric, delayed momentum. In the WTI Oil Return equation, a positive shock in Gold returns exerts a short-lived, statistically insignificant negative drag at the first lag ($\beta = -0.052$, $p = 0.143$). However, a powerful reversal occurs over a multi-day horizon: Gold returns at lag 2 ($\beta = 0.164$, $p < 0.001$) and lag 3 ($\beta = 0.092$, $p = 0.011$) exert highly significant positive predictive effects on WTI returns. This demonstrates that while immediate cross-market shocks from gold to oil are initially muted or slightly negative, a pronounced positive momentum systematically develops after a two-to-three-day operational lag.

Table 4. Vector Autoregression (VAR(3)) Estimation Results for Gold and WTI Oil Returns

Dependent Variable	Variable	Coefficient	Std. Error	t-statistic	p-value
Gold Return	Const	0.009967	0.034740	0.287	0.774
	L1.Gold_Return	-0.122974	0.031201	-3.941	0.000
	L1.WTI_Oil_Return	0.094971	0.027147	3.498	0.000
	L2.Gold_Return	0.055447	0.031191	1.778	0.075
	L2.WTI_Oil_Return	-0.045003	0.027083	-1.662	0.097

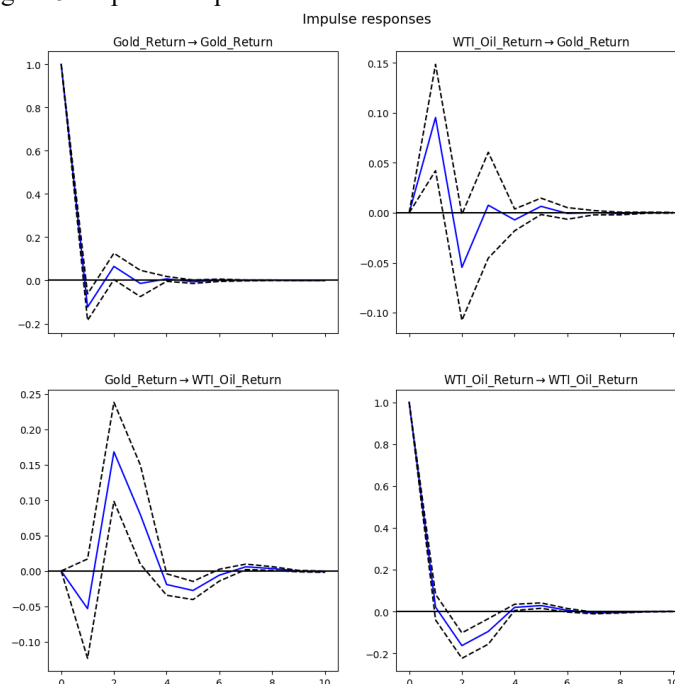
	L3.Gold_Return	-0.017703	0.031222	-0.567	0.571
	L3.WTI_Oil_Return	0.012222	0.027188	0.450	0.653
WTI Oil Return	Const	0.015264	0.039874	0.383	0.702
	L1.Gold_Return	-0.052450	0.035811	-1.465	0.143
	L1.WTI_Oil_Return	0.021511	0.031158	0.690	0.490
	L2.Gold_Return	0.163940	0.035800	4.579	0.000
	L2.WTI_Oil_Return	-0.157474	0.031085	-5.066	0.000
	L3.Gold_Return	0.091664	0.035835	2.558	0.011
	L3.WTI_Oil_Return	-0.105753	0.031205	-3.389	0.001

Note. L1–L3 represent lag periods in the VAR(3) model. Bold values indicate statistical significance at $p < .05$. Coefficients represent estimated effects of lagged returns on current-period returns. Negative coefficients indicate inverse relationships, while positive coefficients indicate direct relationships. Note that while Brent Crude returns are utilized in subsequent impulse response and variance decomposition horizons to check baseline consistency across alternative energy benchmarks, they are omitted from this primary VAR estimation matrix due to the exceptionally weak contemporaneous correlation highlighted in preliminary baseline testing.

3.6 Shock Transmission and Persistence

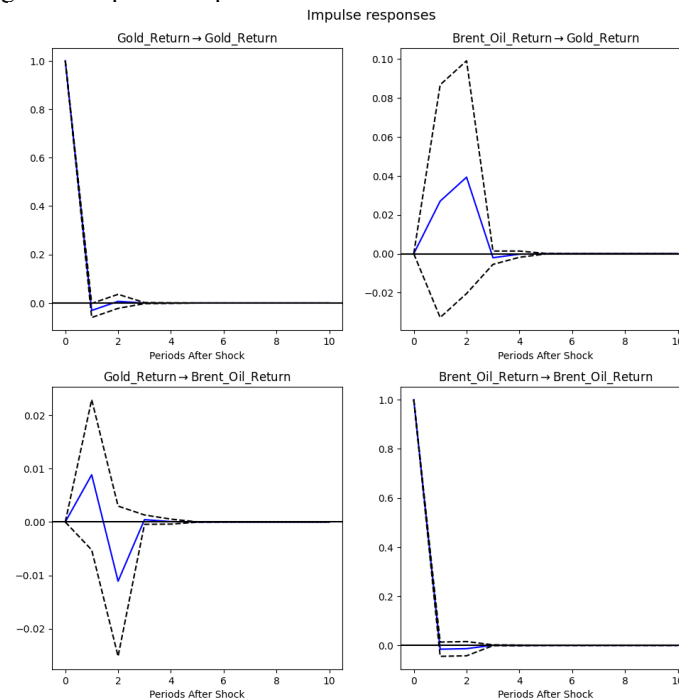
Impulse Response Functions (IRFs) were estimated to evaluate how shocks propagate across markets over time. Results show that each market responds most strongly to shocks originating within itself. These own-market effects decline rapidly and converge toward equilibrium within several forecast periods, suggesting limited persistence. Cross-market responses are present but considerably smaller. Oil shocks generate temporary responses in gold returns, while gold shocks produce comparatively modest adjustments in oil markets. When Brent oil is examined separately, transmission effects appear weaker and dissipate more quickly. The rapid convergence of responses toward zero supports the VAR findings and indicates limited long-run persistence of cross-market shocks. Overall, IRFs indicate that commodity market disturbances are predominantly short-lived and that both markets adjust rapidly following external shocks.

Figure 5. Impulse Response Functions for Gold and WTI Oil Returns



Note. The figure reports impulse response functions estimated from a VAR(3) model using daily logarithmic returns for Gold and WTI oil. Solid lines represent estimated responses following a one-standard-deviation shock, while dashed lines indicate approximate confidence intervals. The horizontal axis represents forecast periods after the shock and the vertical axis represents response magnitude. Responses converging toward zero indicate diminishing shock effects over time.

Figure 6. Impulse Response Functions for Gold and Brent Oil Returns

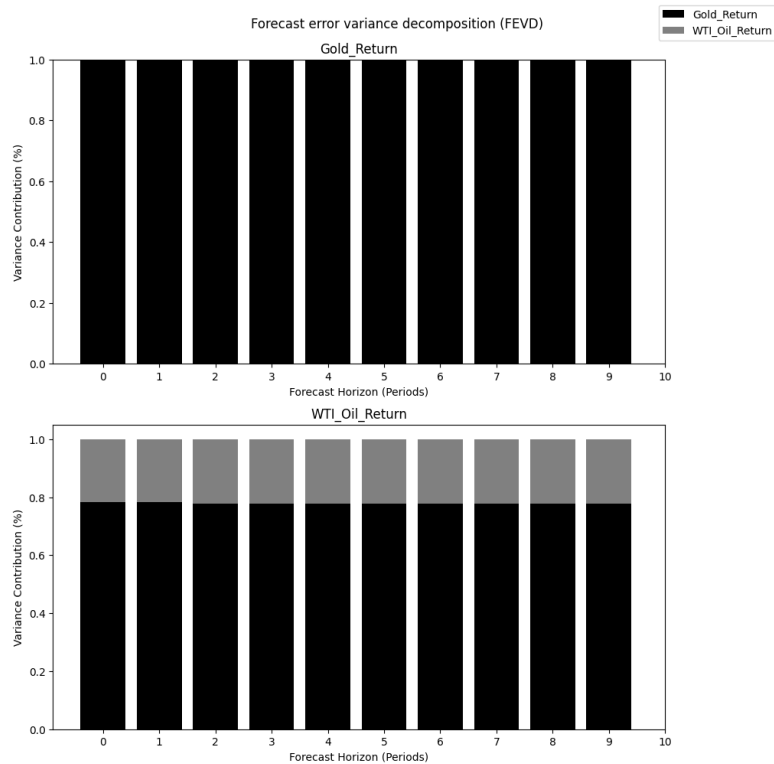


Note. Impulse response functions were estimated using a VAR(3) specification based on daily logarithmic returns. Solid lines represent estimated responses to a one-standard-deviation shock and dashed lines represent confidence intervals. The horizontal axis shows forecast periods after the initial shock and the vertical axis measures response magnitude. Responses converging toward zero indicate diminishing effects of shocks over time.

3.7 Forecast Error Variance Decomposition

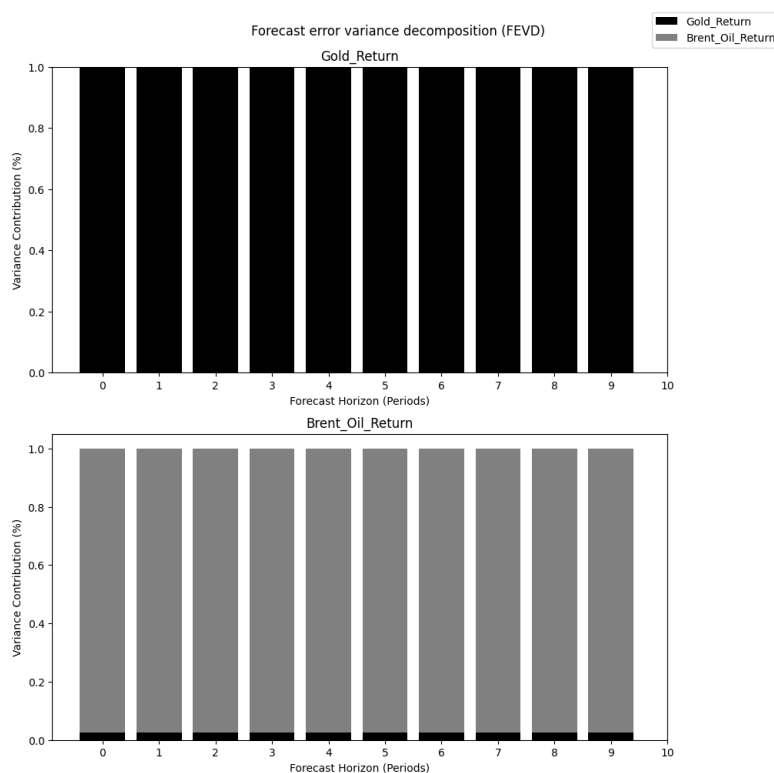
Forecast Error Variance Decomposition (FEVD) was used to determine the proportion of future variability attributable to internal and external shocks. FEVD results indicate that gold returns remain entirely internally driven, with own-market shocks accounting for approximately 100% of their forecast error variance across all horizons. Conversely, WTI returns exhibit a striking susceptibility to external shocks, with gold market disturbances accounting for an estimated 78% of WTI's forecast variance, leaving own-market shocks to explain only the remaining 22% of energy return variance. Variance contributions stabilize relatively quickly, suggesting that the importance of each shock source becomes established early in the adjustment process. These findings indicate asymmetric interdependence across commodity markets, where gold appears comparatively insulated while oil markets demonstrate greater responsiveness to external information.

Figure 7. Forecast Error Variance Decomposition for Gold and WTI Returns



Note. Daily closing prices in USD (2016–2026). Left axis: Gold (SPDR Gold Shares); right axis: Oil (Brent Futures). Scales differ by asset class; movements reflect descriptive historical trends and do not imply direct mathematical parity.

Figure 8. Forecast Error Variance Decomposition for Gold and Brent Returns



Note. Daily logarithmic returns (%) for Gold, WTI Oil, and Brent Oil from 2007 to 2026. The series fluctuate around a stable mean of zero, satisfying preliminary stationarity conditions. The distinct variance profiles highlight the differing risk exposures between precious metals and energy benchmarks, notably the higher extreme-value susceptibility of domestic WTI relative to international Brent crude.

4. Discussion

Collectively, the results suggest that relationships between gold and oil markets are dynamic, asymmetric, and largely short-run in nature. Although visual inspection and correlation analysis reveal periods of co-movement, econometric results indicate that these interactions weaken over time and do not imply persistent long-run dependence. Gold demonstrates characteristics consistent with its role as a defensive asset, while oil remains more sensitive to cyclical and external economic conditions. The evidence further highlights the importance of distinguishing correlation from causation. Observed associations reflect contemporaneous movement rather than direct predictive influence. The significant delayed positive transmission running from lagged Gold returns to WTI crude returns yields distinct macroeconomic implications. Crude oil functions as a primary driver of global industrial production and transport costs; spikes in energy prices typically signal impending inflationary pressures. Because gold operates fundamentally as a structural inflation hedge and safe-haven asset, macro-investors systematically bid up precious metals during early stages of global economic uncertainty or when anticipating inflation.

The subsequent multi-day delayed positive reaction in WTI suggests that early price movements in the gold market function as a leading indicator for broader commodity capital reallocations, explaining the statistical significance of the second-and third-order VAR coefficients. From a portfolio management perspective, these findings suggest that gold may retain diversification benefits despite periods of observed co-movement with oil markets, particularly over longer investment horizons. Limitations of this analysis include reliance on daily data, omission of broader macroeconomic controls, and assumptions embedded within VAR methodology. Nevertheless, the results provide evidence that commodity market interactions are not uniform and that dynamic relationships vary across forecast horizons and market conditions.

5. Conclusion

This study examined the relationship between gold and oil markets using descriptive and multivariate econometric techniques. The findings indicate that although periods of co-movement exist, market interactions are predominantly short-term, delayed, and asymmetric. Gold remains structurally insulated from energy shocks, retaining its independent role as a safe-haven asset, whereas WTI oil returns exhibit a heavy, multi-day delayed dependence on past gold shocks, highlighting gold's capacity to act as a leading macroeconomic indicator for industrial commodity reallocations. Future research may extend this framework by incorporating additional macroeconomic variables, volatility models, or higher-frequency market data to improve understanding of commodity market transmission mechanisms.

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Author Contributions: All authors contributed equally to this work.

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AI and Legal Accountability: Rethinking Responsibility in Algorithmic Decision-Making

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JEL codes: K13; K20; K24.

Abstract: Autonomous artificial intelligence (AI) is reshaping legal doctrine by blurring the lines of agency and accountability. This study asks two intertwined questions: first, how current liability regimes can be recalibrated to address harms caused by self-learning AI; and second, whether recognizing AI as a limited legal subject offers a viable path to meaningful accountability. Drawing on doctrinal analysis, comparative jurisprudence, and philosophical inquiry, the paper examines the EU AI Act (2024/1689), the EU AI Liability Directive, the GDPR, and parallel developments in U.S. and Canadian law. A systematic survey of many peer-reviewed sources and recent case law reveals persistent regulatory gaps: liability is still funneled through human actors, strict-liability models remain scarce, and key terms such as “autonomous” and “high-risk” lack harmonized definitions. The research highlights new frameworks, such as partial legal capacity (Teilrechtsfähigkeit) and the Robotics/AI Legal Entity (RAiLE), that suggest a hybrid model of AI personhood. However, it finds no jurisdiction willing to grant full legal status to AI. Liability chains often break when AI systems go beyond their original programming. This leaves victims under-protected and developers unsure of their risks. This study ends with incremental, adaptive reforms, stranded in distributed agency, clearer constitutional language, and anticipatory governance, which are critical to defend justice and public confidence as intelligent systems turn more profoundly embedded in social and economic life.

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1. Introduction

The rapid embrace of artificial intelligence (AI) into contemporary conceptions of law is changing not only how legal activities are undertaken but also how legal responsibility is conceptualized. Since the 1980s, Artificial Intelligence and Law has transitioned from employing symbolic reasoning and case modeling to advanced machine learning techniques to understand legal texts and emulate human reasoning (Bench-Capon, 2022). As AI systems grow increasingly complex and autonomous, they highlight issues of liability, fairness, transparency, and human oversight. A significant area of current legal debate is around whether AI should be treated as a legal subject. Traditional arguments suggest that legal personhood is dependent on human characteristics, such as sentience or rationality; however, one new argument suggests adopting legal subjectivity for AI because of its growing ability to engage in social life (Wojtczak, 2022). The increased integration of AI systems into human life has generated meaningful policy responses. Notably, UNESCO's Recommendation on the Ethics of Artificial

Intelligence (2021), as well as the European Union's draft Regulation on Artificial Intelligence, highlight meaningful attempts to address the risks associated with AI systems (Neuwirth, 2024).

While these efforts are commendable, multiple gaps remain. Tort law seems to be more flexible than criminal law in covering AI-generated harms, particularly in the absence of identifiable human wrongdoers (Uddin et al., 2024). These regulatory gaps become more visible as AI systems are increasingly embedded in critical domains, intensifying concerns about transparency, fairness, and explainability (Cohen et al., 2023; Graham et al., 2024; Parycek et al., 2024). As AI systems become more opaque, they challenge legal norms that depend on transparency, accountability, and explainability (Greenstein, 2022; Vochozka et al., 2023; Vochozka & Kunju Mol Raj, 2025). Across sectors such as higher education (Makarov et al., 2022), healthcare (Solaiman, 2024), and translation services (Moneus & Sahari, 2024), the rapid adoption of AI has exposed persistent gaps in preparedness and regulatory capacity. These developments reinforce the need for strong explainability standards and auditing mechanisms to ensure accountability in automated decision-making (Sachan & Liu (Lisa), 2024). Judges have expressed uncertainty about the pace of AI integration and the implications of delegating reasoning tasks to opaque algorithmic systems (Martinho, 2025).

These issues not only have ethical dimensions but also structural ones. Researchers are increasingly promoting interdisciplinary approaches by combining information law, human rights constructs, and socio-technical frameworks (Kostenko et al., 2024; Voudouris et al., 2024). Legal equity is an issue here as well, especially in algorithmic decisions where certain attributes, such as race, sex, or age, interact, making it too simple to apply other stakeholder standards. Non-discrimination requires dynamic frameworks to model equity and assess types of unfairness (Lavalle et al., 2022). This debate also requires distinguishing accountability, concerned with oversight, governance duties, and institutional responsibility, from liability, which determines who bears the legal and financial consequences for harm. Existing AI scholarship often blends these concepts, obscuring the different legal functions they serve. The rapid evolution of autonomous and self-learning systems raises foundational questions about how existing doctrines of negligence, product liability, and administrative oversight can adapt to situations where human control is partial or indirect.

Despite the breadth of regulatory and ethical discussions surrounding artificial intelligence, the central doctrinal difficulty addressed in this article is more specific: the instability of liability attribution in highly autonomous AI systems. Existing legal frameworks continue to allocate responsibility through identifiable human actors (developers, deployers, manufacturers, or users). However, when AI systems engage in adaptive, self-learning, or opaque decision-making processes, causal attribution and fault assessment become increasingly difficult. This creates a structural tension between traditional fault-based liability doctrines, grounded in foreseeability, control, and intent, and distributed algorithmic agency. The article, therefore, focuses on the problem of attribution and evidentiary burden in autonomous AI ecosystems, rather than on AI regulation in general. So, this leads to two central research questions:

RQ1: How can existing legal frameworks be adapted to assign responsibility for harms caused by autonomous artificial intelligence systems?

RQ2: Is it conceptually and legally justifiable to attribute agency or personhood to artificial intelligence to establish accountability?

For clarity, this article primarily examines civil liability, particularly tort-based and product liability frameworks, with comparative reference to fault-based doctrines in EU and common law jurisdictions. Criminal liability and administrative sanctions are considered only insofar as they illuminate the broader allocation of responsibility. The central analytical focus remains on private law mechanisms for compensation and risk allocation. This study looks at recent legal developments, theoretical discussions, and sector-specific implementations in an attempt to offer a coherent framework for re-imagining legal responsibility in the age of intelligent machines. By examining these issues through a doctrinal and comparative legal lens, this study seeks to clarify the conceptual gaps in current frameworks and identify the limits of existing liability models when applied to autonomous AI.

2. Literature Review and Theoretical Background (Optional)

2.1 Legal Personhood, Rights, and Identity of AI

Legal scholarship is increasingly considering whether AI systems should be regarded as legal persons. Researchers, such as Mocanu, (2022), Jowitt, (2021), and Laukyte, (2019) , who discuss theoretical notions such as partial legal capacity and noumenal agency, argue that intelligent agents may merit limited legal rights. Dremluga et al., (2019) posit generally applicable legal theories for recognizing humanoid robots as persons having social recognition and compatibility with the system. Novelli et al., (2022) outline an AI personality as a collection of inferential relationships, and Broman & Finckenberg-Broman, (2017) offer the notion of the Robotics/AI Legal Entity (RAiLE©) within international legal systems. Lima et al., (2021) offered an empirical study to suggest how public-based emotion has a significant influence on perceptions of AI-based fault. Kiskis, (2023) develops the case for a non-anthropocentric legal regime for AI consciousness, asserting that rights between humans and machines should be recognized mutually.

2.2 Ethical, Regulatory, and Governance Challenges

The introduction of AI technologies to the legal domain has raised substantial ethical and regulatory issues, from the risks of a black-box model (Dahan et al., 2023; Sachan & Liu (Lisa), 2024) to issues around data privacy in financial regulation (Roussos & Hajduk, 2025), with all scholars suggesting there is a need for specific and targeted legislation addressing the issues of AI. Giraudo et al., (2024), Kattinig et al., (2024), and Unver, (2023) were arguing that AI in law moving forward must be met by targeted legislation, including the EU AI Act, or we risk a disconnect between technical advancement against the legal provisions. Cunningham, (2025) identified the philosophical and legal issues of AI-generated art and how ethical issues plague the sector. Bayer, (2024), and van Hilten et al., (2025) have recommended an ethical framework for journalists and the agri-food sector, respectively, in the context of sector-specific ethical challenges. With the dialogue expanding around AI in other functional areas, Kumar & Suthar, (2024) examined AI-related bias and discrimination in marketing, while Sipior et al., (2024) explored discrimination in human resources recruiting. The integration of ethics and legal education (Balan, 2024; Prakash & Nair, 2024) and the overlap between the ethical nature of AI ethics and the ethical nature of legal ethics (Unver, 2023) appear to represent a significant area of need for reform.

2.3 AI in Legal Practice and Education

Artificial intelligence tools are increasingly changing legal practice and education. Ashley & Goldin, (2011), and El-Farahaty, (2025) demonstrated the educational value of AI when it comes to peer review analytics and corpus-based legal translation. Meanwhile, industry researchers Murphy, (2023), and Palmirani, (2022) used DataLex (Greenleaf et al., 2019; Mowbray et al., 2020) to explore AI in legal drafting and teaching. Hagan, (2024) encouraged community participation in AI tool design, while Zhang & Meng, (2024) writing about how Bayesian models can use statistical evidence to replicate legal reasoning. Terzidou, (2025) discussed how generative AI could interfere with lawyers' duty of confidentiality, and Asif & Palmirani, (2024) explained how integrating natural language processing with symbolic AI could clarify legal text. All of these studies pointed to the importance of digital literacy and awareness of AI applications in legal education.

2.4 Applications of AI in Legal Operations and Decision-Making

AI deployments in judgment summarization (Liu & Lin, 2024), smart contract formulation (Aejas et al., 2025), and document automation (Vayadande et al., 2024) show us its demonstrable capacity to improve the processes and practices of law. Some researchers, such as Ho et al., (2020), provide empirical assessments of strategies for adoption and use for organizations contemporaneous with an advisory body, and others note the concern that AI tools may subtract the emotive-cognitive nuance from AI-augmented court judgments (Contini et al., 2024). Legal AI platforms that leverage Natural Language Processing, rhetorical and semantic tools, and standard legislative formats such as LegalXML (Palmirani et al., 2021) are now paving the way for positive change in the legislative drafting sector. Equally illustrating the dynamic conflict of AI in medical and sports liability (Martín-Noguerol et al., 2024; Orlando, 2022) is the ongoing tension/shared responsibility that requires a legislative structure and framework to adapt.

2.5 Policy Futures, AI Governance, and Societal Implications

Increasingly, with generative AI at the forefront of public and private decision-making, the global policy discussion becomes elevated and urgent. Li et al., (2023), and Cheng & Liu, (2023), among others, advocate for human-centered governance that acknowledges ethical pluralism; Becher & Alarie, (2025) articulate decentralized, participatory AI legal systems such as LexOptima; Okuno & Okuno, (2025) consider the readiness of corporate structures for the integration of AI; Castan, (2024) critiques the definitional drift in EU policymaking related to AI; Al-Dulaimi & Mohammed, (2025), and Giraudo et al., (2024) identify liability shortcomings for public administration and incoherent cross-sectoral regulation; and McLaren & Rowe, (2025) highlight the issue of AI misinformation while advocating for human oversight mechanisms. These scholarly articles identify the need for interdisciplinary, anticipatory governance to mediate the responsible integration of AI in law and society.

The findings from this diverse and rich literature indicate that we require methodological pluralism to examine the intersection of AI and law. Prior works have used a mix of various methodological approaches, including normative legal-philosophical analysis, doctrinal analysis, experimental research, case-study investigation, content analysis, and combined AI-legal system design. These methodological contributions not only confirm the difficulties

associated with regulating AI within a legal context but also highlight the opportunity to connect legal reasoning with various technical tools (e.g., natural language processing, machine learning algorithms, analysis of corpora). Given this interdisciplinary foundation, the methodology of this research will consist of single-based analysis that will utilize qualitative methods of legal analysis and computational methods of qualitative analysis to examine the emerging legal regime for AI through the legal lenses of potential regulatory regimes, institutional practices, and societal norms.

3. Materials and Methods

3.1 Research Design and Doctrinal Method

This study adopts a qualitative doctrinal research design to examine the allocation of liability in the context of autonomous artificial intelligence systems. The primary method consists of statutory interpretation and doctrinal analysis of existing legal instruments governing AI-related harms. The analysis focuses principally on Regulation - EU - 2024/1689 the EU AI Act, the General Data Protection Regulation (GDPR), proposed AI Liability Directive (Secretariat, 2024), and selected national civil liability frameworks within EU and common law jurisdictions (White Paper on Artificial Intelligence). The doctrinal inquiry evaluates how existing private law mechanisms, particularly fault-based tort liability and product liability, allocate responsibility when AI systems generate autonomous or self-learning outputs. Judicial developments, including cases such as *Thaler v. U.S. Copyright Office* (Błaszczuk, 2025), are examined to assess the current judicial stance on AI agency and authorship.

3.2 Comparative Scope

A comparative approach is employed to analyse developments across three legal environments: the European Union, the United States, and Canada. These jurisdictions were selected due to their regulatory prominence in AI governance, the coexistence of civil law and common law traditions, and their active engagement in debates concerning AI accountability. The comparative method enables the identification of cross-jurisdictional consistencies, doctrinal divergences, and regulatory gaps in the treatment of liability attribution for autonomous systems.

3.3 Normative and Conceptual Framework

Beyond black-letter doctrinal interpretation, the study incorporates a normative legal analysis to evaluate the adequacy of current frameworks. The assessment is guided by three analytical criteria: Coherence of liability attribution, Effectiveness in victim compensation, and Preservation of legal certainty for developers and deployers. In addressing the second research question (RQ2), the analysis engages with legal-philosophical theories of agency and personhood, including Gewirth's theory of agency and Kantian conceptions of moral personhood. These frameworks are used to assess whether limited legal subjectivity for AI systems could function as a doctrinal tool for stabilizing accountability, rather than as a metaphysical claim about machine consciousness. Comparisons are also drawn to established legal constructs such as corporate personhood and other forms of non-human legal recognition to evaluate whether similar instrumental mechanisms could be adapted to AI systems.

3.4 Literature Review and Thematic Synthesis

Secondary sources consist of peer-reviewed scholarship on AI governance, legal personhood, algorithmic accountability, and sector-specific AI liability challenges. The literature was systematically reviewed and thematically coded to identify dominant methodological approaches and normative trends (see Table 1). Rather than conducting a quantitative meta-analysis, the review functions as a structured synthesis aimed at situating the doctrinal analysis within broader academic debates.

Table 1. Summary of Recent Literature on Legal AI, Methodologies, and Key Findings

Author(s) and Year	Methodology	Focus Area	Key Findings
Li et al., (2023)	Legal and policy analysis	AI governance	Calls for human-centered legal frameworks to govern generative AI.
W. Li et al., (2025)	Legal-philosophical review	AI-generated creativity	Critiques human-centered legal biases in recognizing machine creativity.
Dahya & Morris, (2019)	Socio-technical analysis	AI design and legal reasoning	Proposes frameworks to align AI design with legal constraints.
Cheng & Liu, (2023)	Ethical-legal discourse	Human-AI relationships	Promotes ethical-legal convergence for responsible AI integration.
Atabekov, (2020)	Legal commentary	AI in legal administration	Highlights need for harmonized international laws on AI agency.
Asif & Palmirani, (2024)	Symbolic AI + NLP annotation	Legal definition mining	Annotated 15,082 EU legal texts to improve AI interpretability in law.
Balan, (2024)	Multidisciplinary analysis	AI in legal education	Addresses equity and digital divide challenges; proposes ethical training.
Bayer, (2024)	Normative-analytical methodology	Generative AI in journalism	Proposes hybrid authorship for accountability in AI-generated content.
van Hilten et al., (2025)	Case-based qualitative method	Ethical AI in agri-food	ELSA Scan helps domain-specific ethical assessment for AI in farming.
Sipior et al., (2024)	Legal-analytical methodology	AI bias in recruitment	Offers employer guidelines to reduce liability in automated hiring.
Murphy, (2023)	Professional community insights	AI in legal practice	Reflects growing legal sector engagement with AI implications.
Laukyte, (2019)	Legal theory analysis	AI legal personhood	Suggests granting AI legal status similar to corporations under certain conditions.
Lima et al., (2021)	Empirical public perception study	AI blame attribution	Finds public often attributes blame to AI despite lack of legal capacity.
Prakash & Nair, (2024)	Curriculum critique	Legal education and AI	Advocates integrating AI ethics and training in law education.
Zhang & Meng, (2024)	Technical proposal	Bayesian deep learning for law	Bayesian deep learning can improve legal reasoning in AI systems.
Hagan, (2024)	Community-oriented legal tech design	Public use of legal AI	Stresses the need to align AI legal tools with community perspectives.

Mowbray et al., (2020)	Legal AI infrastructure case	AI-aided free legal platforms	Presents DataLex as a sustainable AI tool for public legal support.
Roman & Natalia, (2019)	Comparative legal proposal	AI regulation models	Suggests licensing frameworks to manage AI risks like transportation rules.
Jowitt, (2021)	Normative legal-philosophical analysis	AI moral personhood	Argues AI with noumenal agency deserves legal recognition under Kantian ethics.

Note: This table compiles key studies on legal applications of AI, summarizing their methodologies, focus areas, and core insights.

3.5 Limitations

This study is theoretical and interpretative in nature. It does not rely on empirical datasets or statistical modelling. The scope is limited to textual and doctrinal sources within selected jurisdictions and does not attempt to exhaust all global AI regulatory developments. Accordingly, the findings should be interpreted as a conceptual and normative clarification of liability allocation challenges, rather than as empirical validation of AI harm patterns.

4. Results

4.1 Adapting Existing Legal Frameworks for Liability in Autonomous Artificial Intelligence

4.1.1 Interpretation of EU AI Act (2024/1689), Article 16 and Related Provisions

Article 16 of the EU AI Act (2024/1689) establishes a detailed imposition of obligations for AI providers, especially where high-risk systems are placed in the EU market. These obligations include requirements for risk management systems, technical documentation, recording logs, transparency, and human oversight, for example. Providers must also provide a conformity assessment, place the CE marking, and register the system in the EU public database before starting to use the system. The process of establishing traceability, safety, and accountability across the lifecycle of the AI is pertinent through these mechanisms.

However, when the Act is considered in the context of autonomous AI systems, particularly those that learn and adapt in real time, the Act has significant shortcomings. Importantly, the Act does not impose a strict liability regime for harms attributable to such systems. The Act does provide a mechanism of liability through human actors, namely the provider, deployer, importer, and distributor if sale or lease, but leaves open the matter of whether, when AI is acting outside its programming or as it evolves, the human actors could remain liable in instances whereby it is neither expected nor warranted. Therefore, there are interpretive difficulties in establishing liability, particularly when damage arises from an unforeseeable algorithm outcome.

Furthermore, the Act's human-focused regulatory schema may not even fit the challenge of the legal vacuum that distances us from self-sustaining AI behaviour, which invokes questions of causation, foreseeability, and intent in the face of autonomous decision-making. While identifying procedural and compliance obligations within the Act represents a positive development, there remains unarticulated consideration of what substantive, if any, liability

attaches to high autonomy or changes in behaviour caused or induced by machine learning elements of autonomous AI. A significant limitation of Article 16 is that, despite imposing detailed procedural obligations on providers, it does not create a substantive liability regime for harms caused by autonomous or self-learning behaviour. Its obligations remain entirely human-centric, assuming predictable system behaviour and continuous human control. As a result, the Act struggles to address situations in which the system's outputs are not foreseeable or cannot be meaningfully traced to a breach of a human actor's duty.

4.1.2 Comparative Legal Findings: Liability for AI-Caused Harms Across Jurisdictions

A wide-ranging comparison of three AI liability regimes, involving the European Union (EU), the United States (U.S.), and Canada, demonstrates that these jurisdictions are not willing to treat systems of artificial intelligence as liable agents. Instead, in all of these jurisdictions, liability is imposed on human actors- typically the developers, deployers, or users of AI, through existing doctrines of negligence, product liability, and fault.

In the EU, the AI Act (2024/1689) is buttressed by the AI Liability Directive (2022/1340), which presumes causality when claimants can demonstrate a breach of obligations relating to AI. However, like the AI Act, the AI Liability Directive does not create a scheme of strict liability or recognize AI systems as legal persons, so human actors are the focus of liability. In the U.S. law, with its tort principles based on common law, the courts expressly recognize that AI systems are not capable of agency or liability. The courts have addressed accountability related to AI systems through product liability, duty of care, and respondeat superior doctrines. There are ongoing discussions on how to extend these common law doctrines to various states of AI systems that may be acting whimsically and autonomously. It is also notable that the AI Liability Directive proposal was withdrawn by the European Commission in 2024, leaving a regulatory gap in harmonizing burden-of-proof standards and causality presumptions for AI-related harms.

Courts and researchers within Canada typically advocate for fault-based liability frameworks, and new scholarship is providing additional scrutiny on whether AI should be viewed in the same way as corporations as "non-natural persons." However, Canadian law does not have any applicable statutory provisions entitling AI agents to independent liability, and the proposed reforms address the transparency and duty of care of developers. In all three jurisdictions, it appears that there is a consistent trend: AI is not approached as a legal actor with the capacity to accept responsibility. Rather, its liability passes through human intermediaries; a situation that creates ongoing difficulties when AI behaves unexpectedly or operates beyond its explicit design parameters. This opens the door to the possibility of new legal constructs or even hybrid liability frameworks to acknowledge the new complexity of algorithmic decision-making.

Notwithstanding existing legal developments such as the EU AI Act (2024/1689), deep challenges remain in making accountability for AI-system harms operational. The principled legal problems begin with a lack of harmonized legal definitions in essential terms such as "autonomous" and "high-risk" AI. The absence of a shared baseline of definitions creates inconsistency in our understanding, regulations, and enforcement across jurisdictions (Castan, 2024; Palmirani et al., 2021). In addition, Article 22 GDPR, governing decisions based solely on automated processing, remains a critical but underdeveloped safeguard in the context of highly autonomous AI. While it grants individuals the right not to be subjected to fully

automated decisions, the provision presumes meaningful human oversight, which becomes increasingly difficult when systems generate opaque, self-learning outputs. This tension further illustrates the regulatory gap between traditional data-protection principles and the operational realities of modern AI systems.

Secondly, the layered decision-making process in AI ecosystems presents additional areas of legal uncertainty. How liability is assigned becomes extremely vague in systems developed by multiple developers and in hybrid systems developed through collaboration between a human and an AI. AI systems based on a multi-tiered architecture provide a disconnected chain of causation when each layer makes decisions based on other layered training inputs, data from third parties, or through machine-optimized autonomy to enable AI to reach a decision (Giraud et al., 2024; Laukyte, 2019). These issues indicate that, under the current regime of uncertainty surrounding better legal definitions and guidance, existing rules and frameworks could be inadequate to provide justice in high-risk or potentially harmful ecosystems. In this context, it is important to distinguish between accountability, concerned with governance, oversight, and compliance obligations, and liability, which allocates the legal and financial consequences of harm. Current frameworks adequately define accountability duties but remain underdeveloped in establishing consistent liability rules for autonomous behaviour.

4.1.3 Positioning the Analysis vis-à-vis the AI Liability Directive

The proposed AI Liability Directive adopted a procedural approach aimed at facilitating claims under existing fault-based regimes. Its key innovation consisted of introducing disclosure obligations and rebuttable presumptions of causality in cases involving high-risk AI systems. However, the Directive did not establish strict liability for autonomous systems, nor did it fundamentally depart from the human-centric model of liability attribution. Instead, it sought to ease evidentiary burdens while maintaining traditional negligence-based structures. The analysis advanced in this article goes further by questioning whether procedural adjustments alone are sufficient in contexts where algorithmic behaviour may be emergent, self-modifying, or only partially foreseeable. If liability remains entirely dependent on demonstrating human fault, even softened through presumptions, certain forms of distributed algorithmic harm may remain structurally under-compensated. This doctrinal tension motivates the exploration of alternative or hybrid liability configurations.

4.2 Legal Agency and Artificial Intelligence Personhood as a Basis for Accountability

4.2.1 Functional Relevance of AI Personhood to Liability Allocation

The question of AI personhood is not addressed here as a symbolic or philosophical exercise, but as a functional response to attribution gaps in liability law. If responsibility cannot be reliably allocated through existing doctrines of negligence or product liability, one theoretical response is to consider whether limited legal subjectivity could serve as a mechanism for risk pooling, asset segregation, or procedural standing. In this context, proposals such as partial legal capacity (*Teilrechtsfähigkeit*) or the Robotics/AI Legal Entity (RAiLE) should be understood not as metaphysical claims about machine consciousness, but as institutional tools aimed at stabilizing accountability structures. This functional framing distinguishes legal subjectivity from moral agency. While moral responsibility presupposes intentionality and consciousness, legal personhood in corporate contexts has historically served instrumental and

allocative purposes. The key question is, therefore, whether limited, carefully circumscribed legal capacity could enhance victim protection without eroding human accountability.

The question of whether artificial intelligence can attain (or ought to receive) legal personhood continues to be intensely debated. In important jurisdictions, including the European Union, the United States, and Canada, AIs are not, at this time, legally recognized as legal persons. The liability systems in place also continue to place liability on human agents, companies, or legal persons that develop, enable, or use AIs (Laukyte, 2019; Murphy, 2023). Some proposals range from models of *Teilrechtsfähigkeit* (limited/partial legal capacity) and other vaguely defined levels of contributing to a situation in which AI systems could be considered non-human legal subjects in a limited sense, but only in very limited situations. Such models present a means to propose a middle ground between non-recognition and legal personhood, promoting responsibility in very limited situations (Mocanu, 2022; Novelli et al., 2022). However, doctrinal developments in major jurisdictions consistently reject this approach. Courts have repeatedly emphasized that legal personhood is conceptually tied to human intention, agency, and moral responsibility. Without these elements, AI systems cannot satisfy the prerequisites for bearing duties or holding rights.

Many academics use the debates surrounding corporate personhood as a metaphor. Many argue that if corporations can achieve legal personhood with rights and obligations, autonomous AI could similarly achieve legal personhood. However, many others point out that there are notable differences. Opponents warn that granting personhood to AI could weaken human accountability, reduce legal legitimacy, and bring ethical issues that separate responsibility from intentionality or moral agency (Jowitt, 2021; Lima et al., 2021). Recent case law reinforces this position. In *Thaler v. United States Copyright Office* (2023–2024), the court held that authorship, and by implication, legal standing, requires human origin. This jurisprudence demonstrates the unwillingness of courts to extend personhood-like attributes to AI, even in domains where AI output is central.

New concepts like the RAiLE© (Robotic/AI Legal Entity) exhibit hesitant efforts to create legitimacy around robotic personhood. These efforts will mostly be situated within costly regulatory constraints and ethical conditions aimed at preventing risk to society by irresponsible growth that seeks unfettered legal status (Broman & Finckenberg-Broman, 2017).

Further complicating the issue are ethical and philosophical perspectives on granting agency to a system that has no capability of consciousness, indication, or motive. This complicates the discourse because it leads to issues of fairness and legitimacy. The resistance from the public is strong, and most cultures and societies won't acknowledge a right or duty of a non-human entity, especially where sentience or self-awareness determines social status (Hagan, 2024; Kiskis, 2023). These proposals remain theoretical and have not been incorporated into any statutory or judicial framework, reflecting widespread legislative and judicial caution.

In conclusion, some theoretical pathways and frameworks are limited, and the general agreement across legal systems and ethics frameworks is not to support conceptions of full personhood for artificial intelligence. Stories of accountability and responsibility for humans, accounting for the technology, remain the basis of how human societies always decide to approach legislation and ethics. The doctrinal obstacle is clear: legal systems rely on notions of intention, foreseeability, and moral agency, none of which can be meaningfully attributed to current or foreseeable AI systems.

5. Discussion

There is presently no legal framework for holding any AI systems as accountable as autonomous agents. This reflects a deeper doctrinal difficulty: traditional liability frameworks rely on human intention, foreseeability, and control, all of which become unstable when AI systems generate outputs that are not directly attributable to human actors. The review indicates that AI harms may be legally attributed to human actors like developers, deployers, manufacturers, and end-users (rather than being directly attributable to AI systems as autonomous entities) in contemporary legal systems across most jurisdictions (including the European Union, United States, and Canada). There is presently no legal framework for holding any AI systems as accountable as autonomous agents. The imposition of responsibility onto humans is presently supported by the legal principle that legal liability must attach to a moral or cognizant agent capable of intent or negligence, either of which AI, being non-sentient software, is recognized as by existing doctrines.

Nonetheless, the review found that increasing numbers of scholars, policymakers, and legal practitioners regard conventional liability regimes, specifically in highly autonomous, opaque, or self-learning systems. As limited, these systems may operate under conditions that are unpredictable, even to the developer, evoking profound gaps in assigning fault based upon conventional strict liability or fault-based liability models. The gap has chastened heightened enthusiasm related to reform propositions in attempting to delineate accountability within complex AI deployment chains or through renewing the fundamental principles of proximate cause and foreseeability.

The status of AI as a legal person is highly contested. Although theoretical models (e.g., partial legal capacity (Teilrechtsfähigkeit) or legal agents for AI like RAiLE (Robotics/AI Legal Entity) have greater recognition for AI under limited conditions) have been discussed, these models have not made it into legal form. Legal scholars are divided on the normative and practical justification for AI legal standing, and critics have warned that providing legal standing could weaken human responsibility, weaken regulatory protections, and create uncertainty in legal proceedings. All told, while authors are engaging with this topic, legal systems have not offered any official recognition of AI as subjects of law in their own right. The findings in this study contribute to the existing debate by synthesizing doctrinal inconsistencies across jurisdictions and clarifying how definitional gaps, particularly around autonomy, oversight, and causation, shape the limits of current legal remedies. While not proposing a unified model, the analysis identifies the structural weaknesses that any future regulatory solution must address.

AI systems and other digital technologies often easily transcend jurisdictional boundaries, while legal frameworks and institutions don't. The current fragmented situation with national legal and regulatory approaches creates practical problems for both businesses and regulators. Attempts to hold AI to account could be undermined in a vacuum if there isn't some degree of international cooperation, considering that developers, users, and platforms may all be based in different jurisdictions. In this context, it is important to work towards a greater level of convergence in global standards-setting, through the EU or OECD or via international processes in other fora, for the sake of consistency, legal certainty, and fairness. Although policy frameworks continue to evolve, doctrinal analysis remains essential for determining how

accountability and liability should be allocated in systems where human and algorithmic agency intersect.

6. Conclusion

This study has examined the doctrinal instability that arises when traditional liability frameworks confront highly autonomous and self-learning artificial intelligence systems. The analysis focused on two central questions: first, how existing civil liability regimes, particularly fault-based tort and product liability, can adapt to harms generated by autonomous AI; and second, whether attributing legal agency or limited personhood to AI systems provides a viable solution to emerging accountability gaps. The findings demonstrate that contemporary legal frameworks across the European Union, the United States, and Canada remain firmly human-centric. Liability is consistently channelled through developers, deployers, manufacturers, or users. While this approach preserves foundational principles of moral agency and responsibility, it becomes increasingly strained in contexts of distributed algorithmic decision-making, opaque model architectures, and self-modifying systems. In such cases, traditional doctrines grounded in foreseeability, control, and fault encounter structural limitations.

This article argues that procedural reforms alone, such as disclosure duties and rebuttable presumptions of causality, are unlikely to fully resolve these attribution gaps. While such mechanisms represent important progress, they do not fundamentally alter the human-centred architecture of liability allocation. A more coherent response would involve a layered approach: (1) strengthened evidentiary presumptions in complex AI cases; (2) carefully circumscribed strict liability for clearly defined high-risk autonomous systems; and (3) mandatory insurance or risk-pooling mechanisms linked to system deployment. Such a model would preserve human accountability while ensuring effective victim compensation in situations of distributed harm. With respect to AI personhood, the analysis does not support granting full legal status to artificial intelligence systems. Existing doctrines of legal subjectivity remain closely tied to concepts of intention, moral agency, and normative responsibility, attributes not meaningfully attributable to current AI systems. However, the exploration of partial legal capacity or instrumental legal constructs is not merely speculative. It reveals the pressure that autonomous systems exert on conventional attribution models and highlights the need for institutional tools capable of stabilizing liability allocation without eroding human responsibility.

The broader regulatory landscape remains fragmented, marked by definitional inconsistencies, divergent national approaches, and unresolved tensions between innovation and accountability. Overregulation risks suppressing technological development, while under-regulation may produce legal uncertainty and insufficient protection for affected individuals. The challenge is therefore not whether to regulate, but how to recalibrate liability doctrines in a manner that remains coherent, proportionate, and adaptable to technological evolution. Ultimately, the contribution of this study lies in clarifying the structural doctrinal tensions at the intersection of autonomy and accountability. Rather than advocating radical legal personhood for AI, the analysis supports a principled recalibration of human-centred liability frameworks, reinforced by targeted strict liability mechanisms and institutional risk-sharing models. Future reforms must reconcile technological autonomy with foundational legal values, ensuring that accountability remains intelligible, enforceable, and just, even as artificial intelligence systems evolve beyond predictable human oversight.

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Gold versus Bitcoin: A Comparative Analysis of Risk, Return, and Risk-Adjusted Performance

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Abstract: This study compares the investment performance and risk characteristics of gold and Bitcoin over a five-year period. Daily historical price data for Gold futures (GC=F) and Bitcoin (BTC-USD) were obtained from Yahoo Finance and analyzed using a quantitative approach. Investment performance was evaluated using Compound Annual Growth Rate (CAGR), while risk was assessed through daily volatility, the Sharpe ratio, and maximum drawdown. The results show that gold achieved a higher CAGR of 19.13%, compared with 11.31% for Bitcoin. Gold also demonstrated lower daily volatility (0.0115 versus 0.0282), a higher annualized Sharpe ratio (1.00 versus 0.37), and a substantially smaller maximum drawdown (-20.43% versus -76.63%). These findings indicate that gold provided a more favorable risk-return profile during the period examined. However, the results are specific to the selected observation period and should not be interpreted as evidence of permanent superiority. The study highlights the importance of considering both return and risk when comparing traditional and digital assets.

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1. Introduction

Gold has traditionally been considered one of the most important assets for preserving wealth and reducing investment risk, particularly during periods of economic and financial uncertainty. Its long history as a store of value, relatively stable market structure, and role in portfolio diversification have made it an important asset for both individual and institutional investors. The emergence of Bitcoin has, however, introduced a new alternative. Since its introduction as a decentralised digital currency, Bitcoin has developed into a major financial asset and is frequently described as “digital gold” because of its limited supply and independence from traditional monetary systems. As a result, whether Bitcoin can provide investment benefits comparable to, or greater than, those of gold has become an important question in financial research.

Gold and Bitcoin nevertheless have very different risk and return characteristics. Gold is generally associated with stability and safe-haven behaviour, whereas Bitcoin has experienced substantial price increases together with periods of extreme volatility and large losses. Existing research generally supports the defensive characteristics of gold but provides less consistent

evidence for Bitcoin. Kumar & Padakandla, (2022), for example, found that gold demonstrated relatively consistent safe-haven properties during the COVID-19 period, while Bitcoin produced mixed results. Dutta et al., (2020) similarly found gold to be a safe haven for crude-oil markets, whereas Bitcoin mainly served as a diversifier. Fabris & Ješić, (2023) confirmed safe-haven properties for gold in European markets but rejected the same hypothesis for Bitcoin. Let & Siemaszkiewicz, (2020) also found gold to be a safe haven during periods of market stress, while the performance of Bitcoin depended more strongly on the investment horizon.

However, Bitcoin should not simply be regarded as an ineffective alternative to gold. Its investment role appears to change considerably according to market conditions. Bahloul et al., (2023) found that Bitcoin provided strong hedging properties for some markets during the COVID-19 pandemic. Su et al., (2026) showed that Bitcoin exhibited safe-haven characteristics during COVID-19 and at longer horizons during the Russia–Ukraine war. Hoque et al., (2023) further demonstrated that the behaviour of both gold and Bitcoin changes between short- and long-term horizons. Cheng et al., (2025) also found that the hedging properties of gold and Bitcoin vary across financial assets and market conditions. These findings suggest that the relative attractiveness of the two assets cannot be evaluated independently of the period and market environment being examined.

Recent financial crises have further increased interest in comparing these assets. Ustaoglu, (2023) found that gold generally provided better hedging and more stable diversification benefits than Bitcoin during the Russia–Ukraine war. Manzli & Jeribi, (2024) similarly reported that gold was a stronger safe haven than Bitcoin during major crises, particularly the Russia–Ukraine war and the Silicon Valley Bank collapse. Manzli & Jeribi, (2024a) found that gold also outperformed Bitcoin as a diversifier and safe haven against commodities during crisis periods. Evidence from BRICS Plus economies presented by Belguith et al., (2025) further indicates that gold provides more consistent protection during market downturns, although Bitcoin can offer safe-haven benefits in particular countries.

Another important issue is the increasing connection of Bitcoin and gold with other financial markets. Gkillas et al., (2022) identified spillovers among Bitcoin, gold, and crude oil markets, demonstrating that relationships between these assets can affect investment risk. Zhang et al., (2022) showed that COVID-19-related news produced return and volatility spillovers in oil, gold, and Bitcoin markets, with Bitcoin playing an important role in risk transmission. Zhu et al., (2022) also demonstrated that gold and Bitcoin respond differently to pandemic-related news sentiment. Zeng et al., (2023) identified changing relationships between gold, Bitcoin, and Asian equity markets following COVID-19, while Shaik et al., (2024) showed that volatility connectedness between gold, Bitcoin, equities, bonds, oil, and geopolitical risk changed during COVID-19 and the Russia–Ukraine war.

Other studies have examined these assets from portfolio, forecasting, and market-efficiency perspectives. S. Kumar, (2024) found changes in the market efficiency of both gold and Bitcoin during COVID-19. Li et al., (2022), Xie et al., (2023), Xue et al., (2022) examined investment and trading strategies involving gold and Bitcoin and demonstrated the importance of their different price and volatility characteristics for portfolio decisions. X. Su & Li, (2020) identified time-varying sentiment spillovers between Bitcoin, gold, and oil, while Badshah et al., (2023) found that the COVID-19 pandemic increased volatility in both gold and Bitcoin.

More recent evidence continues to demonstrate that the relationship is complex. Terraza et al., (2024) found that Bitcoin provided diversification opportunities during COVID-19, while Joo & Park, (2024) showed that gold can provide hedging benefits against Bitcoin. Wang et al., (2024) highlighted the importance of gold as a stabilising asset under bearish market conditions, whereas Choudhary et al., (2024) demonstrated increasing integration between Bitcoin and conventional financial markets. Khan & Faryal, (2025) found negative relationships between Bitcoin and gold in some periods and confirmed the comparatively stable hedging role of gold. Gokgoz et al., (2025) also reported that gold offered better hedging effectiveness than Bitcoin against blue and green financial assets.

The literature therefore provides no single conclusion regarding the superiority of gold or Bitcoin. Gold generally appears to provide greater stability and more consistent safe-haven properties, while Bitcoin can provide high returns, diversification benefits, and hedging opportunities under particular market conditions. The effectiveness of both assets depends on the selected period, market conditions, investment horizon, and measure of risk. Even gold's traditional role should not be treated as unconditional. For example, Ergul & Karakas, (2024) find only partial evidence that gold acts as an inflation hedge, while finding no statistically significant relationship between Bitcoin and gold prices in their analysis.

Despite the growing literature, many studies concentrate on safe-haven properties, correlations, spillovers, or asset behaviour during individual crises. A simpler but important question remains relevant for investors: when gold and Bitcoin are evaluated over the same investment period, which asset provides the better balance between return and risk? Comparing returns alone may be misleading because an asset generating high returns may also expose investors to substantially greater volatility and losses. A meaningful comparison should therefore consider both investment performance and the amount of risk required to achieve that performance.

Accordingly, this study provides a direct quantitative comparison of Gold futures (GC=F) and Bitcoin (BTC-USD) over a five-year period. Investment performance is evaluated using Compound Annual Growth Rate (CAGR), while risk is assessed through daily return volatility, the Sharpe ratio, and maximum drawdown. These measures allow the two assets to be compared from both return and risk perspectives. The study therefore addresses two main research questions: (1) Which asset provides superior annualised returns over the five-year period? and (2) Which asset provides a more favourable risk and risk-adjusted performance profile? By addressing these questions within a common analytical framework, the study provides straightforward empirical evidence that can support investment and portfolio-allocation decisions.

2. Materials and Methods

2.1 Data

This study employs daily historical price data for two major investment assets: gold and Bitcoin. Gold is represented by the continuous gold futures contract (GC=F), while Bitcoin is represented by its US dollar spot price (BTC-USD). The data were obtained from Yahoo Finance using the Python yfinance library. The analysis covers a five-year observation period, allowing both assets to be evaluated over the same investment horizon. Daily closing prices are used as the basis for calculating returns and risk measures. An important difference between

the two markets is their trading frequency. Gold futures are primarily traded on weekdays during established market hours, whereas Bitcoin trades continuously, 24 hours a day and seven days a week. To improve comparability between the two series, the analysis restricts observations to weekday closing prices. Missing observations are handled using forward-fill imputation. This procedure creates comparable daily series, although excluding weekend Bitcoin observations may slightly underestimate its measured volatility. The study follows a descriptive quantitative research design and focuses on the historical risk–return characteristics of the two assets rather than forecasting future prices. Four indicators are used: Compound Annual Growth Rate (CAGR), volatility, Sharpe ratio, and maximum drawdown (MDD). CAGR measures long-term annualised performance, while the remaining indicators capture different dimensions of investment risk and risk-adjusted performance.

2.2 Return Measurement

The annualised performance of gold and Bitcoin is evaluated using the Compound Annual Growth Rate (CAGR). CAGR represents the constant annual rate at which an investment would have grown from its initial value to its final value over the observation period and is calculated as:

$$CAGR = \left(\frac{V_T}{V_0} \right)^{1/n} - 1 \quad (1)$$

where V_T represents the asset value at the end of the observation period, V_0 represents its initial value, and n denotes the number of years. CAGR is particularly useful for comparing assets because it incorporates compounding and provides a standardised annual measure despite differences in their absolute price levels.

2.3 Daily Returns and Volatility

Daily log returns are calculated from consecutive closing prices as:

$$r_t = \ln \left(\frac{P_t}{P_{t-1}} \right) \quad (2)$$

where P_t and P_{t-1} represent the closing prices at time t and $t - 1$, respectively. The use of returns rather than price levels enables a more meaningful comparison between gold and Bitcoin despite their substantially different price scales. Investment risk is first evaluated using the standard deviation of daily returns:

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{t=1}^N (r_t - \bar{r})^2} \quad (3)$$

where r_t denotes the daily return, $\bar{r}$ is the mean daily return, and N represents the number of observations. A higher standard deviation indicates greater price variability and therefore

greater volatility. This approach is consistent with the treatment of volatility as a measure of investment risk within the portfolio framework of Markowitz, (1952).

2.4 Risk-Adjusted Performance

To compare the return generated relative to the risk undertaken, the study employs the Sharpe ratio (Sharpe, 1966, 1994). It is expressed as:

$$SR = \frac{R_p - R_f}{\sigma_p} \quad (4)$$

where R_p represents the return of the asset, R_f is the risk-free rate, and σ_p represents the standard deviation of returns. A higher Sharpe ratio indicates that an asset generates a greater return relative to the level of risk assumed. Following the original analytical design, the risk-free rate is assumed to be 0%. The daily Sharpe ratio is annualised using 252 trading days. Accordingly, the annualised measure can be represented as:

$$SR_{annual} = \frac{\bar{r}}{\sigma_r} \sqrt{252} \quad (5)$$

where $\bar{r}$ and σ_r denote the mean and standard deviation of daily returns, respectively. The zero risk-free-rate assumption simplifies the comparison but represents a limitation because actual risk-free interest rates varied during the observation period.

2.5 Maximum Drawdown

The analysis further incorporates Maximum Drawdown (MDD) to capture downside risk. Unlike volatility, which measures the overall dispersion of returns, MDD identifies the largest observed decline from a previous price peak to a subsequent trough:

$$MDD = \min_t \left(\frac{P_t - P_t^{peak}}{P_t^{peak}} \right) \times 100 \quad (6)$$

where P_t^{peak} represents the highest asset value reached before the subsequent decline. A more negative MDD indicates a greater historical capital loss and therefore higher downside exposure. MDD complements volatility and the Sharpe ratio because it directly captures the severity of losses that an investor could have experienced during the observation period.

2.6 Analytical Procedure

All calculations are performed using Python, with pandas and NumPy employed for data processing and numerical calculations. After retrieving the daily prices, the series are cleaned and aligned, daily returns are calculated, and the four performance indicators are estimated separately for gold and Bitcoin. The results are then compared directly to determine which asset generated the stronger annualised return and which exhibited the more favourable risk and risk-adjusted performance profile. The methodology is intentionally transparent and descriptive. It

does not employ forecasting models or formal hypothesis testing; instead, it provides a consistent framework for comparing the historical investment characteristics of gold and Bitcoin over the selected five-year period. This design also means that the findings should be interpreted as period-specific rather than universal, particularly because Bitcoin's performance measures can change substantially depending on the selected start and end dates.

3. Results

This section presents the empirical comparison of gold and Bitcoin over the five-year observation period. The analysis focuses on four dimensions: annualised return, daily volatility, risk-adjusted performance, and maximum drawdown. The results are reported in Table 1: Comparative Performance and Risk Metrics for Gold and Bitcoin, while the graphical analysis is presented in Figure 1: Cumulative Returns of Gold and Bitcoin over the Five Years and Figure 2: Distribution of Daily Returns for Gold and Bitcoin.

3.1 Return Performance

The results indicate a clear difference in the annualised performance of the two assets. As reported in Table 1: Comparative Performance and Risk Metrics for Gold and Bitcoin, gold recorded a CAGR of approximately 19.13%, compared with 11.31% for Bitcoin. Thus, over the specific five-year period examined, gold generated the higher annualised return.

Table 1. Comparative Performance and Risk Metrics for Gold and Bitcoin

Performance/Risk Measure	Gold (GC=F)	Bitcoin (BTC-USD)
CAGR	19.13%	11.31%
Daily Volatility	0.0115	0.0282
Annualised Sharpe Ratio	1.00	0.37
Maximum Drawdown	-20.43%	-76.63%

Note: CAGR = Compound Annual Growth Rate. The Sharpe ratio is calculated using a 0% risk-free rate.

However, interpret the performance difference within the specific observation period. Bitcoin's performance is particularly sensitive to the choice of starting and ending dates because the period includes substantial market fluctuations, including the severe decline associated with its 2022 bear market. The original analysis therefore recognises that the relative performance identified here should not be interpreted as evidence that gold will systematically outperform Bitcoin across all investment periods.

This difference is also evident in Figure 1: Cumulative Returns of Gold and Bitcoin over the Five Years. The cumulative-return trajectories show that gold followed a comparatively more stable upward path with moderate corrections, whereas Bitcoin experienced much larger fluctuations, including strong upward movements followed by substantial declines.



Figure 1. Cumulative Returns of Gold and Bitcoin over the Five years

3.2 Volatility

The risk analysis reveals an even greater difference between the two assets. As shown in Table 1, the standard deviation of daily returns is 0.0115 for gold and 0.0282 for Bitcoin. Bitcoin's daily volatility is therefore approximately 2.45 times higher than that of gold. This result indicates substantially greater day-to-day price uncertainty for Bitcoin. While gold's daily returns fluctuate by approximately 1.15% relative to their mean, the corresponding value for Bitcoin is approximately 2.82%. Investors holding Bitcoin during the observation period were therefore exposed to considerably larger short-term price movements.

The difference is illustrated in Figure 2: Distribution of Daily Returns for Gold and Bitcoin. Bitcoin's return distribution is considerably wider and exhibits heavier tails than that of gold, reflecting the greater occurrence of extreme positive and negative daily movements. Gold's returns, in comparison, are more concentrated around the centre of the distribution.

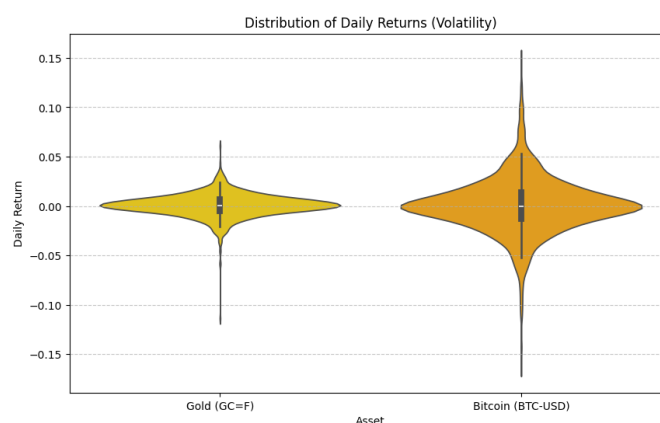


Figure 2. Distribution of Daily Returns for Gold and Bitcoin

3.3 Risk-Adjusted Performance

The Sharpe ratio provides further evidence of differences in the risk-return profiles of the two assets. Gold achieved an annualised Sharpe ratio of 1.00, compared with only 0.37 for Bitcoin. Gold therefore generated approximately 2.7 times more return per unit of risk during the observation period. The higher Sharpe ratio suggests that gold provided a substantially more favourable balance between return and volatility. Bitcoin generated a positive return but

required investors to accept much greater variability in daily returns. Importantly, this finding relates specifically to the five years examined and does not imply that Bitcoin always produces weaker risk-adjusted performance. Its Sharpe ratio can vary considerably across different market cycles.

3.4 Maximum Drawdown

The biggest difference in downside risk is observed in maximum drawdown. Bitcoin recorded a maximum drawdown of -76.63% , compared with -20.43% for gold. Bitcoin's maximum loss from a previous peak was therefore approximately 3.75 times greater than that experienced by gold. The magnitude of Bitcoin's drawdown demonstrates the substantial downside risk associated with the asset. An investor exposed from a local Bitcoin peak to the subsequent trough could have experienced a loss exceeding three-quarters of the investment's value before recovery. Gold also experienced periods of decline, but its maximum drawdown was considerably smaller.

Taken together, the results consistently favour gold within the selected five-year period. Gold generated a higher CAGR (19.13% versus 11.31%), exhibited lower daily volatility (0.0115 versus 0.0282), achieved a higher Sharpe ratio (1.00 versus 0.37), and experienced a substantially smaller maximum drawdown (-20.43% versus -76.63%). Therefore, the findings answer both research questions consistently: gold generated the higher annualised return and exhibited the more favourable risk profile during the period examined. Nevertheless, these findings remain specific to the selected observation window, particularly given Bitcoin's sensitivity to market cycles and start/end-date selection.

4. Discussion

The findings provide a clear comparison between gold and Bitcoin in terms of return, volatility, risk-adjusted performance, and downside risk. Overall, gold performed more favourably across all four indicators during the five-year period examined. Gold recorded a higher CAGR of 19.13% , compared with 11.31% for Bitcoin, while also exhibiting lower daily volatility, a higher Sharpe ratio, and a substantially smaller maximum drawdown. These results suggest that, within the selected period, the higher volatility associated with Bitcoin was not compensated by superior returns.

The return results are particularly interesting because Bitcoin is often associated with high growth potential. However, the findings show that its performance depends strongly on the period under consideration. The five-year observation window includes substantial fluctuations in the Bitcoin market, including the 2022 bear market, when Bitcoin experienced a severe decline. Gold followed a comparatively more stable trajectory during the same period. Therefore, the results demonstrate the importance of considering market cycles when comparing the long-term performance of traditional and digital assets.

The findings are broadly consistent with previous studies that identify gold as the more stable safe-haven and hedging asset. Kumar and Padakandla (2022) found that gold consistently demonstrated safe-haven characteristics across most of the markets examined, while Bitcoin produced mixed results. Similarly, Dutta et al. (2020) identified gold as a safe haven for crude-oil markets during COVID-19, whereas Bitcoin primarily acted as a diversifier. Fabris and Ješić (2023) also confirmed the safe-haven role of gold for European equity markets but rejected the

same hypothesis for Bitcoin. These studies support the present finding that gold provides a more stable risk-return profile than Bitcoin.

The volatility results provide further evidence of the substantial difference between the two assets. Bitcoin's daily volatility of 0.0282 was approximately 2.45 times greater than gold's 0.0115. The wider distribution of Bitcoin's daily returns shown in Figure 2: Distribution of Daily Returns for Gold and Bitcoin also reflects its greater exposure to extreme price movements. This finding is consistent with Badshah et al. (2023), who documented substantial volatility in both Bitcoin and gold and showed that their dynamics were affected by the COVID-19 crisis. Gkillas et al. (2022) also emphasised the importance of volatility and higher-order risk relationships between Bitcoin, gold, and other financial markets.

The Sharpe ratio provides an important additional perspective because return alone does not indicate whether investors were adequately compensated for the risk they assumed. As reported in Table 1: Comparative Performance and Risk Metrics for Gold and Bitcoin, gold achieved a Sharpe ratio of 1.00, compared with 0.37 for Bitcoin. This indicates that gold generated substantially greater return relative to its level of volatility during the observation period. The result strengthens the argument that investment performance should not be evaluated only through price appreciation. An asset can generate positive returns while still providing relatively weak risk-adjusted performance when those returns are accompanied by substantial volatility.

Maximum drawdown provides an even clearer indication of the difference in downside risk. Bitcoin experienced a maximum drawdown of -76.63% , whereas gold's maximum drawdown was -20.43% . This difference is economically important because large drawdowns can expose investors to substantial losses even when an asset ultimately generates positive long-term returns. The result is consistent with Ustaoglu (2023), who found that gold generally provided better hedging and more stable diversification benefits than Bitcoin during the Russia–Ukraine war. Manzli and Jeribi (2024b) similarly identified gold as the more prominent safe-haven asset during major periods of financial stress.

Nevertheless, the results should not be interpreted as evidence that Bitcoin has no diversification or safe-haven value. Previous research demonstrates that its role varies considerably across markets and periods. Bahloul et al. (2023), for example, found that Bitcoin provided strong hedging properties in some markets during COVID-19, while Su et al. (2026) identified safe-haven characteristics for Bitcoin at different time horizons and during different crisis periods. Belguith et al. (2025) similarly found that Bitcoin demonstrated safe-haven characteristics for certain BRICS Plus markets, although gold generally provided more consistent protection. This mixed evidence suggests that Bitcoin's investment characteristics are more dependent on market conditions than those of gold.

The findings therefore have practical implications for portfolio decisions. During the period analysed, gold offered a combination of stronger annualised performance, lower volatility, higher risk-adjusted returns, and substantially lower downside exposure. Bitcoin, in contrast, displayed considerably greater fluctuations and drawdown risk. However, these results do not imply that one asset is universally superior to the other. The original analysis itself recognises that Bitcoin's CAGR and risk measures can change substantially when different five-year windows are selected. The comparison should therefore be interpreted as evidence for the specific market period examined rather than as a permanent ranking of the two assets.

Overall, the findings support the broader literature suggesting that gold remains the more stable investment and risk-management asset, while Bitcoin offers a different risk-return profile whose attractiveness is more sensitive to market cycles and investor risk tolerance. The study also demonstrates why return, volatility, risk-adjusted performance, and downside risk should be considered jointly when comparing traditional and digital assets. Future research could strengthen these findings by applying rolling-window analysis, additional downside-risk measures, and portfolio optimisation techniques to determine whether the relative advantages of gold and Bitcoin remain consistent across different market conditions.

5. Conclusion

This study compared the investment performance and risk characteristics of gold and Bitcoin over a five-year period using four key financial measures: Compound Annual Growth Rate (CAGR), daily volatility, the Sharpe ratio, and maximum drawdown. The results demonstrate clear differences between the two assets in both return and risk. Gold recorded a CAGR of 19.13%, compared with 11.31% for Bitcoin, indicating stronger annualised performance during the period examined. The differences were even more pronounced in terms of risk. Gold recorded daily volatility of 0.0115, compared with 0.0282 for Bitcoin, showing that Bitcoin was approximately 2.45 times more volatile. Gold also achieved a higher annualised Sharpe ratio of 1.00, compared with 0.37 for Bitcoin, indicating better risk-adjusted performance. Furthermore, Bitcoin experienced a maximum drawdown of -76.63% , substantially greater than the -20.43% recorded for gold. Taken together, these findings show that gold provided both higher annualised returns and a more favourable risk profile during the selected observation period.

The findings also highlight the importance of evaluating investment performance beyond returns alone. Although Bitcoin is commonly associated with substantial growth potential, its higher volatility and severe drawdowns can significantly increase investment risk. Gold, in contrast, demonstrated greater stability and generated stronger returns relative to the level of risk undertaken. These findings are broadly consistent with previous research showing that gold tends to provide more consistent safe-haven and hedging characteristics, whereas the role of Bitcoin varies considerably across market conditions and investment horizons. Nevertheless, the results should be interpreted with caution. The comparison is based on a specific five-year period, and Bitcoin's performance is particularly sensitive to the choice of starting and ending dates. The analysis also assumes a zero risk-free rate and does not account for transaction costs, taxation, liquidity constraints, or other factors that may influence actual investment performance. Therefore, the findings should not be interpreted as evidence that gold will always outperform Bitcoin.

Overall, the study concludes that gold provided a superior risk–return profile relative to Bitcoin during the five years examined. At the same time, Bitcoin remains a distinct alternative asset whose performance and diversification benefits may vary considerably across market cycles. Future research could extend the analysis by considering different observation periods, rolling-window estimates, additional risk measures such as Value-at-Risk and the Sortino ratio, and portfolios combining gold and Bitcoin. Such extensions would provide a more comprehensive understanding of the changing role of traditional and digital assets in investment portfolios.

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Use of social networks in selected commercial insurance companies in Slovakia

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Abstract: The presented scientific article deals in detail with the issue of strategic online networks with a specific focus on the analysis and evaluation of the use of social media in the environment of five selected commercial insurance companies operating on the Slovak insurance market. In the current technologically advanced and modern world, social networks play an irreplaceable role in the everyday lives of individuals, representing a key means of communication, sharing knowledge, information and visual content with a mass audience. The main objective of the article is to examine the effectiveness of digital activities of these institutions in the context of their business plans, which define strategies for the acquisition and retention of clients in the online space. The practical part of the study is based on our own quantitative survey conducted on a sample of 500 respondents, which we consider statistically relevant and sufficient given the set goals. Advanced statistical tools were used to compare the implementation of marketing activities and to analyze the relationships between variables in more depth, namely the calculation of gamma coefficients and correspondence analysis. These methods allowed us to identify key connections between the presentation of insurance companies and the perception of their brand by consumers. The article then evaluates how potential customers currently reflect the activities of insurance companies on social networks and to what extent these interactions determine their final decision-making when choosing a specific insurance product or provider. In the final part, the author synthesizes the acquired knowledge and formulates targeted recommendations for the management of insurance entities. These proposals are aimed at optimizing online communication strategies so that they better meet the dynamic needs of the modern market and increase the competitiveness of insurance companies in the digital ecosystem.

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1. Introduction

Social networks in today's advanced and modern world play an increasingly vital role in our everyday lives, transforming not only how individuals communicate but also how corporate institutions operate. These digital platforms serve as dynamic spaces through which we can instantly connect with a large number of people, share diverse information, knowledge, and multimedia content, such as images and videos. This pervasive nature points to their extensive use not only in personal everyday life but also in working life, business, and corporate communication. It is through social networks that continuous, real-time contact with people in the digital environment occurs. Consequently, commercial insurance companies have recognized this shift and increasingly utilize social networks to communicate not only with their existing clients but also with the wider public and potential consumers.

The financial services sector, and commercial insurance in particular, faces unique challenges in the modern marketplace. Unlike tangible goods, insurance products are inherently abstract

and complex, and their value is often realized only in the future when an unexpected event occurs. Because of this intangibility, building and maintaining consumer trust is the cornerstone of any successful insurance business. Historically, this trust was built through personal contact on physical branches or via insurance agents. Today, however, consumer behavior is shifting rapidly. Modern clients expect immediate access to information, transparency, and the ability to interact with their financial institution from the comfort of their homes. Social media platforms such as Facebook, Instagram, or YouTube offer insurance companies a unique opportunity to bridge this gap. By presenting an accessible corporate identity and engaging in direct dialogue, these institutions can humanize their brand, demystify complex terms, and respond effectively to the needs of a digitally active audience.

However, simply operating a profile on social networks does not automatically guarantee marketing or business success. Insurers must strategically manage these channels to ensure they genuinely support their long-term corporate goals. There is a continuous need to assess whether the energy and capital invested in online communication translate into stronger customer relationships or higher brand visibility. Furthermore, because different generations use digital technologies with varying intensity, insurance companies must understand how demographic factors, such as age, influence how often and in what manner users interact with their corporate profiles. Without a deep understanding of these consumer patterns, digital marketing efforts risk becoming ineffective and rigid.

We will deal with this complex digital phenomenon in this paper, the essence of which is to provide a comprehensive, comparative analysis of the current state of digital marketing in the insurance sector. The main objective of this article is to examine and evaluate the effectiveness of the digital activities of five selected commercial insurance companies on the Slovak market in the context of their business plans, which define strategies for the acquisition and retention of clients in the online space. To achieve a holistic perspective, the investigation focuses on comparing corporate subscriber channels on social networks while simultaneously evaluating the use of these platforms from the perspective of the users themselves. Additionally, the paper investigates the statistical dependencies between the demographic profile of respondents and the frequency of their interactions with insurance brands.

Structurally, the paper is organized as follows: Section 2 establishes the theoretical framework through a comprehensive literature review; Section 3 delineates the research methodology and data collection instruments; Section 4 presents the empirical results and correspondence analysis; and Section 5 delivers the concluding discussion with practical implications for the insurance market.

2. Literature Review and Theoretical Background (Optional)

In the current dynamic market environment, marketing communication is undergoing a radical transformation, with traditional marketing mix concepts giving way to interactive strategies oriented towards digital ecosystems (Mazurek et al., 2022). As a result of this development, social networks are no longer just an additional communication tool, but are becoming an integral part of strategic business plans that define modern approaches to the acquisition and retention of a client portfolio (Kamboj et al., 2024). In the service sector, this success is closely linked to the ability to flexibly respond to the changing preferences of digital consumers, which requires a permanent and consistent brand presence in the online space (Ananda et al., 2023).

Following this trend, Dwivedi et al. (2023) emphasize that the implementation of advanced digital platforms allows companies to optimize the allocation of marketing capital and achieve significantly higher cost-effectiveness in reaching target groups. Furthermore, content marketing implemented through social media contributes to the systematic shaping of a positive customer experience and strengthening overall market competitiveness (Chintagunta et al., 2024). Mirroring these findings is the warning formulated by Verhoef et al. (2025), according to which companies that fail to effectively integrate these modern communication channels into their long-term corporate strategy face a fatal risk of losing market share to more digitally advanced competitors.

This need for digital adaptation is even more pronounced when applying marketing tools in the specific environment of commercial insurance. As Anand & Mishra (2022) point out, insurance products exhibit a high degree of specificity, as they are inherently intangible, abstract and their consumption is deferred to the future, which makes their direct visualization difficult. The purchase of insurance is therefore critically dependent on a high level of consumer trust and long-term stability of the provider, which can only be built with difficulty using traditional methods in the digital era (Raza et al., 2024). However, it is in this context that social networks such as Facebook, Instagram and YouTube offer financial institutions a unique platform for “humanizing” corporate identity and systematically overcoming the natural barriers of consumer distrust (Kuchciak & Wiktorowicz, 2023). Through transparent communication and sharing authentic content, insurance companies can effectively educate the market in the area of risk management, which directly strengthens their market credibility (Alhazmi, 2023).

Recent empirical research clearly shows that active customer engagement on insurance company profiles directly correlates with positive perceptions of brand image and value (Priya, 2023). This assumption is further developed by Grover et al. (2024), according to which timely responses to user inquiries and interactive customer service in the online environment act as a strong stabilizing element that demonstrably minimizes the departure of existing clients. Building a strong brand perception through social media thus becomes a key determinant of sustainable success in a highly saturated insurance market (Kaur & Singh, 2025). All these digital activities of financial institutions subsequently enter the final phase of consumer behavior, where they massively determine the choice of a specific insurance product or commercial provider (Florendo & Estelami, 2022). Modern customers rely less and less on one-sided proclamations of companies in their decision-making and, on the contrary, actively seek out so-called social proof, such as online reviews, comments, and ratings of other users in digital communities (Cheung et al., 2023). However, the way consumers reflect on the digital activities of financial institutions is strongly moderated and differentiated by their demographic characteristics, especially age (Vrontis et al., 2023).

Younger age cohorts, such as members of Generation Z and millennials, perceive a high level of digital presentation of an insurance company as an absolute standard, and the absence of online activity may be a reason for them to immediately exclude a provider from the shortlist (Narasimhan et al., 2024). On the contrary, older generations of consumers show different cognitive styles, and on social networks they rather require factual accuracy, security of communication channels and stability of information (Schumann et al., 2025). In parallel, Taylor & Costanzo (2026) add that a detailed understanding of these statistical dependencies between the demographic profile of users and the intensity of their interactions on social networks is an absolutely necessary basis for effective market segmentation and the correct

targeting of online campaigns. These demographic aspects are organically followed by comparative studies that examine subscriber behavior directly on insurance company profiles. For example, Vassiliou et al. (2022) found in their comparative analysis of the profiles of leading European insurance companies that the number of followers alone does not automatically guarantee higher market conversion if the shared content lacks an interactive and educational dimension. Similarly, Stanić et al. (2023) examined the use of social networks by commercial insurance companies and confirmed that these institutions often encounter limited potential of the platforms due to rigid and purely product marketing, which fully corresponds to the assumption of insufficient use of the digital space.

In terms of frequency of interactions, very similar research was carried out by Lamberton et al. (2024), who, using advanced statistical methods, determined how often users actually visit the profiles of financial institutions; their conclusions confirmed a direct dependence between the younger age of respondents and the daily intensity of information search on corporate channels. The issue of demographic differentiation and perception of client service at insurance companies is concluded by Mörtenhuber and Eisingerich (2025), whose empirical data showed that older age groups visit these profiles sporadically, but show significantly higher loyalty to the selected insurance company if the institution provides them with a safe and understandable environment through digital platforms. All these similar international studies thus create a robust theoretical and empirical framework for verification and comparison of data obtained in the specific conditions of the Slovak insurance market.

3. Materials and Methods

The survey focused on analyzing the use of social networks by commercial insurance companies. This focus logically leads us to its main objective, which is to comprehensively analyze the use of social networks in selected commercial insurance companies in the Slovak Republic.

The objective was set as follows: to compare and evaluate the perception of social media use through the eyes of users or followers, or subscribers to the profiles of selected commercial insurance companies. At the same time, we wanted to use the survey to find out how often these followers or subscribers visit the user profiles of selected commercial insurance companies. In order to achieve this objective and process the survey, several smaller or partial objectives were set to help us achieve this goal. However, these objectives need to be distinguished in terms of two main parts, namely the theoretical and empirical parts. Depending on this, the following objectives are involved in the processing of the theoretical part:

- defining several basic concepts related to marketing communication and the use of social networks,
- selection of specific commercial insurance companies.

In connection with this objective, we have defined several sub-objectives in the empirical part:

- preparation of a questionnaire survey,
- contacting potential survey participants,
- sending the questionnaire survey to respondents,
- summarizing the returned questionnaires and analyzing the individual data,
- interpreting the results of the questionnaire survey,

- processing selected survey data using correspondence analysis,
- evaluating the findings of the questionnaire survey,
- formulating proposals and recommendations for the use of social networks by commercial insurance companies.

By setting these sub-goals and achieving them, we expect to achieve a more comprehensive processing of the empirical part so that we not only fulfil the main goal of the empirical part, but also achieve the overall main goal of the survey. In the theoretical part, the procedure or methodology for its processing is as follows:

- collection, analysis and classification of knowledge related to the use of social networks,
- interpretation and summarization of selected knowledge into a comprehensive theoretical whole in the field of social network use,
- selection of commercial insurance companies for analysis of social network use.

In the case of the empirical part, the procedure and methodology were as follows:

- analysis and description of selected public profiles and subscriber channels of selected commercial insurance companies,
- compilation of a questionnaire survey,
- contacting potential survey participants,
- sending questionnaires to those interested in participating in the survey,
- collection of completed questionnaires,
- detailed analysis of completed questionnaires and summarization of data obtained,
- interpretation of the data obtained and summarized from the completed questionnaires,
- processing correspondence analysis based on selected data from the questionnaire survey,
- formulation of proposals and recommendations in the area of social media use by commercial insurance companies.

The above methodology for processing both parts of the survey used several processing methods, namely:

- literature review method – in processing the theoretical part,
- deduction method – used mainly in the empirical part of the work and in predicting the survey results,
- the method of interpretation – used in evaluating the survey results,
- correspondence analysis method – used in the empirical part of the work to achieve a comprehensive analysis of social network use.

All these methods were used for comprehensive processing and to fulfil its main objective.

4. Results

4.1 Selected insurance companies on the Slovak Market, which we will examine

There are several companies operating in the Slovak insurance market that are engaged in insurance activities. The commercial insurance companies we are examining are insurance companies that not only offer a wide range of products in the Slovak Republic, but also have a wide range of clients. The following three insurance companies were selected:

- Allianz – Slovenská poisťovňa, a. s.,
- Kooperativa poisťovňa, a. s. Vienna Insurance Group,
- Union poisťovňa a. s.

In addition, we added two insurance companies, or rather branches of insurance companies from other Member States, namely:

- Generali Poist'ovňa, a. s. branch,
- MetLife Europe d.a.c.

However, in order to carry out the analysis itself, we will first provide a brief overview of the most popular social networks in the world. Every year, Cloudflare, one of the largest providers of web infrastructure services focused on protecting and improving the reliability and performance of websites, compiles a ranking of the most popular social networks with the highest activity based on data obtained from its websites. Based on data relating not to the total number of users, but to the volume of activity that the company obtained in 2025, it compiled the following ranking of social network popularity, with the following social networks in the top five places:

1. TikTok.com,
2. Facebook.com,
3. YouTube.com,
4. Twitter.com,
5. Instagram.com.

In addition, Snapchat.com, Reddit.com, Pinterest.com, LinkedIn.com and Quora.com can also be ranked among the most popular social networks in terms of activity volume.¹ This is also confirmed by new statistics from Global Social Media Statistics, which provide several interesting insights. A detailed analysis by Kepios included in the statistics shows that in October 2024, there were 5.22 billion social media users worldwide, equivalent to 63.8 per cent of the total global population.²

Table 1. The largest social media platforms in the world

Platform	Users (in million)
Facebook	3 070
YouTube	2 530
Instagram	2 000
WhatsApp	2000
Tik Tok	1690
We Chat	1370
Telegram	950
Facebook Messenger	937
Snapchat	850
X (Twiter)	590
Pinterest	522

Source: Kepios analysis, 2022.

¹ <https://strategie.hnonline.sk/news/marketing/96193357-5-2-miliardy> [online]

² <https://wearesocial.com/us/blog/2024/10/digital-2024-october-global-statshot-report/>

The above information clearly (Table 1) shows that social networks have become an integral part of our lives. And this is quite understandable. These platforms allow us to easily obtain information, communicate with friends and family, and even earn money. However, it should be noted that as the number of users grows, so does the number of threats we may encounter in the online space. Social networks as such are not bad. It is the users who determine their perception across society, who lay the foundations for innovation and change, who influence the direction these platforms will take in the future. The social networks listed above represent the top 5 most preferred social networks among their users. However, in the Slovak Republic, the situation with social network usage is slightly different from that of globally popular social networks. We base this on a survey conducted by Go4insight between February and March 2024, which was carried out on a sample of 1,000 respondents of various ages. This survey not only identified which networks the respondents visit, but also how many times a day they visit a selected social network. According to this survey, Facebook dominates among social networks in the Slovak Republic, with up to 55% of Slovaks using it daily, either once or several times a day (Table 2).

4.2 How is it in Slovakia

According to the report Digital 2024: Slovakia published on datareportal.com, at the beginning of 2024 there were 5.25 million internet users in Slovakia, representing an internet penetration rate of 91.4 per cent. At that time, Slovakia was home to 4.16 million active social media users, representing 72.4 per cent of the total population. There were as many as 6.47 million mobile connections, representing 112.7 per cent of the total population. The year 2024 was a dynamic one for social networks in our market.

Table 2. Comparison of social media usage in the Slovak Republic in terms of users and % of advertising reached

Users	Advertising reach in %
Facebook	2,40 mil.
YouTube	4,14 mil.
Instagram	1,60 mil.
Messenger	2,20 mil.
Tik Tok	1,06 mil.
Liniked-in	830 thous.
Snapchat	585 thous.
X (Twiter)	344 thous.
Pinterest	855 thous.
Overall 4,16 mil.	72,40%
Mobile connection 6,47 mil.	112,70%

Source: data for Global Digital Reports 2024 provided by We Are Social and Metwate.

Table 2 shows that Facebook significantly dominates among Slovak social network users, with YouTube lagging slightly behind. The top three most used networks in the Slovak Republic are rounded out by Instagram, with more than users visiting it daily, regardless of whether once or several times a day. These three social networks also ranked high in terms of activity volume in the survey conducted by the company. For this reason, when analyzing the use of social networks by commercial insurance companies in the Slovak Republic, we will focus on these social networks, i.e., Facebook, YouTube and Instagram. We will therefore analyze these social networks in relation to the activities of selected commercial insurance companies, analyzing their profile on the given social network, the number of followers or subscribers, etc.

4.3 Use of social networks by selected commercial insurance companies

We analyzed whether selected commercial insurance companies have created user profiles or subscriber channels on selected social networks. Our analysis revealed that almost all insurance companies have created such a profile or channel on selected social networks.

Table 3. Analysis of user accounts/channels created on selected social networks

Insurance company	Facebook	YouTube	Instagram
Allianz	Yes	Yes	Yes
Kooperativa	Yes	Yes	Yes
Union	Yes	Yes	Yes
Generali	Yes	Yes	Yes
Metlife	Yes	Yes	No

Source: own processing based on insurance company statistics.

We also analyzed how many followers and subscribers selected commercial insurance companies have on individual social networks. Our analysis revealed that insurance companies not only have significantly different numbers of followers on each social network, but also on all three selected social networks combined.

Table 4. Analysis of the number of followers/subscribers on selected social networks

Insurance company	Facebook	YouTube	Instagram	Total
Allianz	29,367	295	2796	32,458
Kooperativa	3,900	211	3147	7,258
Union	24,042	563	4,644	29,249
Generali	21,517	366	88	21,971
Metlife	668	6	0	674
Total	79,494	1,441	10,675	91,610

Source: own processing based on insurance company statistics.

Based on the analysis and individual data, we can summarize that selected commercial insurance companies use selected social networks in connection with their business activities. At the same time, we found that these insurance companies carry out various activities on selected social networks, not only those that highlight their products and services, but also activities related to sponsorship, volunteering, health promotion, etc.

As we expected, not all those approached were willing to participate in the survey. Some completely ignored our message and questionnaire, while others replied that they were not interested. The third group of respondents consisted of individuals who wanted to participate in the survey and completed the questionnaire we had compiled. In total, we sent out 500 questionnaires, but only 289 were returned to us. Of the 500 questionnaires sent out, only 249 were returned to us, so we contacted another 100 respondents in order to obtain the minimum number of respondents required for this survey, which was set at 250. When the questionnaires were sent out for the second time, the willingness of those approached was also low, but we received another 40 questionnaires. This means that the return rate for the questionnaire, which we sent out online, was 58%. From the completed questionnaires we received, we can evaluate the dependencies of our sample, i.e., the respondents who participated in the survey, on the object of the survey. From the completed questionnaires we received, we can specify the sample very precisely based on two initial pieces of information, namely the gender and age of the respondent. In terms of the gender of respondents, women predominated as participants in the

questionnaire survey, with 187 women completing the questionnaire, accounting for 65% of the total sample.

Table 5. Respondents by gender

Gender	Number (pcs)	Percentage
Female	187	65
Men	102	35
Total	289	100

Source: own processing.

We also evaluated the number and proportion of respondents in terms of their age, setting several age categories in the questionnaire so that respondents could always select the age range that corresponded to their age.

Table 6. Respondents by age category

Age category	Number (pcs)	Proportion (in %)
18-25	56	19
26-35	108	37
36-45 years	59	20
46-55 years	54	19
55 and over	12	4
Total	289	100

Source: own processing.

The table shows that the largest group of respondents were individuals aged 26 to 35, who accounted for 37% of the total sample. However, respondents aged 18-25 and respondents aged 46 to 55 were represented in relatively equal numbers. We considered these two pieces of identifying information about the respondents to be sufficient to identify the sample that participated in our questionnaire survey. The question focused on which social networks the respondents use. It should be noted that respondents did not have to choose only one answer from the options provided, i.e., they could select more than one answer to this question. The specific numbers of answers to this question are shown in the table.

Table 7. Overview of respondents' answers to the question: What social networks do they use?

Question No. 1	Number of answers (in pcs)	Percentage of responses (%)
Facebook	234	30
YouTube	217	28
Instagram	142	18
LinkedIn	81	10
Twitter	104	13
Total	777	100

Source: own processing.

We can see that respondents gave a large number of answers to the first question. Many of them gave one answer option, but there were also a large number of respondents who even mentioned using 3 or 4 social networks as their answer. We also show the proportion of responses from these respondents graphically, where we can clearly see the use of the social networks we selected.

Question No. 1: Which social networks do you use

Table 8. Which social networks do you use

Facebook	30%
YouTube	28%
Instagram	18%
LinkedIn	11%
Twitter	11%

Source: own processing.

The second question was similar in nature to the first questionnaire question. In it, we focused in more detail on which social network the respondents use the most. This means that in this case, we asked them to give only one answer, which would indicate which social network the respondent prefers the most. The results of the responses are summarized in Table 9.

Table 9. Overview of respondents' answers to question no. 2 in the questionnaire survey

Question No. 2	Number of responses (in pcs)	Percentage of responses (in %)
Facebook	139	48
YouTube	32	11
Instagram	93	32
LinkedIn	10	3
Twitter	15	5
Total	289	100

Source: own processing

The responses clearly show that Facebook is the most common and preferred social network among respondents, followed by Instagram. The third question was directed at commercial insurance companies. We asked which of the selected commercial insurance companies the respondent follows, or which commercial insurance companies' channels they follow on social media. The individual responses are shown in Table 10.

Table 10. Overview of respondents' answers to question no. 3 in the questionnaire survey

Question No. 3	Number of responses (in pcs)	Percentage of responses (in %)
Allianz Slovenská poisťovňa, a. s.	72	25
Kooperativa Insurance Company, a. s.	101	35
Union Insurance Company, a. s.	83	29
Generali Insurance Company, a. s.	26	9
Metlife Europe d. a. c.	7	2
Total	289	100

Source: own processing.

The sample of respondents was broad, so the individual responses of respondents were diverse in terms of following profiles or subscribing to channels of individual commercial insurance companies. Most respondents stated that the commercial insurance company whose profile they follow on social media or whose channel they subscribe to is Kooperativa poisťovňa, a. s. We used data processing in the SPSS programme for the calculation, where correspondence analysis can be processed as a whole if we enter the basic input data correctly. We imported the above inputs into the programme and can therefore further evaluate the relevant results of the correspondence analysis. The individual row profiles are shown in Table 11.

Table. 11. Row profiles (ROW PROFILES)
How often do you visit the user profile of a commercial insurance company on social media?

Age category	Daily	Several times a week	Once a week	Once a month	Sporadically	MASS
18-25	0.146	0.229	0.239	0.172	0.177	0.194
26-35	0.417	0.375	0.418	0.328	0.339	0.374
36-45	0.125	0.188	0.224	0.219	0.242	0.204
46-55	0.271	0.125	0.075	0.281	0.194	0.187
55 years and older	0.042	0.083	0.045	0.000	0.048	0.042
TOTAL	1.00	1,000	1.000	1,000	1,000	1,000

Source: own processing.

The table shows that the largest share of respondents who follow the social media accounts of a selected insurance company are in the 26-35 age group, with 41.8% following them once a week. Conversely, the fewest respondents who follow the social media accounts of a specific commercial insurance company are aged 55 and over, i.e., 4.2% of respondents follow the user profile of commercial insurance companies on social media on a daily basis. We calculate the column profiles by dividing the value in the relevant column by the total number of responses in that column, and our results are shown in Table 12.

Table 12. Column profiles
How often do you visit the user profile of a commercial insurance company on social media?

Age category	Daily	Several times a week	Once a week	Once a month	Sporadically	TOTAL
18-25	0.125	0.196	0.286	0.196	0.196	1.000
26-35	0.185	0.167	0.259	0.194	0.194	1.000
36-45	0.102	0.153	0.254	0.237	0.254	1.000
46-55	0.241	0.111	0.093	0.333	0.222	1.000
55 years and older	0.167	0.333	0.250	0.000	0.250	1.000
MASS	0.166	0.166	0.232	0.221	0.215	1.000

Source: own processing.

The results show that most respondents, i.e., 33.3%, follow the user profile of a selected commercial insurance company several times a week – these are respondents in the 55+ age group and also once a month in the 46-55 age group. Conversely, the fewest respondents, i.e., 9.3% in the 46-55 age group, follow the profile of a selected insurance company on a social network once a week. Of course, it should be noted that we do not take into account the zero values shown in the table above.

5. Conclusion

In this survey, we focused in detail on the issue of social media use by commercial insurance companies, where we focused on defining basic marketing terms related to the issue of social media use. Communication in general is the process of exchanging information or knowledge sent by the sender to the recipient of this knowledge and information, i.e., the recipient of the message. Marketing communication can currently be carried out in various ways. We are increasingly seeing the use of more modern, contemporary, and innovative means of marketing communication, leading to its more effective and targeted implementation. Social networks are a contemporary means of communication. It is a communication platform where anyone can create their own user profile or subscriber channel, through which it is possible to easily

communicate, inform about various activities, send or share many images, videos or posts, both publicly and privately, and so on.

The survey and evaluation of social media use also included a correspondence analysis, in which we analyzed the relationship between the age category of the respondent and the frequency of visits to the social media of selected commercial insurance companies. When performing a comprehensive correspondence analysis, we found that people aged 26-35 visit the social networks of selected commercial insurance companies several times a week. At the same time, our correspondence analysis revealed that younger age groups visit the social networks of selected commercial insurance companies more often than older age groups. The analysis also showed that some selected commercial insurance companies use them less, while others use them more and more frequently.

From an overall perspective, however, we can say that selected commercial insurance companies do not fully utilize the potential of social networks, as the number of followers or subscribers could be much higher than currently recorded on these social networks. It should be noted, however, that from a global perspective, selected commercial insurance companies have created profiles on selected social networks and use them in their activities, but in our view, they use them to a limited extent as a modern means of marketing communication. They should devote significantly more attention to developing their marketing communication through the use of social networks, which are already a common means of communication, especially for the younger generation, sometimes even more so than "classic" personal communication between people.

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