The Role of Green Innovation on Firm Value Moderated by Digital Transformation in the Basic Industry and Chemical Sector Listed on the IDX

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ABSTRACT
This study examines the effect of green product innovation (GPI) and green process innovation (GCI) on firm value, and tests the moderating role of digital transformation (DT) in these relationships among basic industry and chemical firms listed on the Indonesia Stock Exchange (IDX). Using panel data from 33 firms during 2019–2023 (165 observations) selected through purposive sampling, green innovation is measured via manual content analysis (κ = 0.884) while digital transformation is measured through dictionary-based content analysis of seven strategic digital technology categories. Panel data regression with the Common Effect Model is used after all classical assumptions are met. The results show that GPI ($\beta = -0.0079$; $p < 0.01$) and GCI ($\beta = -0.0080$; $p < 0.01$) have a significant negative direct effect on firm value. However, digital transformation positively and significantly moderates the effects of GPI ($\beta = 0.0013$; $p < 0.01$) and GCI ($\beta = 0.0008$; $p < 0.05$) on firm value, exhibiting a sign-reversing moderation effect at sufficient levels of digital transformation. These findings contribute to Dynamic Capabilities Theory and Signaling Theory, and provide practical implications that integrating green innovation with digital transformation is a critical strategy for firm value creation in the Indonesian basic industry and chemical sector.

***Keywords**: green product innovation; green process innovation; digital transformation; firm value; Tobin's Q.*

1. INTRODUCTION

Environmental sustainability has become an increasingly urgent global concern, especially for the basic industry and chemical sector, which produces direct and substantial environmental impacts. In Indonesia, sustainability commitments are reflected in regulations such as OJK Regulation No. 51/POJK.03/2017 on Sustainable Finance, which requires listed firms to integrate environmental, social, and governance (ESG) aspects into their business strategies. This sector is also subject to environmental laws including Law No. 32 of 2009 on Environmental Protection. In this context, green innovation—both in product and process dimensions—becomes increasingly relevant as a strategy that not only addresses regulatory and social demands but also potentially creates economic value.

Chen et al. (2006) distinguish green innovation into two dimensions. Green product innovation (GPI) involves energy savings, pollution prevention, recycling, non-toxic materials, and eco-friendly design. Green process innovation (GCI) refers to clean production technologies, emission reduction, energy efficiency in manufacturing, and environmental management systems (Wang & Ahmad, 2024). The distinction is important in the basic industry and chemical sector because the two have different value-creation mechanisms: GPI is market-facing (e.g., low-carbon cement, bio-based chemicals), while GCI is operations-facing (e.g., waste heat recovery, closed-loop water systems) (Xie et al., 2019).

However, the relationship between green innovation and firm value is not always linear. Ji et al. (2023) and Su et al. (2025) show that environmental disclosure has a negative effect on ROA but a positive effect on Tobin's Q, indicating that markets value environmental investment as a signal of long-term resilience despite short-term cost burdens. This gap opens space to explore moderating variables—particularly digital transformation. Vial (2019) defines digital transformation as a process aimed at improving an entity by triggering significant changes in its properties through combinations of information, computing, communication, and connectivity technologies. Within Dynamic Capabilities Theory (Teece et al., 1997), digital transformation can strengthen the impact of green innovation through analytics, AI, automation, big data, cloud computing, and digital twins. This study aims to analyze the separate effects of GPI and

GCI on firm value and to test whether digital transformation moderates each of these relationships in basic industry and chemical firms listed on the IDX.

2. LITERATURE REVIEW AND HYPOTHESES

2.1 Green Product Innovation and Firm Value

Based on Signaling Theory (Spence, 1973), green product innovation sends a strong signal of R&D capability and proactive responsiveness to sustainability trends. Stakeholder Theory (Freeman, 1984) argues that GPI responds to customer and societal expectations for environmentally friendly products, while the Natural Resource-Based View (Hart, 1995) sees GPI as a source of hard-to-imitate differentiation. Wang and Ahmad (2024) and Zhao et al. (2026) confirm a positive effect of GPI on firm value.

H1: Green product innovation has a positive effect on firm value.

2.2 Green Process Innovation and Firm Value

Based on the NRBV (Hart, 1995), green process innovation enables cost leadership through energy and waste efficiency. Signaling Theory suggests that GCI signals operational efficiency and reduced regulatory risk. Wang and Ahmad (2024) and Zhang et al. (2020) find a positive effect of GCI on Tobin's Q, ROA, and ROE.

H2: Green process innovation has a positive effect on firm value.

2.3 Moderating Role of Digital Transformation: GPI–Firm Value

Within Dynamic Capabilities Theory, digital transformation enhances the firm's ability to develop, market, and communicate green products through analytics, business intelligence, AI, machine learning, and cloud platforms. Santamaria et al. (2021) and Chen and Hao (2022) show that digitalization strengthens the link between sustainability practices and firm performance.

H3: Digital transformation positively moderates the effect of GPI on firm value.

2.4 Moderating Role of Digital Transformation: GCI–Firm Value

Digital technologies such as automation, big data, data science, and digital twins enable real-time monitoring and optimization of clean production processes. Bag et al. (2021) and Ghobakhloo and Fathi (2020) show that the convergence of digital technology and sustainable manufacturing creates synergies that simultaneously enhance operational, environmental, and economic performance.

H4: Digital transformation positively moderates the effect of GCI on firm value.

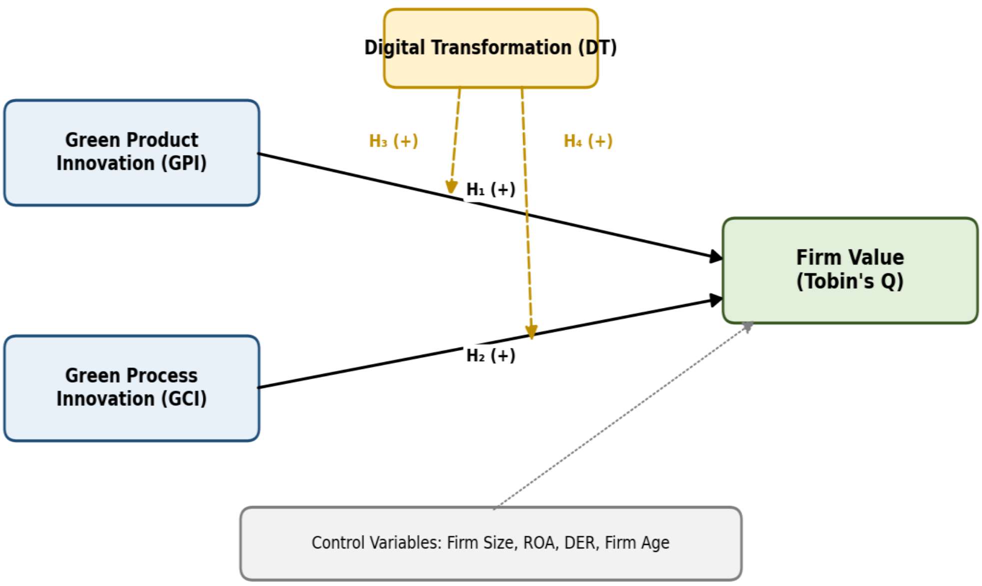

Figure 1. Research Framework

3. RESEARCH METHODOLOGY

This study employs a quantitative causal design using secondary panel data from 33 basic industry and chemical firms listed on the IDX during 2019–2023, yielding 165 firm-year observations selected through purposive sampling (firms continuously listed, not reporting losses, publishing complete annual and sustainability reports, and disclosing green innovation practices). Firm value (TQ) is proxied by Tobin's Q (Chung & Pruitt, 1994): TQ = (MVE + D) / TA. Green product innovation (GPI) and green process innovation (GCI) are measured through content analysis of annual and sustainability reports using indicators adapted from Wang and Ahmad (2024) and Zhao et al. (2026), with each indicator scored 0 (no disclosure), 1 (simple disclosure), or 2 (full and detailed disclosure); inter-coder reliability is verified by Cohen's Kappa (mean κ = 0.884). Digital transformation (DT) is measured via normalized keyword frequency across seven categories (analytics, automation, AI, big data, cloud computing, digitization, machine learning), following Chen and Hao (2022). Control variables include firm size (Ln Total Assets), profitability (ROA), leverage (DER), and firm age. Two regression models are estimated:

$$Model\ 1:\ TQ = \beta_0 + \beta_1 GPI + \beta_2 GCI + \beta_3 SIZE + \beta_4 ROA + \beta_5 DER + \beta_6 AGE + \varepsilon$$

$$Model\ 2:\ TQ = \beta_0 + \beta_1 GPI + \beta_2 GCI + \beta_3 DT + \beta_4 (GPI \times DT) + \beta_5 (GCI \times DT) + \beta_6 SIZE + \beta_7 ROA + \beta_8 DER + \beta_9 AGE + \varepsilon$$

Model selection between Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM) is performed via the Chow, Hausman, and Lagrange Multiplier tests (Baltagi, 2021). All classical assumptions are tested before hypothesis testing.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Table 1. Descriptive Statistics

Variable	Mean	Std. Dev.	Median	Min	Max
TQ	1.225	0.144	1.216	0.888	1.588
GPI	1.323	0.664	1.500	0.000	2.000
GCI	1.014	0.670	1.000	0.000	2.000
DT	3.036	6.653	0.000	0.000	36.000
SIZE	29.104	1.641	28.743	26.164	32.683
ROA	0.064	0.083	0.043	0.001	0.758
DER	1.608	4.617	0.698	0.046	27.707
AGE	40.242	11.684	43.000	12.000	66.000

Source: STATA processed data (n = 165)

Tobin's Q averages 1.225 (median 1.216), indicating that the market values sample firms above book value. GPI (mean 1.323) is slightly higher than GCI (mean 1.014), suggesting firms more actively disclose product-level green initiatives, which are market-facing and have higher communicative value to industrial customers. DT shows a strongly right-skewed distribution (median 0.000, max 36.000), indicating that digital adoption in this sector remains uneven and concentrated among a few firms. ROA and AGE confirm that the sample consists of mature, profitable firms.

4.2 Pearson Correlation

The correlation matrix shows that GPI ($r = -0.537$; $p < 0.01$) and GCI ($r = -0.568$; $p < 0.01$) are negatively correlated with TQ at the bivariate level—an early indication that green innovation creates front-loaded costs before benefits materialize through interactions with supporting capabilities. The interaction terms GPI×DT ($r = 0.297$; $p < 0.01$) and GCI×DT ($r = 0.142$; $p < 0.10$) are positively correlated with TQ, signaling that digital transformation may reverse the direction of these relationships. DT is positively correlated with both GPI ($r = 0.190$; $p < 0.05$) and GCI ($r = 0.374$; $p < 0.01$), confirming that the two are mutually reinforcing strategies. No correlation among independent variables exceeds the 0.80 threshold, indicating no serious multicollinearity (Aiken & West, 1991).

4.3 Model Selection and Classical Assumption Tests

For both Model 1 and Model 2, the Chow test ($p = 0.4485$ and 0.6323), Hausman test ($p = 0.2015$ and 0.2620), and Breusch-Pagan LM test ($p = 1.0000$ and 1.0000) all converge on Common Effect Model (Pooled OLS) as the most appropriate estimator. The $\sigma_u = 0$ in REM estimates confirms no individual-specific variance. All classical assumptions are satisfied: residuals are normally distributed (Shapiro-Wilk W = 0.989 and 0.991; $p > 0.05$); no multicollinearity (mean VIF 1.67 and 2.30, all below 10); homoskedasticity confirmed by Breusch-Pagan ($p = 0.8468$ and 0.7080) and White's tests ($p = 0.3829$ and 0.5932); and no autocorrelation by the Wooldridge test ($p = 0.9693$ and 0.7648).

4.4 Hypothesis Testing

Table 2. Regression Results (Pooled OLS)

Variable	Model 1		Model 2		
	Coef.	p-value	Coef.	Std. Err.	p-value
GPI	−0.0079	0.000***	−0.0057	0.0016	0.001***
GCI	−0.0080	0.000***	−0.0075	0.0019	0.000***
DT	—	—	−0.0004	0.0003	0.162
GPI × DT	—	—	0.0013	0.0004	0.002***
GCI × DT	—	—	0.0008	0.0003	0.011**
SIZE	−0.0010	0.160	−0.0009	0.0007	0.192
ROA	0.0358	0.020**	0.0415	0.0146	0.005***
DER	−0.0003	0.326	−0.0004	0.0003	0.114
AGE	0.0001	0.183	0.0001	0.0001	0.374
Constant	1.2643	0.000***	1.2603	0.0195	0.000***
R^2	0.4556		0.5192		
Adj. R^2	0.4349		0.4913		
F-stat	22.03	0.000	18.60		0.000
N	165		165		

*Notes: * p < 0.10; ** p < 0.05; *** p < 0.01. Source: STATA processed data.*

Adjusted R^2 increases from 0.4349 in Model 1 to 0.4913 in Model 2, indicating a substantive improvement in explanatory power from including digital transformation as a moderator.

H_1 (rejected): GPI has a significant negative effect on firm value ($\beta = -0.0079$; $p < 0.01$). H_2 (rejected): GCI also exhibits a significant negative effect ($\beta = -0.0080$; $p < 0.01$). H_3 (accepted): DT positively moderates the GPI–TQ relationship ($\beta = 0.0013$; $p < 0.01$). H_4 (accepted): DT positively moderates the GCI–TQ relationship ($\beta = 0.0008$; $p < 0.05$). The break-even points—where the effective effect of green innovation on TQ becomes positive—are DT ≈ 4.38 for GPI and DT ≈ 9.38 for GCI, indicating that GCI requires more substantial digital transformation than GPI to generate positive value. Among the controls, only ROA is significantly positive in both models, consistent with fundamental valuation theory (Brigham & Houston, 2019).

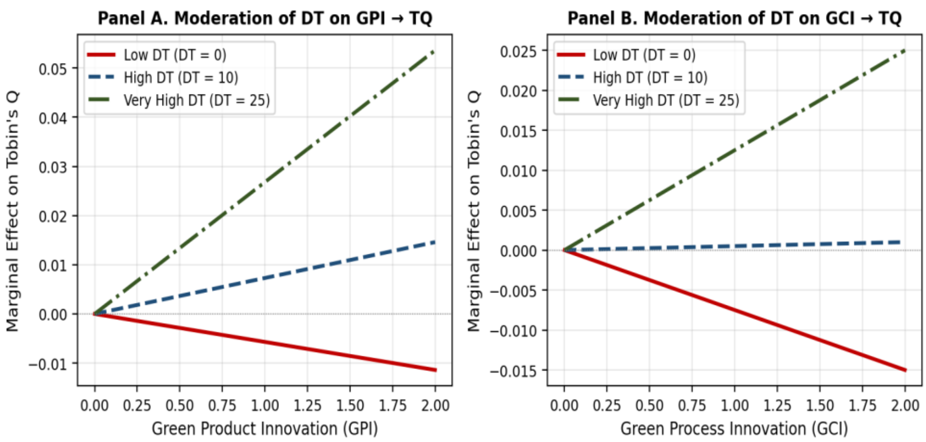

Figure 2. Simple Slope Plot of the Moderation Effect of Digital Transformation

Figure 2 visualizes the sign-reversing moderation pattern. At low DT levels, the marginal effect of green innovation on Tobin's Q is negative (red solid line); as DT increases, the slope rotates and turns positive (blue dashed and green dash-dotted lines). The reversal occurs at a lower DT threshold for GPI (Panel A) than for GCI (Panel B), confirming that market-facing innovation is more responsive to digital enablement.

4.5 Discussion

The negative direct effects of GPI and GCI on firm value can be explained by trade-off mechanisms: green innovation in this capital-intensive sector requires substantial R&D and operational investments with long payback periods. The market may respond negatively to these short-term expenditures before long-term benefits materialize. This is consistent with Tripopsakul (2025), who shows that environmental investment carries short-term cost burdens despite long-term reputational benefits, and with Sigalingging et al. (2025), who find that green innovation has a non-significant negative effect on firm value in the Indonesian food and beverage subsector. In B2B markets, industrial customers prioritize price and technical quality over green attributes, limiting willingness-to-pay premiums.

The positive moderating role of digital transformation can be explained through several channels. For GPI, analytics and business intelligence allow more accurate identification of customer preferences for green products; e-commerce and digital marketing expand market reach; cloud platforms and digital supply chains enhance the credibility of green claims to investors (Santamaria et al., 2021; Chen & Hao, 2022; Luo et al., 2025; Zhang & Song, 2025). For GCI, automation, autonomous technology, and digital twins enable precise real-time optimization of green production (Bag et al., 2021); big data and machine learning facilitate the identification of inefficiency patterns; and analytics enhances accurate environmental performance reporting (Sun et al., 2025). The larger moderation magnitude for GPI×DT (0.0013) than GCI×DT (0.0008) indicates that digital transformation reinforces market-facing innovation more strongly than operations-facing innovation, consistent with Chen and Hao (2022).

5. CONCLUSION

This study yields three main implications. First, on a stand-alone basis, both green innovation dimensions negatively affect firm value in the Indonesian basic industry and chemical sector, indicating that markets do not yet fully reward green initiatives unsupported by adequate digital capabilities. Second, digital transformation is a critical enabler whose moderating power is large enough to reverse the direction of green innovation effects from negative to positive in firms that have achieved sufficient levels of digitalization. Third, the analytical separation of GPI and GCI offers a valuable theoretical contribution: each dimension has a different digital transformation threshold for generating positive impact, with GCI requiring more substantial digital support than GPI. Practically, management should integrate green innovation strategies with digital investments rather than treating them as substitutes, while regulators should formulate policies that simultaneously promote both agendas. Limitations include reliance on annual report disclosures and a single-sector focus, suggesting future research employing multi-sector samples and direct investment data.

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