Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

The impact of economic innovation on natural gas productivity: Evidence from Saudi Arabia

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A R T I C L E I N F O

Article history:
Received 25 December 2024
Received in revised form
28 April 2025
Accepted 4 May 2025

Keywords:
Economic innovation
Natural gas productivity
Shale gas
Waad Al-Shamal
PLS-SEM

A B S T R A C T

Many researchers have shown interest in different types of economic innovation, considering it an important management concept that can improve the productivity of natural gas, especially shale gas. This study aims to explore the relationship between economic innovation and the productivity of natural gas (shale gas) in Waad Al-Shamal Industrial City. It also seeks to identify any significant differences between these two factors. The research will use a descriptive-analytical method and a survey to describe the characteristics and variables related to the research problem and to test its hypotheses. Partial Least Squares Structural Equation Modeling (PLS-SEM) will be used to analyze the relationship between the independent and dependent variables. The results show that acceptance, ongoing efforts, and problem sensitivity have a significant effect on the productivity of natural gas.

1. Introduction

The global energy landscape is undergoing rapid transformations, influencing prices, competitive dynamics, and environmental outcomes. Heightened demand and rising production costs have escalated competition among producers and consumers, accompanied by the emergence of non-traditional energy sources that disrupt established frameworks and contribute to environmental degradation (Arnold-Keifer et al., 2025). Since the 1970s, Saudi Arabia has captured natural gas released as a byproduct from its oil platforms, which were historically flared, and redirected it for power generation, notably for the Saudi Electricity Company. This early innovation enabled the Kingdom to partially pivot its energy model toward greater sustainability by deploying natural gas in its electric grid. Over time, this strategy evolved into a deliberate shift in Saudi energy policies to diversify power sources in line with Vision 2030 and broader sustainable development goals. However, the expansion of renewable energy has been constrained by technological challenges and higher upfront costs. Consequently, Saudi Arabia continues to prioritize natural gas, supported by its cost-effectiveness and lower carbon footprint, as a bridge fuel in its transition toward a cleaner energy system (Benhacene and Hussien, 2025). Our objective was to improve access to this valuable energy resource through the exploration and development of extensive unconventional gas reserves in Saudi Arabia. Contributing elements include heightened competition among organizations, limited resources, large corporate entities, elevated consumer expectations, a sizable and diverse workforce, increasing employee aspirations, economic stagnation, inflation, declining productivity, high unemployment expenses, increased management costs, job inflation, decreasing wages, reduced demand, growing excess inventory, rising financing expenses, increasing unmet needs, growing demand for novel ideas to address existing challenges, and conflicts with social and behavioral issues. The Waad Al-Shamal Industrial City is recognized as a strategic driver of Saudi Arabia's economic development. Its establishment has led researchers to explore innovative strategies to generate competitive advantages aligned with national goals. In particular, studies highlight the critical role of economic innovation in increasing natural gas productivity and fortifying the sector on both domestic and international fronts (Alsulamy et al., 2025). A primary obstacle to economic innovation is the absence of financial incentives or policies that

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https://doi.org/10.21833/ijaas.2025.05.014
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promote innovation, coupled with geological complexities. These factors make it challenging to forecast productivity and maintain high production rates over time.

Saudi Aramco has fully marketed unconventional gas for the first time, leveraging its extensive expertise, cutting-edge technologies, and a unique integrated business model. This marks the initial stage of a company's program for extracting unconventional resources. Subsequently, Saudi Aramco initiated the second phase of its strategy, aiming to increase unconventional gas production to over 190 million standard cubic feet daily through the construction of four additional production facilities that have been finalized. The company's endeavors in Waad Al-Shamal serve as a tangible demonstration of its unwavering commitment to employing state-of-the-art technologies and methodologies that enhance the financial efficiency of its projects. This approach also contributes to environmental conservation and creates promising employment opportunities for Saudi youths. In the development of an unconventional gas system for Waad Al-Shamal, the company implemented a network of non-metallic pipes spanning 300 km in length. This marks the first instance of these materials being used in gas projects in the Kingdom of Saudi Arabia. These materials offer advantages in terms of sustainability and reduce the construction and maintenance expenses. Moreover, as part of the second phase of establishing unconventional gas production facilities, Saudi Aramco pioneered the use of a solar-powered system to supply energy to remote gas wells in the Al-Jalamid field in the north. In addition to being cost-effective, given the nature of unconventional gas wells in the region, this technology provides environmental benefits by harnessing solar power as a renewable energy source. As noted in the study by Lubis and Muniapan (2024), there is a growing need to improve its products and establish a competitive position in both local and global markets, particularly with the expansion of market reach and evolving competition methods due to the entry of multinational and transcontinental companies.

This research was ultimately divided into multiple phases, with Part 2 concentrating on hypothesis formulation and a literature review. Section 3 outlines the research design and methodology. Section 4 provides a summary of the findings and the data analysis. Finally, Section 5 presents the discussion, conclusions, and implications of the study.

2. Literature review and development of hypotheses

The notion of “economic innovation” has garnered growing interest in both scholarly and practical domains. This concept bridges the gap between the commercial and academic spheres and represents a highly collaborative and decentralized form of innovation. It embodies widespread knowledge distribution, implying that no single organization, regardless of its resources or scale, can innovate effectively in isolation. This aligns with findings by Yoo and Yi (2022), who describe how digital economic innovation is accelerated through distributed, cross-sector collaboration, highlighting the critical role of open knowledge-sharing ecosystems. This section examines recent research that investigates the relationship between economic innovation and natural gas productivity. These investigations seek to comprehend how economic innovation enhances productivity and fosters new approaches to boost economic growth, particularly in the natural gas industry. Himri et al. (2022) investigated Algeria’s energy transition, focusing on the evolution of the natural gas industry, reserves, consumption patterns, and the critical role natural gas plays in the national energy mix. Their study highlights key influencing factors such as domestic consumption, export values, and proven reserves. Using historical data and trend analysis, the research outlines the challenges and opportunities facing Algeria's gas production system, particularly in the context of sustainability and long-term planning. The authors emphasize that while natural gas remains central to Algeria’s energy strategy, its production trajectory may be influenced by both domestic energy demand and international market dynamics. Sharif et al. (2020) examined various indicators of sustainable smart cities and their influence on economic growth in Saudi Arabia. These indicators include foreign direct investment, population growth, total workforce in existing industries, and carbon dioxide emissions. This study employed the Autoregressive Distributed Lag (ARDL) methodology to analyze time-series data spanning 1991 to 2019, aiming to identify long-term relationships between variables. The findings reveal a long-term cointegration relationship between the studied factors and GDP. Specifically, foreign direct investment and carbon dioxide emissions demonstrated a positive long-term relationship with GDP, whereas population growth and workforce in existing industries showed a negative long-term relationship. Howells et al. (2012) investigated the short- and long-term effects of the natural gas boom on the economy, and explored energy production using natural gas or clean sources. While natural gas reduces carbon emissions, this study contends that the natural gas boom does not promote innovation in clean energy, potentially delaying or reversing the transition to zero-emission energy. This study quantitatively assessed these forces using a reference model for technological changes in the energy sector. The findings suggest that the shale gas response increases emissions and pushes the U.S. economy into a "fossil fuel trap," where long-term innovations shift away from renewable energy sources. In the absence of political intervention, the shale gas boom diminishes social welfare, although appropriate policy responses can significantly enhance it. Caragliu and Del Bo (2019) conducted a study to examine the impact of environmental sustainability strategies and smart city initiatives on urban challenges in Saudi Arabia from 2000 to 2022. Their analysis revealed that these approaches effectively mitigated pollution and environmental degradation, resulting in decreased nitrogen dioxide emissions and fossil fuel usage through the adoption of renewable energy programs. The strategies also enhanced public transit, infrastructure, and tourism, creating employment opportunities and safeguarding historical landmarks. Moreover, the research emphasized the importance of knowledge-based approaches in tackling manufacturing sector issues and employing Saudi youth, as foreign workers previously dominated this field. This has led to industrial sector expansion, decreased reliance on oil income, diverse job creation, and advancements in technology and economic growth.

The present study distinguishes itself by concentrating on economic innovation (problem sensitivity, continuous trend, and acceptance) and natural gas productivity in Waad Al-Shamal Industrial City. This is an inaugural study conducted at Al-Jouf University. The focus on Waad Al-Shamal stems from its notable scientific, practical, and community accomplishments, including the realization of economic innovation, enhanced innovation outputs, cost efficiency, promotion of innovation and entrepreneurship, and advancement of technological excellence and services. These factors position Waad Al-Shamal as a formidable competitor, both domestically and internationally. Economic innovation is viewed as a crucial element for sustaining success. This study underscores the efficacy of various dimensions and emphasizes that Waad Al-Shamal, situated in the northern border region, is an industrial project with developmental and economic significance, contributing to a promising future with diversified income sources and generating employment opportunities for the country's youth. In presenting the main and subsidiary research problems, this study proposes the following central hypothesis.

H1: Acceptance of stakeholders has a significant positive impact on the productivity of natural gas in the Waad Al Shamal Industrial City.
H2: The continuation of current trends in the natural gas industry has a significant positive impact on the productivity of natural gas in the Waad Al Shamal Industrial City.
H3: Economic innovation in the energy sector leads to a significant improvement in the productivity of natural gas in the Waad Al Shamal Industrial City.
H4: Sensitivity to external problems negatively impacts the productivity of natural gas in Waad Al Shamal Industrial City.

3. Methodology and research design

This research focuses on employees at Saudi Aramco in Waad Al-Shamal Industrial City, encompassing a total of 200 workers. To meet the goals of the study, the researcher chose to include the entire population in the sample, resulting in 200 participants. The investigation employed a descriptive-analytical methodology that was deemed suitable for addressing the research questions and problems. Primary data collection relied on questionnaires as the main instrument for the field aspect of the study. The questionnaire items pertaining to the study variables were developed based on insights from existing literature and expert opinions in the field. This data collection tool was selected to gather the necessary field information and was reviewed by a panel of experts to ensure its effectiveness in achieving the objectives of the study.

PLS-SEM, which is excellent for managing research models with many interrelated latent variables (constructs), was used in this study. It is particularly designed to handle complex models with many constructs, indicators, and paths. PLS-SEM provides an effective alternative when examining several direct and indirect variable correlations. Compared to traditional techniques, such as regression or covariance-based SEM (CB-SEM), which frequently struggle with model complexity or require greater sample numbers, this approach is especially beneficial.

4. Data analysis and findings

4.1. Descriptive analysis

Table 1 presents the demographic characteristics of the study participants (N=132). The analysis revealed that the majority of the respondents were male (91.7%, n=121), with female participants representing 8.3% (n=11) of the sample. The age distribution shows that the largest group falls within the 30-40 years range (40.2%, n=53), followed by the 20-30 years (32.6%, n=43), indicating a relatively young workforce. In terms of educational qualifications, high school graduates constituted the largest segment (40.2%, n=53), followed by master's degree holders (30.3%, n=40), bachelor's degree holders (26.5%, n=35), and Ph.D. holders (3%, n=4). The experience profile shows a diverse distribution, with the largest group having 6-10 years of experience (27.3%, n=36), followed by 16-20 years (23.5%, n=31), and ≤5 years (22%, n=29).

Table 2 presents descriptive statistics of the study variables. Continue Trend demonstrates the highest average mean (M=4.320, SD=0.720), suggesting a strong emphasis on maintaining operational continuity. Economic Innovation showed the second-highest average mean (M=4.080, SD=0.820), indicating positive perceptions of innovation practices. Sensitivity to Problems (M=4.060, SD=0.798) and Natural Gas Productivity (M=4.020, SD=0.804) both showed similar mean levels, while acceptance recorded a comparatively lower average mean (M=3.072, SD=0.768). At the item level, NGP5 showed the highest individual mean (M=4.38, SD=0.671), followed by CT3 (M=4.29, SD=0.683), and CT1 (M=4.26, SD=0.672). The lowest mean value was recorded for NGP2 (M=3.87, SD=0.992). The standard deviations ranged from 0.643 to 0.992, indicating a moderate variability in the responses. All means above the scale's midpoint (3.0) suggest generally positive perceptions across all measured constructs.

Table 1: Demographic characteristics of respondents

Characteristic	Category	Frequency	Percent
Gender	Male	121	91.7
	Female	11	8.3
Age	20-30 years	43	32.6
	30-40 years	53	40.2
	40-50 years	28	21.2
	50+ years	8	6.1
Qualification	High school	53	40.2
	Bachelor	35	26.5
	Master	40	30.3
	Ph.D.	4	3.0
Experience	≤5 years	29	22.0
	6-10 years	36	27.3
	11-15 years	22	16.7
	16-20 years	31	23.5
	≥21 years	14	10.6

Table 2: Descriptive statistics of measurement items

Construct	Items	Mean	SD
Economic innovation (average mean: 4.080, average SD: 0.820)	EI1	3.92	0.772
	EI2	4.15	0.805
	EI3	4.14	0.839
	EI4	4.07	0.858
	EI5	4.12	0.811
Sensitivity to problems (average mean: 4.060, average SD: 0.798)	SP1	4.11	0.807
	SP2	4.04	0.860
	SP3	3.92	0.792
	SP4	4.03	0.847
	SP5	4.20	0.682
Continue trend (average mean: 4.320, average SD: 0.720)	CT1	4.26	0.672
	CT2	4.14	0.802
	CT3	4.29	0.683
	CT4	4.17	0.793
	CT5	4.23	0.727
	CT6	4.24	0.643
Acceptance (average mean: 3.072, average SD: 0768)	AC1	4.08	0.721
	AC2	4.03	0.761
	AC3	4.08	0.801
	AC4	4.06	0.789
Natural gas productivity (average mean: 4.020, average SD: 0.804)	NGP1	4.11	0.897
	NGP2	3.87	0.992
	NGP3	4.14	0.729
	NGP4	4.21	0.731
	NGP5	4.38	0.671

1: Strongly disagree to 5: Strongly agree

Demographic analysis revealed a predominantly male workforce (91.7%), with the majority of respondents aged between 30-40 years (40.2%). Educational qualifications were diverse, with high school graduates forming the largest group (40.2%), followed by master's degree holders (30.3%). Most respondents had 6-10 years of experience (27.3%). The descriptive statistics generally indicate positive responses across all constructs, with means ranging from 3.87 to 4.38 on a 5-point scale. The Continue Trend items show consistently high means (4.14-4.29), suggesting a strong emphasis on maintaining operational continuity. Natural Gas Productivity demonstrated the highest individual item mean (NGP5: 4.38), indicating strong perceived productivity outcomes.

4.2. Measurement model analysis

The assessment of the measurement model followed the systematic approach recommended by Hair et al. (2019), which evaluated reliability and validity through multiple criteria. This section presents an analysis of construct reliability, convergent validity, and discriminant validity. The PLS-SEM path model with factor loadings is shown in Fig. 1. The assessment of construct reliability and convergent validity revealed strong psychometric properties across all the constructs. As shown in Table 3 and Fig. 1, all constructs demonstrate excellent internal consistency reliability, with Cronbach's alpha values ranging from 0.897 (acceptance) to 0.946 (Economic Innovation), and composite reliability values ranging from 0.925 to 0.956, well above the recommended threshold of 0.70 (Hair et al., 2019). Additionally, the average variance extracted (AVE) values for all constructs exceeded the critical threshold of 0.50, ranging from 0.690 (continuous trend) to 0.815 (Economic Innovation), indicating strong convergent validity and confirming that each construct explains more than half of the variance in its respective indicators (Fornell and Larcker, 1981).

In Table 3, the analysis of indicator reliability shows strong loadings across all items with values ranging from 0.741 to 0.952, exceeding the recommended threshold of 0.708 (Hair et al., 2019). The Economic Innovation construct demonstrates particularly robust indicator reliability with the highest loadings (EI3: 0.952, EI4: 0.934), while CT2 shows the lowest but still acceptable loading (0.741). All other indicators across the constructs of Acceptance (0.866-0.889), Natural Gas Productivity (0.747-0.930), and Sensitivity to Problems (0.819-0.886) demonstrate strong reliability, confirming the overall quality of the measurement model at the indicator level.

The assessment of discriminant validity employs two key approaches: The Fornell-Larcker criterion and the heterotrait-monotrait ratio (HTMT) of correlations (Hair et al., 2019). Tables 4 and 5 present these results.

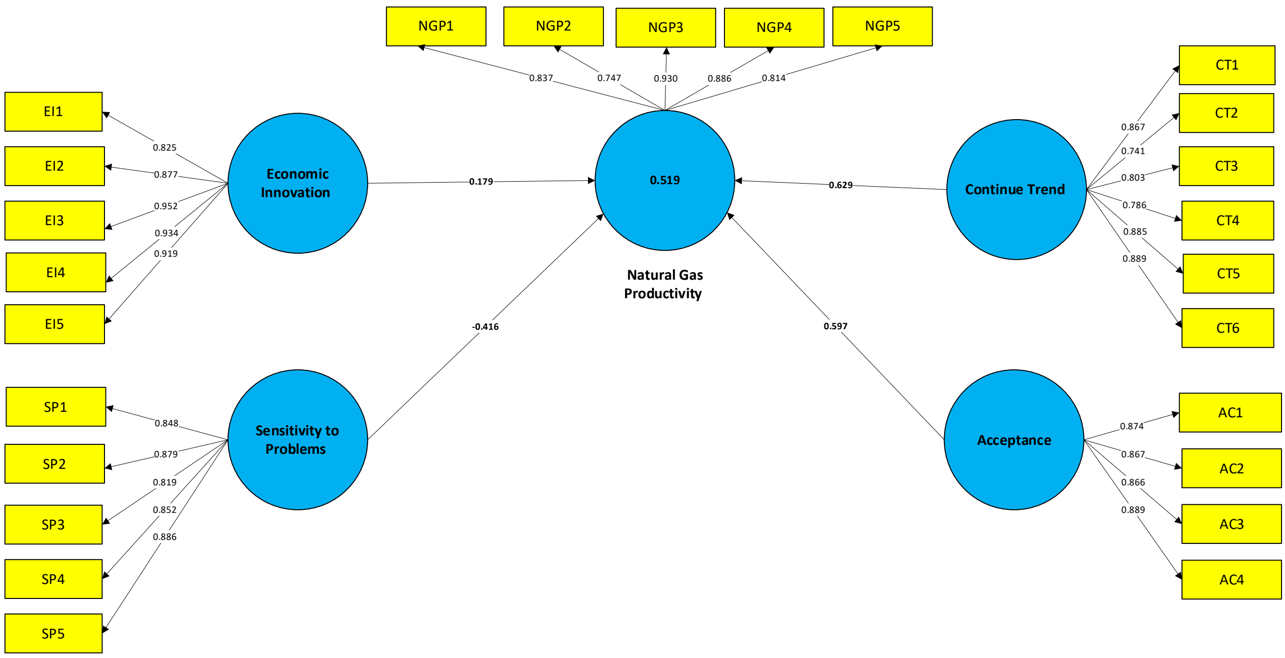

Fig. 1: PLS-SEM path model with factor loadings

Table 3: Measurement model results: factor loadings, reliability, and convergent validity analysis

Indicators	Outer loading	Cronbach's alpha	CR	AVE
AC1	0.874	0.897	0.928	0.764
AC2	0.867			
AC3	0.866			
AC4	0.889			
CT1	0.867	0.915	0.93	0.69
CT2	0.741			
CT3	0.803			
CT4	0.786			
CT5	0.885			
CT6	0.889			
EI1	0.825	0.946	0.956	0.815
EI2	0.877			
EI3	0.952			
EI4	0.934			
EI5	0.919			
NGP1	0.837	0.899	0.925	0.714
NGP2	0.747			
NGP3	0.93			
NGP4	0.886			
NGP5	0.814			
SP1	0.848	0.91	0.933	0.734
SP2	0.879			
SP3	0.819			
SP4	0.852			
SP5	0.886			

Factor loadings > 0.708; Cronbach's alpha > 0.70; CR > 0.70; AVE > 0.50

Table 4: Fornell-Larcker criterion results

Construct	Acceptance	Continue trend	Economic innovation	Natural gas productivity	Sensitivity to probability
Acceptance	**0.874**				
Continue trend	0.742	**0.830**			
Economic innovation	0.654	0.774	**0.903**		
Natural gas productivity	0.645	0.579	0.352	**0.845**	
Sensitivity to probability	0.725	0.850	0.831	0.402	**0.857**

Bold diagonal values represent the square root of AVE

The Fornell-Larcker criterion results demonstrate adequate discriminant validity, as the square root of AVE for each construct (shown in bold on the diagonal) exceeds its correlations with other constructs. However, the HTMT analysis reveals a potential discriminant validity concern between continuous trend and sensitivity to problems (0.965), slightly exceeding the conservative threshold of 0.90 (Gold et al., 2001). All other HTMT values remained within acceptable ranges, suggesting generally satisfactory discriminant validity among the constructs, although the relationship between Economic Innovation and Sensitivity to Problems (0.898) approached the threshold.

4.3 Hypothesis testing results

The results of the hypothesis testing are presented to demonstrate the strength and significance of the proposed relationships between the model constructs, as summarized in Table 6 and visually depicted in Fig. 2.

4.4. Model's explanatory power

The structural model in Table 7 exhibits moderate explanatory power, with an R^2 value of 0.519 (R^2 adjusted=0.504), indicating that approximately 51.9% of the variance in Natural Gas Productivity is explained by the predictor variables (Hair et al., 2019). Analysis of effect sizes reveals that acceptance (f^2=0.309) and continuous trend (f^2=0.193) demonstrate medium effects, while Sensitivity to Problems (f^2=0.070) and Economic Innovation (f^2=0.019) show small effects on Natural Gas Productivity.

Table 5: Heterotrait-Monotrait ratio (HTMT)

Construct	Acceptance	Continue trend	Economic innovation	Natural gas productivity
Continue trend	0.823			
Economic innovation	0.709	0.868		
Natural gas productivity	0.696	0.546	0.319	
Sensitivity to probability	0.791	0.965	0.898	0.414

Table 6: Results of hypothesis testing

Hypothesis	Relationship	Path coefficient (β)	T-value	P-value	95% CI	Decision
H1	Acceptance → Natural gas productivity	0.597	5.494	0.000	[0.381, 0.806]	Supported
H2	Continue trend → Natural gas productivity	0.629	5.406	0.000	[0.395, 0.857]	Supported
H3	Economic innovation → Natural gas productivity	-0.179	1.048	0.295	[-0.544, 0.129]	Not Supported
H4	Sensitivity to problems → Natural gas productivity	-0.416	2.238	0.025	[-0.756, -0.036]	Supported

T-values > 1.96 indicate significance at $p < 0.05$; T-values > 2.58 indicate significance at $p < 0.01$

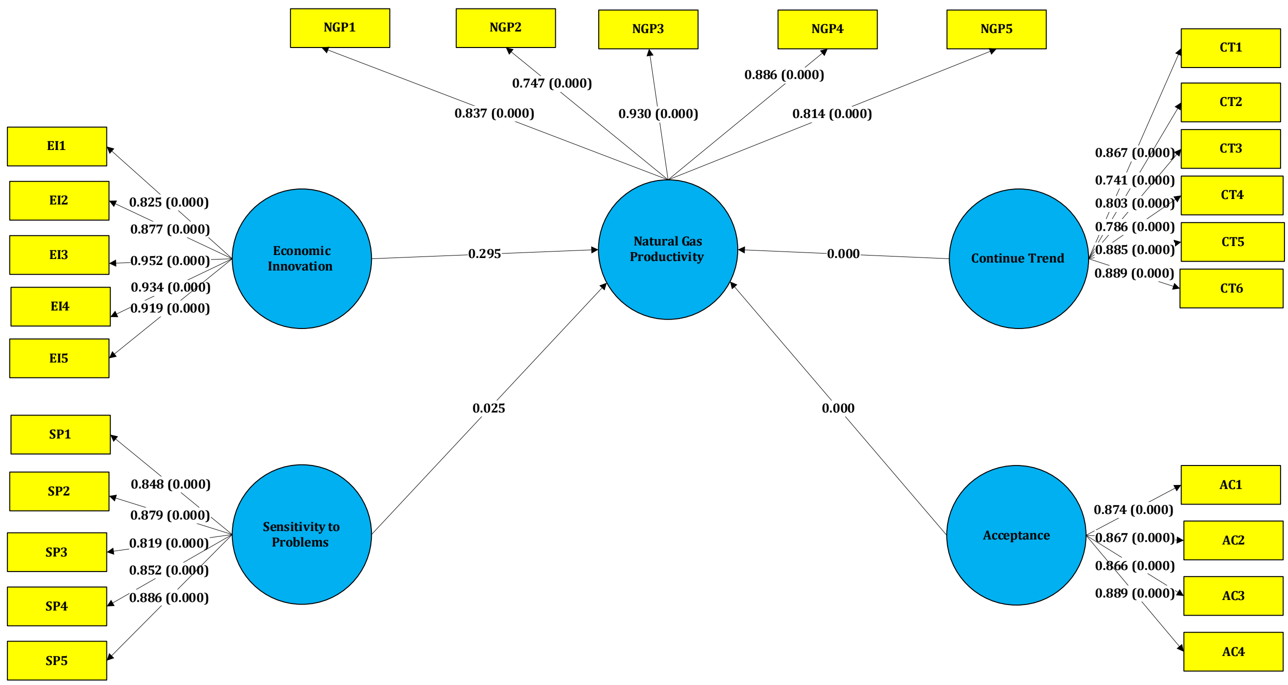

Fig. 2: LS-SEM path model with factor loadings and p-values (in parentheses)

4.5. Predictive relevance

The predictive power of the model was evaluated using Stone-Geisser's Q^2 value and PLSpredict metrics (Table 8). The Q^2 value for Natural Gas Productivity (0.355) exceeded the threshold of 0, indicating a medium predictive relevance (Hair et al., 2019).

The PLSpredict assessment showed that all indicators demonstrated positive Q^2_predict values ranging from 0.170 to 0.495, with NGP3 showing the highest predictive power (Q^2_predict=0.495) and NGP2 showing the lowest (Q^2_predict=0.170). These results confirm the model's out-of-sample predictive power for natural-gas productivity.

Table 7: Effect sizes (f^2)

Predictor	f^2 value	Effect size
Acceptance	0.309	Medium
Continue trend	0.193	Medium
Economic innovation	0.019	Small
Sensitivity to problems	0.070	Small

Effect size thresholds: 0.02 (small), 0.15 (medium), and 0.35 (large)

Table 8: Prediction metrics for natural gas productivity indicators

Indicator	RMSE	MAE	MAPE	Q^2_predict
NGP1	0.781	0.556	16.712	0.248
NGP2	0.908	0.709	22.246	0.170
NGP3	0.521	0.412	10.544	0.495
NGP4	0.548	0.428	11.003	0.445
NGP5	0.561	0.434	10.790	0.308

5. Discussion

Table 6 and Fig. 2 show that the results of the hypothesis testing reveal several significant relationships between the study variables. H1, which proposed a positive relationship between Acceptance and Natural Gas Productivity, is strongly supported (β=0.597, t=5.494, p<0.001). The positive and significant path coefficient, along with the confidence interval [0.381, 0.806] not containing zero, provides robust evidence for this relationship. H2, which predicts a positive relationship between continuous trends and natural gas Productivity, is also strongly supported (β=0.629, t=5.406, p<0.001). The confidence interval [0.395, 0.857] demonstrated the stability of this relationship. This represents the strongest effect among all the hypothesized relationships, suggesting that continuous improvement and trend maintenance are crucial for productivity enhancement in natural gas operations. H3, which hypothesized a positive relationship between Economic Innovation and Natural Gas Productivity, was not supported (β=-0.179, t=1.048, p=0.295).

The confidence interval [-0.544, 0.129] was zero, indicating a non-significant relationship. This unexpected finding suggests that economic innovation might have a more complex relationship with productivity than initially theorized. H4, proposing a positive relationship between Sensitivity to Problems and Natural Gas Productivity, shows a significant but negative relationship (β=-0.416, t=2.238, p<0.025).

While the relationship is statistically significant, as evidenced by the confidence interval [-0.756, -0.036], not containing zero, the negative direction is contrary to the hypothesized positive relationship. This finding warrants further investigation, as it suggests that higher sensitivity to problems might impede productivity, possibly due to increased caution or risk-averse behavior in operations. The overall model explains a substantial portion of the variance in Natural Gas Productivity (R^2=0.519, adjusted R^2=0.504), indicating that these factors collectively account for approximately 52% of the variation in productivity outcomes. This suggests that, while the model captures important determinants of natural gas productivity, there might be other relevant factors not included in the current study.

6. Conclusion

The significance of this study lies in its examination of economic innovation as an interconnected system of elements, including data collection, analysis, processing, and retrieval, which contributes to efficient and effective planning within the innovation process. The study's outcomes and suggestions are anticipated to aid in interpreting previous research findings on related topics and to reinforce the results of the current study. It aims to inspire researchers to focus on future investigations of the variables explored and verify their findings. The practical value of this research stems from its potential to benefit Saudi Arabia by enhancing natural gas productivity in the Waad Al-Shamal Industrial City and fostering a culture of economic innovation. This study's importance is further underscored by its scientific approach to examining the application of economic innovation in natural gas productivity within an industrial city. It is expected to highlight the necessity for institutions to implement economic innovation, a contemporary approach that motivates employees and guides them towards goal achievement. Furthermore, the study emphasizes the need to raise awareness of the importance of economic innovation across Saudi Arabia, promoting an understanding of its role in improving natural gas productivity.

Recent research, including an examination of Saudi Arabia's natural gas industry, highlights the pivotal role of technological innovation in enhancing productivity. Scholars contend that advancements in artificial intelligence, automation, and digital technologies boost efficiency across various industries, with Saudi Arabia specifically addressing this in the context of natural gas, a crucial energy source. Saudi research's emphasis on resource management aligns with the contemporary models of sustainable innovation. For instance, the circular economy concept underscores how innovation can enhance resource utilization, minimize waste, and promote sustainability. This study contributes to broader innovation theories that view resource optimization as a key factor in innovation-driven productivity gains.

This study advances the understanding of innovation in the energy sector by illustrating how economic innovation, through technological progress and effective policies, can significantly improve natural gas production efficiency. It mirrors many findings from broader innovation-driven productivity models while providing deeper insights into the specific dynamics of the energy industry, particularly in a resource-rich nation such as Saudi Arabia. This study contributes to both theoretical and practical knowledge of how innovation drives productivity improvements in the energy sector and may offer valuable lessons for other countries and industries seeking to enhance their energy productivity.

List of abbreviations

PLS-SEM	Partial least squares structural equation modeling
CB-SEM	Covariance-based structural equation modeling
AVE	Average variance extracted
CR	Composite reliability
SD	Standard deviation
N	Number (sample size)
EI	Economic innovation
SP	Sensitivity to problems
CT	Continue trend
AC	Acceptance
NGP	Natural gas productivity
RMSE	Root mean square error
MAE	Mean absolute error
MAPE	Mean absolute percentage error
Q^2	Stone-Geisser's Q^2 (predictive relevance)
Q^2_predict	Stone-Geisser's Q^2 for a specific indicator
HTMT	Heterotrait-monotrait ratio
T-value	Test statistic (from hypothesis testing)
β	Path coefficient
CI	Confidence interval
R^2	Coefficient of determination
f^2	Effect size

Acknowledgment

The authors would like to thank the Deanship of Graduate Studies and Scientific Research at Jouf University for funding and supporting this research through the initiative of DGSR Graduate Studies Research Support (GSR) at Jouf University, Saudi Arabia.

Compliance with ethical standards

Ethical considerations

This study involved voluntary, anonymous survey responses from adult participants. Participation was entirely voluntary, and informed consent was obtained from all individuals. The study complied with relevant ethical standards and posed no risk of harm to participants.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Alsulamy N, Shoukat A, and Elgammal I (2025). Business strategies for managing non-renewable energy dynamics in Saudi Arabia's manufacturing sector. Sustainability, 17(10): 4331. https://doi.org/10.3390/su17104331

Arnold-Keifer S, Hirzel S, and Rohde C (2025). Integrating the assessment of environmental costs and the non-energy benefits of energy efficiency into an energy demand analysis of the tertiary sector. Energies, 18(9): 2354. https://doi.org/10.3390/en18092354

Benhacene HLM and Hussien AM (2025). The impact of adopting renewable energy resources on sustainable development in Saudi Arabia: A qualitative view. Sustainability, 17(2): 768. https://doi.org/10.3390/su17020768

Caragliu A and Del Bo CF (2019). Smart innovative cities: The impact of smart city policies on urban innovation. Technological Forecasting and Social Change, 142: 373-383. https://doi.org/10.1016/j.techfore.2018.07.022

Fornell C and Larcker DF (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, 18(1): 39-50. https://doi.org/10.1177/002224378101800104

Gold AH, Malhotra A, and Segars AH (2001). Knowledge management: An organizational capabilities perspective. Journal of Management Information Systems, 18(1): 185-214. https://doi.org/10.1080/07421222.2001.11045669

Hair JF, Risher JJ, Sarstedt M, and Ringle CM (2019). When to use and how to report the results of PLS-SEM. European Business Review, 31(1): 2-24. https://doi.org/10.1108/EBR-11-2018-0203

Himri Y, Rehman S, Mostafaeipour A, Himri S, Mellit A, Merzouk M, and Merzouk NK (2022). Overview of the role of energy resources in Algeria's energy transition. Energies, 15(13): 4731. https://doi.org/10.3390/en15134731

Howells J, Ramlogan R, and Cheng SL (2012). Universities in an open innovation system: A UK perspective. International Journal of Entrepreneurial Behavior & Research, 18(4): 440-456. https://doi.org/10.1108/13552551211239483

Lubis M and Muniapan B (2024). International market development strategies for enhancing global expansion in the export industry. Involvement International Journal of Business, 1(1): 14-28. https://doi.org/10.62569/iijb.v1i1.3

Sharif A, Aloui C, and Yarovaya L (2020). COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: Fresh evidence from the wavelet-based approach. International Review of Financial Analysis, 70: 101496. https://doi.org/10.1016/j.irfa.2020.101496 **PMid:38620230 PMCid:PMC7227524**

Yoo I and Yi CG (2022). Economic innovation caused by digital transformation and impact on social systems. Sustainability, 14(5): 2600. https://doi.org/10.3390/su14052600