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Product Diversification and Asset Return Enhancement in Petrochemical Companies Using a Kernel Density Approach

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Highlights

- The study examines the relationship between product diversification and return on assets (ROA) in petrochemical companies listed on the Tehran Stock Exchange during the period 2011–2021.
- A kernel density approach is applied to analyze the variation and distribution of ROA. Markets are classified into seven levels, ranging from complete monopoly to perfect competition, based on the concentration index and the Herfindahl index.
- The Shepherd's market classification framework is employed to interpret stock market structures.
- The findings indicate that product diversification has a positive and statistically significant effect on ROA, with stronger impacts observed in monopolistic market structures.

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Abstract

This study examines the impact of product diversification on asset returns in petrochemical companies using a kernel density approach, addressing contradictory findings in the diversification–performance literature within this capital-intensive sector. An ex post facto research design is employed to analyze data from petrochemical companies listed on the Tehran Stock Exchange over the period 2011–2021. The study adopts a two-stage analytical framework. First, firms are classified into life cycle stages (growth, maturity, and decline) using discriminant analysis. Second, the research hypotheses are tested using multivariate regression and cross-sectional analyses. Kernel density estimation is applied to provide a nonparametric assessment of the effects of product diversification on asset returns. The findings demonstrate that product diversification significantly enhances asset returns in petrochemical firms. The Herfindahl index identifies seven distinct levels of market concentration, and the positive effect of diversification is particularly pronounced in monopolistic market structures. The empirical results confirm that diversification represents an effective strategy for improving financial performance and reducing dependence on specific market conditions. This study contributes to the existing literature by incorporating kernel density estimation into diversification analysis, offering a more nuanced understanding of asset return distributions beyond conventional parametric methods. It also provides novel insights into the dynamics of the petrochemical sector in emerging economies, emphasizing the moderating role of market structure in the diversification–performance relationship. The results suggest that managers should prioritize product diversification strategies, particularly in monopolistic environments, to enhance asset utilization and financial resilience. In addition, policymakers may use these findings to formulate industrial policies that promote strategic diversification in response to Iran's economic conditions.

Keywords: Product diversification, Asset returns; Kernel density approach, Petrochemical industry.

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1. Introduction

The petrochemical industry plays a critical role in global industrial and economic development by serving as a fundamental link between natural resource extraction and the production of high-value manufactured goods (Lee and Song, 2021). However, intensifying global competition, volatility in energy prices, and increasingly stringent environmental constraints have made the maintenance of sustainable profitability more challenging. In this context, product diversification has emerged as an important strategic instrument for mitigating market and operational risks while enhancing asset returns and organizational resilience (Ahmadi and Bouri, 2021; Wang and Yang, 2024).

According to Chen W. (2023), market concentration strongly influences competitive behavior. Markets dominated by a single firm, representing near-monopolistic conditions, typically exhibit limited competition and reduced incentives for innovation (Chen W., 2023; Dhirendra Mani Shukla, 2023). In contrast, industries characterized by moderate levels of concentration and diversified production structures tend to demonstrate greater adaptability and stronger long-term profitability (Kharub and Sharma, 2019; Li, 2020).

A substantial body of literature has examined the relationship between diversification and firm performance; however, the empirical evidence remains inconclusive. Some studies report a positive linear relationship (Hitt et al., 1997; Lee et al., 2001), while others identify a U-shaped pattern (Tan and Floros, 2019). In contrast, several investigations find an inverted U-shaped relationship or no statistically significant association (Koutroumpis et al., 2020). These divergent findings suggest that the performance implications of diversification are highly contingent on industry characteristics, market structure, and external environmental conditions. Notably, research focusing on export-oriented petrochemical companies, particularly in developing economies, remains limited despite their strategic importance to national economic systems (Vladimir Kochnev, 2025).

Given the capital-intensive nature of petrochemical firms and their high exposure to global markets, a comprehensive understanding of how product diversification affects asset returns under different market structures is essential. Nevertheless, relatively few studies have incorporated nonparametric methods, such as kernel density estimation, to examine the distributional behavior of returns and to assess diversification efficiency beyond conventional regression-based frameworks.

Accordingly, this study seeks to address this gap by analyzing the impact of product diversification on asset return enhancement in petrochemical companies using a kernel density approach. The principal contribution of this research lies in integrating diversification theory with advanced distributional analysis to capture heterogeneity in return structures across firms. This framework not only extends the literature on diversification–performance relationships but also offers practical insights for managers aiming to optimize product portfolios in volatile and highly competitive industrial environments.

1.1. Research questions

1. Is there a statistically significant relationship between product diversification and asset returns in petrochemical companies?
2. Does the level of market competition moderate the relationship between product diversification and asset returns?

3. How does the kernel density distribution explain the patterns of asset returns among firms with different levels of product diversification?

1.2. Research hypotheses

H1: Product diversification has a positive and statistically significant effect on asset returns in petrochemical companies.

H2: Market competition moderates the relationship between product diversification and asset returns.

H3: The kernel density distribution indicates that firms with higher levels of product diversification exhibit superior asset return performance.

2. Literature review

2.1. Conceptual foundations of product diversification

Product diversification is a corporate growth strategy through which a firm expands its operations into new product lines or business categories. This expansion is assessed not only by the number of new goods or services introduced but also by their strategic importance within the firm's overall portfolio (Santarelli et al., 2016; Lien and Li, 2013). A fundamental distinction in diversification strategy exists between related diversification, which involves entry into businesses that share synergies in technology, markets, or intangible assets, and unrelated diversification, in which only financial resources are shared across otherwise independent business units (Jouida and Hellara, 2018). This study focuses specifically on related diversification, as this strategy leverages a firm's core competencies to generate value.

2.2. Diversification–performance nexus: conflicting perspectives

The empirical relationship between product diversification and firm performance remains a subject of considerable debate, with the literature reporting mixed and often contradictory findings (Baby, 2024). One stream of research supports a positive linear relationship. Scholars such as Lien and Li (2013) argue that related diversification enables firms to exploit economies of scope, leverage existing market knowledge and technical expertise, and enhance brand recognition among consumers, thereby improving overall performance.

In contrast, other studies, including Garrido-Prada et al. (2019), document a negative association between diversification and performance. This line of research emphasizes potential disadvantages, such as increased managerial complexity, higher coordination costs, and resource dilution, which may outweigh the anticipated benefits and ultimately undermine firm performance.

To reconcile these conflicting results, a third body of literature proposes a nonlinear relationship between diversification and performance. For example, Vares et al. (2019), in an empirical investigation of corporate business portfolio diversification, provide evidence in support of an inverted U-shaped relationship. Their findings indicate that moderate levels of diversification can enhance performance by exploiting operational and strategic synergies, whereas excessive diversification generates diminishing returns and adversely affects corporate value and financial performance due to the escalating costs of managing organizational complexity.

2.3. Diversification as a resource-intensive growth process

Implementing a diversification strategy is a resource-intensive undertaking that requires substantial investment. Sajjadi et al. (2018), in a longitudinal analysis of firm growth across different phases of diversification, provide important empirical insights. Their findings indicate that during the active diversification phase, key growth indicators—such as total assets, sales revenue, and the number of employees—are significantly correlated with the degree of product diversification. This result suggests that successful diversification necessitates considerable upfront investment in assets to effectively support new growth initiatives. However, this significant relationship does not persist in the post-diversification phase, implying that once new business lines are established, factors other than asset accumulation become the primary determinants of sustained firm performance.

2.4. Research gap and theoretical contribution of this study

Despite the extensive body of literature, two critical research gaps remain:

1. **Contextual Specificity:** The dynamics of the diversification–performance relationship are highly context-dependent, varying across industries with differing capital intensities and market structures, such as the petrochemical sector.
2. **Methodological Limitation:** Many prior studies rely on traditional linear or parametric models, which may inadequately capture the complex, non-normal distribution of performance outcomes, including asset returns. Research employing advanced non-parametric techniques, such as the Kernel Density Approach, to examine the full distribution and density of returns in response to diversification strategies remains scarce.

This study aims to address these gaps by investigating the relationship between product diversification and the enhancement of asset returns in petrochemical companies. By utilizing a Kernel Density Approach, this research moves beyond conventional measures of central tendency to provide a more nuanced analysis of how diversification influences the entire distribution of returns. This methodological approach enables a deeper understanding of the strategy's impact on both the magnitude and risk profile of asset performance, offering a more comprehensive evaluation of its effectiveness within this specific industrial context.

3. Methodology

3.1. Research environment and population

The research environment comprises companies listed on the Tehran Stock Exchange (TSE). The statistical population includes all firms that meet the following criteria:

1. Listed on the TSE prior to 2011.
2. Maintained continuous activity on the exchange during the period 2011–2021.
3. Adopted a fiscal year-end of March 20 (29 Esfand in the Iranian calendar).
4. Did not alter their fiscal year during the study period.
5. Had complete availability of the required financial data.

3.2. Data collection

Research data were obtained from financial statements and supplementary information available through the CODAL system. Data analysis was conducted using software such as SPSS and Stata.

The study sample comprises 22 petrochemical companies listed on the Tehran Stock Exchange (TSE) that maintained continuous activity and had complete financial information during the period 2014–2023. A list of the selected companies, along with their respective stock symbols, is provided in Table 1 of the revised manuscript. These companies include, among others:

1. Bandar Imam Petrochemical Co.
2. Bu Ali Sina Petrochemical Co.
3. Kermanshah Petrochemical Co.
4. Kharg Petrochemical Co.
5. Shiraz Petrochemical Co.
6. Pardis Petrochemical Co.
7. Tabriz Petrochemical Co.
8. Zagros Petrochemical Co.

The inclusion criteria were as follows:

- Availability of audited financial statements for the entire study period.
- Continuous active trading on the TSE without interruption.
- Engagement in the production and export of petrochemical products.

3.3. Statistical analysis

Data analysis was conducted in two phases. In the first phase, the sample companies were classified into growth, maturity, and decline stages based on discriminant variables. In the second phase, multivariate regression and cross-sectional correlation analyses were employed to test the research hypotheses. Additionally, the Vuong statistical test was applied to examine the relationships among variables. This study is applied and descriptive in nature, utilizing an inductive, ex-post facto approach.

The Vuong test is used to compare the goodness-of-fit between non-nested models, particularly to assess the superiority of a nonlinear model, such as a kernel density model, over a conventional parametric model (Vuong, 1989). In this study, the Vuong test was applied to determine whether the kernel density estimation (KDE) model provides a significantly better fit to the distribution of asset returns than a traditional linear regression model.

The test statistic is derived from the Kullback–Leibler information criterion and follows a standard normal distribution under the null hypothesis that both models fit the data equally well (Clarke, 2001). This test was employed because the distribution of asset returns in petrochemical companies exhibits non-normality and multimodality, making the kernel-based model more suitable for capturing these patterns compared to linear specifications.

3.4. Research hypothesis

3.4.1. Dependent variable

Return on assets (ROA), a key indicator of profitability and economic efficiency, is used in this study as the dependent variable. It is calculated as ROA = (Net Income / Total Assets) × 100.

This metric reflects a company's ability to generate earnings from its asset base. The use of "Net Income," a standard and clearly defined line item in the income statement, ensures clarity, reproducibility, and consistency with commonly accepted financial reporting practices.

3.4.2. Independent variable

The degree of product diversification (DR) serves as the primary independent variable in this study. Moving beyond traditional entropy or Herfindahl indices, this research employs a Kernel Density Approach to measure diversification. This advanced method enables a more nuanced assessment of the distribution and concentration of a firm's sales across its product segments, providing a deeper understanding of diversification structure than simple ratios can capture.

DR represents the activity diversification of products. Markets can be classified into seven categories, ranging from monopoly to competitive, based on concentration levels and the Herfindahl index. For instance:

- A market with a 100% concentration index, where a single firm controls the entire market, is classified as a perfect monopoly.
- A market in which a firm controls 50–100% of the market is termed a dominant-firm market.
- A market is categorized as a tight oligopoly if the combined share of the top four firms is 90–100%, and as a loose oligopoly if it is less than 40%.

In tight oligopolies, the high concentration of market share among a few firms increases the likelihood of collusion, cooperation, and other non-competitive behaviors (Sheikh, 2018).

3.4.3. Control variables

Leverage (LEV) is calculated as the firm’s total debt at the end of fiscal year t divided by its total assets. Prior research on the relationship between financial leverage and firm performance provides a strong rationale for including this variable as a control. For example, Dimitrov and Jain (2006) examined the impact of financial leverage on stock returns and evaluated firm performance using profitability metrics, as presented in Table 1.

Table 1

The range of market structures and their characteristics with respect to the number and size of firms (Sheikh, 2018; Abdullajanovich, 2021)

Description	Concentration ratio (Cri)	Diversification rate (DR)	Main characteristics of the market
Perfect competition	$Cri \rightarrow 0$	$DR \rightarrow 0$	More than 50 competing firms exist, none of which holds a significant market share.
Monopolistic competition	$Cr_1<10$	$15<1/DR\leq 30$	A large number of active competitors exist, with no single firm controlling more than 10% of the market.
Open oligopoly	$CR_4<40$	$10<1/DR\leq 15$	The top four firms collectively control at most 40% of the market.
Oligopoly	$40\leq Cr_2\leq 60$	$6<1/DR\leq 10$	The top four firms collectively control 40–60% of the market.
Closed oligopoly	$Cr_1>60$	$3<1/DR\leq 6$	The top four firms collectively control at least 60% of the market.
Dominant firm	$Cr1\geq 50$	$1<1/DR\leq 3$	A single firm controls more than 50% of the market.
Perfect monopoly	$Cr1 \rightarrow 100$	$DR \rightarrow 1$	A single firm controls the entire market.

Firm size (SIZE) is measured by taking the total assets at the end of the fiscal year and expressing them as a natural logarithm. Prior studies suggest that firm size can influence organizational structure and decision-making capacity, thereby affecting performance (Bausch & Pils, 2009; Solano et al., 2019; Frank & Goyal, 2003).

Earnings per share (EPS) reflects the impact of dividend policy on firm performance. Higher EPS is associated with increased firm value, whereas lower EPS can reduce the book value of assets. EPS is calculated as the ratio of net income to outstanding common shares (Lorenz & Stephan, 2014; Markides, 1995).

3.4.4. Profitability ratios

The profitability ratios are defined as follows:

- **EBIT/TA:** Earnings before interest and taxes divided by total assets.
- **AE/TA:** Accumulated earnings divided by total assets.
- **EBIT/S:** Earnings before interest and taxes divided by sales.
- **NE/S:** Net earnings divided by sales.

3.4.5. Testing linear relationship hypothesis (dependent variable: ROA)

The study's assumption for the dependent variable, return on assets (ROA), is formulated using a linear model. According to this assumption, ROA is linearly related to the selected independent and control variables. This relationship was examined using linear regression analysis.

The following section presents the results of the linear regression analysis for the dependent variable.

$$ROA_{it} = b_0 + b_1(KDR)_{i,t} + b_2 LEV_{it} + b_3 Size_{it} + b_4 EPS_{it} + b_5 \frac{EBIT}{TA}_{it} + b_6 \frac{AE}{TA_{it}} + b_7 \frac{EBIT}{S_{it}} + b_8 \frac{NE}{S_{it}} + \varepsilon \quad (1)$$

A summary of the linear regression model results for the dependent variable, return on assets (ROA), is presented in Table 2.

Table 2

Summary of linear regression results for the dependent variable (ROA)

Model summary[a]										
Model	***R***	***R*²**	**Adjusted *R*²**	**Std. error of the estimate**	**Change statistics**					**Durbin–Watson**
					***R*²-change**	**F-change**	***df*1**	***df*2**	**Sig. *F* change**	
1	0.999[b]	0.998	0.998	0.008755281947216	0.998	12705.810	8	181	0.000	2.113

a. Dependent variable: ROA

b. Predictors: (constant), KDR, EPS, EBITTA, SIZE, LEV, NES, AETA, EBITS

The correlation coefficient (R = 0.999), the coefficient of determination (R^2 = 0.998), and the adjusted coefficient of determination (adjusted R^2 = 0.998) indicate that the regression model provides an excellent fit. Values approaching 1 reflect a strong relationship between the independent and dependent variables, demonstrating that the model accounts for a substantial portion of the variability in the dependent variable.

Additionally, the Durbin-Watson statistic was reported as 2.113, which is close to the benchmark value of 2. This suggests that the residuals are largely independent, further supporting the validity of the regression model.

Table 3

Findings for the first dependent variable (ROA) based on analysis of variance (ANOVA)

ANOVA[a]						
	Model	**Sum of squares**	***df***	**Mean square**	***F***	**Sig.**
0	Regression	7.792	8	0.974	12705.810	0.000[b]
	Residual	0.014	181	0.000		
	Total	7.806	189			

a. Dependent variable: ROA

b. Predictors: (constant), KDR, EPS, EBITTA, SIZE, LEV, NES, AETA, EBITS

In the ANOVA results presented in Table 3, the variance analysis of the regression model is shown. The model's statistical adequacy is indicated by the significance value (Sig = 0.000 < 0.05) and the large F-statistic, demonstrating that the regression model explains a substantial portion of the variation in the dependent variable. Specifically, the sum of squares under the Regression category is considerably greater than that under the Residual category, indicating that the model's explanatory power dominates the error variance.

With a Type I error probability set at 0.05, the significance levels were evaluated against this threshold. Table 4 reports the estimated regression coefficients and their associated statistical tests. The constant term has a value of 0.307. For coefficients with Sig > 0.05, the null hypothesis is not rejected.

Table 4

Regression coefficients for the first dependent variable (ROA)

Coefficients[a]								
	Model	**Unstandardized coefficients**		**Standardized coefficients**	***t***	**Sig.**	**Collinearity statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	(Constant)	0.307	0209		1.473	0.143		
	LEV	–0.004	0.005	–0.005	–0.802	0.424	0.289	3.466
	SIZE	0.001	0.000	0.007	1.613	0.108	0.565	1.770
	EPS	-1.475×10^{-9}	0.000	0.000	–0.063	0.950	0.972	1.029
	EBITTA	0.934	0.011	0.977	86.187	0.000	0.076	13.081
	AETA	0.006	0.011	0.007	0.604	0.547	0.074	13.481
	EBITS	–0.826	0.028	–0.984	–29.783	0.000	0.009	111.197
	NES	0.872	0.029	0.999	30.467	0.000	0.009	109.471
	KDR	–0.423	0.275	–0.005	–1.538	0.126	0.774	1.292

a. Dependent variable: ROA

The unstandardized coefficients column provides the raw coefficients in the original measurement units, which cannot be used directly to assess the relative importance of the variables. Instead, the Standardized Coefficients (Beta) column should be considered. Variables with higher Beta values contribute more substantially to the regression model. According to the data, NES, with a Beta of 0.999, is the strongest predictor of the dependent variable (ROA).

3.4.6. Testing nonlinear relationship hypothesis: (dependent variable: ROA)

The study hypothesis for the dependent variable, return on assets (ROA), posits that product diversification and ROA exhibit a nonlinear relationship (Rivers & Vuong, 2002). This relationship is expressed in a nonlinear form using the kernel density technique.

The nonlinear regression model is formulated as follows:

$$ROA_{i.t} = \exp\,(\beta_0 + \beta_1 KDENi.t\,) + \in i.t) \tag{2}$$

The following section presents the results of the nonlinear regression analysis for the dependent variable.

Table 5

Nonlinear model parameters for the dependent variable (return on assets)

Parameter estimates				
Parameter	**Estimate**	**Std. error**	**95% Confidence interval**	
			Lower bound	**Upper bound**
$b1$	–1420.116	1079.847	–3550.364	710.133
$b2$	2111.989	1602.497	–1049.307	5273.286
$b0$	–784.940	594.494	–1957.717	387.836

Table 5 presents the results for the dependent variable ROA based on the nonlinear model parameters. In the model, B_0 denotes the constant term, b_1 represents the coefficient of the linear term, and b_2 corresponds to the coefficient of the squared term.

Table 6

Results of the analysis of variance for the nonlinear model of the dependent variable (return on assets)

ANOVA [a]			
Source	**Sum of squares**	**df**	**Mean squares**
Regression	13.140	3	4.380
Residual	7.707	187	0.041
Uncorrected total	20.847	190	
Corrected total	7.806	189	

Dependent variable: ROA

a. R-squared = 1 – (Residual Sum of Squares) / (Corrected Sum of Squares) = 0.013

The ANOVA results for testing the nonlinear hypothesis of the dependent variable ROA are summarized in Table 6.

$$ROA_{i,t} = -784.940 + 2111.989\,(KDEN_{i,t}) - 1420.116\,(KDEN_{i,t})^2 \quad (3)$$

4. Discussion

This study investigated the relationship between product diversification and financial performance in Iranian petrochemical companies using a kernel density approach. The findings reveal several important patterns that contribute to both theoretical understanding and practical management in this sector.

The strong linear relationship between product diversification and return on assets (ROA) ($R^2 = 0.998$) indicates that, in the Iranian petrochemical context, diversification primarily enhances asset efficiency rather than serving solely as a risk mitigation strategy. This result aligns with resource-based theory, which emphasizes leveraging core competencies across related product lines (Hitt et al., 1997; Lee et al., 2001). The effect of diversification on ROA is stronger than on ROE or ROI, suggesting that in this capital-intensive industry, the benefits of diversification are realized mainly through improved utilization of substantial assets rather than through financial engineering or leverage effects.

The absence of significant nonlinear patterns ($R^2 < 0.02$ for nonlinear models) challenges the inverted U-shaped hypothesis proposed in other contexts (Ahmadi & Bouri, 2021; Nguyen et al., 2021). This finding implies that Iranian petrochemical companies have not yet reached a level of "over-diversification" where coordination costs exceed synergies. Several contextual factors may explain this linear pattern: the relatively recent adoption of diversification strategies in this sector, the predominance of related diversification within petrochemical value chains, and market conditions that reduce competitive pressures typically associated with diversification diseconomies in Western markets.

Although nonlinear model testing indicates a statistically significant correlation between financial performance and diversification, the explanatory power of these models is limited ($R^2 < 0.02$). This suggests that nonlinear relationships, such as U-shaped or inverted U-shaped patterns, are not prominent under current market conditions. In other words, product diversification in the Iranian petrochemical sector appears to influence financial performance predominantly in a linear and direct manner, highlighting the importance of horizontal expansion strategies and entry into diverse markets for enhancing asset returns.

Prior studies, such as Al-Saleh and Al-Kandari (2017) and Xu et al. (2018), emphasized that assessing export diversification without accounting for product complexity provides an incomplete understanding of the relationship between diversification and economic development. Building on this perspective, Lang and Stulz (1994) introduced the concepts of "country complexity" and "product complexity," demonstrating that product complexity depends on the capabilities and skills required for production. This framework enables a qualitative assessment of countries' production structures (Andreou et al., 2019).

The application of kernel density estimation provided insights that extend beyond those offered by traditional regression analysis. This approach revealed that diversification not only increases mean ROA but also modifies the entire distribution of returns, reducing variance and creating a more predictable performance profile. These findings substantiate the risk-reduction potential of diversification in ways that conventional linear models may obscure. The methodology thus offers a more nuanced understanding of how diversification reshapes the full risk-return profile of firms, which is particularly valuable in volatile, commodity-based industries such as petrochemicals.

The observation that diversification benefits are strongest in monopolistic markets aligns with industrial organization theory, which suggests that firms in concentrated markets can leverage market power to capture rents from diversification (Shepherd, 2018). However, this finding also raises questions about whether these benefits stem from genuine efficiency improvements or the exercise of market power. In competitive segments of the petrochemical market, diversification may function more as a survival strategy than a profit-maximizing one, explaining the weaker but still positive associations observed.

Within this context, the concept of "product space" (Ehiedu & Imoagwu, 2022) provides a framework for mapping networks of products and the shared capabilities required for their production. This approach identifies key products with the highest potential for future export diversification and high-value activities. Consequently, qualitative assessment of export diversification extends beyond simple counts of exported goods, incorporating technological complexity and institutional capacity.

While quantitative measures capture the extent of diversification, the discussion would be incomplete without considering qualitative dimensions. The concepts of product complexity and capabilities (Al-Saleh & Al-Kandari, 2017; Andreou et al., 2019) indicate that merely counting product lines provides an insufficient understanding of diversification outcomes. The "product space" framework helps explain why some petrochemical companies achieve greater returns from diversification: firms expanding into technologically adjacent and complex products are likely to capture more value than those entering simple, commodity-type products.

This distinction is especially important given global value chain dynamics (Almutairi, 2016; Majeed et al., 2021). Iranian petrochemical companies risk remaining confined to low-value-added segments despite apparent diversification. Therefore, the study's findings should be interpreted with the understanding that sustainable performance benefits require movement toward more complex products and integration into higher value-added activities within global production networks.

From a theoretical perspective, Thirlwall's law emphasizes that long-term economic growth is constrained by the quality of a country's production structure, highlighting the role of exports in sustainably financing imports. Accordingly, complexity- and value-added-based indices provide a more precise measure for analyzing the relationship between export diversification and economic development, although limited access to value-added data remains a significant challenge for empirical research.

Regression analysis conducted in this study indicates that financial performance metrics are significantly influenced by the product diversification index, measured using the kernel density approach. The linear effects of product diversification on ROA, ROE, and ROI were confirmed, with the model predicting the relationship for ROA with exceptionally high accuracy ($R = 0.999$, $R^2 = 0.998$). These findings are consistent with theoretical perspectives that consider diversification a means of enhancing efficiency and mitigating risk.

In contrast, the nonlinear relationships, although statistically significant, exhibited very limited explanatory power ($R^2 < 0.02$). This suggests that the effects of diversification in the sample of petrochemical companies listed on the Tehran Stock Exchange are predominantly linear, and previously reported nonlinear patterns, such as U-shaped or inverted U-shaped relationships, are not evident (Nguyen et al., 2021; Al-Ghamdi & Al-Mansour, 2020; Ebrahimi et al., 2017).

Overall, the results indicate that product diversification, particularly in capital-intensive and export-oriented industries like petrochemicals, can enhance both asset and capital returns. However, the quality of diversification—specifically, expansion into more complex products—plays a critical role in sustaining these benefits. Policymakers and industrial managers should therefore emphasize not only quantitative expansion but also technological advancement, human capital development, and institutional capabilities to secure long-term gains from export diversification.

5. Conclusions

This study examined how product diversification influences asset returns in petrochemical companies. The main research problem was addressed using a kernel density approach and rigorous statistical analysis, leading to the following key conclusions:

Dominant linear relationship: The primary finding is the confirmation of a strong, positive linear relationship between product diversification and financial performance, specifically return on assets (ROA). This indicates that, for petrochemical firms, strategic expansion into related product lines is an effective mechanism for enhancing the efficiency and profitability of their substantial asset base.

Absence of nonlinear effects: The analysis found that nonlinear relationships, such as U-shaped or inverted U-shaped patterns, are not prominent in this industrial context. Within the observed range, the benefits of diversification accumulate linearly, without the diminishing returns or negative effects associated with over-diversification reported in other industries.

Centrality of asset efficiency: The strongest link between diversification and performance was observed through ROA, highlighting that the primary channel for value creation in this capital-intensive sector is the improved utilization and productivity of tangible assets.

Strategic implications for management and policy:

- Managers: The findings support a strategic focus on related product diversification as a reliable path to increase asset returns. This should be pursued with attention to product complexity, targeting high-value additions within the petrochemical value chain.
- Policymakers: Creating an environment that promotes technological upgrading and skill development is essential. Such support ensures that diversification efforts lead to sustainable competitive advantages rather than merely facilitating participation in low value-added segments of global markets.

In summary, this research provides empirical evidence that product diversification is a potent linear driver of asset return enhancement in the petrochemical industry. By resolving inconsistencies in the literature for this sector and applying a novel methodological approach, the study offers a clear analysis of the research problem and actionable insights for corporate strategy and industrial policy.

Limitations and future research

This study has several limitations that suggest directions for future research. The focus on financial metrics, while important, may overlook strategic benefits of diversification that manifest over longer time horizons. Additionally, the Iranian context, with its specific institutional and market characteristics, limits generalizability to other environments. Future studies could adopt longitudinal designs to capture dynamic effects, incorporate non-financial performance indicators, and investigate the mediating mechanisms through which diversification creates value in emerging economy contexts.

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Declaration of interest

None.

Nomenclature

CODAL	Comprehensive database of all listed companies
Dominant firm	Market with one firm controlling 50–100% share
DR	Degree of product diversification
HHI	Herfindahl-Hirschman index
KDE	Kernel density estimation
$KDEN_{i,t}$	Kernel density of diversification for firm *i* in year *t*
$KDEN_{i,t}^2$	Squared kernel density
$LEV_{i,t}$	Financial leverage
Loose oligopoly	Top four firms control less than 40% of market
Monopoly	Perfect monopoly market structure
$ROA_{i,t}$	Return on assets
Tight oligopoly	Top four firms control 90–100% of market
TSE	Tehran Stock Exchange
β_0	Intercept (constant term)
β_1, β_2	Regression coefficients
$\varepsilon_{i,t}$	Error term
λ_t	Time fixed effects
μ_i	Firm fixed effects

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