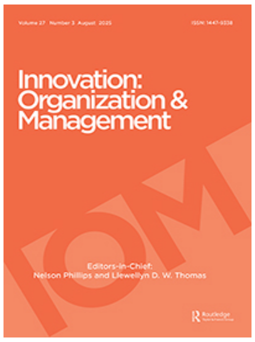

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Unravelling the impact of design-engineering capability on firm performance

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ABSTRACT

Integrating design and technological innovations throughout the new product development process is essential for creating market-successful products. This study investigates how firms' capability to effectively combine design and technology—termed design-engineering capability—affects financial performance and moderates the link between innovation activity and performance. Drawing on patent data for 1,659 US-headquartered public firms from 1980 to 2015, we identify design engineers as inventors contributing to both design and utility patents, capturing their role as integrators of aesthetic, functional, and market considerations. Using panel generalised least squares regressions, our results confirm that design-engineering capability not only directly enhances financial performance but also strengthens the positive impact of innovation activity. Firms with higher shares of design engineers achieve greater returns from their innovation efforts, while those with lower integration capabilities may fail to translate technological advances into market success. These findings underscore the strategic value of cross-disciplinary expertise and the need for organiations to foster collaboration between design and engineering functions. By highlighting the performance benefits of design-technology integration, this study contributes to research on innovation management, human capital, and the resource-based view of the firm.

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Design-technology integration; new product development; innovation activity; design engineer; design innovation

Introduction

To ensure effective product development and market success, it is essential to consider design and technology simultaneously throughout the new product development (NPD) process (Gemser & Leenders, 2001; Rubera & Droge, 2013). Technological innovation is the backbone of NPD, empowering products with the necessary functionalities and capabilities. On the other hand, design innovation is instrumental in aligning products with customer needs and preferences, serving as a key driver on the market side of NPD (Primo et al., 2020; Veryzer, 2005). Several studies have shown how design affects NPD performance, including its emotional and symbolic value (Candi et al., 2017), its strategic use for product

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differentiation (Ulrich & Eppinger, 2016), design diversification (Walsh et al., 1992), and lower product prices (Ulrich & Eppinger, 2016). For instance, design helps create a solid emotional connection between the product and end users, increasing customer satisfaction and loyalty (Gilal et al., 2022; Hemonnet-Goujot & Valette-Florence, 2022). Furthermore, design-driven innovation can open new market opportunities by identifying unmet customer needs and envisioning breakthrough solutions beyond incremental improvements (Hur, Chun, et al., 2024). Accordingly, incorporating design into the NPD process is not merely an option but a critical imperative for achieving product success and market competitiveness.

A successful product must not only meet technical and functional specifications but also address market demands and user preferences (Bazzaro & Meyer, 2022). The literature has well-established the complementary nature of design and technology and their synergistic effects on NPD performance (Filippetti & D'Ippolito, 2017; Han et al., 2021; Kim et al., 2019). However, a pivotal yet often overlooked aspect of this effect lies in the organisation's capability to effectively integrate design and technology in the NPD process – a capability we refer to as '*design-engineering capability*'. By facilitating effective knowledge-sharing and collaboration between design and engineering teams, a firm with strong design-engineering capabilities can bridge the gap between aesthetic appeal and technical functionality.

According to the resource-based view, human capital is a key strategic resource that contributes to a firm's sustained competitive advantage (Collins, 2021; Wright et al., 2001). Variation in the quality and configuration of human capital across firms leads to heterogeneity in firm performance (Ployhart, 2021). From this perspective, the composition of a firm's inventor pool becomes a critical determinant of innovation outcomes. This paper focuses on *design engineers*—individuals who contribute to both design and technological development – as a distinctive form of hybrid human capital. Design engineers possess the expertise to address both design aesthetics and technical feasibility (Hur, Hwang, et al., 2024; Kim & Kim, 2019) enabling them to act as integrators in the NPD process.

These individuals play a crucial role in facilitating knowledge sharing, cross-functional coordination, and shared decision-making through interdisciplinary communication. Their involvement allows firms to effectively integrate design and engineering considerations throughout the NPD process, leading to the creation of products that are not only technically robust but also responsive to user needs and market expectations. By centring on this dual-domain capability, the study extends the human capital-based view of RBV, highlighting how specific configurations of cross-disciplinary expertise can enhance firm innovation and performance.

This study examines the moderating effect of design engineers, as a proxy for firms' design-engineering capability, on the relationship between their innovation activity and financial performance. To test our hypotheses, we used the DISCERN database, which aggregates all patent data published by US-headquartered publicly traded firms at the parent company level from 1980 to 2015. The final sample comprises 1,492 firms and 11,094 firm-year observations. A firm's design-engineering capability was measured by quantifying the number of design engineers, representing key individuals bridging the gap between design and technology and facilitating successful product development through interdisciplinary collaboration. Using inventor information related to patents from the PATSTAT database, we identified design engineers based on their association with design and utility patents. The results of panel generalised least squares regressions support our hypotheses, confirming the direct effect of design-engineering capability on firm performance and its moderating role in the innovation – performance relationship. These results underscore the importance of having a solid integration of design and technology expertise within the organisation.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on the effects of innovation activities and the interdependence of design and technology in product development. Section 3 outlines the data and variables used to test the hypotheses and the research methodology employed. Section 4 presents the findings of the empirical tests, and Section 5 concludes the paper with a discussion of the implications and limitations.

Literature review and hypotheses

Design-engineering capability and firm performance

Studies have confirmed the significance of design in aligning products with customer needs and preferences, thereby contributing to a product's market success. Design influences how consumers perceive and value products and plays a key role in enhancing product competitiveness (Parkhi et al., 2022). Various empirical studies have demonstrated the effects of design on product innovation. First, visually appealing and user-centric designs can positively shape consumer perceptions and influence preferences and behaviour (Candi et al., 2017; Kim et al., 2019). For instance, when evaluating product quality, consumers consider both tangible and intangible factors, such as visual characteristics, shape, texture, and symbolic value (Verganti, 2009). Second, design is closely tied to a brand's image (Gilal et al., 2022; Hemonnet-Goujot & Valette-Florence, 2022). Innovative designs can strengthen brand identity, infuse it with positive associations, and enhance customer loyalty. Third, design contributes to product differentiation in competitive markets where many products offer similar functionalities (Ulrich & Eppinger, 2016). Research has shown that both formal mechanisms such as design registrations (Dan et al., 2018), and informal mechanisms, such as consumer reactions to design similarity (Filitz & Henkel, 2016) and reputation for original design (Gemser & Leenders, 2001), can serve as natural barriers to imitation. Furthermore, firms can leverage design variations to reflect emerging product trends or appeal to specific customer segments. Existing technologies can be redesigned to target niche markets or increase visual diversity within a product line, thereby enhancing marketability (Verganti, 2009). Finally, design also affects a product's final price by influencing material choices and manufacturing complexity (Candi et al., 2017; Robinson, 2012).

However, it is not merely the emphasis on design or a firm's investment in design-related activities that determines a product's success. Rather, it is the seamless integration of design throughout the entire product development process that is critical. Design should not be treated as an afterthought or confined to the aesthetic phase; instead, it must be considered in tandem with technological development – from idea generation and concept formulation to technical development and prototyping. This approach moves beyond the traditional 'form follows function' paradigm, promoting a more iterative and collaborative model in which design and engineering evolve together.

Previous literature exploring the effects of integrating design and technology in NPD has primarily focused on two aspects: the engagement of designers in NPD projects and the synergistic impact of design and utility patents on firm performance. For instance, Rubera and Droge (2013) uncovered a synergistic interaction effect between design and utility patents, demonstrating positive influences on sales and Tobin's q. They posited that technology innovation serves as a platform for design innovation, while design innovations facilitate the adoption of technology innovations. Additionally, studies by Gemser and Leenders (2001) and Roper et al. (2016) found that the integration of industrial designers into NPD projects is positively associated with improved firm performance.

However, the involvement of designers in NPD projects should not be equated with the integration of design and technology, as their participation is often limited to the final product design stage (Roper et al., 2016). The traditional 'form follows function' paradigm implies that design is incorporated into the NPD process after the technology has been developed (Chan et al., 2018). The development-first, design-second approach tends to prioritise the technical aspects of a product, potentially limiting consumer-centric product development. Furthermore, addressing design considerations in the later stages of the NPD process may incur significant costs and time for product modifications and improvements (Zhang et al., 2023). Successful integration of design and engineering requires a holistic approach to product development, ensuring that technical feasibility and marketability are considered from the outset.

While prior research has highlighted the importance of both design and engineering in NPD, what remains largely overlooked is the organisation's capability to effectively integrate these domains throughout the entire NPD process. Specifically, the role of interdisciplinary communication and shared decision-making in bridging design and engineering knowledge has received limited attention. To address this gap, the present study investigates the impact of what we term *design-engineering capability*—the firm's ability to integrate design and technological expertise in the NPD process – on financial performance.

We focus on *design engineers* as a key human capital resource embodying this integrative capability (Hur, Chun, et al., 2024; Hur & Kim, 2025). These individuals possess expertise in both design and engineering domains and are well-positioned to facilitate cross-functional collaboration within firms. Importantly, tensions often arise between engineers, who prioritise technical functionality, and designers, who emphasise user experience and the final product's appeal to consumers (Veryzer, 2005). Aligning technological solutions with market needs presents a significant challenge, and design engineers can serve as mediators between these two heterogeneous groups. By bridging disciplinary boundaries, they help ensure that product development efforts are both technically feasible and market-oriented. In addition, design engineers can infuse design thinking into the R&D process, particularly during the early research phase. They not only contribute directly to product outcomes but also help embed design thinking practices among engineers. By introducing a user-centred perspective early on, they enable the identification of latent customer needs and the framing of problems in ways that foster more innovative solutions (Magistretti et al., 2022). We argue that a greater share of design engineers among a firm's inventors promotes more effective knowledge exchange between design and engineering teams, which, in turn, enhances the quality of product innovation and leads to improved financial performance. Based on this premise, we propose the following hypotheses:

Hypothesis 1. Design-engineering capability is positively associated with firms' financial performance.

Hypothesis 2. Design-engineering capability positively moderates the relationship between firms' innovation activities and financial performance.

Data and methods

Data and sources

To construct the patent portfolios of firms, we employed the DISCERN database, which extensively integrates all patent data published by US-headquartered publicly-traded firms at the parent company level, including private and publicly-owned subsidiaries, from 1980 to 2015 (Arora et al., 2021). The sample is restricted to firms with at least one patent and positive research and development (R&D) expenditures in at least one year during the sample period. To capture the full scope of each firm's patent holdings, we collected all design and utility patents owned by firm *i* and its subsidiaries, using the standardised assignee identifiers (*psn_id*) provided in the DISCERN database. We restricted our analysis to U.S. patents to leverage the consistency and rigour of the USPTO's examination process, particularly for design patents, which undergo substantive review for novelty and non-obviousness – unlike design registrations in many other regions (e.g., the EU), which do not require such scrutiny at the registration stage. Company and financial information was obtained from the Compustat database, while detailed information on patents, including inventors and forward citations, was sourced from the PATSTAT database. The final sample comprises 1,492 firms and 11,094 firm-year observations spanning 1980 to 2015.

Variables

Financial performance (ROA_t)

To study the interrelationship between a firm's innovation activities, design-engineering capabilities, and financial performance, we calculated the firm's return on assets (ROA) as a proxy for firm performance. We calculated ROA by dividing a firm's net income by its total assets.

Innovation activity (TOTAL PATENT i(t-3))

Consistent with prior studies (Bloom & Van Reenen, 2002; Hagedoorn & Cloodt, 2003), we used the cumulative number of design and utility patents filed by the firm up to time *t* to measure a firm's innovation activities. Previous studies have demonstrated the significance of design patents (Dan et al., 2018) and utility patents (Andries & Faems,

2013) for firms' innovation and financial performance. Design patents primarily protect a product's unique visual or ornamental aspects, whereas utility patents protect the functional aspects. By considering both types of patents, we gained a comprehensive view of a firm's innovation activities, encompassing aesthetic and functional dimensions.

Design-engineering capability (DE-CAPít)

We assessed a firm's design engineering capability using the ratio of design engineers to the total number of inventors within the firm. Design engineers who engage in both design and technology development activities represent the key individuals who bridge the gap between the market side and the development side (Hur, Hwang, et al., 2024; Hur & Kim, 2025; Primo et al., 2020), thereby contributing to successful product development. Collaborating with interdisciplinary teams (i.e., design, engineering, and marketing teams) facilitates the exchange of interdisciplinary knowledge and the spread of design thinking within firms. This collaboration enables holistic and integrative product development, ultimately leading to successful outcomes (Chen et al., 2008). Hence, the greater the number of design engineers within a firm, the greater the potential for interdisciplinary collaboration, knowledge spillover, and integration of design and technology expertise throughout the product development process.

Building on this understanding, we initially compiled all design and utility patents held by the sample firms. By leveraging the inventor information associated with these patents, we identified design engineers for each firm-year. Specifically, an individual was classified as a design engineer if they were associated with both design and utility patents within a given year

During this process, two main challenges were encountered. Due to the nature of the PATSTAT database, design engineers were assigned two separate person identification numbers (*person_id*)-one for design patents and the other for utility patents – resulting in them being identified as sole engineers or designers. To resolve this issue, we harmonised their person_ids by considering inventors as design engineers only if they shared the same name (*person_name*) and patented design and utility patents within the same firm (*assignee*). The second challenge involved cases where an inventor had the same *person_id*, but their patents belonged to two or more different firms. Approximately 4.9% of inventors were classified in this category. This discrepancy can be attributed to factors such as changes in the firm name and organisational structure (e.g., mergers and acquisitions), joint R&D, or inventor mobility. We excluded these inventors from the sample for several reasons. First, a patent with two or more assignees may indicate 'interfirm collaboration', which is beyond this study's scope. Second, determining to which company an inventor belongs in joint R&D and M&A cases is complex, as it could involve inter-firm collaborations, outsourcing, or licencing. Third, distinguishing between inventor mobility and joint R&D proved challenging, particularly when an inventor with the same *person_id* patented different patents at different firms within the same year. Overall, this accounted for a relatively small percentage (4.9%). Finally, it is important to consider potential differences in the compositions of inventors and the number of R&D personnel among the sample firms. Therefore, we used the ratio of design engineers to the total number of inventors as a proxy for the firm's design-engineering capability.

Table 1. Description of variables.

	Variables	Abbreviation	Description	Data sources
Dependent variable	Financial performance	ROA_{it}	The natural logarithm of the percentage of net income divided by the average total assets	COMPUSTAT
Independent variables	Design-engineering capability	DE_CAP_{it}	The natural logarithm of the ratio of design engineers to the total number of inventors in firm *i* at time *t*	PATSTAT
	Innovation activity	$TOTAL\_PATENT_{i(t-3)}$	The cumulative number of design and technology patents filed by firm *i* up to time *t*	PATSTAT
Control variables	Firm size	EMP_{it}	The natural logarithm of the number of employees in firm *i* at time *t*	COMPUSTAT
	R&D expenditure	$XRD_{i(t-3)}$	The natural logarithm of the amount of money invested on research and development by firm *i* at time *t*	COMPUSTAT
	Innovation quality	$CITATION_{i(t-3)}$	The natural logarithm of the number of citations received for design and technology patents within 5 years after its publication	PATSTAT
	Scientific paper publication	$PUB\_STOCK_{i(t-3)}$	The natural logarithm of the number of cumulative scientific publications published by firm *i* up to time *t*	DISCERN Arora et al., (2021)
	Industry classification	$INDUSTRY\_Dummy_i$	Industry dummy variables using two digit NAICS codes	COMPUSTAT

Control variables

Drawing from the existing literature on the relationship between innovation activities and firm performance, we incorporated the following control variables: First, to account for potential economies or diseconomies of scale in innovation activities and their subsequent outcomes, we included the number of employees as a measure of firm size (Andries & Faems, 2013). Second, we introduced an input measure of innovation – R&D expenditure – to control the impact of a firm's investment in innovation activities, which is closely associated with firm performance (Laursen & Salter, 2006). Additionally, we included the number of forward citations as an indicator of the impact and significance of a firm's patented innovations (Belenzon, 2012; Hall et al., 2005). In addition, considering the linkages between scientific knowledge generation and innovation activities, we incorporated the stock of scientific publications to control for the potential effects of scientific research output on firm performance (Steven mcmillan et al., 2003). All control variables were log-transformed to address skewness and ensure comparability across firms. Finally, to account for potential variations in firm performance across industries (Hawawini et al., 2003), we included industry dummy variables ($INDUSTRY\_Dummy_i$) using the two-digit North American Industry Classification System (NAICS). Table 1 shows the summary of all the variables used in the analysis.

Empirical model

The theoretical framework used in this study incorporates a moderation methodology. We developed an empirical model that contains TOTAL_PATENT and DE_CAP and the interaction term between the two variables. TOTAL_PATENT and DE_CAP were mean-centred before generating the interaction term to reduce multicollinearity between the variables and the interaction itself. This model

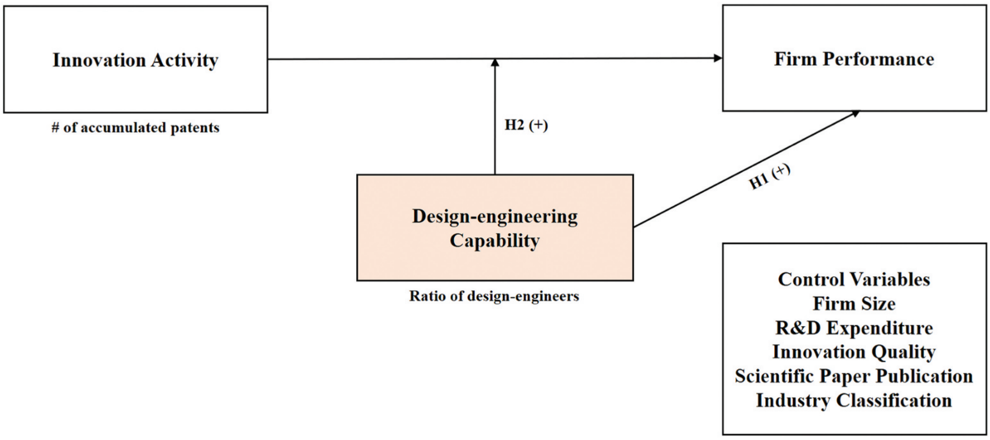

Figure 1. Hypothesised research model.

demonstrates how firms' design-engineering capabilities moderate the relationship between their innovation activities, captured by the number of patents, and financial performance.

$$\begin{aligned} ROA_{it} = {} & \beta_0 + \beta_1 EMP_{it} + \beta_2 XRD_{i(t-3)} + \beta_3 CITATION_{i(t-3)} + \beta_4 PUB\_STOCK_{i(t-3)} \\ & + \beta_5 INDUSTRY\_Dummy_i + \beta_6 TOTAL\_PATENT_{i(t-3)} + \beta_7 DE\_CAP_{it} \\ & + \beta_8 TOTAL\_PATENT_{i(t-3)} \times DE\_CAP_{it} + \mu_{it} \end{aligned} \tag{1}$$

In this equation, the subscript i refers to the firm, and t refers to the year. To account for any delayed effects associated with patents (Ernst, 2001), we introduced a time lag of three years for all R&D-related variables. The number of employees (EMP) and design engineers (DE_CAP) are human resource-related variables considered to have a more direct and immediate impact on firms' financial performance without significant delays. Consequently, we included these variables in our model without time lags.

To estimate Equation (1), we utilised panel data comprising 1,492 firms observed over 35 years, from 1980 to 2015. This data type requires a regression method that accounts for both time-varying effects and firm-specific variations. By conducting the Breusch-Pagan test and Wooldridge test, we found evidence indicating the presence of heteroscedasticity and autocorrelation in the dataset. Therefore, we employed feasible cross-sectional time-series generalised least squares regressions with panel-specific first-order autoregressive (AR (1)) autocorrelation. The AR(1) model specifies that the dependent variable is influenced by its previous value for each firm, capturing the dynamic nature of the relationship over time. This approach enables us to consider the heterogeneity among firms and address potential issues related to time-variant and cross-sectional endogeneity (Baltagi, 2021). Figure 1 illustrates the relationships between the key variables in the model.

Table 2. Descriptive statistics and correlations of variables.

Variables		1	2	3	4	5	6	7
1	EMP	1.00						
2	XRD	0.56	1.00					
3	CITATION	0.41	0.61	1.00				
4	PUB_STOCK	0.53	0.66	0.52	1.00			
5	TOTAL_PATENT	0.57	0.64	0.75	0.63	1.00		
6	DE_CAP	−0.01	−0.01	−0.01	−0.01	−0.01	1.00	
7	TOTAL_PATENT × DE_CAP	0.22	0.29	0.29	0.15	−0.32	0.22	1.00
Min		0	−0.397	0	0	1	0	0
Max		876.8	12540	68166	15267.01	37321.87	1	158.04
Mean		11.33	133.48	288.58	119.12	179.24	0.004	0.464
S.D.		35.81	594.46	1574.08	662.57	795.10	0.035	3.307

Untransformed values are used for correlations and descriptive statistics.

Table 3. Generalised least square regression results of DE_CAP on logROA.

		Dependent variable: logROA				
		Model 1	Model 2	Model 3	Model 4	Model 5
Independent variables	TOTAL_PATENT		0.0001***	0.0001***		0.0005***
			(0.000)	(0.000)		(0.000)
	DE_CAP			0.081***	0.056***	0.075***
				(0.007)	(0.003)	(0.007)
	TOTAL_PATENT × DE_CAP					0.00005***
						(0.000)
Control variables	EMP	1.390***	1.207***	1.213***	1.209***	1.227***
		(0.011)	(0.007)	(0.008)	(0.008)	(0.009)
	XRD	0.542***	0.819***	0.814***	0.800***	0.795***
		(0.010)	(0.007)	(0.009)	(0.008)	(0.009)
	CITATION	0.013***	0.060***	0.039***	0.041***	0.032***
		(0.003)	(0.004)	(0.004)	(0.003)	(0.004)
	PUB_STOCK	0.044***	0.021***	0.034***	0.034***	0.038***
		(0.003)	(0.002)	(0.003)	(0.002)	(0.003)
	Constant	10.608***	10.836***	11.146***	10.822***	11.124***
		(0.559)	(0.366)	(0.427)	(0.308)	(0.444)
	INDUSTRY_Dummy	Included	Included	Included	Included	Included
N (group)		11,094	11,094	11,094	11,094	11,094
		(1,492)	(1,492)	(1,492)	(1,492)	(1,492)
Wald χ^2		73726.59***	248444.38***	157543.73***	166900.38***	138131.53***
BP (χ^2)		269.90***	310.65***	202.76***	180.36***	210.75***

In this analysis, DE_CAP was measured as the ratio of design engineers to the total number of inventors. However, the results remain consistent when using the absolute number of design engineers as an alternative measure. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Standard errors are in parentheses below the coefficient.

Results

Descriptive statistics

Table 2 displays the descriptive statistics and correlation matrix for the variables used in the empirical analysis. The variance inflation factor values range from 1.06 to 3.18, averaging 2.02. These values are well below the commonly accepted threshold of 4, indicating minimal concern regarding multicollinearity (Kutner et al., 2004).

Regression analysis

Table 3 shows the regression results for logROA. The industry dummy variables are included in all models to control for variations across industries. The first model includes the control variables, whereas the second and fourth models introduce the baseline model with only TOTAL_PATENT and DE_CAP as independent variables. All control variables used in the estimation models demonstrate statistical significance at the 0.01 level. EMP used as a measure of firm size, displays a positive and statistically significant relationship. R&D expenditure (XRD) and the number of citations received for design and technology patents (CITATION) also show the expected positive signs and are statistically significant. The coefficients of PUB_STOCK, which serves as a proxy for knowledge output, are statistically significant and positive.

Building on the findings of previous literature, Models 2, 3, and 5 consistently demonstrate a significant positive impact of TOTAL_PATENT on firms' financial performance. This result provides further empirical support for the established relationship between firms' innovation activities and financial performance. DE_CAP consistently exhibits a positive and statistically significant coefficient in Models 3 to 5. This finding supports Hypothesis 1, which posits that design and engineering capabilities positively affect firms' financial performance. Theoretically, this result suggests that firms with more robust design-engineering capabilities are more likely to achieve better financial outcomes. Finally, Model 5 introduces the interaction term between TOTAL_PATENT and DE_CAP and the results continue to support the previous findings from our study. The interaction

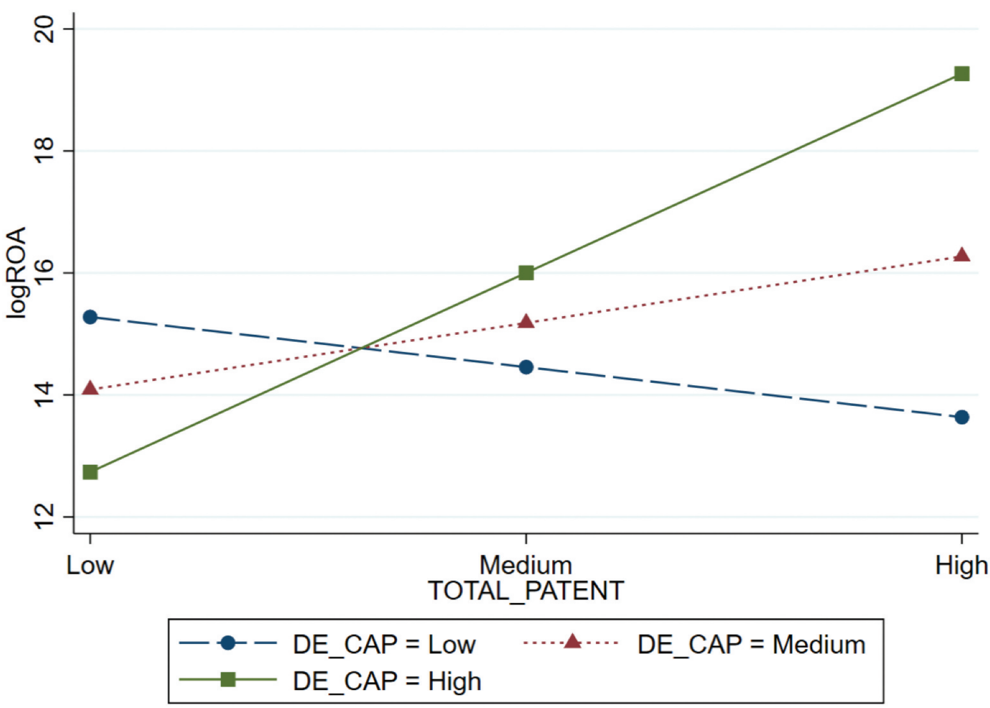

Figure 2. Impact of TOTAL_PATENT on logROA at different levels of DE_CAP.

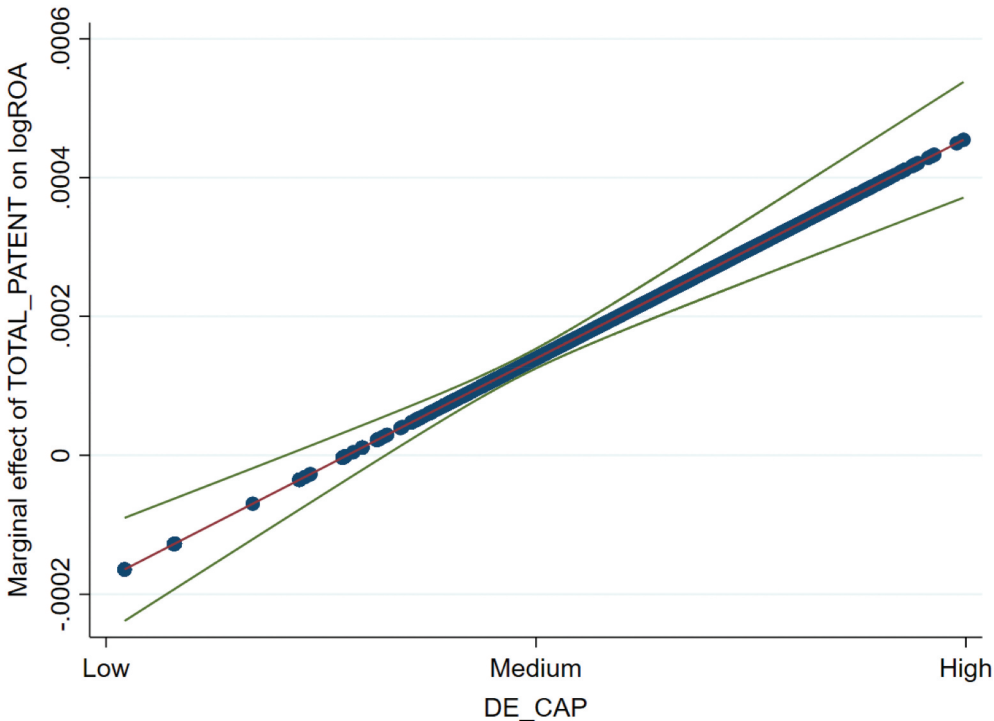

Figure 3. Marginal effects of TOTAL_PATENT on logROA conditional on DE_CAP.

term has a statistically significant positive impact at the 0.01 level. This finding provides empirical support for Hypothesis 2, which posits that firms' design-engineering capabilities have a positive moderating effect on the relationship between their innovation activities and financial performance.

Figure 2 shows the interaction plot illustrating the moderating effect of design-engineering capability. The figure plots the relative firm performance when the degree of innovation activities, measured by the cumulative number of design and technology patents, moves from low to high under low, medium, and high levels of design-engineering capability. It is evident that firms with a greater portion of design engineers experience a more substantial boost in relative firm performance as their degree of innovation activities, indicated by accumulated patent stock, increases from low to high. However, firms with lower design-engineering capabilities exhibit an even negative relationship between innovation activities and firm performance, suggesting that merely engaging in a greater degree of innovation activities may be insufficient. A supporting design-engineering capability is crucial for translating innovative ideas into market success and improving firm performance. Figure 3 depicts the marginal effects of TOTAL_PATENT on logROA across the complete range of standardised DE_CAP levels. It demonstrates that the effect of TOTAL_PATENT on logROA conditional on DE_CAP is negative for low levels of DE_CAP and positive for medium and high levels of DE_CAP.

Table 4. Sub-industry analysis using generalised least square regression models for logROA.

		Dependent variable: logROA					
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Independent variables	TOTAL_PATENT	0.0001***	0.0003***	0.003***	0.006***	0.0001***	0.0002
		(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
	DE_CAP	0.050***	0.053***	0.115***	0.131***	0.024	0.022
		(0.017)	(0.018)	(0.044)	(0.045)	(0.025)	(0.025)
	TOTAL_PATENT×DE_CAP		0.00003**		0.0006*		0.000
			(0.000)		(0.000)		(0.000)
Control variables	EMP	1.192***	1.230***	1.374***	1.375***	1.491***	1.491***
		(0.021)	(0.021)	(0.126)	(0.126)	(0.038)	(0.038)
	XRD	0.840***	0.808***	0.532***	0.536***	0.661***	0.662***
		(0.019)	(0.020)	(0.089)	(0.089)	(0.036)	(0.036)
	CITATION	0.056***	0.044***	−0.023	−0.024	0.008	0.008
		(0.009)	(0.009)	(0.021)	(0.021)	(0.012)	(0.012)
	PUB_STOCK	0.006	0.006	0.097***	0.095***	0.022**	0.022**
		(0.004)	(0.005)	(0.023)	(0.023)	(0.011)	(0.011)
	Constant	10.679***	10.817***	12.272***	12.352***	11.053***	11.042***
		(0.128)	(0.132)	(0.311)	(0.314)	(0.180)	(0.183)
N (group)		3,140 (436)	3,140 (436)	281 (37)	281 (37)	1,189 (160)	1,189 (160)
Wald χ^2		25421.25***	22351.54***	1278.79***	1315.90***	7407.77***	7439.27***

Models 1 and 2 present regression results for the computer and electronic product manufacturing sector (NAICS 334); Models 3 and 4 for fabricated metal product manufacturing (NAICS 332); and Models 5 and 6 for machinery manufacturing (NAICS 333). Each set of models corresponds to a separate sub-sector analysis within the broader manufacturing industry. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Standard errors are in parentheses below the coefficient.

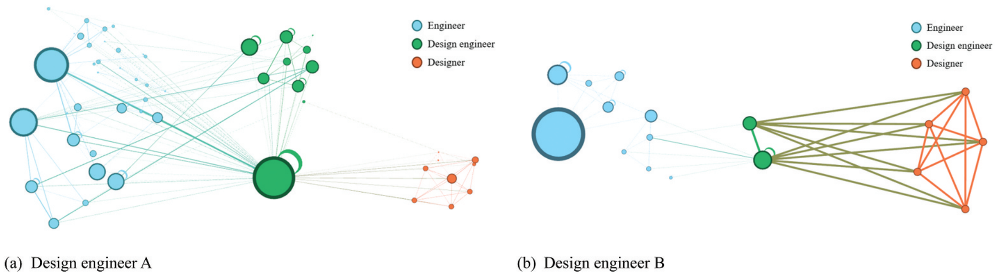

Figure 4. Design engineers as bridging agents in collaboration networks (Google Inc., period: 2013–2015).

Additional analysis

Sub-sector analysis

Considering that the effect of design-engineering capability may vary across sectors, we conducted a sub-sector analysis within the manufacturing industry. Sectoral differences in the emphasis on design can influence the degree to which design-engineering capability contributes to firm performance. In consumer-facing industries (B2C), such as electronics and computer products, product appearance, usability, and user experience are often critical to market success. In contrast, business-to-business (B2B) sectors, such as machinery manufacturing, tend to prioritise technical functionality and performance, with relatively less emphasis on aesthetic design.

To explore this variation, Table 4 presents the results of sub-sector analyses. Models 1 and 2 report regression results for the computer and electronic product manufacturing sector (NAICS 334), Models 3 and 4 for the fabricated metal product manufacturing sector (NAICS 332), and Models 5 and 6 for the machinery manufacturing sector (NAICS 333). The results show that the positive effect of design-engineering capability is consistent and statistically significant in the first two sectors – both of which are more consumer-oriented. However, the effect is not statistically significant in the machinery manufacturing sector, suggesting that the relevance and impact of design-engineering capability may be context-dependent and more pronounced in industries where design plays a strategic role in customer value creation.

Case study

To illustrate how design-engineering capability supports successful product development, we present a case study from Google Inc.[1] Figure 4 shows the company's inventor collaboration network, with nodes representing engineers (blue), designers (orange), and design engineers (green). Node size reflects the degree of collaboration, measured by degree centrality. The figure shows that design engineers occupy bridging positions in the network, connecting otherwise siloed technical and design teams.

This case exemplifies how design engineers facilitate cross-functional coordination and help prevent the common pitfalls of fragmented product development. Both design engineers highlighted hold engineering backgrounds and lead design strategies within the company. Their interdisciplinary expertise enables effective communication between technical and design teams, ensuring that products achieve a balance between functionality and user-centred design. Their multiple patents in both design and utility reflect this dual contribution. Without such roles, firms often default to function-driven products with limited design consideration, or conversely, designs that lack technical feasibility. Design engineers thus play a crucial role in harmonising these elements to drive product innovation and overall firm performance.

Discussions

Theoretical implications

The results of the present study suggest that firms' design-engineering capabilities, as represented by the presence of design engineers, significantly impact their product development and overall firm performance. These findings make several theoretical contributions to the field of firm innovation and strategic human resource management. One significant theoretical contribution of this study is a comprehensive understanding of the value that design engineers bring to the product development process. By recognising the role of design engineers as a source of competitive advantage, we contribute to the literature on firms' resource-based view (Barney, 1991; Wernerfelt, 1984) and strategic human capital resource (Nyberg & Moliterno, 2019; Ployhart, 2021).

The positive effects of firms' design-engineering capabilities can be explained by the mechanisms through which design engineers contribute to successful product development. First, design engineers have access to essential design information and a good understanding of manufacturing constraints, making them valuable contributors to successful product development. They ensure that the product meets functional aspects, such as quality and manufacturability, as well as market needs, including product price and design improvements (Hong et al., 2005).

Second, design engineers facilitate cross-functional collaboration and communication, playing a crucial role in promoting the integration of knowledge and ideas between designers and engineers (Robinson, 2012). Hong et al. (2005) support this view by arguing that design engineers play a vital role in improving product development productivity by establishing clear project targets and sharing customer knowledge. These findings also align with previous literature highlighting the importance of knowledge sharing and collaboration among interdisciplinary teams for overall product development performance (Koufteros et al., 2010; Ou et al., 2023). For instance, Chen et al. (2008) proposed that successful product design depends on the efficient management and sharing of engineering knowledge and experience throughout the entire product development process.

Lastly, design engineers are vital in disseminating design thinking within firms and shaping a corporate culture that prioritises a customer-centred approach to product development (Felder et al., 2023). Studies have shown that design thinking and customer-focused development positively influence innovation and market performance (Magistretti et al., 2022; Robbins & Fu, 2022). According to Venkatesh et al. (2012), design thinking requires a holistic approach that fosters collaboration among interdisciplinary teams. In this context, design engineers – who work closely with both designers and engineers – are uniquely positioned to act as catalysts for embedding design thinking across engineering teams. Their ability to integrate diverse perspectives and expertise contributes to a collaborative environment that supports the development of innovative and customer-centric product solutions. Overall, the successful integration of design and technology in the NPD process through design engineers is essential for creating innovative and market-responsive products that meet customer needs while leveraging the firm's technical capabilities.

Managerial implications

These findings have significant implications for human resource practitioners and managers aiming to strengthen innovation capabilities through the integration of design and technology. One important challenge lies in the recruitment and development of design engineers. In practice, it is often difficult for firms to hire individuals with dual expertise from the outset. Design engineers are more commonly recruited initially as engineers and later engage in design-related activities as they gain experience across domains. Engineers are typically better positioned to understand and assess the technical feasibility of design concepts, while designers may lack the technical depth required for engineering tasks. This asymmetry suggests that fostering design-engineering capability is not only about hiring the right talent but also about cultivating it over time.

Managers should, therefore, prioritise strategies that promote cross-functional collaboration and provide opportunities for engineers to engage in design development. One effective approach is to form interdisciplinary project teams that include both designers and engineers. These teams can work together on new product development initiatives, facilitating knowledge exchange, creative problem-solving, and a holistic understanding of customer needs and technical constraints. By creating a collaborative environment that values both design aesthetics and technical performance, firms can encourage the emergence of design engineers organically from within their existing talent pool. Furthermore, cultivating a culture that values design is essential. Managers should encourage inventors to recognise the strategic role that design plays in driving innovation outcomes.

Limitations

This study has several limitations that warrant consideration. First, our measure of design-engineering capability relies on patent data, specifically the identification of design engineers as individuals who hold both design and utility patents. This approach assumes that the type of patent applications reflects inventors' roles and responsibilities within the firm. However, patents may not fully capture the actual job positions or the depth of involvement in product development. For example, individuals such as project managers or supervisors may be listed as co-inventors on patent applications despite limited hands-on participation in the design or engineering work. As a result, the patent-based identification of design engineers may introduce some degree of measurement error. Future research could benefit from integrating qualitative data – such as interviews, or detailed job descriptions – to more precisely capture interdisciplinary roles within product development teams.

Second, the generalisability of our findings may be limited to industries where design is a strategically important component of product development. As shown in our sub-sector analysis, the positive effect of design-engineering capability is more pronounced in consumer-facing (B2C) industries. This suggests that the value of design-engineering capability may be context-dependent and more relevant in sectors where design serves as a key driver of differentiation and competitive advantage.

Note

1. To preserve confidentiality, the names of individual inventors have been anonymised. Background information for the design engineers was obtained from publicly available professional sources such as LinkedIn.

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