State-owned enterprises vs. non-state-owned enterprises

Due to variations in property rights among firms, the impact of firms' digital transformation on innovation may vary. Indeed, many state-owned enterprises in emerging economies are intricately linked to the bureaucratic system, maintaining close ties with politicians, businessmen and government officials (Mansha et al., 2022; Tee et al., 2022; Wong & Hooy, 2018; 2024). Due to these political connection, state-owned enterprises often gain access to greater resources for digital infrastructure development, and governments may implement policies to facilitate the implementation of digital transformation within these entities (Liu et al., 2024). This political support and resource advantage empower state-owned enterprises to drive digital transformation and play a pivotal role in innovation activities.

In contrast, non-state-owned enterprises may face constraints due to financial limitations, which may restrict their investments and efforts in digital transformation. These enterprises may rely more heavily on their own profitability to support the process of digital transformation (Li & Xia, 2008), potentially impacting the effectiveness of their innovation activities. Additionally, non-state-owned enterprises may encounter pressures from market competition, leading them to prioritise short-term profits and survival over long-term investments and innovation (Sun et al., 2022). Consequently, compared to state-owned enterprises, non-state-owned enterprises may encounter greater challenges in driving digital transformation.

To test this hypothesis, this study conducted sub-sample analyses on state-owned enterprises and non-state-owned enterprises separately in columns (3) and (4), as shown in Table 9. The results indicate that the coefficient of digital transformation for state-owned enterprises is statistically significant at the 1% level, while the coefficient for non-state-owned enterprises is not significant. Thus, the impact of digital transformation on corporate innovation is more pronounced in state-owned enterprises.

High-tech industry vs. non-high-tech industry

With the continuous development and widespread adoption of digital technology, an increasing number of enterprises are accelerating their pace of digital transformation. In China, firms increasingly leverage advanced technologies such as artificial intelligence, big data analytics, cloud computing and blockchain to expedite product development cycles and enhance product quality, thereby boosting innovation levels (Peng & Tao, 2022). Indeed, firms in high-tech industries possess higher innovation capabilities, largely relying on knowledge

innovation and intellectual capital (Wang & Du, 2022). These firms often adopt asset-light strategies, prioritising intangible assets and their relatively fixed business models are less susceptible to influence from digital technologies (Yoo et al., 2010). Conversely, firms in non-high-tech industries with higher fixed asset ratios are more likely to benefit from digital transformation, improving production processes, enhancing research and development efficiency, and driving collaboration along the upstream and downstream of the industry chain (Wang & Du, 2022). Therefore, this study anticipates a stronger positive impact of digital transformation on innovation among firms in non-high-tech industries.

Columns (5) and (6) of Table 9 reveal the disparity in the impact of digital transformation on innovation between high-tech and non-high-tech industries. Specifically, the promotion effect of digital transformation on innovation is only significant and positive in firms of non-high-tech industries. This finding suggests that the relationship between digital transformation and corporate innovation exhibits pronounced heterogeneity based on the technological characteristics of industry.

CONCLUSION AND IMPLICATION

Using panel data of Chinese listed firms from 2012 to 2021, this study uses machine learning methods to construct a measure of digital transformation and discusses the influence of digital transformation on corporate innovation, along with the underlying mechanisms and heterogeneous impact factors. The main conclusions are as follows:

1. Digital transformation facilitates corporate innovation. This conclusion is robust, validated through five rigorous tests (substitution of dependent variable, substitution of independent variable, subsample regression test, Tobit model and additional fixed effects test) and three endogeneity treatments (Heckman two-stage model, controlling managerial ability using a two-stage DEA model and two-step system GMM estimator).
2. Digital transformation significantly promotes corporate innovation by increasing R&D investment and enhancing innovation efficiency.
3. This facilitative effect is particularly pronounced in the context of high-quality innovation output, with a more significant impact observed in state-owned enterprises and non-high-tech industry enterprises.

Our findings have some important contributions as follows: first, this study utilises text mining techniques of machine learning and combines them with information extracted from annual reports to construct a comprehensive digital transformation indicator for companies.

This indicator serves as a valuable reference for evaluating the extent of a firm's digital transformation and assessing its innovation outcomes. Second, there is limited literature addressing the overall impact of digital transformation on innovation activities (input, output and efficiency). By focusing on patent output and examining the dynamic changes in input and efficiency, we contribute to enriching the literature on the multifaceted effects of digital transformation on innovation. Third, our study supplements the evidence of digital transformation alleviating information asymmetry (R&D investment). Moreover, in enhancing the efficiency of innovation activities, our findings align with the previously emphasised perspective of resource dependence (e.g., Han-Song & Tian, 2022; Loonam et al., 2018; Peng & Tao, 2022; Sun et al., 2022), affirming digital transformation as a nexus of interdependence and interaction between firms and digital technologies. These insights not only deepen our understanding of the economic effects and mechanisms of digital transformation but also enrich theoretical research on factors influencing corporate innovation. Fourth, this study examines the heterogeneous effects of digital transformation on corporate innovation based on the characteristics of innovation quality, property rights and technological characteristics of the industry, providing a deeper and more comprehensive understanding of the economic benefits of corporate digital transformation and informing the development of differentiated policies.

Based on the above analysis, the government should consider implementing targeted policies. First, the government should strengthen the construction of digital technology infrastructure to support enterprises' digital transformation. Second, it is crucial to develop policies that aim to reduce the financial burden of digitalisation on non-state-owned and high-tech industry enterprises. Third, regulatory mechanisms for knowledge protection should be enhanced to facilitate the flow of innovation elements. Additionally, managers, especially those in non-state-owned and high-tech industries, should fully recognise the role of digital transformation in driving innovation within firms, thereby narrowing the innovation gap with industry leaders.

While our results highlight how digital transformation of firms contribute to innovation success, this study still has a few limitations. First, it only relies on the overall frequency of digital transformation to measure the degree of digital transformation. For comparative analysis, future studies could consider dividing

digital transformation into more specific subdomains (such as artificial intelligence, blockchain, cloud computing and big data). Second, the sample of this study is limited to Chinese listed companies. In future studies, there is potential for greater insight into the impact of digital transformation on innovation by incorporating other transitioning economies into the sample.

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