Technology Empowerment and Internal Governance Substitution: How Generative Artificial Intelligence Reshapes Corporate Investment Efficiency

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Abstract. Against the backdrop of normalized centralized volume-based procurement (VBP) and tighter price and fulfillment constraints in pharmaceutical distribution, customer structure has become an important supply-chain determinant of long-term innovation. Using 2,653 firm-year observations from 324 Chinese A-share-listed pharmaceutical manufacturers during 2011-2024, this study examines the relationship between customer concentration and R&D intensity with firm and year fixed effects. Customer concentration significantly reduces R&D intensity, and the result remains robust to alternative measures and city-by-year fixed effects. Decomposition tests show that customer concentration does not significantly reduce absolute R&D expenditure but is associated with faster revenue growth, indicating a dilution effect in R&D intensity. Mechanism evidence points to resource reallocation toward fulfillment capacity and weaker R&D human capital. The negative relationship is concentrated among firms with a higher share of technically oriented executives, lower digital transformation, and lower business diversification. These findings extend the customer-dependence perspective on pharmaceutical innovation under VBP and offer implications for balancing major-customer relationships with long-term R&D

Keywords: Customer Concentration, R&D Intensity, Pharmaceutical Manufacturing, Resource Reallocation, R&D Human Capital

1 Introduction

Pharmaceutical manufacturing is characterized by long R&D cycles, high failure risk, and intensive knowledge and capital requirements. Since China launched the “4+7” pilot in 2018, centralized volume-based procurement (VBP) has become increasingly institutionalized, reshaping drug pricing, distribution, and fulfillment obligations. Existing evidence does not support the view that VBP necessarily suppresses innovation. Recent studies suggest that VBP may increase pharmaceutical R&D intensity or innovation quality on average, although low bid-winning rates and excessive price cuts can weaken innovation incentives [1]. This indicates that the average policy effect of VBP should be distinguished from firm-level resource constraints associated with customer dependence.

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Customer concentration reflects the extent to which sales rely on a small number of major buyers. Stable customer relationships may reduce search costs and facilitate information sharing and supply-chain integration [2]. Excessive concentration, however, can strengthen customer bargaining power, increase supplier dependence, tighten financing constraints [3], and reduce R&D investment through lower decision autonomy and higher operating risk [4]. Conversely, concentrated customer relationships may also support innovation through demand information and technical feedback [5].

Three gaps remain. Existing pharmaceutical studies mainly evaluate VBP's average effects, while customer-concentration research largely uses broader manufacturing samples; internal resource reallocation and R&D-related human capital receive limited attention; and heterogeneity across digital capability, executive technical orientation, and business diversification remains underexplored. Using 2,653 firm-year observations for 324 Chinese A-share-listed pharmaceutical manufacturers from 2011–2024, this paper addresses these gaps by examining customer dependence, internal resource reallocation, R&D human capital, and heterogeneous effects.

2 Theoretical Analysis and Hypotheses

2.1 Customer Concentration and R&D Investment

Resource dependence theory and the attention-based view suggest that reliance on major customers can reduce managerial autonomy and redirect attention toward short-term fulfillment, raising the opportunity cost of pharmaceutical R&D [4]. Customer concentration may also strengthen buyer bargaining power, tighten financing constraints, and suppress R&D investment [6]. Moreover, customer-specific technological and capacity adaptation can create lock-in and narrow external technology search [7]. Consequently, R&D intensity may decline through resource constraints or because revenue grows faster than absolute R&D spending.

H1: Higher customer concentration is associated with lower R&D intensity among listed pharmaceutical manufacturers.

2.2 Resource Reallocation and Fulfillment-Capacity Mechanism

Repeated transactions with major customers can reduce selling and channel-maintenance expenses, but the released resources need not flow into R&D. Stable fulfillment may instead require additional plants, equipment, quality-control systems, and other relationship-specific assets [1,3,7]. For pharmaceutical firms, such capacity commitments are relatively irreversible and may limit discretionary resources available for long-cycle R&D.

H2: Higher customer concentration is associated with a reallocation of operating resources from market expansion toward fulfillment capacity, thereby reducing R&D intensity.

2.3 R&D Human-Capital Weakening Mechanism

Pharmaceutical R&D depends on specialized, cumulative human capital. When major-customer fulfillment becomes more salient, personnel and budget priorities may shift toward production, quality, supply-chain, and delivery functions, slowing the expansion of knowledge-intensive and R&D positions. Customer dependence can alter managerial attention [4], while customer concentration is also associated with lower labor-investment efficiency [8].

H3: Higher customer concentration weakens knowledge-intensive and R&D human-capital investment, thereby reducing R&D intensity.

3 Research Design

3.1 Data and Variables

The sample covers Chinese A-share-listed pharmaceutical manufacturers from 2011 to 2024. After excluding ST/*ST firms, observations with missing core variables, and firms observed for only one year, the final sample contains 324 firms and 2,653 firm-year observations. Continuous variables are winsorized at the 1% tails. R&D intensity (RDInt) is measured as R&D expenditure divided by operating revenue. Customer concentration (CustConc) is the share of annual sales to the five largest customers. Mechanism variables include the selling-expense ratio, fixed-asset growth, the log number of employees with a bachelor degree or above, and the log number of R&D employees. Controls include firm size, firm value, ownership concentration, leverage, and state ownership. Following Jiang (2022) [9], mechanism tests focus on whether customer concentration significantly predicts the proposed channel variables rather than interpreting stepwise regressions as strict causal mediation.

$$RDInt_{i,t} = \alpha_0 + \beta_1 CustConc_{i,t} + \sum \gamma_k Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Descriptive statistical results are shown in Table 1.

Table 1. Descriptive Statistics of Variables.

Variable	Obs.	Mean	Std. Dev.	Min	Max
RDInt	2653	8.934	15.057	0.490	123.020
CustConc	2653	25.901	17.669	5.120	83.620
Size	2653	22.032	0.965	20.145	24.628
FirmVal	2653	2.404	1.512	0.936	8.980
Top1	2653	33.137	13.155	10.567	68.991
Lev	2653	0.298	0.174	0.040	0.808
SOE	2653	0.208	0.406	0.000	1.000

4 Empirical Results

4.1 Benchmark Regression and Robustness

With firm and year fixed effects, the coefficient on CustConc is -0.076 and significant at the 1% level: a one-percentage-point increase in the sales share of the five largest customers is associated with a 0.076-percentage-point decline in R&D intensity, supporting H1. Decomposition tests show no significant effect on the log of absolute R&D expenditure (0.001), but a positive effect on revenue growth (0.005, 1%), suggesting that the lower R&D intensity mainly reflects revenue growing faster than R&D spending rather than an outright decline in R&D expenditure. The result remains robust when R&D personnel share is used as an alternative outcome, the largest-customer sales share replaces CustConc, city-by-year fixed effects are added, and a post-2020 interaction is included. The specific regression results are shown in Table 2 and Table 3.

Table 2. Benchmark Regression Results.

	(1)*RDInt*	(2)*RDInt*	(3) *lnRDSpendSum*	(4)*Rev_Growth*
$CustConc$	-0.071*** (0.029)	-0.076*** (0.029)	0.001 (0.001)	0.005*** (0.002)
cons	10.776*** (0.749)	55.792** (26.284)	1.003 (1.078)	-2.271*** (0.781)
Controls	No	Yes	Yes	Yes
Firm/ Year Fixed Effects	Yes	Yes	Yes	Yes
observations	2653	2653	2649	2516
Adj.R^2	0.846	0.847	0.930	0.172

Note: Robust standard errors clustered at the firm level are reported in parentheses; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3. Robustness Test Results.

	(1)$RDPerson$	(2)*RDInt*	(3)*RDInt*	(4)*RDInt*
$CustConc$	-0.023* (0.013)		-0.101** (0.046)	-0.058** (0.024)
$TopCust$		-0.100* (0.052)		
$Post2020 * CustConc$				-0.041* (0.023)
Firm/ Year Fixed Effects	Yes	Yes	Yes	Yes
observations	2238	2030	1831	2653
Adj.R^2	0.857	0.848	0.820	0.848

4.2 Mechanism Analysis

Resource reallocation: CustConc is negatively associated with the selling-expense ratio (-0.002, 1%) and positively associated with fixed-asset growth (0.004, 5%). Together, these results are consistent with operating resources shifting from dispersed customer acquisition toward fulfillment capacity; they do not establish that saved selling expenses are mechanically transferred into fixed assets.

R&D human capital: CustConc is negatively associated with both highly educated employees (-0.003, 1%) and R&D employees (-0.003, 5%), consistent with weaker R&D-related human-capital accumulation. These headcount results should not be interpreted as direct evidence of wage cuts or layoffs.

The results of mechanism analysis are shown in Table 4.

Table 4. Mechanism Test Results.

	(1)SER	(2)$FAGR$	(3)$lnHighEdu$	(4)$lnRD$
$CustConc$	-0.002*** (0.000)	0.004** (0.002)	-0.003*** (0.001)	-0.003** (0.001)
Firm/ Year Fixed Effects	Yes	Yes	Yes	Yes
observations	2653	2519	2606	2238
Adj.R^2	0.814	0.089	0.947	0.902

4.3 Heterogeneity Analysis

Executive technical background: CustConc is insignificant in the low-technical-executive group (0.006) but strongly negative in the high group (-0.159, 1%), suggesting greater R&D adjustment pressure where innovation orientation is stronger.

Digital transformation: The negative effect appears in firms with low digitalization (-0.110, 5%) but not in highly digitalized firms (-0.039), consistent with digital capabilities buffering resource-allocation pressure.

Business diversification: The effect is significant in low-diversification firms (-0.133, 1%) but not in high-diversification firms (-0.009), indicating a potential risk-sharing role for diversified business portfolios.

The results of heterogeneity analysis are shown in Table 5.

Table 5. Heterogeneity Analysis Results.

	(1) Executive technical background		(2) Digital transformation		(3) Business diversification	
	Low	High	Low	High	Low	High
$CustConc$	0.006 (0.027)	-0.159*** (0.051)	-0.110** (0.048)	-0.039 (0.034)	-0.133*** (0.045)	-0.009 (0.018)
Firm/ Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
observations	1283	1332	1291	1296	1239	1261
Adj.R^2	0.773	0.872	0.879	0.541	0.843	0.722

5 Conclusion and Implications

Using Chinese listed pharmaceutical manufacturers from 2011 to 2024, this study finds that customer concentration is significantly associated with lower R&D intensity. The decline mainly reflects a relative dilution effect: revenue grows faster while absolute R&D spending does not significantly fall. Mechanism evidence is consistent with operating resources shifting toward fulfillment capacity and with weaker accumulation of R&D-related human capital. The negative relationship is concentrated among firms with a higher share of technically oriented executives, lower digital transformation, and lower diversification. These findings suggest that pharmaceutical firms should balance the short-term benefits of major-customer relationships with stable long-term R&D budgets and talent accumulation, while using digitalization and diversified business portfolios to improve resource-allocation flexibility. Policy design under continued VBP should likewise consider the innovation pressures faced by firms that are highly dependent on a small number of customers and support digital upgrading, R&D capabilities, and innovation-oriented human capital.

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