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R&D, intellectual capital, organizational learning, and firm performance: a study of Chinese software companies

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Abstract: This research establishes a theoretical model to test the interrelationships among R&D investment, intellectual capital, organizational learning, and firm performance. Based on the collection and investigation of a panel dataset gleaned from 26 software companies in 28 time periods, we find that: (1) R&D investment of software enterprises and firm performance are positively correlated; (2) intellectual capital fully mediates the R&D investment–performance relationship; and (3) organizational learning of software security vulnerabilities moderates the relationship between R&D investment and intellectual capital in the form of human capital. Based on our findings, we draw both theoretical and managerial implications.

Keywords: Intellectual capital; R&D investment; Vulnerability learning; Organizational learning; Organizational performance

Introduction

Although it is widely accepted that R&D investment is an important driver for achieving and sustaining firm competitiveness (Lucas, Knoben, & Meeus, 2018), research shows inconsistent conclusions. For example, Bottazzi et al. (2001), Chen et al. (2015), and Lu et al. (2011) find either insignificant or negative relationships between R&D investment and firm performance. This discrepancy calls for investigating the conditions under which R&D investment can be effective.

In this paper, we extend this stream of research by focusing on the conditions for R&D investment to be effective for Chinese software firms. R&D is the foundation to support software companies' development of new products and services. To continue innovating and to sustain competitive advantage, software companies invest heavily in R&D every year. Because the majority of their operating expenditures is allocated to R&D (Shields, 2014), it is natural to ask whether and how the R&D investment pays off and improves financial performance.

R&D investment does not have a direct impact on performance of software firms. Rather, the investment must first enhance a firm's intellectual capital and then affect firm performance through

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the enhanced intellectual capital. In essence, intellectual capital mediates the relationship between R&D investment and firm performance. This reasoning is supported by the resource-based view (RBV) of the firm (Barney, 1991), which maintains that a firm's sustainable competitive advantage can be attributed to resources that are valuable, rare, inimitable, and non-substitutable, or VRIN. To acquire and develop such resources, firms must make the right investment decisions. The fact that intellectual capital is software firms' main resource supports our argument that R&D investment must first be turned into VRIN resources—intellectual capital, in our context—and then financial performance can be improved.

Another proposition of this research is that organizational-learning capability moderates the relationship between R&D investment and intellectual capital. For software firms, the learning principally involves studying software security vulnerabilities to circumvent the emergence of errors in the previous product releases. Two software companies may invest the same amount in R&D, but their ability to learn from past vulnerability experience differentiates their human capital performance. Organizational learning allows firms to combine new and different debugging skills with existing ones and create better products in the future. In the process, software developers gain skill and experience, yielding a set of more competent human resources (Ruigrok & Wagner, 2003).

Model and hypotheses

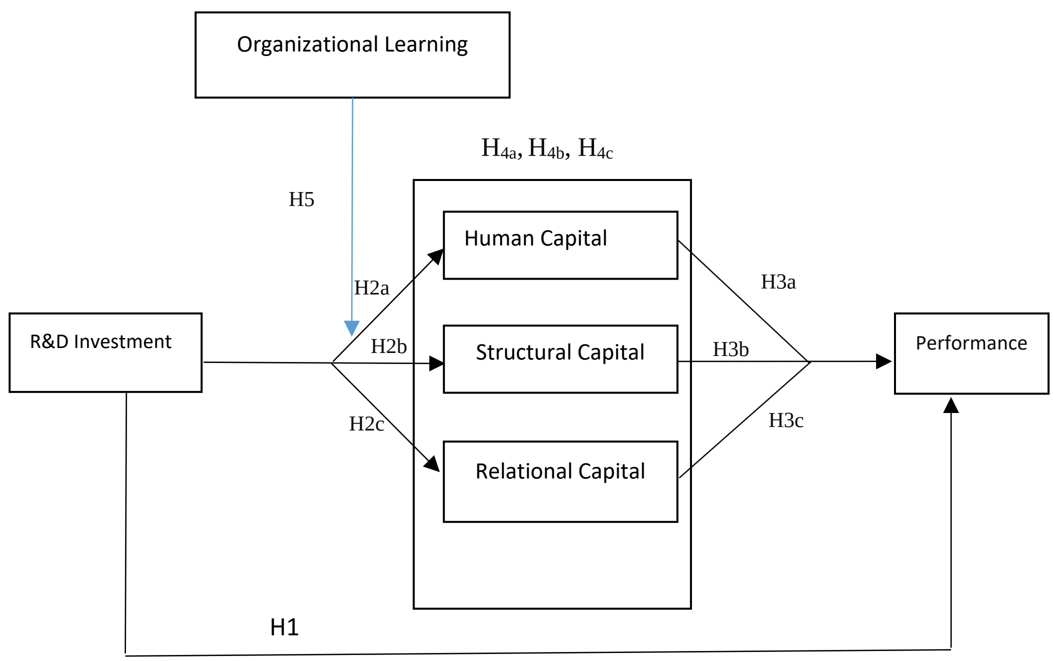

Fig 1: R&D Investment, Intellectual Capital, Organizational Learning, and Performance

Main Effects
R&D Investment → Firm Performance
H1： R&D investment and firm performance are positively correlated.
R&D Investment → Intellectual Capital
H2a：R&D investment and human capital are positively correlated. H2b：R&D investment and structural capital are positively correlated. H2c：R&D Investment and relational capital are positively correlated.
Intellectual Capital → Firm Performance
H3a: Human capital and firm performance are positively correlated. H3b: Structural capital and firm performance are positively correlated. H3c: Relational capital and firm performance are positively correlated.
Mediation Effects
H4a: Human capital mediates the relationship between R&D and firm performance. H4b: Structural capital mediates the relationship between R&D and firm performance. H4c: Relational capital mediates the relationship between R&D and firm performance.
Moderation Effects
H_5：Organizational Learning moderates the relationship between R&D and human capital.

Table 1: Hypotheses

Data collection and description

We obtained our data in three steps. First, we collected vulnerability and patch information between 2010 and 2016 from the China Information Security Vulnerability Library (CNNVD). We then used the common weakness enumeration (CWE) number to match the vulnerability types disclosed by CNVVD with international vulnerability disclosure standards. The CWE is a free international dictionary of security vulnerability categories proposed by MITRE. It provides a standardized and measurable vulnerability classification and cataloging method that can uniformly describe and measure software vulnerabilities. After eliminating the vulnerabilities with few occurrences, we selected nine classes of common vulnerability characteristics: configuration, boundary condition, input validation, design, race condition, source verification, access verification, unexpected, and other errors.

Second, we matched the firms corresponding to the selected vulnerability data with the Wind and Bloomberg financial databases to obtain R&D investment, intellectual capital, and performance data. For those firms for which we could not find data from the databases, we collected data manually by searching their annual reports. This procedure allowed us to match 26 software vendors. Finally, because the performance, R&D investment, and intellectual capital–related data were reported quarterly, we compiled the vulnerability information of each software enterprise and patch information into quarterly data as well. After eliminating outliers and missing values, our eventual sample size was 526 data points.

For firm performance, we collected seven variables: return on net assets (x1), return on total assets (x2), operating profit margin (x3), total asset turnover rate (x4), current assets turnover rate (x5), equity growth rate (x6), and total asset growth rate (x7).

For R&D investment, to scale for the size differences among firms, we used R&D investment/Sales.

Model estimations

	P	HCE	SCE	RCE
RD	0.177** (3.22)	0.222*** (5.42)	0.022 (0.336)	0.218*** (4.54)
SIZE	0.308*** (4.38)	0.183*** (5.42)	0.088 (1.051)	0.286*** (4.671)
LEV	0.206** (4.62)	0.07 (0.203)	0.032 (0.612)	0.07 (1.804)
CI	0.128** (2.136)	0.525*** (11.74)	-0.044 (-0.619)	0.321*** (6.152)
R^2	0.30	0.61	0.009	0.47
Adj R^2	0.29	0.60	0.002	0.46
F	54.56***	202***	1.213	113.11***

***, **, * significant at the 0.01, 0.05, and 0.1 levels, respectively.

Table 2: Estimation of direct relationships

	P	P	P
RD			
HCE	0.860*** (19.66)		
SCE		0.027 (0.72)	
RCE			0.63*** (15.20)
SIZE	0.138*** (3.25)	0.460*** (8.88)	0.16*** (3.44)
LEV	0.200*** (5.86)	2.12*** (4.7)	0.16** (4.34)
CI	-0.320** (-6.50)	0.08 (1.45)	-0.84 (-1.67)
R^2	0.59	0.29	0.51
adjR^2	0.58	0.27	0.49
F	185.38***	51.13***	131.13***

***, **, * significant at the 0.01, 0.05, and 0.1 levels, respectively.

Table 3: Intellectual Capital and Performance

RD	-0.015 (-0.344)	0.041 (0.880)
HCE	0.864*** (19.19)	
SCE		
RCE		0.623*** (14.73)
SIZE	0.150*** (2.754)	0.130* (2.152)
LEV	0.201*** (5.864)	0.163*** (4.319)
CI	-0.325 (-0.299)	-0.072 (-1.381)
AdjR^2	0.583	0.498
F	148.08***	105.19***

***, **, * significant at the 0.01, 0.05, and 0.1 levels, respectively.

Table 4: Mediation Effects

	HCE	HCE
RD	0.221*** (5.62)	0.196*** (4.99)
LV	0.175*** (6.89)	0.411*** (5.61)
LV*RD	-	0.357** (3.43)
SIZE	0.170** (3.39)	0.181*** (3.64)
LEV	0.017 (0.52)	0.019 (0.541)
CI	0.547*** (12.74)	0.547*** (12.88)
Adj R^2	0.637	0.645
F	185.90***	160.08***

***, **, * significant at the 0.01, 0.05, and 0.1 levels, respectively.

Table 5: Moderation Effects of Organizational Learning

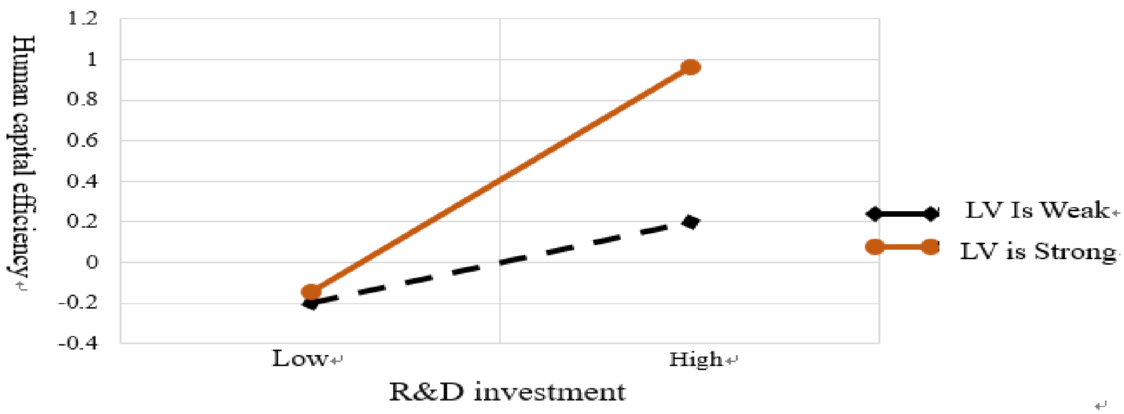

Figure 2. The Moderation Effect of Organizational Learning

Conclusion

Based on a dataset of 26 software companies with their vulnerability and patch incidents between 2010 and 2016 and financial data from the Wind and Bloomberg databases, we study the interrelationships among R&D investment, intellectual capital, organizational learning, and firm performance. Factor analysis is used to construct a comprehensive financial performance variable based on profitability, operational capability, and development capability of the software firms. We establish a positive relationship between this performance measure and R&D investment of the software firms. In addition, intellectual capital (both human capital and relationship capital) mediates the R&D investment–performance relationship. Finally, treating software security vulnerability learning as a form of organizational learning, we argue that software vulnerability learning allows software firms to accumulate intellectual capital, especially in the form of human capital, and eventually leads to better organizational performance. That is, organizational learning moderates the relationship between R&D investment and human-capital value-added efficiency.

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