THE PENROSE EFFECT IN RESOURCE INVESTMENT FOR INNOVATION: EVIDENCE FROM INFORMATION TECHNOLOGY AND HUMAN CAPITAL

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Abstract

Resource-based theory views the firm as a bundle of resources administrated and coordinated by managers. We introduce the theoretical lens of Penrose effect to IS research, which refers to the fact that finite managerial capacities will suffer if the complexity of resource coordination is high. Therefore, although investment in knowledge-related assets, such as information technology (IT) and human capital, is associated with better innovation performance on the one hand, too much capital investment is likely to induce diminishing return on the investment because of Penrose effect. Accordingly, we take a curvilinear approach and propose that the relationships between IT/human capital investments and innovation performance are likely to be inverted U-shaped. Furthermore, we suggest that, in addition to bringing resource synergy, resource coordination also incurs costs, especially when the complexity of coordination among multiple resources is high. Thus, we take a nonlinear approach to examine the interaction effect of IT and human capital investments on innovation performance, which may not be always positive as past research often maintained. Longitudinal data from 404 German firms across several recent years confirm inverted U-shaped relationships between IT/human capital investments and innovation performance. In addition, we find that IT and human capital investments have a negative interaction effect, suggesting that high level of investment in one capital will lead to increasing coordination costs and diminishing return on investment in the other.

Keywords: IT capital investment, human capital investment, IT value, IT innovation, Penrose effect, resource-based theory, resource-based view.
1 Introduction

Resource-based view (RBV) of the firm maintains that firms that are able to accumulate and deploy valuable, rare, inimitable, and non-substitutable (VRIN) resources are positioned to generate and sustain competitive advantage and superior performance (Barney 1986, 1991). For the resources possessed by a firm, a distinction is often made between physical and invisible assets (Itami 1987). It has been documented that “physical (visible) assets must be present for business operations to take place but invisible assets are necessary for competitive success” (Barney and Arikan 2001, p. 136). Invisible assets are those knowledge-based resources that are produced by the firm’s knowledge-based workers (Grant 1996), which are often regarded as having such VRIN characteristics prescribed by RBV (Kogut and Zander 1992). In particular, scholars have recognized that a firm’s knowledge that enables it to generate sustainable competitive advantage is often embedded in its human capital (Hitt et al. 2001). As Kogut and Zander (1992) point out, “the knowledge of the firm must be understood as socially structured, or, more simply stated, as resting in the organizing of human resources” (p. 385; emphasis added). In this regard, the role of the firm is to create a system that facilitates the sharing and recombination of individually possessed knowledge. Nowadays, a key component of this system is a firm’s information technology (IT) assets, which facilitate creation, assimilation, and application of knowledge (Alavi and Leidner 2001). So, contemporary firms keep investing in acquiring superior IT resources and assembling a capable team of knowledge-based workers (Aral and Weill 2007).

Grounded in the resource-based theory by Penrose (1959), RBV not only theorizes the conditions under which strategic resources can contribute to building and sustaining competitive advantage, but also points out the constraints that a firm faces along with increasing investment in strategic resources (Shen 1970). Such constraints, called Penrose effect, can cause a decline of efficiency in resource deployment when finite managerial capacities encounter the complexity of resource coordination resulted from extensive expansion of a firm’s resource bundle (Hay and Morris 1991). The firm relies on its managers to coordinate resources, which are increasingly accumulated in the process of firm growth (Penrose 1959). Penrose effect refers to the fact that finite capacities of a firm’s managers limit the rate at which the firm can grow and expand, because their experiences, teamwork and attention are inelastic in the short run and cannot meet the requirement of increased complexity in resource coordination (Tan and Mahoney 2005). This important implication from resource-based theory, however, is usually omitted in past resource-based analysis.

While past studies on Penrose effect were dedicated to investigate the change of firm growth rate across time (e.g., Shen 1970, Tan and Mahoney 2005), we extend this stream of research and introduce Penrose effect to IS literature to investigate the diminishing return on resource investment, with a focus on IT and human capital in knowledge-intensive innovation context. When examining the return on IT capital investment, recent studies suggested it is necessary to recognize that a firm’s performance at the process level (e.g., innovation performance) serves as a more proper unit of analysis than overall financial performance (Ray et al. 2005). Since the return on IT and human capital investments in innovation activity may be diminishing due to Penrose effect, we argue that the relationships between these investments and innovation performance are more likely to be inverted U-shaped. That is, while IT and human capital investments may initially increase a firm’s innovation performance, excessive investment in these resources will be likely to result in managerial inefficiency (e.g., Penrose 1959, Tan and Mahoney 2005). As a consequence, more investment in IT or human capital may reduce innovation performance. We test our theoretical arguments using longitudinal data from 404 German firms, which are distributed across all industries in Germany. We found strong evidence that the relationships between IT/human capital investments and innovation performance were inverted U-shaped. In addition, we found that IT (human) capital investment negatively moderated the inverted U-shaped relationship between human (IT) capital investment and innovation performance, suggesting excessive investment in one capital can further alleviate the return on the other. This finding can also be explained by Penrose effect about managerial inefficiency in complex coordination among multiple resources.

The paper is organized as follows. We develop our theory and associated hypotheses in Section 2. Methodology used in this study is described in Section 3. We then report empirical results in Section 4. Finally, we discuss the main findings, contributions and limitations of this study, and meanwhile shed light on future research and managerial practices in Section 5.

2 Theory Development

Innovation has long been suggested as an important source of competitive advantage (Barney 1991, Nelson and Winter 1982). Knowledge assets serve as vital inputs in innovation activity, which are also regarded as the
drivers of a firm’s competitiveness (Nelson and Winter 1982). Contemporary firms are now making extensive IT and human capital investments to develop their knowledge in order to innovate and win in competition (Aral and Weill 2007), as the former facilitates knowledge-based innovation activity (Joshi et al. 2010, Kleis et al. 2012, Tambe et al. 2012), and the latter is the ultimate generator of new knowledge and innovation (Kogut and Zander 1992). Therefore, we investigate a firm’s investment in knowledge-related assets – IT and human capital – and maintain that these investments serve as key drivers of a firm’s innovation activity with complex impacts. So far, most applications of RBV documented linear relationships between IT/human capital investments and innovation and synergistic effect of IT and human capital investments (e.g., Nevo and Wade 2010, Ployhart et al. 2009, Xue et al. 2012). We, however, propose curvilinear explanations and coordination costs logic by a theoretical lens of Penrose effect. Below we provide an overview of our theory development in this study, by tabulating our research questions, summarizing relevant findings in prior literature, and providing our arguments and underlying rationale in Table 1.

### Table 1. Summary of prior literature and theory development of this study

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Selected Past Study</th>
<th>This Study</th>
<th>Rationale</th>
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<tr>
<td><strong>RQ1: What is the relationship between IT capital investment and innovation performance?</strong></td>
<td>IT value research reveals that IT investment has linear and positive effect on productivity, productability, efficiency, and innovation (Hitt and Bryjoljsson 1996, Xue et al. 2012). However, there is a profitability paradox of the return on IT investment (Dedrick et al. 2003).</td>
<td>IT innovation research reveals that IT investment has linear and positive effect on various innovation outcomes, such as patent invention (Kleis et al. 2012), new product development (Tambe et al. 2012), and new product introduction (Joshi et al. 2010).</td>
<td>1) Excessive IT resources increases the difficulty of system integration and makes finite managerial efficiency to suffer; 2) Large scale of IT resources is likely to bring the problem of information overload and make scarce managerial attention to suffer.</td>
</tr>
<tr>
<td><strong>RQ2: What is the relationship between human capital investment and innovation performance?</strong></td>
<td>Human capital has long been recognized to have a linear and positive effect on knowledge and innovation outcomes (Barney 1991, Damanpour 1991, Grant 1996, Ployhart et al. 2009).</td>
<td>Human capital investment and innovation performance have an inverted U-shaped relationship.</td>
<td>1) Excessive human capital increases the complexity of knowledge processing and makes managerial efficiency to suffer; 2) Human capital slack is likely to induce lax discipline in project selection and result in poor performance.</td>
</tr>
<tr>
<td><strong>RQ3: What is the interaction effect between IT and human capital investments on innovation performance?</strong></td>
<td>On the one hand, the performance effect of IT resources is suggested to be strengthened by complementary resources, such as labor skills (Aral and Weill 2007, Bresnahan et al. 2002).</td>
<td>IT (human) capital investment positively moderates the inverted U-shaped relationship between human (IT) capital investment and innovation performance.</td>
<td>IT resources are complementary to human resources in knowledge-intensive work, which jointly create synergic effect on performance.</td>
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<td></td>
<td>On the other hand, the productivity of IT and labor inputs are suggested to be substitutable (Dewan and Min 1997, Chwesol et al. 2010).</td>
<td>IT (human) capital investment negatively moderates the inverted U-shaped relationship between human (IT) capital investment and innovation performance.</td>
<td>Excessive resource investment increases the difficulty of coordination among multiple resources, leading managerial efficiency to suffer.</td>
</tr>
</tbody>
</table>
2.1 The Curvilinear Relationship between IT Capital Investment and Innovation Performance

Recent IT innovation studies increasingly suggested that IT is an important enabler of innovation for contemporary firms. For example, it has been found that firms’ investment in and use of IT resources are associated with various innovation outcomes, such as patent invention (Kleis et al. 2012), new product development (Tambe et al. 2012), and new product commercialization (Joshi et al. 2010). This is because IT resources can facilitate knowledge creation and utilization in innovation activity in multiple ways. For example, IT systems such as KMS can improve the efficiency of knowledge sharing and dissemination across functional teams in a firm (Alavi and Leidner 2001). As firms grow in size, they typically rely on IT to systematically organize knowledge dispersed within their boundaries (Gattiker and Goodhue 2005). In addition, network technologies and IT systems such as SCM and CRM facilitate access to and assimilation of new knowledge by creating electronic links with external partners (Malhotra et al. 2005). Besides the benefits of IT resources in facilitating knowledge-based routines and innovation activity, we further suggest that there is a contradictory force that diminishes these benefits when IT capital investment is excessive for two reasons.

First, as a firm continues to invest in IT, it usually uses a larger amount of IT components in knowledge-based work. The additional IT components – which are deployed as a result of the incremental IT capital investment – need to be systematically integrated into an ecosystem of existing IT infrastructure and applications (Fichman 2004). More importantly, in order to fully realize the value of these new IT components in innovation activity, a firm needs to integrate them with other complementary resources (Aral and Weill 2007). Such integration between IT and complementary resources often requires high level of managerial capacities for resource coordination (Bharadwaj et al. 2007), which a firm often lacks. Penrose (1959) suggested that efficient managerial capacities for resource coordination reside on internally experienced management team, which cannot be hired from outside and must be developed within the firm over time (Penrose 1959). In other words, managerial capacities of resource coordination are finite and inelastic in the short run, which limits the expansion of resources in a period of time (Penrose 1959). Excessive expansion of IT resources will result in too much complexity of resource coordination, leading to managerial efficiency being more likely to suffer (Tan and Mahoney 2005). Namely, too much IT capital investment will incur the Penrose effect due to dynamic adjustment costs with managerial inefficiency (Hay and Morris 1991). Thus, excessive investment in IT capital is expected to generate high dynamic adjustment costs, which thereby reduces the return of innovation activity.

Second, high level of IT capital investment may result in information overload (Simon 1976), which is likely to reduce the efficiency of managerial administration. Simon (1976) maintained that “the scarce resource is not information; it is processing capacity to attend to information” (p. 270). This is because the increased amount of information generated by IT resources intensifies the competition for scarce attention of bounded rational managers, likely compromising the firm’s process and quality of decision making in innovation activity (Cyert and March 1963). Such information overload problem could arguably explain the presence of IT productivity paradox where it is evidenced that increasing IT capital is not associated with an increase of productivity (Hitt and Brynjolfsson 1996). In innovative tasks such as idea generation, it has been found that information overload can cause reduction of productivity in face-to-face electronic meetings (Grise and Gallupe 2000). This problem becomes particularly serious in today’s innovation activity under information-rich environment based on the booming Internet, making bounded rationality of managers more salient when they are facing the big data gathered by IT resources (Brynjolfsson and McAfee 2011, Tambe et al. 2012). Due to the challenges associated with managing this information overload problem, the return of innovation activity is also likely to suffer in the presence of excessive IT capital investment.

Thus, aforementioned theoretical arguments indicate a diminishing return on IT capital investment in innovation activity, which initially improves innovation performance but hinders further performance improvement if IT capital investment is excessive above the optimal level. Accordingly, we propose an inverted U-shaped relationship between IT capital investment and innovation performance as follows.

\[ H1: IT \text{ capital investment and innovation performance have an inverted U-shaped relationship.} \]

2.2 The Curvilinear Relationship between Human Capital Investment and Innovation Performance

Knowledge is usually classified as articulable or tacit, depending on whether it is easily codified and transferred or not (Lane and Lubatkin 1998). Tacit knowledge, which is not articulable, is usually embedded in individual skills under firm-specific context (Nelson and Winter 1982). Because tacit knowledge is often unique and
difficult to imitate, it is particularly important for producing competitive advantage in innovation activity. Much of a firm’s knowledge resides in its human capital (Hitt et al. 2001), which is thereby suggested as the most critical competitive assets (Grant 1996). Unlike low-skilled labor force can be directly hired from labor market, however, human capital is firm-specific investment and developed through formal education or training on the job (Hitt et al. 2001). Firms often consider investing in human capital an essential strategy to effectively compete with other firms through knowledge creation and innovation (Ployhart et al. 2009). Organization research has documented a general support for a positive relationship between human capital investment and firm performance (Damanpour 1991, Ployhart et al. 2009). Besides the benefits of human capital in conducting knowledge-based routines and innovation activity, we further suggest that there is a contradictory force that diminishes these benefits when human capital investment is excessive for two reasons.

First, human capital investment necessarily increases the diversity of knowledge and complexity of interactions among knowledge-based workers, leading to high requirement of coordination among diverse knowledge flows within a firm. In order to aggregate and apply individuals’ knowledge at the organizational level, individually possessed knowledge elements need to be pooled and shared (Grant 1996). This is particularly important for innovation activity, because new knowledge is created through an interactive process of recombination among knowledge elements (Grant 1996). Also, managerial capacities of coordination for cross-functional knowledge flows are critical to innovation (Song et al. 1998). However, the ease of the management team to efficiently govern diverse knowledge flows resulted from excessive human capital decreases. As the level of human capital investment increases, finite managerial capacities for coordination also increasingly suffer from the Penrose effect (Hay and Morris 1991). Therefore, managerial capacities can only play a little role in coordinating socially complex interactive processes for transferring and sharing of tacit knowledge (Tan and Mahoney 2005). The dynamic adjustment costs that management team incurs increase in innovation activity based on human capital and tacit knowledge, which thereby reduces the return of innovation activity.

Second, high level of human capital investment is likely to go beyond the need of a firm for knowledge-based work, introducing organizational slack and lax discipline to innovation activity. While human capital and embedded tacit knowledge are critical resources for innovation, unnecessary human capital investment may also be counterproductive. Nohria and Gulati (1996) found an inverted U-shaped relationship between organizational slack and innovation. Although rich organizational resources support slack search, too much slack also leads to lax discipline that is exercised in selection, ongoing support, and termination of innovation projects (Nohria and Gulati 1996). Therefore, increasing human capital slack may increase the likelihood of managers to select, fund, and not terminate high-risk and poor-performing innovation projects, simply because of the existence of unused human capital. This is particularly true if managers are bounded rational and lose their focus in search (Cyert and March 1963). As Nohria and Gulati (1996) maintained, “excess slack can result in both type I (selecting projects that should not have been funded) and type II (stopping projects that should have been continued) errors” (p. 1249). The return of innovation activity is thus expected to suffer as the investment in human capital exceeds the optimal level, as a result of more “low-end” projects are induced by human capital slack.

Thus, aforementioned theoretical arguments indicate a diminishing return on human capital investment in innovation activity, which initially improves innovation performance but hinders further performance improvement if human capital investment is excessive beyond the optimal level. Accordingly, we propose an inverted U-shaped relationship between human capital investment and innovation performance as follows.

H2: Human capital investment and innovation performance have an inverted U-shaped relationship.

2.3 The Interaction Effect between IT and Human Capital Investments on Innovation Performance

Prior resource-based analysis in IS literature suggested that IT can create competitive advantage only when it is combined with complementary resources (Mata et al. 1995, Ray et al. 2005), such as labor skills (Aral and Weill 2007, Bresnahan et al. 2002). It indicates a positively moderating role of human (IT) capital investment in the relationship between IT (human) capital investment and innovation performance as a result of resource synergy (Nevo and Wade 2010). However, IT productivity analysis evidenced counter findings about a net substitute between IT and labor resources (Chwelos et al. 2010, Dewan and Min 1997). Thus, we think that resource synergy arising from coordination is only a partial picture, because prior studies did not take into account finite managerial capacities and the costs of resource coordination.

Too much investment in IT or human capital may render it difficult for finite managerial capacities to efficiently coordinate one type of resources with the other in innovation activity (Tan and Mahoney 2005), leading to less
resource synergy to be realized. Also, limited managerial attention will be occupied to allocate IT (human) resources when they have a large scale, leading to little attention to efficient deployment of human (IT) resources for innovation. In this situation, the benefits of resource synergy in innovation activity may be eventually canceled out by high coordination costs among different types of resources. Even worse, when IT (human) capital is excessively invested in, the net benefits that a firm can derive from human (IT) capital investment can be gradually weakened. Because one capital investment may either strengthen or diminish the effect of another capital investment on innovation performance, it makes the interaction effect of IT and human capital investments an empirical question. Thus, we propose competing hypotheses with counter arguments based on the logic of resource synergy between IT and human capital investments versus the logic of managerial inefficiency due to Penrose effect.

H3a: IT (human) capital investment positively moderates the inverted U-shaped relationship between human (IT) capital investment and innovation performance, such that certain amount of human (IT) capital investment leads to higher innovation performance when IT (human) capital investment is higher than lower.

H3b: IT (human) capital investment negatively moderates the inverted U-shaped relationship between human (IT) capital investment and innovation performance, such that certain amount of human (IT) capital investment leads to lower innovation performance when IT (human) capital investment is higher than lower.

3 Methodology

3.1 Data

We use the data from Mannheimer Innovation Panel (MIP) database provided by Center for European Economic Research (ZEW) to test our hypotheses. MIP database includes high-quality, detailed data about firm innovation activity from a random sample across all industries in Germany. The data were collected in annual base by surveying managers of each firm, leading to an unbalanced panel across years. However, not every question was surveyed in each year, disallowing us to apply advanced panel data analytical techniques in this study. In particular, IT data are not available for most of the years. Thus, we use the most recently available IT data in the year of 2003 as the starting point of sampling. We take advantage of the panel structure and use one- to three-year lagged dependent variable by matching 2003 survey with subsequent waves of survey till 2006 by firm identifiers1. It results in a final sample of 404 firms across all industries in Germany2.

Specifically, we use three-year lagged innovation performance in main analysis (and one- and two-year lagged innovation performance in additional analysis), in order to take into account the lagged effect of IT and human capital investments. Using lagged dependent variable has a number of empirical advantages in testing causal relationships, which are often threatened by alternative explanations such as common method bias and endogeneity bias (i.e., reverse causality and simultaneity). First, it can avoid the threats from common method bias in a cross-sectional survey. Second, a lagged dependent variable rules out reverse causality because of temporal precedence. Third, longitudinal design with long time lag also helps to alleviate the concern of simultaneity, because it is less likely that any omitted variables keep influencing independent variables and dependent variable occurring in a few years later.

3.2 Key Measures

Innovation Performance (InnoPerf): We select a widely used innovation performance measure, by the percentage of sales from new or substantially improved products or services (Leiponen and Helfat 2011). Since a careful check of literature revealed that innovation processes typically last for three years, we follow Joshi et al. (2010) and use three-year lagged innovation performance as our dependent variable in hypotheses testing. We also use one- and two-year lagged innovation performance as the dependent variable in additional analysis.

IT Capital Investment (ITCap): We measure IT capital investment by the percentage of capital investment in IT, such as hardware, software, and services. This is a comprehensive indicator of a firm’s IT intensity, similar to IT investment measures used in past research (Mata et al. 1995, Ray et al. 2005).

1 We also match the data with 2002 wave of survey in order to control for past innovation performance in analysis.
2 More details about the data used in this study can be obtained by sending request to the authors.
Human Capital Investment (HumanCap): Prior literature did not document a standard measure of human capital investment. Hitt et al. (2001) suggested that human capital is obtained through either formal education or training on the job. Thus, we construct our proxy of human capital as a combination of two components: education level and training investment. Education level of employees was extensively used in past research to represent human capital from recruitment (Bresnahan et al. 2002). After recruitment, the development of human capital is typically achieved by investing in training programs for employees to conduct their jobs (Booth and Bryan 2005). Specifically, we follow normalization approach of Tambe et al. (2012) to aggregate these two components by summing the standardized percentage of employees with college degree and the standardized percentage of investment in training programs.

3.3 Control Variables

To further rule out rival explanations due to potential confounds, we control a number of variables that may impact innovation performance. The longitudinal nature of our data allows us to control for past innovation performance reflecting a firm’s base of innovation capabilities. Using past innovation performance can also control the effects of unobservable variables that impact innovation performance, which is critical to address endogeneity concerns. Thus, we control the innovation performance in 2002. Mergers and acquisitions may dramatically change a firm’s innovation performance (Banker et al. 2011), which is controlled by a dummy variable indicating whether the firm was M&A for each firm in a three-year period (yes = 1, no = 0). We also control firm size by the natural logarithm of total sales, and firm age by a dummy variable indicating whether the firm was new entrant established within three years (yes = 1, no = 0), which are related to a firm’s innovation performance (Hansen 1992). Because the number of observations in each industry is relatively small, we found multicollinearity problem if industry dummies are added. Alternatively, we create two dummy variables to control for the fixed effects of high technology versus low technology industries and manufacturing versus services sectors based on NACE Rev. 1.1 two-digit codes. High technology industries typically perform better than low technology industries in innovation activity, and manufacturing sectors are suggested to carry out innovation activity different with services sectors. In addition, geographic differences may affect the average innovation performance (Lahiri 2010). We thus control this effect by a dummy variable indicating the location of a firm in East Germany or West Germany.

4 Results

Due to length limit, we only provide descriptive statistics and correlations of variables for enquiry. We follow recent studies on curvilinear relationships and formulate our model by adapting a Polynomial model (Katila and Ahuja 2002, Lahiri 2010). Ordinary least squares (OLS) regression is used to sequentially estimate the following model in a stepwise manner. To examine H1 and H2, we use the original and quadratic forms of IT and human capital investments. If the inverted U-shaped relationship between IT/human capital investments and innovation performance does exist, we should be able to observe significant and positive coefficients for the original forms and significant and negative coefficients for the quadratic forms. To examine H3, we add the interaction term of IT and human capital investments, as well as the interaction term of IT (human) capital investment squared and human (IT) capital investment, in order to capture the moderating role of IT (human) capital investment in both the positive (in original form) and negative (in quadratic form) effects of human (IT) capital investment on innovation performance (Katila and Ahuja 2002, Lahiri 2010). In all our analysis, heteroskedasticity-consistent robust standard errors are used.

Table 2 reports the regression results for hypotheses testing. Overall, our model demonstrated a good fit and explained over 40% variation of innovation performance. Column (1) represents the results for a model with controls only. Then, we added IT capital investment and its square term to the control model to test H1. Consistent with the finding of past resource-based analysis (e.g., Mata et al. 1995, Ray et al. 2005), we did not observe linear and significant effect of IT capital investment on innovation performance in column (2). After additionally adding IT capital investment squared to the model as column (3) shows, however, IT capital investment showed significant and positive effect while IT capital investment squared had significant and negative effect on innovation performance. It indicates that a curvilinear model of inverted U-shaped relationship better captures the relationship between IT capital investment and innovation performance, supporting H1.
### Controls

<table>
<thead>
<tr>
<th>Controls</th>
<th>Test of H1</th>
<th>Test of H2</th>
<th>Test of H3</th>
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<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
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<tr>
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Note: $N = 404$. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Heteroskedasticity-consistent robust standard errors are in parentheses. Dependent variable is $InnoPerf_{t+3}$. Control variables are not tabulated due to length limit.

### Table 2. Regression results for hypotheses testing

To examine H2, we added human capital investment to the control model as column (4) shows, and then additionally added human capital investment squared as column (5) shows. It was found that human capital investment had significant and positive effect on innovation performance, while human capital investment squared had significant and negative effect on innovation performance. In indicates there is an inverted U-shaped relationship between human capital investment and innovation performance as well, supporting H2. To show the shape of the relationships between IT/human capital investments and innovation performance, we plot the effects of IT and human capital investments on innovation performance in Figure 1, which show inverted U-shape.

**Figure 1. Curvilinear effects of IT and human capital investments on innovation performance**

To examine H3, we first added IT capital investment, IT capital investment squared, and their interaction terms with human capital investment to the control model as column (6) in Table 2 shows. We found a significant and negative interaction effect between IT and human capital investments, and a significant and positive interaction effect between IT capital investment squared and human capital investment. Then we alternatively added human capital investment, human capital investment squared, and their interaction terms with IT capital investment to the control model as column (7) in Table 2 shows. Again, we observed a negative moderating effect of IT capital investment on the curvilinear relationship between human capital investment and innovation performance. Thus, these results jointly show that IT (human) capital investment weakened the positive effect of IT capital investment (in original form) on innovation performance and strengthened the negative effect of IT capital investment.
investment (in quadratic form) on innovation performance, rejecting H3a and supporting H3b. To show this negative moderating effect of human capital investment more clear, we plot the effect of IT capital investment on innovation performance at varying levels of human capital investment. Similar pattern can be seen if we use IT capital investment as moderator. As Figure 2 shows, the curvilinear effect of IT capital investment on innovation performance at low level of human capital investment is always higher than its effect at high level of human capital investment. The peak point (optimal level of IT capital investment) moves down and to the left with increasing investment in human capital.

Figure 2. The effect of IT capital investment on innovation performance at different levels of human capital investment

We conducted several additional analyses to provide better insights on the curvilinear effects of IT and human capital investments on innovation performance. We used different year lagged innovation performance as the dependent variable from $t+1$ to $t+3$. The results confirm our selection of three-year lagged innovation performance as the dependent variable in main analysis. In one year after IT and human capital investments, we failed to observe any significant effect. In two years after investments, we found that IT capital investment had an inverted U-shaped relationship with innovation performance while human capital investment did not. Only in three years after investment, we found that both IT and human capital investments demonstrated inverted U-shaped relationships with innovation performance. This interesting finding also suggests that human capital investment realize its return in innovation activity with longer lag than IT capital investment.

We also conducted subsample analysis across large versus small and medium firms (above the mean of firm size as large, otherwise as small and medium) and across high technology and low technology industries as Table 3 shows. Interestingly, we found that while IT capital investment had inverted U-shaped relationship with innovation performance for large firms, human capital investment had a linear and positive effect on innovation performance. In small and medium enterprises (SMEs), only human capital investment had significant relationship with innovation performance, which was inverted U-shaped. Human capital investment seems “the more the better” for innovation in large firms, while SMEs do not take advantage of IT resources in their innovation activity. Thus, above findings suggest that large firms can generally better leverage IT and human resources in innovation activity, which is perhaps because large firms often have larger and stronger management teams (Penrose 1959).

In addition, we found that high technology firms mainly rely on human capital in innovation activity, while low technology firms mainly take advantage of IT capital for innovation, which are both in curvilinear manner. This interesting finding may be explained by the heterogeneity in the nature of innovation for high technology and low technology industries, confirming the necessity of controlling this effect in our analysis. High technology firms often develop radical innovation, which is based on novel knowledge embedded in strong human capital (Hitt et al. 2001). On the other hand, low technology firms usually introduce incremental innovation, which is related to better product quality by use of IT for automation (Dedrick et al. 2003).
5 Discussion and Conclusion

This study has twofold contributions to IS and RBV literature. First, we recognize and examine the possible downsides of resource investment in IT and human capital. By a lens of Penrose effect, we theorize and explain the curvilinear effects of IT/human capital investments as inverted U-shaped on the performance of knowledge-intensive work in innovation context. We found that excessive IT and human capital investments are likely to be detrimental to innovation performance. It thus provides an answer to the question about why RBV has only received marginal support in past studies (Newbert 2007). Our finding enriches IS literature and helps to resolve the paradox of IT value with mixed findings in past research. In addition, we found Penrose effect manifested by the diminishing return on IT (human) capital investment when the level of human (IT) capital investment is high, which evidences the difficulty and costs of coordination among multiple resources. The net effect of coordination therefore depends on the relative magnitude of resource synergistic benefits and dynamic adjustment costs, which is not always positive as past research maintained. Our findings suggest that resource coordination is not without costs, especially when a firm has developed a large resource bundle. As a result, coordination of excessive human resources in innovation activity may occupy managerial attention and lead to inefficiency in deployment of IT resources.

Second, we provide a possible resolution for the paradox of IT business value which has been long debated in IS literature (Hitt and Brynjolfsson 1996). We reconcile both sides of opinions about “IT doesn’t matter” (Carr 2003) and “IT does matter” (Aral and Weill 2007), by a contingency view relaxing linearity assumption held by past studies. We found that the effect of IT capital investment on innovation is not significant in a linear form but significant in a curvilinear manner. Our results reveal that curvilinearity is more capable than linearity to accurately predict the consequences of various organizational contingencies and resolve mixed findings on a relationship (Johns 2006). While prior study by Oh and Pinsonneault (2007) did not observe significant effect in nonlinear model for the relationship between IT alignment and firm performance, we found strong evidence on the curvilinear effect of IT capital investment and the interaction effect between IT and human capital investments in innovation context. Thus, prior mixed findings on IT-performance relationship may be partially due to methodological shortages, which need to be advanced by nonlinear approach of modeling.

This study has several limitations with room for future research. First, our data were collected by longitudinal surveys, which are not feasible to construct a panel. Thus, in this study we use between-firm differences to capture the variation of resource investment across firms. Ideally, however, a panel data set reflecting the process of resource investment in each firm over time is better. Further study may seek to collect panel data and provide more insights about the performance impact of resource investment across time. Second, while we take advantage of longitudinal design in empirical tests, it is not possible for us to apply more advanced panel data analytical techniques. In particular, recent applications of dynamic panel regression technique such as system GMM can leverage internal instruments in panel data and better address endogeneity concerns. Future studies may put effort to construct panel data and provide more evidence on the causality underlying our theoretical arguments. Third, we focus on IT and human capital investments in this study, because they are arguable two of the most important knowledge-related assets. Future research may extend our theory to examine whether

<table>
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<th>Large Firms</th>
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<td>$ITCap_t^2$</td>
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Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Heteroskydasticity-consistent robust standard errors are in parentheses. Dependent variable is $InnoPerf_{t+3}$. Control variables are not tabulated due to length limit.
diminishing return occurs with excessive investment in other strategic resources. Finally, our evidence was derived from a random sample of German firms. While it is reasonable to expect that our findings will repeatedly appear in other national contexts, future study may collect data from other countries and test our theory.

This study also allows important implications to managers. It reminds the danger of oversimplified interpretation of RBV, because excessive investment in strategic resources may also induce managerial inefficiency in resource coordination and reduce the return on capital investment. Therefore, the level of resource investment needs to fit the managerial capacities that a firm has. Otherwise, managerial capacities will suffer in coordination of resources and among different types of resources. On the other hand, it also indicates a need of developing managerial capacities along with firm growth and expansion of resource bundle. Strong managerial capacities are necessary for a firm to direct the investment and deployment of resources in a more efficient and economic value-increasing way.

References


