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# DEBT FINANCING AND TECHNOLOGICAL INNOVATION: EVIDENCE FROM CHINA

Kuang XIN[1*], Yuchun SUN[2], Ran ZHANG[3], Xiao LIU[4]

[1, 2]*School of Economics & Management, Tongji University, Shanghai, China*
[3]*School of Statistics and Information Management, Xinjiang University of Finance & Economics, Urumqi, China*
[4]*School of Management, Shanghai University of Engineering Science, Shanghai, China*

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**Abstract.** The availabilities of debt for Chinese firms have been increased since 2008 due to the expansionary monetary policies. These policies triggered concerns over the impact of debt financing on firms' technological innovation activities. Based on a sample of 225 listed computer and telecommunications equipment firms in China within 2008–2015, this study explored the effect of debt financing on two types of technological innovation, namely radical and incremental innovation. Specifically, both the direct effect of debt financing on technological innovation and its moderating effect on the relationship between R&D intensity and technological innovation were investigated. Results of this study reveal that radical innovation decreases with debt financing at decreasing rates, while incremental innovation is not affected by debt financing itself. In addition, debt financing interacted with R&D intensity exerts positive effect on both radical and incremental innovation. This study adds meaningful insights to the literature on financing technological innovation and builds a bridge connecting macroeconomic policies to firm activities.

**Keywords:** debt financing, radical innovation, incremental innovation, R&D, negative binomial regression, China.

**JEL Classification:** M10, M21, O32.

## Introduction

Debt played and will continue to play an important role in financing Chinese firms. According to data from National Bureau of Statistics of China, debt financing accounts for more than 90% of the aggregate financing to the real economy in the past decade. On November 9th 2008, the State Council of the People's Republic of China released a four trillion yuan (586 billion dollars) monetary stimulus package to fight against the global financial crisis (Deng, Morck, Wu, & Yeung, 2015; Zheng, Wang, & Xu, 2018). Nearly one decade later, the People's

*Corresponding author. E-mail: *kuangxinkx@gmail.com*

Bank of China (China's central bank) announced that it would cut the reserve requirement ratio for RMB (an abbreviation for Renminbi, which is the official currency of the People's Republic of China) deposits by one percentage point as of October 15th, 2018[1], which was predicted to release 750 billion yuan (108 billion dollars). Meanwhile, commercial banks loosened the credit policies to increase the availability of debt for firms.

The expansionary monetary policies triggered concerns over the impact of debt financing on firms' activities. Among these activities, the activities related to technological innovation draw tremendous attentions from both economists and practitioners, as technological innovation is deemed to be a principle driver for firms to survive and thrive (Coccia, 2017). The realization of technological innovation inherently requires substantial amount of initial capital infusion to buy high-tech related equipment and pay knowledge workers (Bronwyn H. Hall & Lerner, 2010; Howell, 2016). Consequently, technological innovation is particularly sensitive to financial constraints. In the absence of sufficient internal funds, firms can only rely on raising external capital, for instance debt, to motivate technological innovation (Howell, 2016; Mancusi, Vezzulli, Frazzoni, Rotondi, & Sobrero, 2018).

In this study, the effect of debt financing on firms' technological innovation was explored. Based on the degree of marketing and technological discontinuities, technological innovation is categorized into radical and incremental innovation (Garcia & Calantone, 2002). Radical innovation is defined as products or services that are technologically and thoroughly new to the markets, while incremental innovation is defined as products or services that are technologically improved versions of existing ones (Oerlemans, Knoben, & Pretorius, 2013). To provide the empirical evidence on the relationships between debt financing and two types of technological innovation, 225 listed Chinese computer and telecommunications equipment firms over the period of 2008–2015 were studied as sample firms. In an effort to switch from "Made in China" to "Designed in China", China is very generous on R&D expenditure, which accounts for 2.046% of GDP in 2014, nearly tripled 0.75% in 2001 (Howell, 2016). The financial architecture of China is characterized as bank-based systems, which foster more rapid technological progress in high-tech related sectors than other sectors (Benfratello, Schiantarelli, & Sembenelli, 2008; Tadesse, 2006). The unique and interesting setting would help us understand how the macroeconomic policies influence technological innovation on the micro level.

The remaining sections are organized as follows. Section 1 summarizes previous research and describes hypotheses. Section 2 explains sample selection, measures and the regression models. Section 3 reports and interprets the empirical results. The last section concludes.

## 1. Literature review and hypotheses development

### 1.1. Literature review

Previous literature has documented that debt financing is an important source to raise external capital for technological innovation, especially in bank-based counties (Czarnitzki & Kraft, 2009). The availabilities of bank financing, which is the most common type of debt

[1] http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/3639441/index.html

financing, were reported to impact the level, quality and trajectory of firm-level innovation (Backman & Wallin, 2018; Brancati, 2015; Kerr & Nanda, 2015; Nanda & Nicholas, 2014; Robb & Robinson, 2014). Consistent with this, prior research found that an expansion in credit supply brought by the US interstate banking deregulations over the 1980s was associated with increased quantity and quality of the patents afterwards (Chava, Oettl, Subramanian, & Subramanian, 2013). Easier access to bank financing resulted from monetary stimulation was also reported to benefit bank-connected firms by increasing the number of granted patents in these firms, with 18% to 20% more than control firms (Zheng et al., 2018). Besides bank debt, informal debt, which is defined as borrowing from friends, family, suppliers or others, was also demonstrated to prompt innovation by increasing the chance of acquiring capital and shortening the time lapse involved with seeking capital (Wu, Si, & Wu, 2016).

However, more recent and growing research highlights various constraints that made debt unsuitable for financing innovation. It was reported that the relationship between bank financing and technological innovation varied among firms due to heterogeneous internal conditions of firms. Bank financing for troubled firms with weak incentive systems had no or little effect on innovation (Kim & Park, 2017). Gu, Mao, and Tian (2017) argued that banks were able to affect firms' innovation policies through bankruptcy threat or payment default. As a result, they believed that bank interventions imposed a significantly negative effect on the innovation quantity (Gu, Mao, & Tian, 2017). Therefore, current literature unequivocally demonstrates the importance of debt financing but its impacts on technological innovation differ in various contexts.

### 1.2. Hypotheses

Debt financing, as captured by debt ratio on the firm level, exerts a negative effect on technological innovation. The rational is that debt financing helps creditors extract information rents from information monopolies, which impose negative influences on the quantity and novelty of innovation projects. The negative influence of debt financing may exist in two stages. First, at the stage of capital seeking, firms are willing to share confidential information on innovation projects with creditors to seek as much capital as possible (Mancusi et al., 2018). To evaluate the underlying quality of innovation projects, creditors have strong incentives to collect information on innovation projects (Tadesse, 2006). The information may include the marginal funding costs of firms, the success probabilities and future returns of innovation projects (Adam & Streitz, 2016; Mattes, Steffen, & Wahrenburg, 2013). Based on the information, creditors may bid for innovation projects only if the projects will succeed in the future, which stifles the development of high risk and high returns innovation projects. Creditors may price the loan above the marginal funding costs to earn positive expected profits. Although the extra financing costs is regarded as innovation input for firms, it does not generate any extra innovation output. Additionally, to protect the confidential information from leaking to third parties including firms' competitors, firms with valuable innovation projects can't easily communicate to other investors (Gu et al., 2017). The limited access to potential investors makes firms vulnerable to the strong bargaining power from creditors. Second, once the creditor-firm relationship has been established, debt contracts empower incumbent creditors to screen and monitor the ongoing innovation projects and thus facilitate information collection that is unavailable for competitor investors (Santos & Winton, 2008). Due to the payoff structure of debt, creditors do not share the innovation success but suffer from innovation failure (A. Etzkowitz & H. Etzkowitz, 2017; Gu et al., 2017). If creditors monitored that firms' innovation projects were of high possibilities to fail, creditors would ask firms to terminate long-term and risky projects to ensure that firms would create stable cash flow to meet the obligations of debt (Gu et al., 2017). In the worst scenario, when the creditors refuse to roll over their initial loans, firms have to refinance innovation projects from outside creditors. During the refinancing process, firms may encounter great difficulties, as the outside creditors would suspect that the project may be a lemon.

However, the negative sides of debt financing may be mitigated gradually with the increasing of debt ratio. Firms with higher debt ratio are more likely to initiate multiple creditor-firm relationships, which have a positive effect on the completion of innovation projects. Giannetti (2012) found that financing decisions of the main bank were affected by the lending behaviors of other banks. The mutual influence may trigger competitions among incumbent creditors (Boot & Thakor, 2000; Farinha & Santos, 2002; Ongena & Smith, 2000; Santos & Winton, 2008; Yin & Matthews, 2017), which can limit the ex-post rent extraction (Aristei & Gallo, 2017). As suggested by Berglöf and Von Thadden (1994)'s model, even relationships with two banks will largely prevent firms from rent extraction (Berglöf & Von Thadden, 1994). Under the circumstances of refinancing, multiple relationships increase the likelihood that at least one incumbent creditor provides loans to firms. With these loans, firms may be able to avoid premature liquidation and thus protect the completion of innovation projects (Benfratello et al., 2008; Ferraris & Minetti, 2007). Empirical evidence suggests that multiple creditor-firm relationships are positively correlated with innovative capability in both small and high-tech firms (Giannetti, 2012). Therefore, the first two hypotheses were proposed and listed as follows.

**H1**: Radical innovation decreases with debt ratio at decreasing rates.

**H2**: Incremental innovation decreases with debt ratio at decreasing rates.

Although debt financing itself has a negative effect on firms' technological innovation, debt financing interacted with R&D resources has the opposite effect. Debt contracts require firms to generate enough returns to cover interest payments. Structured cash flow obligations urge managers to efficiently allocate R&D resources to valuable R&D projects, rather than to pursue personal benefits, such as growing the firm beyond efficient scale or nicer offices (B. H. Hall, 2002). The strong commitments also push the boundedly rational managers into allocating managerial resources (such as managers' time and efforts) to R&D projects (B. Choi, Kumar, & Zambuto, 2016). It was reported that debt financing reduced the differences between weakly and strongly controlled managers when they performed innovation projects (Czarnitzki & Kraft, 2009). Managers are aware of the various severe consequences of the default on cash flow obligations on their control and career. When debt contracts are violated, substantial control rights will be shifted from managers to creditors, whom are able to influence firms' innovation policies to recover creditors' investment. Creditors' interventions include terminating the loan, accelerating the debt principal and increasing the intensity of monitoring (B. Choi et al., 2016; Gu et al., 2017). The maximum penalty of failing to meet the pay-out commitments is bankruptcy (Czarnitzki & Kraft, 2009). The managers' personal costs resulting from bankruptcy include compensation losses and position replacement. It was found that forced CEO turnover was higher during bankruptcy; two-thirds of incumbent CEOs left the executive labor market after bankruptcy and experienced large compensation losses (Eckbo, Thorburn, & Wang, 2016). Prior literature also reported that the compensation of CEOs started to fall two years before bankruptcy (Henderson, 2007). These ex post consequences provide ex ante incentives for managers to conduct innovation projects in a manner that meets debt obligations (B. Choi et al., 2016). Consequently, managers tend to efficiently allocate R&D resources to productive and valuable R&D projects. Therefore, two hypotheses were proposed accordingly.

**H3**: Debt financing interacted with R&D intensity exerts positive effect on radical innovation.

**H4**: Debt financing interacted with R&D intensity exerts positive effect on incremental innovation.

## 2. Data and methodology

### 2.1. Data

The sample consists of 225 listed Chinese computer and telecommunications equipment firms with 796 firm-year observations within 2008–2015 in China Stock Market & Accounting Research (CSMAR) Database. The sample is an unbalanced panel as firms with missing values in annual reports in CSMAR or experiencing mergers and acquisitions or marked with ST (special treatment) were excluded. For the sample firms, audited annual accounting information (long term debt, total assets, net sales, ownership structure, R&D expenditure), patent application data (application data of invention, utility model and design patent) and basic introductions (year of incorporation, number of employees) over the period of 2008–2015 were gathered.

### 2.2. Measures

*1. Dependent variables*

Technological innovation was measured by the number of patent applications filed by a firm in a given year. Patent is a quantified indicator of technological innovation outcomes (Schilling & Phelps, 2007), which is a function of all of the innovation input and thus encompasses both observable and unobservable input (Acharya & Subramanian, 2009; Aghion, Van Reenen, & Zingales, 2013). Also, patent was reported to correlate well with other technological innovation outcome measurements, for instance, new product (Ahuja & Katila, 2001). Patent application data was used rather than patent citation data as there were time lags between applying for patent and receiving citation. If patent citation data was used, the firm-year observations with patents applied in the last one year in the sample should be deleted, which would downsize the sample. To get more accurate regression results, it is needed to enlarge the sample as much as possible, and therefore patent citation data was not used.

The filing year of patent application was used rather than the granted year as patenting is a time-consuming process and the application year is more accurate in measuring the actual timing (Ulku, 2007).

According to Chinese patent laws, patent is categorized into three types, namely invention, utility model and design (Zheng et al., 2018). Complying with Chinese patent law, the patent data in CSMAR database was also categorized into the same three types. According to the definitions in CSMAR database, invention refers to completely unique or novel method, process, product or service, and is of great novelty and may change the market structure or create a new market; utility model refers to the improvements in the forms or combinations or constructions of products; design refers to the changes in the shape or colors or design of the products to cater to the customers. Comparing with the definitions of radical and incremental innovation in Oerlemans et al. (2013)'s study, the definition of invention matches that of radical innovation; the definitions of utility model and design match that of incremental innovation.

Therefore, *Radical innovation* was measured by the number of patent applications for invention filed by a firm in a given year. *Incremental innovation* was measured by the summing number of patent applications for utility model and design filed by a firm in a given year.

*2. Independent and interaction variables*

*Debt financing* was measured by the ratio of total long-term debt to total assets (T. Y. Wang & Thornhill, 2010). To estimate the quadratic relationship between *Debt financing* and technological innovation, the square term *(Debt financing)*$^2$ was generated. To mitigate multicollinearity, mean-centered *Debt financing* was used to generate the square term (Wu et al., 2016).

*R&D intensity* was used to measure R&D resources and was calculated as the ratio of total R&D expenditure to net sales (T. Y. Wang & Thornhill, 2010). To investigate the moderating effect of *Debt financing* on the relationship between *R&D intensity* and technological innovation, the interaction variable *DF*×*RD* was constructed. *DF* represents *Debt financing*; *RD* represents *R&D intensity*. *Debt financing* and *R&D intensity* were mean-centered before they were calculated to generate the interaction term *DF*×*RD*, to reduce the potential multicollinearity (Wu et al., 2016).

*3. Control variables*

Some firm specific characteristics and systematic period effects may affect technological innovation and thus should be controlled. Previous studies indicate that technological innovation is more likely to be created in firms with more tangible assets, more net sales, more cumulative patent applications, larger scale or smaller age (Cucculelli, 2018; Heirman & Clarysse, 2007; Petruzzelli, Ardito, & Savino, 2018; Schilling & Phelps, 2007; G. P. Wang & Miao, 2015). Previous studies also indicate that macro-level factors, for instance, tax reform, changes in financial markets and knowledge protection laws, influence technological innovation (Brown, Fazzari, & Petersen, 2009; Howell, 2016; Sofka, de Faria, & Shehu, 2018).

In line with prior research, *Tangible assets*, *Firm age*, *Firms size*, *Ownership*, *Sales*, *Presample stock* were used to control the unobserved heterogeneity in firm specific characteristics and *Year dummies* was introduced to control the systematic period effects. *Tangible assets* captures sample firm's capability to pledge collateral and was measured as total property divided by total assets (Heirman & Clarysse, 2007). *Firm age* was measured by the log transformed (one plus) sample firm's age (Brancati, 2015). *Firm size* was measured by the log transformed (one plus) number of employee (Brancati, 2015). *Ownership* controlled for sample firm's ownership structure and was a dummy variable, which took on 0 for state-owned firms, and 1 otherwise (Fang, Lerner, & Wu, 2017). *Sales* was a proxy for the sample firm's market performance and was measured as the log transformation of net sales (de Jong, Verbeke, & Nijssen, 2014). *Presample stock* controlled for the stock of technological innovation and was computed by cumulative patent applications in previous four years (Ahuja & Katila, 2001). *Year dummies* was used to control for the differences in macro-level factors (Coad, Segarra, & Teruel, 2016).

### 2.3. Models

The negative binormal regression models were employed to analyze the data and test the hypotheses. The model selection depends on the characteristics of dependent variables. The dependent variables in this study were measured by the number of patent applications and thus took on only integer and nonnegative values. Modelling count data variables requires specific regression methods, for instance, Poisson regression or the negative binormal regression, as liner regression model causes heteroscedastic abnormal problems in the distribution of residuals (Hausman, Hall, & Griliches, 1984; Schilling & Phelps, 2007). The Poisson distribution is the simplest form of a count data model, in which the variance of dependent variable is set equal to the mean (Schilling & Phelps, 2007). However, the over dispersion problems do exist in both dependent variables. Therefore, the negative binomial regression models were adopted, in which heterogeneity between the mean and variance is allowed.

One-year lag between the dependent variable and other variables was introduced into each model for two reasons. First, time lags can mitigate the endogeneity issue that results from bi-directional relations between the dependent variables and other variables. Earlier research has shown that there is a bi-directional relation between R&D intensity and technological innovation outcomes. Firms with higher R&D intensity create more technological innovation, and more technological innovation outcomes earn more R&D subsidies and thus motivate firms to invest more in R&D projects (Bronzini & Piselli, 2016; Rojas, Solis, & Zhu, 2018). The bi-directional relations also exist between technological innovation outcomes and some of control variables, for insta nce, sales. Market success brings more resources for promoting technological innovation, and technological innovation changes the market structure (S. B. Choi & Williams, 2014; G. P. Wang & Miao, 2015). Second, the time lags between R&D and the introduction of a new product was investigated, where the first returns were realized within one year after beginning of the development (Ravenscraft & Scherer, 1982).

Accordingly, the following negative binomial regression models were specified:

$$Y_{1(2)it} = exp(\beta_{1it-1}X_{1it-1} + \beta_{2it-1}X_{2it-1} + \beta_{3it-1}X_{3it-1} + \beta_{4it-1}X_{4it-1} + \beta_{5it-1}X_{5it-1} + \beta_{6it-1}X_{6it-1} + \beta_{7it-1}X_{7it-1}); \quad (1)$$

$$Y_{1(2)it} = exp(\beta_{1it-1}X_{1it-1} + \beta_{2it-1}X_{2it-1} + \beta_{3it-1}X_{3it-1} + \beta_{4it-1}X_{4it-1} + \beta_{5it-1}X_{5it-1} + \beta_{6it-1}X_{6it-1} + \beta_{7it-1}X_{7it-1} + \beta_{8it-1}X_{8it-1} + \beta_{9it-1}X_{9it-1}); \quad (2)$$

$$Y_{1(2)it} = exp(\beta_{1it-1}X_{1it-1} + \beta_{2it-1}X_{2it-1} + \beta_{3it-1}X_{3it-1} + \beta_{4it-1}X_{4it-1} + \beta_{5it-1}X_{5it-1} + \beta_{6it-1}X_{6it-1} + \beta_{7it-1}X_{7it-1} + \beta_{8it-1}X_{8it-1} + \beta_{9it-1}X_{9it-1} + \beta_{10it-1}X_{10it-1} + \beta_{11it-1}X_{11it-1}). \quad (3)$$

Where $Y_1$ represents *Radical innovation*; $Y_2$ represents *Incremental innovation*; $X_1$ represents *Tangible assets*; $X_2$ represents *Firm age*; $X_3$ represents *Firm size*; $X_4$ represents *Ownership*; $X_5$ represents *Sales*; $X_6$ represents *Presample stock*; $X_7$ represents *Year dummies*; $X_8$ represents *Debt financing*; $X_9$ represents *R&D intensity*; $X_{10}$ represents *(Debt financing)*$^2$ ; $X_{11}$ represents *DF×RD*. The variables in the models are indexed by firm *i*, also are indexed by time $t$ or $t-1$. The data was pooled for regression analysis due to the limited time span (8 years) and sample size. All the analyses were conducted with Stata 13.0.

## 3. Results

### 3.1. Descriptive statistics

Table 1 reports means, standard deviations, minimum and maximum values for the variables used in the analyses. Table 2 reports the correlation matrix, which indicates that multicollinearity is not a major concern as the correlations among the independent variables are relatively low. Only the correlation between two control variables, *Sales* and *Firm size*, is high. Both control variables were documented to be associated with technological innovation (de Jong et al., 2014; Shefer & Frenkel, 2005), to control for unobserved heterogeneity as much as possible, both variables were kept in models.

Table 1. Descriptive statistics

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Radical innovation | 41.452 | 307.877 | 0.000 | 5787.000 |
| Incremental innovation | 32.298 | 127.679 | 0.000 | 2265.000 |
| Tangible assets | 0.238 | 0.141 | 0.005 | 0.782 |
| Firm age | 1.190 | 0.112 | 0.699 | 1.477 |
| Firm size | 3.624 | 0.463 | 2.000 | 5.181 |
| Ownership | 0.235 | 0.424 | 0.000 | 1.000 |
| Sales | 9.539 | 0.583 | 8.316 | 11.797 |
| Presample stock | 236.991 | 1138.294 | 0.000 | 17541.000 |
| Debt Financing | 0.088 | 0.103 | 0.000 | 0.741 |
| *R&D intensity* | 0.019 | 0.026 | 0.000 | 0.342 |

Table 2. Correlation matrix

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Radical innovation | 1 | | | | | | | | | |
| Incremental innovation | 0.316 | 1 | | | | | | | | |
| Tangible assets | –0.101 | –0.030 | 1 | | | | | | | |
| Firm age | –0.008 | 0.020 | 0.070 | 1 | | | | | | |
| Firm size | 0.266 | 0.307 | 0.107 | 0.189 | 1 | | | | | |
| Ownership | 0.113 | –0.058 | –0.109 | –0.089 | –0.038 | 1 | | | | |
| Sales | 0.240 | 0.346 | 0.040 | 0.150 | 0.794 | –0.129 | 1 | | | |
| Presample stock | 0.597 | 0.369 | –0.109 | 0.0444 | 0.336 | 0.125 | 0.323 | 1 | | |
| Debt Financing | –0.018 | –0.049 | 0.403 | 0.101 | 0.132 | –0.103 | 0.155 | –0.012 | 1 | |
| R&D intensity | –0.014 | 0.037 | –0.148 | –0.086 | –0.145 | 0.039 | –0.175 | –0.006 | –0.074 | 1 |

### 3.2. Main regression results

The negative binomial regression results are reported in Table 3. For each dependent variable, *Radical innovation* or *Incremental innovation*, three different models have been established. The first model (Model 1/4) includes control variables and is the baseline model against which the other two models can be evaluated. The second model (Model 2/5) is the linear-fitting model, which adds *Debt financing* and *R&D intensity* to the first model. The third model (Model 3/6) is the quadratic-fitting model, which adds *(Debt financing)*$^2$ and the interaction variable *DF*×*RD* to the second model. The coefficients and standard errors are reported in the table with the latter in parentheses right under the former. Log likelihood, p-values of Wald test and the number of observations are also reported in Table 3. The values of log likelihood and p-values of Wald test suggest that for each dependent variable, quadratic-fitting model is better than linear-fitting model, both of which are better than baseline model. Therefore, for each dependent variable, the coefficients and the corresponding significance in the third model (Model 3/6) are used to interpret the relationship between *Debt financing* and *Radical/Incremental innovation*.

H1 predicts a negative relationship between *Debt financing* and *Radical innovation*. In Model 3 of Table 3, the coefficient for *Debt financing* is negative and statistically significant and the coefficient for *(Debt financing)*$^2$ is positive and statistically significant. These results suggest that the direct relationship between *Debt financing* and *Radical innovation* follows a quadratic pattern. The quadratic model indicates that with the increasing of *Debt financing*, *Radical innovation* gradually decreases at decreasing rates but eventually increases after the turning point. However, whether the turning point occurs within the sample range for *Debt financing* could not be drawn from the coefficients and significance from Model 3 in Table 3. To test the presence of the turning point and to visualize the relationship between *Debt fi-*

*nancing* and *Radical innovation*, this relationship was plotted in Figure 1. The horizontal axis of Figure 1 represents the values of *Debt financing* and ranges from 0 to 0.75 (the minimum value of *Debt financing* in the sample is 0, and the maximum is 0.741); the vertical axis of Figure 1 represents the values of *Radical innovation*. Figure 1 indicates that the turning point does not occur within the sample range. In sum, within the sample range, *Radical innovation* decreases with *Debt financing* at decreasing rates. H1 receives strong support.

Table 3. Effect of debt financing on radical and incremental innovation

| | Radical innovation | | | Incremental innovation | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Constant | −2.622* | −4.906*** | −5.108*** | −7.200*** | −9.707*** | −9.491*** |
| | (1.492) | (1.569) | (1.572) | (1.799) | (1.911) | (1.908) |
| Tangible assets | −1.258*** | −0.922** | −1.103*** | −1.142** | −0.805 | −0.805 |
| | (0.375) | (0.424) | (0.421) | (0.457) | (0.495) | (0.494) |
| Firm age | −3.113*** | −2.798*** | −2.932*** | −1.980*** | −1.516** | −1.748** |
| | (0.587) | (0.573) | (0.568) | (0.701) | (0.699) | (0.700) |
| Firm size | 0.476** | 0.425** | 0.413* | 0.169 | 0.0925 | 0.0688 |
| | (0.217) | (0.216) | (0.218) | (0.267) | (0.269) | (0.274) |
| Ownership | −0.221 | −0.141 | −0.139 | 0.0408 | 0.107 | 0.0970 |
| | (0.138) | (0.138) | (0.137) | (0.165) | (0.165) | (0.165) |
| Sales | 0.758*** | 0.944*** | 0.989*** | 1.151*** | 1.349*** | 1.364*** |
| | (0.188) | (0.193) | (0.193) | (0.229) | (0.237) | (0.237) |
| Presample stock | 0.000931*** | 0.000855*** | 0.000849*** | 0.00128*** | 0.00119*** | 0.00121*** |
| | (0.000136) | (0.000130) | (0.000129) | (0.000197) | (0.000196) | (0.000197) |
| Year dummies | Included | Included | Included | Included | Included | Included |
| Debt financing | | −1.337** | −1.844** | | −0.928 | −1.195 |
| | | (0.662) | (0.904) | | (0.732) | (1.018) |
| (Debt financing)$^2$ | | | 5.237** | | | 3.282 |
| | | | (2.625) | | | (3.009) |
| R&D intensity | | 0.117*** | 0.139*** | | 0.123*** | 0.136*** |
| | | (0.0287) | (0.0281) | | (0.0357) | (0.0359) |
| DF×RD | | | 1.125*** | | | 0.915** |
| | | | (0.321) | | | (0.416) |
| Log likelihood | −2700.641 | −2689.4141 | −2682.9559 | −2648.4237 | −2641.1536 | −2638.633 |
| Wald test | | | 0.000 | | | 0.000 |
| N | 796 | 796 | 796 | 796 | 796 | 796 |

*Notes*: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; Wald test reports the p-value of a test of joint significance of interaction variables.

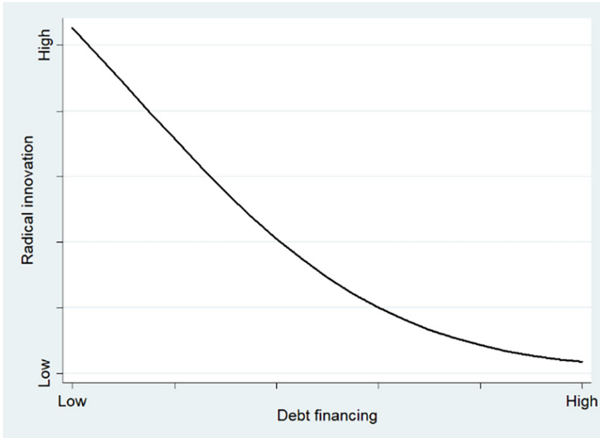


Figure 1. Direct effect of debt financing on radical innovation

H2 predicts a negative relationship between *Debt financing* and *Incremental innovation*. As shown in Model 4 of Table 3, the coefficients for both *Debt financing* and its square term, *(Debt financing)*$^2$, fail to achieve any statistical significance. Therefore, the direct effect of *Debt financing* on *Incremental innovation* is non-significant. H2 is not supported.

H3 predicts that *Debt financing* interacted with *R&D intensity* exerts positive effect on *Radical innovation*. As displayed in Model 3 of Table 3, the coefficients for *R&D intensity* and *DF×RD* are positive and significant. Hence, H3 receives strong support. H4 predicts that *Debt financing* interacted with *R&D intensity* exerts positive effect on *Incremental innovation*. As shown in Model 6 of Table 3, the coefficients for *R&D intensity* and *DF×RD* are positive and significant. Therefore, H4 is supported. Figure 2 and Figure 3 were drawn for visualizing the relationship between *R&D intensity*, *Debt financing* and *Radical/Incremental innovation*. The horizontal axis of each figure represents *R&D intensity*. The vertical axis of Figure 2 and Figure 3 represents *Radical innovation* and *Incremental innovation*, respectively. The sample firms were split into two subgroups based on the levels of *Debt financing*: one subgroup with

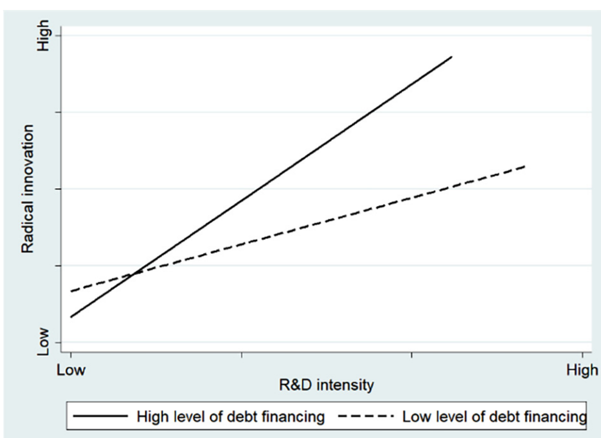


Figure 2. Debt financing, R&D intensity and radical innovation

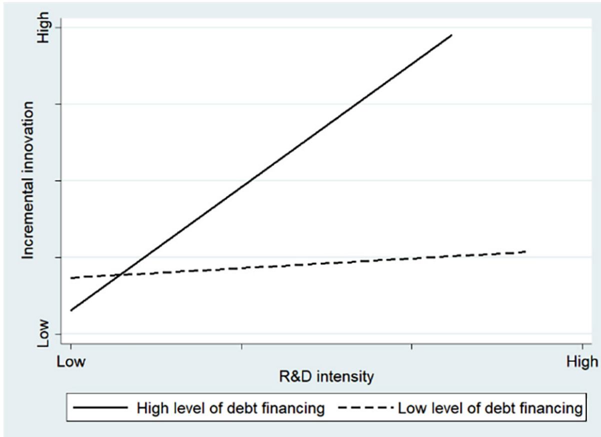


Figure 3. Debt financing, R&D intensity and incremental innovation

*Debt financing* at the high level (upper 50% of *Debt financing*) and the other subgroup with *Debt financing* at the low level (lower 50% of *Debt financing*). Correspondingly, in each figure, the solid line represents the subgroup with *Debt financing* at the high level, the dash line represents the subgroup with *Debt financing* at the low level. Figure 2 and Figure 3 illustrate that *Debt financing* interacted with *R&D intensity* exerts positive effect on both *Radical innovation* and *Incremental innovation*.

### 3.3. Signs of control variables

*Tangible assets* exerts negative effect on *Radical innovation* but non-significant effect on *Incremental innovation*. Firms with more tangible assets may file less patent applications of the radical type. *Firm age* negatively affects both *Radical innovation* and *Incremental innovation*, which suggests that younger firms file more patent applications of both types. Therefore, to foster technological innovation on the firm level, the governments should make policies that bias for younger firms. *Firm size* is positively associated with *Radical innovation* but not with *Incremental innovation*, which indicates that bigger firms file more patent applications of the radical type. *Ownership* doesn't have significant relationships with *Radical innovation* or *Incremental innovation*. *Sales* is linked positively to both *Radical innovation* and *Incremental innovation*. A possible explanation is that larger sales provide firms with abundant internal funds for investing in technological innovation. *Presample stock* is found to be positively associated with both *Radical* and *Incremental innovation*. Firms with more patent stock in the past may embody some characteristics (e.g. high talent pool, better managerial skills, and corporate culture for innovation) that help firms file more patent applications in the future (Howell, 2016; Krasnicka, Glod, & Wronka-Pospiech, 2018; Naqshbandi & Tabche, 2018).

### 3.4. Robustness analysis

To check the robustness of empirical results, the models were re-estimated using an alternative measurement of *Debt financing*, the ratio of long-term debt to total debt (Bertin, Warleta,

& Hoffmann, 2012). The measurements of other variables remained the same in the robustness analysis. The negative binormal regression results are summarized in Table 4. The results obtained for the alternative measurement of *Debt financing* are in line with findings reported in the previous part of this study. Therefore, the results are proved to be robust.

Table 4. Robustness check results

| | Radical innovation | | | Incremental innovation | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Constant | −2.622* | −4.992*** | −4.568*** | −7.200*** | −9.441*** | −9.054*** |
| | (1.492) | (1.652) | (1.640) | (1.799) | (1.936) | (1.940) |
| Tangible assets | −1.258*** | −1.133*** | −1.303*** | −1.142** | −0.744 | −0.673 |
| | (0.375) | (0.424) | (0.416) | (0.457) | (0.484) | (0.487) |
| Firm age | −3.113*** | −2.856*** | −3.079*** | −1.980*** | −1.517** | −1.717** |
| | (0.587) | (0.599) | (0.594) | (0.701) | (0.713) | (0.716) |
| Firm size | 0.476** | 0.449** | 0.459** | 0.169 | 0.122 | 0.119 |
| | (0.217) | (0.220) | (0.225) | (0.267) | (0.268) | (0.277) |
| Ownership | −0.221 | −0.133 | −0.139 | 0.0408 | 0.0579 | 0.0681 |
| | (0.138) | (0.141) | (0.140) | (0.165) | (0.166) | (0.165) |
| Sales | 0.758*** | 0.951*** | 0.936*** | 1.151*** | 1.311*** | 1.296*** |
| | (0.188) | (0.197) | (0.196) | (0.229) | (0.236) | (0.236) |
| Presample stock | 0.000931*** | 0.000827*** | 0.000819*** | 0.00128*** | 0.00116*** | 0.00118*** |
| | (0.000136) | (0.000130) | (0.000129) | (0.000197) | (0.000191) | (0.000192) |
| Year dummies | Included | Included | Included | Included | Included | Included |
| Debt financing | | −0.598* | −1.427* | | −0.847 | −1.274 |
| | | (0.537) | (0.761) | | (0.569) | (0.853) |
| (Debt financing)$^2$ | | | 3.784* | | | 2.137 |
| | | | (2.113) | | | (2.421) |
| R&D intensity | | 0.125*** | 0.137*** | | 0.121*** | 0.124*** |
| | | (0.0291) | (0.0271) | | (0.0354) | (0.0346) |
| DF×RD | | | 0.977*** | | | 0.605** |
| | | | (0.234) | | | (0.301) |
| Log likelihood | −2700.641 | −2598.2934 | −2589.4448 | −2648.4237 | −2547.6182 | −2545.5154 |
| Wald test | | | 0.000 | | | 0.000 |
| N | 766 | 766 | 766 | 766 | 766 | 766 |

*Notes*: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; Wald test reports the p-value of a test of joint significance of interaction variables.

## Conclusions

Using data from Chinese computer and telecommunications equipment firms, the effect of debt financing on two types of technological innovation, namely radical and incremental innovation, was investigated. Debt financing itself has negative direct effects on radical innovation, but non-significant effect on incremental innovation. In addition, debt financing interacted with R&D intensity exerts positive effect on both radical and incremental innovation. The main conclusions of this paper are robust.

Given debt financing is an important source for financing technological innovation in Chinese firms (Howell, 2016), the non-significant relationship between debt financing and incremental innovation is counter-intuitive. One possible explanation is that incremental innovation has already been a common practice in firms and is performed regardless of whether the debt ratio is high or low. Due to the globalization, computer and telecommunications equipment firms are facing up with competition both from domestic and aboard (Betran & Huberman, 2016). In such competitive environment, firms need to constantly improve their products to cater to consumers' various and rapidly changing demands to remain survive and thrive (Coccia, 2017). Incremental innovation, which brings improvements in the forms or combinations or constructions of products and changes in the shape or colors or design of the products, is one promising and effective way to catch consumers' attentions and thus expand the market share (Bouncken, Fredrich, Ritala, & Kraus, 2018; Brettel, Heinemann, Engelen, & Neubauer, 2011). In addition, incremental innovation involves lower risk, less cost, shorter terms but higher certainty in the future returns (Davis & Tomoda, 2018; Fores & Camison, 2016), which encourages the firms to perform incremental innovation frequently regardless of ratios of debt.

Different from previous innovation classification into process and product based on the stage of innovation occurrence (Alessandrini, Presbiteroy, & Zazzaroz, 2010; Benfratello et al., 2008; Brancati, 2015; Giannetti, 2012; Kim & Park, 2017), technological innovation was categorized into radical and incremental innovation in this study. Pursuing radical innovation generally reflects changes in the firms' operations and structures (Dahlin & Behrens, 2005) and exerts differential influences from incremental innovation on market structures (Beck, Lopes-Bento, & Schenker-Wicki, 2016). Therefore, innovation categorization in this study may help anticipate the relationship of debt financing with business development strategies and market responding before the commercialization of innovation.

The findings also have implications on managerial practice and policy making. Given the positive moderating role of debt financing on incremental innovation, it is suggested that firms utilize debt to finance incremental innovation. Considering the mixed role of debt financing on radical innovation, firms in pursuit of radical innovation need to refine the debt ratio so that the benefits from debt exceeds the costs of debts. The results also indicate that policies aiming to increase the availabilities of debt for firms may spur the creation of incremental innovation but not the generation of radical innovation. For countries which emphasize radical innovation capabilities such as China (Howell, 2016), monetary stimulation policy or bank deregulation may not be an effective way of boosting radical innovation.

This study is subject to two limitations. First, the debt financing instrument in this study was confined to bank and commercial loans. Convertible debt and corporate bonds are another two important sources of debt financing (Feldhütter, Hotchkiss, & Karakaş, 2016; Murdock, 2013; Pan & Zhengfei, 2005) but were not able to be included in this investigation for the following reasons. Convertible debt has characteristics of both debt and equity because it can be converted into firms' common stock by their holders under certain circumstances (Lyandres & Zhdanov, 2014). In the balance sheet of CSMAR database, corporate bonds and convertible debt are calculated under the same account title, which makes it hard to find out the mount of corporate bonds. In the future, it will be very interesting to explore the relationships between corporate bonds/convertible debt and technological innovation. Some promising observations seem to support their relationships. Corporate bonds and convertible debt were found to be associated with R&D investment (T. Y. Wang & Thornhill, 2010), which has critical influences on technological innovation. The other limitation is that empirical results are based on the listed Chinese computer and telecommunications equipment firms, raising the possibility of sample bias. Results of this study may not be generalizable to private manufacturing firms, or to firms in other industries, or to firms in market-based countries.

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## Author contributions

Kuang Xin conceived the study, collected and analyzed the data and wrote the manuscript. Yuchun Sun, Ran Zhang and Xiao Liu contributed to the manuscript discussion.

## Disclosure statement

The authors declare that there are no competing financial, professional, or personal interests from other parties.

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