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Disruptive Innovation and R&D Ownership Structures of the Firm

Di Guo, Haizhou Huang, Kun Jiang, Chenggang Xu[1]

Abstract

Among the 87 revolutionary innovations in the world over the life of the Soviet Union, 86 were invented in capitalist economies (Kornai, 2013). This paper studies why this is the case. This paper provides a theoretical foundation, which explains why disruptive innovations are organized and financed with a large number of independent small firms in a capitalist economy. Whereas not allowing private ownership, this kind of arrangement is not an option in an economy where only state ownership exists. This paper also contributes to empirical work on disruptive innovation, which is missing in the literature. We use FDA approved new molecular entities (NMEs) in the pharmaceutical industry as a proxy of disruptive innovation in the industry. Although pharma firms are often very large in size, their R&Ds for developing NMEs depend deeply on forming R&D alliances with independent small R&D firms. We find NMEs invented by a pharma firm is positively and significantly associated with the number of R&D alliances that the firm creates.

[1] The authors are from Brunel University London, CICC, University of Nottingham and Cheung Kong Graduate School of Business, respectively. The views and errors are of the authors, and they do not necessarily reflect those of their affiliated institutions. We thank Eric Maskin for his comments and generous help to an early version of this paper; and would like to thank Zhongming Shi for his able research assistance. Chenggang Xu acknowledges support from the CKGSB and hospitality of Imperial College.

1. Introduction

Janos Kornai has studied economic systems extensively and intensively in decades of his career (Kornai, 1971, 1980, 1992, 2013). In his recent book (Kornai, 2013), *Dynamism, Rivalry, and the Surplus Economy*, he analyzes the fundamental differences between capitalism and socialism[2] in innovation in general, and in Schumpeterian creative destruction in particular. By providing 87 examples of break-through, revolutionary innovations in the recent century since the birth of the Soviet Union, he finds that 86 out of the 87 were invented in market economies. Thus, not being able to create revolutionary innovation distinguishes socialism from capitalism.

Disruptive innovation is the driving force of the Schumpeterian creative destruction, which determines the long-term growth of any economy. In reality, it also determines the fates of socialism and capitalism in the long run. One of the most striking findings from Kornai's list of revolutionary innovations (we will call it Kornai Table in the rest of the paper), which profoundly impacted all the human beings in the past century, is that the Soviet socialist economy only made one disruptive innovation, whereas all the others were invented in capitalist economies, and an overwhelmingly large proportion of disruptive innovations were created by the US, particularly in the recent half-century. This finding is perhaps also very puzzling to those who believe state power in R&D for various reasons.

Indeed, in the same book, Schumpeter coins the concept of creative destruction, arguing that only large firms, particularly monopolistic firms, are interested in innovation to reinforce their monopolistic positions; and, capitalism will eventually be replaced by socialism (Schumpeter, 1950). In parallel to Schumpeter's view on monopolistic firms' dominant roles in disruptive innovation is the view on market failure. According to this view, unable to capture positive externalities of R&D outcomes carried out by small firms in the market, there will be an under-investment problem in a market economy (Hall, 2002). Thus, state investment in R&D is necessary for correcting market failure. If one pushes this argument further, one might even conclude that socialism should do better in innovation than capitalism as there is no market failure there.

The reality, however, is that socialism is not good at disruptive innovation, neither are big firms alone in capitalist economies. In a capitalist economy, not all types of businesses, and not all types of institutions, are good at creating disruptive innovation. Venture capital (VC) and VC financed startup firms are responsible for creating most of the disruptive innovations in the last six decades. Some of the startup firms grew rapidly and became industrial leading giants, such as Apple, Microsoft, Amazon, Google, and Intel, etc., whereas most of the startups were purchased by leading giants, such as DeepMind, Skype, Mobileye, etc. In contrast, matured large corporations tend to restrict their internal R&D activities in less uncertain and less new-product-related innovation while devote more attention to perfection-related or cost-reduction-related innovation (Scherer, 1991, 1992); they often choose not to integrate high-uncertain R&D projects but finance them as stand-alone small firms jointly with other financiers, e.g., via forming R&D alliances.Consistently, "idea-rich small firms originate a disproportionate share of innovations" (Scherer, 1992).

This paper studies, theoretically and empirically, why disruptive innovations are mainly created by outsourced R&D alliances, many of which involve venture capital (VC) financed startups, and why internal R&D departments/divisions of large corporates or R&D branches of centralized socialist economies fail to do so. The underlying logic of our theory is a generalized soft-budget constraint theory (a la Kornai, 1979, 1986, 2013; Dewatripond and

[2] Kornai (1992) defines socialism as an economy where state ownership dominates. Because the state is the sole owner and controls state firms, there is no clear boundary between the state and the firm in socialism. By this definition, welfare states in the West are not socialism. This paper defines socialism in the same way.

Maskin, 1995; and Qian and Xu, 1998). Since disruptive innovation is highly uncertain that ex-ante no one knows the statistical distribution of a project, the ex-post screening ability is critical for solving the incentive problems associated with R&D, and this ability relies on the extent of hard-budget constraint (HBC), i.e., the commitment of terminating failing projects. Centralized institutions lack commitment capacity in ex-post R&D project screening because they face the "soft budget constraints (SBC)" problems. Through this logic, our theory explains why disruptive innovations are rarely invented in a centralized institution, such as large corporations in a market economy or a centralized economy; and why they are mostly created in VC financed startups initially, and further developed via outsourced R&D alliances, involving multiple owners/financiers.

The question of the boundary of the firm by Coase (Coase, 1937) addresses the ownership structure of firms, from the smallest firms in the market to the largest firm, the socialist economy, where all assets are state-owned (Lenin, 1917). Indeed, understanding the Soviet economy was one of the major motivations in this paper (Coase, 1937, 1991[1993]). Along with this logic, it is not surprising that very large corporations in a market economy might share some features with a centralized economy, such as the SBC problem in dealing with highly uncertain R&D financing, as we will discuss below. According to Coasian analysis, a large number of transactions take place within the firm rather than in the market because doing so costs less than it does in the market. In this paper, we analyze what affects a large firm's decision on whether or not to have a full ownership of an R&D project, i.e., whether or not to carry out an R&D project internally. More specifically, if R&D in disruptive technology is vital to a large corporation, e.g., a leading pharmaceutical company, what should be the optimal strategy and its corresponding ownership structure of this firm? Should its major R&D projects be conducted internally with full ownership, or be outsourced with shared ownership or even no ownership at all, e.g., via forming R&D alliances with other stand-alone firms? We identify conditions under which a large firm prefers to integrate an R&D project with full ownership to finance it internally; and conditions under which the firm prefers to finance the project externally, jointly with other financiers, i.e., without holding ownership at least at earlier stages.

The more recent mainstream theory of the firm is based on residual control rights of properties by Hart (Hart, 2017; 2005), sometimes called Grossman-Hart-Moore theory in the literature (Grossman and Hart, 1986; Hart and Moore, 1990). Applying this theory to our question directly, if an R&D project is complementary to the core business of a large firm, the firm should carry out the project internally with full ownership; otherwise, it should be outsourced.

Then the question to be addressed is if a large firm is not constrained by wealth to self-finance an R&D project, which is complementary to its core business, why should it ever choose to finance R&D externally as empirically observed overwhelmingly? A concrete example is a leading pharmaceutical firm's efforts in developing new drugs through R&D alliances, instead of investing internally.

A theory addressing the above question is, at the same time, an answer to its mirror question regarding R&D in a socialist economy. In contrast to large firms in capitalist economies that are free to choose the optimal ownership structure for their R&D projects, state-owned enterprises (SOEs) in socialist economies have no alternative ownership structure for R&D projects. They can only conduct R&D under state ownership, which is equivalent to internal finance in our theory. In reality, nominally, there are many SOEs in any socialist economy. But all the SOEs are controlled by the same government; thus, from the control right point of view (Hart, 2017), all the SOEs are actually divisions of one firm.

In this paper, we provide a theory to link the boundary of the firm, or the ownership of R&D projects, with the features of such projects. We argue that the optimal allocation of a firm's boundary in R&D projects depends on the characteristics of R&D projects and the

external financial environment. In our theory, we suppose that the uncertainty associated with an R&D project is so high that no one even knows its statistical distribution. And the uncertainty can only be reduced when the project is carried out. Therefore, the ex-post selection is crucial, whereas ex-ante selection can hardly be effective. However, an ex-post screening mechanism requires a commitment that a bad project will be stopped even when refinancing the bad project is ex-post profitable (which means that the earlier sunk costs of the project are not taken into consideration in an ex-post decision).

Our model shows that non-integration, in which a firm finances a project externally with other financiers, e.g., by forming an R&D alliance, can be deployed as a commitment device for a large firm to terminate bad projects when they are discovered ex-post. With full ownership of an R&D project (call it as integration), i.e., carrying R&D within the firm, this firm may lose the badly needed commitment capacity. That is, there is a cost of possessing full ownership over an R&D project, which is the owner's loss of commitment capacity. Moreover, the more uncertain an R&D project is, the higher the cost for holding full ownership of an R&D project from the very beginning is. Therefore, the allocation of the boundary of R&D projects for firms is determined by the trade-off between the efficiency gain from solving the commitment problem — gaining the capacity to make ex-post selections — and the institutional cost of external financing. Here, the institutional cost of external financing refers to that of moral hazard and of adverse selection problems, which have been extensively discussed in the literature. As a result of this trade-off, if a project is relatively certain, integration, i.e., internal R&D, is more efficient; if a project is more uncertain, non-integration, i.e., forming outsourcing R&D alliances, is more efficient.

Our theory is inspired by the Dewatripont-Maskin model (1995) of soft budget constraints (a la Kornai, 1980), which is centered on an institution's capability of committing to terminate unprofitable projects ex-post. Borrowing from Maskin (1992), we provide a new contractual foundation for hardening budget constraints that investors are not constrained by the needed wealth to finance a project alone if they choose so. The new contractual foundation allows us to expand the soft budget constraint paradigm to not only the issue we address in this paper but also many other issues, which we will briefly discuss in conclusion.

Compared with capitalist economies, why are socialist economies unable to invent revolutionary products? In addressing the question, Kornai (2013) examines the characteristics of the innovation process in capitalist and socialist economies, which is summarized in the following table.

Factors (A), (C), (D) and (E) in Table 1 are related to competition and conflicts between winners and losers of the process, which are substantially different if they have HBC in capitalism and SBC in socialism. In our paper, based on private property rights, capitalism has options of carrying R&D with different ownership structures of R&D projects, from having complete exclusive ownership, i.e., internal R&D, to completely outsourcing even without ownership at early stages. The HBC is a critical factor in creating disruptive innovations, which is the foundation of the Schumpeterian destruction process. "[T]he Schumpeterian process of innovation…has inevitably two sides: many projects are needed for the few great successes, and at the same time, we get too many of them." (Kornai, 2013, p. 34). The upside of the process is the creation of new outcomes. The downside is the destruction that implies the bankruptcy of old firms (HBC) and the "extinction" of old products. This downside is an essential part of the Schumpeterian process and necessary for innovation and market mechanisms. However, only capitalism supports HBC (Kornai et al., 2003), which provides conditions for investing in promising projects and substantially rewarding successful entrepreneurs (Kornai, 2013, p. 15). By contrast, in socialism with SBC, lose-making firms are protected from going bankrupt, and innovation has to be conducted through a bureaucratic planning mechanism. Consequently, investment in R&D is limited to a smaller number of projects, and the rewards of success are limited (Kornai, 2013, p. 15).

Table 1. Characteristics of innovation processes in capitalist and socialist economies

	Capitalism	Socialism
A. R&D initiatives and decisions	Entrepreneurs/Firms	Government
B. Financial reward to successful entrepreneurs	Enormous	Insignificant
C. Competition	Tough	Very weak
D. Parallel experiments	Extensive	Very limited
E. Project financing	Flexible	Rigid

Qian and Xu (1998) and Huang and Xu (1998) analyze innovation in capitalist and socialist economies; and endogenize points (A), (C), (D) and (E) in the two systems. The predictions of their models[3] are consistent with the facts discussed in Kornai (2013). HBC is intimately related to creative destruction.

Similar to Schumpeter and Hayek, Kornai believes that the dynamic features of capitalism and socialism are among the most important subjects in economics. However, he feels frustrated or even "angry" that "most people and even … most professional students of alternative systems" "completely ignored" this "highly visible great virtue of capitalism" (p. 3). He discusses the lack of understanding within our profession and among the population on the high capacity of capitalism to invent and innovate, which determines the long-term growth, survival, and many other good or bad features of capitalism, compared with socialism or any alternative system. This paper intends to explore the mechanism of this "highly visible great virtue of capitalism" theoretically and empirically.

The mechanism that we study in the paper shares some insights with Hart and Moore (1995) and Bolton and Scharfstein (1996), in which conflicts of interest between the multi-investors play important roles. However, our focus is on the commitment problem, and we endogenize a renegotiation-proof institution.

It is interesting to point out that the theory of the firm based on information issues alone might not be good enough in analyzing the dynamics of disruptive R&D. It has been famously argued that the informational asymmetries related to external financing can make an investment more costly due to moral hazard and adverse selection problems between the entrepreneur and the financiers (e.g., Stiglitz and Weiss, 1981; and Kamien and Schwartz, 1978). And only large firms can finance R&D internally. Furthermore, given that almost all R&D projects involve substantial sunk costs (implying low liquidation value), external financing might incur more severe moral hazard and adverse selection problems (Bernanke and Gertler, 1989; Calomiris and Hubbard, 1990; Hubbard and Kashyap, 1992). If we push their logic to the extreme, a socialist economy with state ownership will eliminate external financing altogether, and thus will minimize information problems and be the best in R&D. But this is just opposite to our observations.

Our theory is also related to the literature on R&D financing (e.g., Allen and Gale, 1999; Bhattacharya and Chiesa, 1995). This strand of literature concerns about difficulties in transferring knowledge and looks for ways to make the knowledge transfer easier. In contrast, our theory argues a different side of informational asymmetry between co-financiers that difficulties in knowledge transfer can be beneficial to financiers in helping the termination of bad R&D investment promptly.

Our paper is complementary to the recent literature on R&D. Ahgion et al. (2005) study the dynamic relationship between competition and innovation intensities in different

[3] Models of Qian and Xu (1998) and Huang and Xu (1998) are based on Maskin and Dewatripont (1995), which endogenizes hard and soft budget constraints in capitalism and socialism, respectively.

sectors. Acemoglu et al. (2006) explore the relationship between the development stage of an economy and innovation. They argue that for an economy on the technology frontier, the capability of selecting high-skilled entrepreneurs is the key for the economy to grow. With a similar spirit, Acemoglu et al. (2018) analyze the dynamics of firm entry and exit in innovation. The authors argue that high-type firms expand when the low-type firms exit because of the lack of innovation. As such, high-skilled labor resources are shifted from low-type to high-type firms, thereby leading to more innovation. Complementing their pictures of innovation explained in that literature, we look at how disruptive innovation projects are financed, and how the ownership structure or the boundary of the firm are chosen in generating disruptive innovation.

Our theory also sheds light on syndicated financing. It is documented that the "syndicated loan market [is] not only one of the largest but also one of the fastest-growing sources of corporate financing available today" and "the market has been growing at a compound annual rate of more than 10% per year over the last decade." In the year 2000 banks extended $2 trillion of syndicated loans (Esty and Megginson, 2001) – in contrast, the total amount of loans and leases in bank credit in the US in the same year was $3.88 trillion, and the total value of bank assets was about $6 trillion. Our theory helps to explain the paramount importance of such a financial phenomenon from a theoretical perspective. Indeed, as long as there are multiple financiers with different specializations are involved, their information and interests are naturally diverse that can be deployed strategically as a commitment device.

Empirically testing our theoretical predictions is a great challenge as there is no well-recognized approach to measure disruptive innovation in the R&D literature. For this purpose, our empirical part focuses on the pharmaceutical industry for two reasons. First, this industry is the most R&D-intensive industry with the highest R&D inputs. In 2017, biopharmaceutical companies invested about $97 billion in R&D (21.8% of their total sales) in the US (PhRMA, 2018). Moreover, inventing drugs involves an extraordinarily high level of uncertainties; whereas, this industry indeed generates revolutionary inventions. According to the American Cancer Society (2010), between 1990 and 2006, mortality from cancer decreased by 21.0 percent for men and 12.3 percent for women in the US; between 1999 and 2006, new cases dropped by about 1 percent annually. Second, there is a systematic and objective measurement of the R&D outputs, which is the development of new molecular entities (NMEs) in the pharmaceutical industry approved by the FDA. We take this as our measure of disruptive innovation, and we employ the data of all the NMEs discovered in the past two decades.

NMEs are compounds that contain novel moieties, i.e., they are not a version or a derivative of an existing substance. They promise to provide critical new therapies against certain diseases. FDA has set up criteria for measuring new types of drugs, which are disruptive to existing drugs, and the standards are rigorously implemented based on evidence[4]. As we will further explain in Section 6.1, the total number of patents granted is not a good measure for disruptive innovations. Patents are too broadly defined and granted that most often, they do not lead to revolutionary inventions. Indeed, the total number of patents granted on relevant drug research over the same sample period is 229 times bigger than the number of NMEs, which are thus far more likely to lead to revolutionary inventions than patents. We believe NMEs approved by the FDA provide us objectively measured data of disruptive

[4] Using FDA approved NMEs as a proxy for disruptive innovation is the best choice we can find for our purpose among all alternatives. We are aware of the debates on the bureaucracies and deficiencies of FDA, which might affect quality of the drugs approved by them. For example, Lasser et al. (2002) document that among total 548 new chemical entities (NCEs studied in that paper are associated with much less potent drugs than those of the NMEs, which are the measurement that we are using) approved by the FDA during 1975-99, 2.9% have to be withdrawn from the market due to adverse drug reactions and many more have to have warnings. The deficiencies of the FDA could lower the accuracy of NMEs as a proxy of disruptive innovation in drug R&D. This inaccuracy is equivalent to adding type I and type II errors in our variable. We thank a referee for pointing this out and for suggesting this literature.

innovation in the industry.

In Table 2, we extend the Kornai Table by looking at NMEs invented by all the nations in the last two decades. The findings on the development of NMEs are similar in nature to those of the Kornai Table. All NEMs approved between 1998 and 2018 are invented by firms in capitalist economies, and 56% are invented by firms in the US. Whereas, in the former or current socialist economy defined by state ownership, including the Soviet Union and China, no company invented any NME during this period[5].

Consistent with our theory, R&D in the pharma industry involves a large number of small independent biotech firms interacting with super large pharmaceutical companies. Since 1980, 4,156 American biotech startup firms (or 90% of biotech startups in the US) have received 9,152 rounds of VC investment, among which 1,210 firms (29%) are backed by corporate VC funds.[6] Almost all large pharmaceutical firms are active in setting up corporate VCs to engage in small independent biotech startup firms. The 15 largest pharmaceutical firms managed 60 investment arms and 90 limited partnership (LP) VC funds for financing biotech startups. Between 1980 and 2009, there were 29,968 R&D agreements signed between large pharmaceutical firms and small bi-tech firms or other independent research institutes (Deloitte ReCap).

Table 2. NEMs Invented by all the Nations, 1998-2018[7]

Country	NEM (1998-2018)	Share
USA	360	56.34%
Switzerland	55	8.61%
UK	50	7.82%
Japan	39	6.10%
Germany	38	5.95%
Ireland	26	4.07%
France	21	3.29%
Canada	8	1.25%
Denmark	8	1.25%
Netherlands	7	1.10%
Sweden	6	0.94%
Belgium	5	0.78%
Israel	5	0.78%
Italy	3	0.47%

[5] Not being able to invent NMEs, Russia and China rely heavily on importing new drugs. “Russia currently imports about 80% of its pharmaceuticals. But even domestically produced drugs are often made from active ingredients obtained abroad, notes Tatiana Nikolenko, director of infrastructure programs at Rusnano, adding that less than 1% of novel drugs sold in the country are produced there.” Katsnelson, A. Russia pushes for domestic drug development. Nature (2010). Meanwhile, it is important to distinguish medical treatment from drug development. There is a limitation on what medical treatment alone can do without disruptive inventions in drugs.

[6] All the statistics are sorted based on the information from CapitalIQ, a financial database constructed by Standard and Poor. According to a report, about one-third of the drugs in the pipelines of the top ten pharmaceutical firms were initially developed elsewhere (Jonathan Rockof, Wall Street Journal: https://www.wsj.com/articles/pharmaaceutical-scouts-seek-new-star-drugs-for-cancer-diabetes-1394415062). The role of outsourcing is even more important for developing NMEs. According to the Global Pharma Intelligence Center database and Scorecard report, 51% of NMEs approved in 2018 were outsourced. In comparison, only 33% of non-NMEs approved in 2018 were outsourced (https://www.pharmaaceutical-technology.com/comment/cmo-outsourcing-2018/).

[7] We define the origin of the pharmaa firms by the location of the headquarters of such firms. It is noted that between 1998 and 2018, 612 NMEs were invented, a small number of which were invented by more than one firm together. In this table, we count each involved firm as one point of calculation. Therefore, the total number of involved firms is 639.

India	2	0.31%
Spain	2	0.31%
Finland	1	0.16%
Korea	1	0.16%
Singapore	1	0.16%
Taiwan	1	0.16%
Total	639	100.00%

By examining NMEs approved during the period between 1998 and 2018, we find forming an R&D alliance is critically important for pharma firms to develop NMEs. In this period, all of the pharma firms which succeeded in developing NMEs have been very active in outsourcing R&D by forming alliances. In total, these 271 firms outsourced 9,544 R&D projects between 1984 and 2009, accounting for 32% of the total number of R&D alliance deals for that period documented by the ReCap database. Moreover, we find that pharma firms with more R&D alliances are more successful in developing NMEs. In our sample, on average, firms failed to develop any NME had 6 R&D alliances, whereas firms succeeded in developing NMEs formed more than 26 R&D alliances (Table 5). Our regressions show that the number of R&D alliances outsourced by pharma firms is significantly and positively associated with their obtaining NMEs (Tables 6 and 7).

The rest of the paper is organized as follows. In Section 2, we set up the model. In Section 3, we endogenize the commitment problem in integration and find a solution for the commitment problem in non-integration. Section 4 compares the efficiencies of in-house or integrated R&D with outsourced or non-integrated R&D. Section 5 presents empirical evidence supporting our theoretical predictions. Finally, Section 6 discusses the conceptual implications of our results for economic growth and financial crisis and presents some concluding remarks.

2. Model

We intend to create a unified general theoretical model, which captures mechanisms of disruptive R&D in a market economy dominated by private ownership and can also explain the R&D mechanisms in a socialist economy dominated by state ownership. Without loss of generality, we consider an economy where there are numerous entrepreneurs and many large firms with dispersed ownership. We model socialism as an opposite extreme case that there is only one large firm, the state-owned firm. Each entrepreneur in either economy has a new idea for an R&D project, but he has no wealth to finance it. There is no wealth constraint on the side of the large firm to finance R&D projects (this simplification assumption reflects reality reasonably well as our model focuses only on R&D; also, relaxing this assumption somewhat will not change the qualitative results of the model). In the market economy, when an entrepreneur proposes a project to a large firm and if the firm is interested in the project, it can choose to either purchase the project and hire the entrepreneur, financing it internally, or, form an R&D alliance jointly with others financiers, financing it externally. In the rest of the paper, we call the internal financing as integration as the project is integrated as a part of the firm. We regard the R&D alliance as non-integration as the firm does not have exclusive ownership of the project. In our model, in contrast, the SOE of the socialist economy has no other choice but to finance R&D internally as there is no other firm or another owner in the economy.

We suppose that among all the projects proposed by entrepreneurs, λ percentages of them are a good type and $1-\lambda$ percentage of them are a bad type. A good project takes two periods to finish and requires a total investment of I_1+I_2, where I_t is the investment needed in the period t, moreover I_1 and I_2 are sunk. And a good project is profitable,

$\hat{V} > I_1 + I_2$. A bad project produces no return after the second period. But it can be reorganized in the third period and the reorganization costs I_3. Thus, it takes three periods for completion and requires a total investment of $I_1 + I_2 + I_3$.

A good project will be completed on date 2, regardless of integration or non-integration. Thus, from the perspective of financing decisions, there is no difference between different ownership cases. In the rest of the paper, we will focus on the case of bad projects.

We suppose that the returns from a completed bad project under the best possible reorganization strategy generated at date 3 can be higher than those of the last period investment; however, it is not efficient to be undertaken after date 1. Therefore, on date 2, a decision has to be made by the financier(s) regarding a bad project: either to refinance it or to liquidate it. To focus on this point, we suppose that at date 0, all projects are worthy of being financed, and we assume that the discount rate is zero.

Concerning information, we assume that ex-ante the distribution of the types of all projects is common knowledge, but neither the large firms nor the entrepreneurs precisely know each project's type. At date 1, after working on a project for one period, the entrepreneur discovers the type of project, but the large firm(s) still does not know its type. That is, there is an informational asymmetry between the entrepreneur and the large firm(s) on date 1.

We suppose that an entrepreneur receives a private benefit b_t from working on a project, where $t = 1, 2, 3$ denotes the date when the project is either completed or terminated. Specifically, if the entrepreneur quits the project at date 1, he gets a low private benefit, $b_1 > 0$. At date 2, a completed good project generates a private benefit, $b_{2g} > b_1$, to the entrepreneur. A bad project will not generate any outcome on date 2, and it will be either liquidated or reorganized. If it is liquidated, the entrepreneur still gets a lower private benefit b_{2b}, where $0 \le b_{2b} < b_1$. If a bad project is reorganized, it will be completed on date 3 without costing the entrepreneur's effort. A completed bad project generates a private benefit $b_3 \in \left(b_1, b_{2g}\right)$, and $b_3 > b_{2g}$.

Presumably, there are two strategies to reorganize a bad project during the third period, but only one of them can generate a profit ex-post. The selection of the right decision depends on signals s_A and s_B, where $s_J \in \left[\underline{s}, \overline{s}\right]$, $\underline{s} < \overline{s}$ and $J = A, B$. Here, we suppose that the signal s_J can only be observed by the financier after I_3 is invested.

In the simplest case, we look at a case that A wishes to find a co-financier B as a commitment device to co-finance a project (or similarly, B looks for A who has a different specialization from that of B). Then the following are the conditions that joint financing by A and B can serve a commitment purpose. These conditions concern how reorganization strategies are related to information s_A and s_B. First, A is specialized in technology A, and B is specialized in technology B, such that A can only observe s_A and B can only observe s_B. Second, the relationship between A and B satisfies the following efficiency condition (A-1.1): strategy b makes the project ex-post profitable if the value of the signal s_A is higher than the value of s_B; and strategy a makes the project ex-post profitable if the value of the signal s_A is lower than that of s_B. Formally,

$$\begin{cases} V_A^b\left(s_A, s_B\right) + V_B^b\left(s_A, s_B\right) > I_3 > V_A^a\left(s_A, s_B\right) + V_B^a\left(s_A, s_B\right), & \text{if } s_A > s_B; \\ V_A^b\left(s_A, s_B\right) + V_B^b\left(s_A, s_B\right) = V_A^a\left(s_A, s_B\right) + V_B^a\left(s_A, s_B\right) = I_3, & \text{if } s_A = s_B; \\ V_A^a\left(s_A, s_B\right) + V_B^a\left(s_A, s_B\right) > I_3 > V_A^b\left(s_A, s_B\right) + V_B^b\left(s_A, s_B\right), & \text{if } s_A < s_B; \end{cases} \tag{A-1.1}$$

where $V_J^j(s_A, s_B)$ is the payoff of the reorganized project to be received by the large firm J when the strategy j is taken, and $j = a$, or b, and $J = A$, or B.

Moreover, the relationship between A and B satisfies the second efficiency condition (A-1.2): the outcome of a wrong strategy is bad enough that the expected net payoff of randomizing between the two strategies is worse than liquidation, i.e.,

$$qV^b(s_A, s_B) + (1-q)V^a(s_A, s_B) - I_3 < 0 \qquad \text{(A-1.2)}$$

Where, $V^a(s_A, s_B) = V_A^a(s_A, s_B) + V_B^a(s_A, s_B)$, $V^b(s_A, s_B) = V_A^b(s_A, s_B) + V_B^b(s_A, s_B)$ and $q = \Pr(s_A > s_B)$.

Finally, the two co-financiers A and B have a conflict of interest (condition (A-2)) in choosing reorganization strategies. In the case that the value of s_A is higher, it is more beneficial to financier A if the project is reorganized under strategy a than under strategy b; and vice versa. This condition implies that each financier J has an incentive to use strategy J if their own signal value becomes higher. That is, for any $s^h > s^l$,

$$V_A^a(s_A^h, s_B) - V_A^a(s_A^l, s_B) > V_A^b(s_A^h, s_B) - V_A^b(s_A^l, s_B) > 0, \qquad \text{(A-2.1)}$$

$$V_B^b(s_A, s_B^h) - V_B^b(s_A, s_B^l) > V_B^a(s_A, s_B^h) - V_B^a(s_A, s_B^l) > 0. \qquad \text{(A-2.2)}$$

In the following, we provide an example to illustrate that the above assumption is relevant to real-life business.

Example: *Suppose a project is to develop a revolutionary gene-therapy-based drug for a broad range of heart diseases. The financier A is specialized in traditional drugs in heart diseases* (*e.g., a large pharmaceutical company*) *and has access to information on marketing/retailing this type of drug $\tilde{s}_A$. The financier B is specialized in evaluating gene-therapy technology* (*e.g., a venture capitalist specialized in the field*) *and has access to information on* the *cost of gene-therapy products $\tilde{s}_B$. Thus, if A finances the project alone* (*e.g., a large firm purchases the R&D project*), *then A will collect $\tilde{s}_A$ without cost and $\tilde{s}_B$ with extra costs* (*e.g., cost of hiring experts*). *If A and B finance the project jointly, A and B will gather relevant information based on their expertise without extra cost. If the project is a good one, it will be completed on date* 2, *regardless of whether it is financed by A alone or jointly by A and B. In the case that the project is a bad one, existing reorganization strategies are the following*: *strategy a – replacing the pure gene-therapy-based approach with a mixed technology* (*e.g., a technology mixed between gene-therapy approach and traditional ones*); *or strategy b – narrowing down the application target to a smaller range of heart diseases while keeping the pure gene-therapy technology. Which reorganization strategy makes the project ex-post efficient depends on the demand for the potential new drug — signal s_A; and the cost of producing the potential new drug-signal s_B. Moreover, s_A and s_B will be learned based on knowledge of $\tilde{s}_A$ and $\tilde{s}_B$. If $s_A > s_B$* (*the revenue generated by the demand from some heart disease patients is higher than the cost of producing the drug by using related gene-therapy technology*), *then* the *strategy b is efficient. Otherwise,* the *strategy a is efficient to reduce* the *cost of* the *new drug. In this example, we suppose that $q = 0.7$ and $I_3 = 109$. The other parameter values and corresponding payoffs are shown in the following table 3.*

Table 3. Parameter Values and their Corresponding Payoffs in the Example

	signal s_A	signal s_B	payoff V_A^a	payoff V_A^b	payoff V_B^a	payoff V_B^b
s_A^l case	0.6	0.4	40	45	40	65

s_A^h case	0.7	0.4	48	47	40	65

It is easy to see that condition (A-1.2) is satisfied; and given $s_A > s_B$ *in both cases, applying condition (A-1.1) strategy* b with a payoff V_B^b *is ex-post efficient,*

Given the above conditions, if a project is externally co-financed, ex-post, if the co-financiers want to reorganize a bad project, they need to find a scheme to share their private information. This is equivalent to say that B needs to find a scheme to buy s_A from A, or vice-versa. Without a loss of generality, B will buy the private information s_A from A only when the price that B has to pay, $T(s_A, s_B)$, is not too high.

Now we summarize the timing of the game as follows:

- Date 0: All parties know the distribution of the projects, but no one knows which project is good and which project is bad. The large firm(s) offer(s) a take-it-or-leave-it contract to the entrepreneur. If the contract is signed, the large firm(s) will invest I_1 units of money into the project during period 1, and the large firm(s) will start to observe $\overline{s}_A$ and $\overline{s}_B$.
- Date 1: By working on the project, the entrepreneur becomes aware of the type of the project, but the large firm(s) still does not know the type. If the entrepreneur stops the project, he gets a private benefit $b_1 > 0$; otherwise, if the project continues, I_2 units of investment are required from the large firm(s).
- Date 2: The type of project becomes public knowledge:
  - If the project is a good type, it will be completed on date 2 and will generate a return of $\hat{V}$ to the large firm(s) after the large firm(s) observe(s) $\overline{s}_A$ and $\overline{s}_B$; and a private benefit of $b_{2g} > b_1$ is generated for the entrepreneur but costs him $e > 0$;
  - If it is a bad project, a decision whether or not to liquidate or to reorganize has to be made.
    * If the project is liquidated, the large firm(s) get(s) zero and the entrepreneur gets $b_{2b} < b_1$; otherwise,
    * If the project is reorganized, I_3 units of investment are required.
- After investing I_3, signals s_A and s_B are observed by the large firm(s), and a reorganization strategy is chosen based on the signals.
- Date 3: A bad project is completed and generates a return of V to the large firm(s) and a return of $b_1 < b_3 < b_{2g}$ to the entrepreneur.

3. Refinancing Decisions

Given that refinancing a (bad) project after date 2 is ex-ante inefficient, only those institutions that are able to commit to stopping bad projects are efficient in dealing with highly uncertain innovative projects. In this section, we show that non-integration, i.e., external co-financing, provides a commitment device to stop bad projects, but integration does not.

3.1 Non-integration

We start with the co-financiers' refinancing decision on date 2 and then consider the entrepreneur's investment decision on date 1. At date 2, when the two financiers discover that

the project is a bad one, they should decide either to liquidate or to reorganize (i.e., the financiers assign a probability of p to refinance the project). If they decide to reorganize the project, they will invest I_3. Then signals s_A and s_B are observed by the two financiers respectively, and they need to determine what reorganization strategy should be selected (i.e., the financiers assign probabilities of $1-q(s_A,s_B)$ and $q(s_A,s_B)$ to use reorganization strategy a and b respectively).

We now show that the asymmetric information between the two financiers will make refinancing ex-post inefficient; thus, they will terminate bad projects on date 2.

Proposition 1. *Under assumptions (A-1) and (A-2), with non-integration, all bad projects are liquidated at date 2.*

We show that if the financier J is able to observe only s_J ($J=A$ or B) after I_3 is invested, under (A-1) and (A-2) there is no efficient incentive-compatible scheme $q(s_A,s_B)$ and $T(s_A,s_B)$ which can induce financier J to tell the true value of s_J; thus there is no efficient scheme to reorganize the project. As a result, the financiers choose to liquidate the bad project.

In the following proof, we first analyze the financier A's incentive problem. For this purpose, we fix s_B at an arbitrary value $s^* \in (0,1)$.

Given the compensation scheme $T(s_A,s_B)$ and strategy $q(s_A,s_B)$, the financier A should tell the truth only if the expected payoff of doing so is not worse than false reporting. That is, the incentive compatibility (IC) condition is:

$$\begin{aligned} &q(s_A,s_B)V_A^b(s_A,s_B)+\big(1-q(s_A,s_B)\big)V_A^a(s_A,s_B)+T(s_A,s_B) \\ &\geq q(\hat{s}_A,s_B)V_A^b(s_A,s_B)+\big(1-q(\hat{s}_A,s_B)\big)V_A^a(s_A,s_B)+T(\hat{s}_A,s_B), \end{aligned}$$

where $\hat{s}_A$ is the false report of the signal.

In the case that the information $s_A=s_A^h>s^*$, the IC is

$$\begin{aligned} &q(s_A^h,s_B)V_A^b(s_A^h,s_B)+\big(1-q(s_A^h,s_B)\big)V_A^a(s_A^h,s_B)+T(s_A^h,s_B) \\ &\geq q(s_A^l,s_B)V_A^b(s_A^h,s_B)+\big(1-q(s_A^l,s_B)\big)V_A^a(s_A^h,s_B)+T(s_A^l,s_B), \end{aligned}$$

that is,

$$\begin{aligned} &T(s_A^h,s_B)-T(s_A^l,s_B)\geq\big(q(s_A^l,s_B)-q(s_A^h,s_B)\big)V_A^b(s_A^h,s_B)+ \\ &\big(q(s_A^h,s_B)-q(s_A^l,s_B)\big)V_A^a(s_A^h,s_B). \end{aligned} \tag{1}$$

The IC for A's information $s_A=s_A^l<s^*$ is:

$$\begin{aligned} &q(s_A^l,s_B)V_A^b(s_A^l,s_B)+\big(1-q(s_A^l,s_B)\big)V_A^a(s_A^l,s_B)+T(s_A^l,s_B) \\ &\geq q(s_A^h,s_B)V_A^b(s_A^l,s_B)+\big(1-q(s_A^h,s_B)\big)V_A^a(s_A^l,s_B)+T(s_A^h,s_B), \end{aligned}$$

that is,

$$\begin{aligned} &\big(q(s_A^l,s_B)-q(s_A^h,s_B)\big)V_A^b(s_A^l,s_B)+\big(q(s_A^h,s_B)-q(s_A^l,s_B)\big)V_A^a(s_A^l,s_B) \\ &\geq T(s_A^h,s_B)-T(s_A^l,s_B). \end{aligned} \tag{2}$$

The IC conditions (1) and (2) imply

$$\begin{aligned} &\big(q(s_A^l,s_B)-q(s_A^h,s_B)\big)V_A^b(s_A^l,s_B)+\big(q(s_A^h,s_B)-q(s_A^l,s_B)\big)V_A^a(s_A^l,s_B) \\ &\geq\big(q(s_A^l,s_B)-q(s_A^h,s_B)\big)V_A^b(s_A^h,s_B)+\big(q(s_A^h,s_B)-q(s_A^l,s_B)\big)V_A^a(s_A^h,s_B), \end{aligned}$$

or,

$$\left(q\left(s_A^h, s_B\right) - q\left(s_A^l, s_B\right)\right)\left(V_A^a\left(s_A^h, s_B\right) - V_A^a\left(s_A^l, s_B\right)\right)$$
$$\leq \left(q\left(s_A^h, s_B\right) - q\left(s_A^l, s_B\right)\right)\left(V_A^b\left(s_A^h, s_B\right) - V_A^b\left(s_A^l, s_B\right)\right).$$

According to (A-2.1), $V_A^a\left(s_A^h, s_B\right) - V_A^a\left(s_A^l, s_B\right) > V_A^b\left(s_A^h, s_B\right) - V_A^b\left(s_A^l, s_B\right) > 0$. Thus, the incentive compatibility implies $q\left(s_A^h, s_B\right) \leq q\left(s_A^l, s_B\right)$, i.e., $q\left(s_A^l, s_B\right)$ should be non-increasing in s_A.

However, by (A-1), for any given s_B when s_A increases from $s_A < s_B$ to $s_A > s_B$, for any $q\left(s_A, s_B\right) = \overline{q}$, where $\overline{q} \in [0,1)$ is a constant, the efficiency can be improved by increasing $\overline{q}$, i.e., by $\overline{q} + \varepsilon$, where $\varepsilon > 0$. Thus, efficiency requires $q\left(s_A, s_B\right)$ to be non-decreasing in s_A.

Therefore, the only possible scheme of $q\left(s_A, s_B\right)$ which may satisfy both IC and the efficiency requirement is to keep $q\left(s_A, s_B\right)$ constant, i.e., $q\left(s_A, s_B\right) = \overline{q}$. It is obvious that for any $\overline{q} \in [0,1]$, reorganization based on any $\overline{q} \neq q = \Pr(s_A > s_B)$ is worse than q. However, by (A-1.2), a reorganization decision based on q is worse than liquidation.

The case of financier B can be proven by symmetry.

Given the above results, any randomization between liquidation and reorganization at date 2 will be worse than liquidation. Thus, the probability of liquidation is $1 - p = 1$.

The intuition behind this proposition is the following. The incentives of A lead to a condition that for any given value of s_B, the higher the value of s_A is, the less likely strategy b should be used. However, the efficiency condition (A-1.1) implies that for any given value of s_B, the higher the value of s_A is, the more likely strategy b should be used. The only reconciliation between these two conditions is to keep the probability of using strategy b independent from signal s_A, but the efficiency condition (A-1.2) says that this kind of reorganization will incur losses ex-post, thus it is worse than liquidation.

In the following, we use the same example to illustrate how the commitment mechanism of external co-financing works.

Example (continued): *Given the parameters that* $I_3 = 109$ *and*

	signal s_A	signal s_B	payoff V_A^a	payoff V_A^b	payoff V_B^a	payoff V_B^b
s_A^l case	0.6	0.4	40	45	40	65
s_A^h case	0.7	0.4	48	47	40	65

Only strategy b *is ex-post efficient for both cases. However, when* s_A *increases from* s_A^l *to* s_A^h, *A's payoff increases more if the strategy* a *is used than that of strategy* b *(condition (A-2)). Thus,* A *has an incentive to under-report* s_A *to increase the chance that strategy* a *will be used, which is the critical condition that drives the result of Proposition 1.*

This proposition says that when a bad project is revealed to the large firm on date 2, there does not exist any efficient reorganization scheme which can be agreed upon by both financiers. That is, as a result of the informational asymmetry and conflicts of interest between the two financiers, external co-financing can serve as an ex-post commitment device to stop bad projects. This insight is consistent with that of Maskin (1992) in the context of the auction with private information in that information asymmetry between two parties can make auctions inefficient.

This commitment to liquidate bad projects has a deterrent effect on entrepreneurs who have bad projects. Afraid of further losses by hiding bad news, an entrepreneur with a bad project will choose to quit once he discovers it is a bad one because the losses incurred by quitting at date 1 are smaller than those at date2, i.e., $b_{2b} < b_1$. To summarize, we have the following result:

Corollary1 *Under external co-financing, entrepreneurs are induced to stop bad projects on date 1 but not a good project.*

The model sheds light on syndicated financing. In reality, as long as there are several financiers involved, and they have different specializations, then their information and interests are naturally different. The fact that conditions (A-1) and (A-2) are likely to be satisfied, even without financiers' prior knowledge of any details about these conditions, helps financiers to stop bad projects promptly. Given that banks extended $2 trillion of syndicated loans in 2000 (Esty and Megginson, 2001), our theory also helps to explain the paramount importance of such a financial phenomenon from a theoretical perspective.

R&D financing and the boundary of the firm have also been studied from the perspective of knowledge transfer (see Allen and Gale (1999) and Bhattacharya and Chiesa (1995), among others). This strand of literature is concerned about difficulties in transferring knowledge and tries to make knowledge transfer possible. Our theory provides a complementary theoretical answer, which argues that informational asymmetry between co-financiers that prevents knowledge transfer can also have benefits to financiers because if used wisely, the difficulty in knowledge transfer can stop bad R&D investment promptly.

3.2 Integration

We again begin our analysis with the refinancing decision on date 2 and then consider the entrepreneur's investment decision on date 1. Under integration, a project is internally financed. In that case, the large firm will have all the information, and, s_A and s_B will be able to use this information to choose an efficient ex-post strategy to reorganize the project such that payoff $V^*(s_A, s_B)$ is greater than the ex-post cost of refinancing, I_3. Therefore, the firm is not able to commit to terminating a bad project ex-post.

Moreover, the fact that the large firm cannot commit to terminating a bad project affects the entrepreneur's ex-ante incentives to reveal information. When the entrepreneur at date 1 discovers that his project is a bad one, he expects that the project will always be continued and refinanced by the financier at date 2. Consequently, if he quits the project, he gets private benefit b_1; if he continues the project, the bad project will always be refinanced by the financier and will generate a private benefit $b_3 > b_1$ for the entrepreneur.

Proposition 2. *Under assumption (A-1), at equilibrium, a financier does not reward an entrepreneur for revealing the type of a project at date 1 and does not liquidate bad projects on date 2. As a result, bad projects are always re-organized by the single financier.*

When a project is financed by a single financier, the financier will have all the information s_A and s_B, and will be able to use this information to choose an ex-post efficient strategy to reorganize the project such that payoff $V^*(s_A, s_B)$ is greater than the ex-post cost of refinancing, I_3. Therefore, when the financier learns the bad type of a project on date 2, given that earlier investments are sunk and $V^*(s_A, s_B) > I_3$, the financier will choose to reorganize a bad project.

However, when the entrepreneur at date 1 discovers that his project is a bad one, he expects

that the project will be continued by the financier at date 2 and anticipates a private benefit $b_3 > b_1$. Therefore, the entrepreneur will choose not to tell the type of a project if it is bad. In the following, we show that at equilibrium, the financier will choose not to reward the entrepreneur to reveal the project type at date 1.

Suppose a financier offers a reward, τ, to an entrepreneur at date 1 to induce him to tell the type of a project. There are several possible reward schemes: $\tau_1 \geq b_3 - b_1$; $\tau_2 \in \left(b_{2g} - b_1, b_3 - b_1\right)$; $\tau_3 < b_{2g} - b_1$. Given $b_1 < b_{2g} < b_3$, under the reward τ_1, an entrepreneur will report all projects as bad ones to collect the reward, and the financier is not able to verify the truthfulness from projects stopped at date 1. If the reward is set at τ_2, the entrepreneur will report good projects as bad ones to collect the reward; and will report bad projects as good ones since by doing so, a bad project will be continued. If the reward is τ_3, an entrepreneur will report all projects as good ones anticipating a continuation of bad projects. However, for the financier, no reward is the cheapest for the same outcome of τ_3. Obviously, no reward dominates τ_1, τ_2 and τ_3.

An interesting insight from this result reveals that without conflicts of interest and informational asymmetries on the financier side, single financier financing is not able to solve the asymmetric information problem between the financier and the entrepreneur due to the lack of commitment to liquidate bad projects.

Our model can be interpreted broadly. A key to the model is the number of agents who collect information and make the reorganization decision. Many different institutions are corresponding to our model of integration; that is, they are featured by single-agent coordinated financing. Examples include 'main-bank' coordinated financing in Japan, government-coordinated financing in South Korea, and bank financing in a centralized economy, where the state bank (or the government) finances all the projects and collects all the information.

4. Efficiencies

The above section shows the benefits associated with no-integration or external co-financing. However, there are extra costs associated with no-integration relative to integration or internal financing. The asymmetric information between a startup firm and its financiers gives rise to both moral hazard and adverse selection problems. As a result, if the commitment is not a major problem, no-integration may be more costly than integration.

In this section, we establish the trade-off between the benefits and costs associated with no-integration. To keep our model simple and to focus on our major contribution, we treat the problems incurred by no-integration as institutional costs in a reduced form. We denote each period's institutional cost of no-integration as c^N and the cost of collecting signals in the case of integration as c^I. We assume that both c^N and c^I are exogenously given, and $c^N > c^I$.

According to Proposition 1, in the case of no-integration, in equilibrium, all bad projects will be dropped by the entrepreneur on date 1. Moreover, for any project proposed randomly from the project pool, with probability λ a project is a good one, generates an expected return $\hat{V}$, and requires investments $I_1 + c^N + I_2 + c^N$, with probability $1-\lambda$ a project is a bad one, generates an expected return V, and requires investment $I_1 + c^N$ only. Thus, the expected profits from an externally financed project are,

$$\pi^N = \lambda\left(\hat{V} - I_1 - I_2 - 2c^N\right) + (1-\lambda)\left(-I_1 - c^N\right)$$
$$= -I_1 + \lambda\left(\hat{V} - I_2\right) - (1+\lambda)c^N.$$

Using Proposition 2, in the case of integration, a bad project will always be refinanced. Given that with probability λ a project is a good one, generates an expected return $\hat{V}$, and requires investments $I_1 + I_2$, and that with probability $(1-\lambda)$ a project is a bad one, generates an expected return V and requires investments $I_1 + I_2 + I_3$, the expected profits from an internally financed project are:

$$\pi^I = -I_1 - c^I + \lambda\left(\hat{V} - I_2\right) + (1-\lambda)\left(V - I_2 - I_3\right).$$

$$\pi^I = \lambda(\hat{V} - I_1 - I_2 - 2C^I) + (1-\lambda)(V - I_1 - I_2 - I_3 - 3C^I)$$
$$= -I_1 - (3-\lambda)C^I + \lambda(\hat{V} - I_2) + (1-\lambda)(V - I_2 - I_3)$$

The difference between the profits from an internally financed project and the profits from an externally financed project is

$$\pi^I - \pi^N = -(1-\lambda)\left(I_2 + I_3 - V\right) + (1+\lambda)c^N - c^I.$$

$$\pi^I - \pi^N = (1-\lambda)(V - I_2 - I_3) + (1+\lambda)C^N - (3-\lambda)C^I$$

In contrast, it is easy to see that if liquidation does not deter an entrepreneur from continuing a bad project at date 1, the expected payoff from no-integration would be $\pi^N = \lambda\left(\hat{V} - I_1 - I_2 - 2c^N\right) + (1-\lambda)\left(-I_1 - c^N\right)$. In such a case, liquidation would not be efficient, because

$$\pi^I - \pi^N = 2c^N - c^I + (1-\lambda)\left(V - I_3\right) > 0.$$

To summarize the result, we have the following:

Corollary 2. *Without a deterrent effect, liquidation alone is less efficient than reorganization. However, with a deterrent effect, the institution which commits to liquidation can be more efficient.*

Similar to the literature on bankruptcy (e.g., Aghion, Hart, and Moore, 1992), we show that liquidation per se can be less efficient than reorganization. But unlike the above, we emphasize the ex-ante expectational effects of different 'bankruptcy procedures.' We demonstrate that a commitment to liquidate bad projects plays a fundamental role in deterring entrepreneurs from hiding private information. Therefore, an institution which commits to liquidate bad projects can be more efficient.

However, even with a deterrent effect, no-integration may still be less efficient than integration. The reason is that the difference in the net benefits between integration and no-integration depends on the institutional cost of no-integration, c^N; the uncertainties of the projects, λ; the required investment in the second and third periods, I_2 and I_3; and the realized value of a bad project when it is completed, V. In the following, we conduct a comparative static analysis of the difference between π^I and π^N.

The equation $\pi^I - \pi^N = -(1-\lambda)\left(I_2 + I_3 - V\right) + (1+\lambda)c^N - c^I$ shows the trade-off between integration and non-integration. On the one hand, there is a saving of investment in a bad project under no-integration, $(1-\lambda)\left(I_2 + I_3 - V\right)$. On the other hand, there is an extra cost of no-integration, $c^N(1+\lambda)$. From this trade-off, we solve for a threshold level λ^*, which makes $\pi^I = \pi^N$. Then we have

$$\lambda^* = \begin{cases} \dfrac{I_2 + I_3 - \left(V + c^N + c^I\right)}{c^N + I_2 + I_3 - V}, & \text{if } c^N < I_2 + I_3 - V + c^I; \\ 1, & \text{if } c^N \geq I_2 + I_3 - V + c^I, \end{cases}$$

$$\lambda^* = \begin{cases} \dfrac{(I_2 + I_3 - (V + C^N - C^I)}{C^N + I_2 + I_3 - V}, if\ C^N <= I_2 + I_3 - V + C^I\ and\ C^I <= 2C^N; \\ no\ \lambda\ can\ satisfy\ \pi^I = \pi^N, else \end{cases}$$

such that if λ, the probability that a project is bad is higher than λ^*, no-integration is more efficient than integration, and vice versa. Investigating λ^* leads to the following lemma. It shows extreme cases where an allocation of the efficient boundary of a firm is independent of the uncertainty of the project.

Lemma 1. *If* $c^N - c^I = 0$, *no-integration is always more efficient*; *if* $c^N - c^I \geq I_2 + I_3 - V$, *integration is always more efficient*; *if* $0 < c^N - c^I < I_2 + I_3 - V$, *an allocation of the efficient boundary of a firm depends on* λ.

Against the threshold level of uncertainty λ^*, it follows:

$$\begin{cases} \pi^I > \pi^N, & \text{if } \lambda < \lambda^*, \\ \pi^I \leq \pi^N, & \text{if } \lambda \geq \lambda^*. \end{cases}$$

It is also easy to see that $\dfrac{\partial}{\partial \lambda}\left\{\pi^I - \pi^N\right\} < 0$. That is, the advantage of no-integration vis-a-vis that of integration increases with the uncertainty of the project type as long as no-integration can harden budget constraints. In the following, we summarize the results regarding the optimal strategies for carrying out an R&D project when firms face different degrees of uncertainties and comparative static results.

Proposition 3. *If* $0 < c^N - c^I < I_2 + I_3 - V$, *there is a critical level of uncertainty of the project,* λ^*, *such that if uncertainty is low, that is,* $\lambda < \lambda^*$, *integration is more efficient than no-integration*; *otherwise, no-integration is more efficient.*

Proposition 4. *If* $0 < c^N - c^I < I_2 + I_3 - V$, *the advantage of no-integration over integration increases as*

- **a.** λ *increases*;
- **b.** *the institutional cost of no-integration,* c^N, *decreases*;
- **c.** *the costs of required investment at the second and third periods,* I_2 *and* I_3 *respectively, increase*; *and*
- **d.** *the return from a bad project,* V, *decreases*.

The above propositions suggest that the boundary of a firm is related to the financial institutions and the features of R&D. The creation and development of modern financial intermediaries, which greatly reduce the costs of no-integration, give firms broader choices to deal with R&D projects. Venture capital (VC) financing, including corporate VCs run by large corporates, is an example. In a financially developed economy with low costs of no-integration, to explore highly uncertain R&D projects, large firms will choose to keep them outside. When the uncertainty decreases, large firms will bring those projects in. In reality, that could be taking over or merger and acquisition. As a result, highly uncertain R&D projects tend to be carried out by independent externally financed small firms, while lowly uncertain

projects tend to be concentrated in large firms. When projects are evolving from high uncertain stages to lowly uncertain stages, we expect to observe ownership structure change, from more dispersed at earlier stages to more concentrated at the later stages. In contrast, in a financially underdeveloped economy with high institutional costs of external financing, firms have less choice as internal financing most likely is superior. In the socialist economy, as there is only one firm, R&D will always be internally financed.

Moreover, most high-tech projects in fields such as computers, software, biotech, etc., are characterized by high uncertainties[8]. Thus, the concentration of venture capital financing in high-tech industries in capitalist economies closely matches our results.

Furthermore, when the uncertainty of a project is lower, and/or the costs of required incremental investments decrease, and/or the final return from a bad project increases, our results indicate that integration is more efficient. These predictions are consistent with the observation that large corporations tend to purchase innovative projects at later stages when uncertainties are much lower, and the returns from reorganized bad projects are not too low. Our results thus can explain why cash-rich large corporations devote more attention to perfection-related or cost-reduction-related innovation and less attention to new-product-related innovation, and why corporate executives tend to restrict their R&D activities in more certain and less-novel projects (Scherer, 1991, 1992).

When cash-rich large corporations are interested in investing in R&D, our theory shows that it is in their interest to outsource such projects externally via forming an R&D alliance. Consistent with our theoretical arguments, scholars on drug discovery have argued that fueling R&D pipelines and terminating failing projects quickly (‘fast-fail’ or ‘quick-kill’ strategies) are the key for pharmaceutical firms to deal with the high level of uncertainties, and to sustain (Lendrem and Lendrem, 2013; McMeekin et al.,2019). Unless the failing projects are terminated, otherwise they clog the pipeline and add R&D costs. However, large pharmaceutical firms are unable to terminate failing projects (Peck et al., 2015). The same logic can be applied to explain why in the 1970s, IBM contracted out its first-generation PC CPU chips to Intel and its operating system to Microsoft.

5. Empirical Investigation

Our theoretical model predicts that syndication investment serves as a commitment device to terminate bad projects. Consequently, this improves R&D productivity when the process involves a high level of uncertainties. To test our theory systematically, we need to find a good measure of disruptive innovation, which is missing in the literature. Patent counts and patent-citation counts are not good enough for measuring disruptive innovations, as the definitions of patents are too broad, and most often, patents do not lead to revolutionary discoveries. Our empirical investigations lead us to choose the development of NMEs between 1998 and 2018 as the measure.

Concretely, we look into the development of new molecular entities (NMEs) in the pharmaceutical industry approved by the FDA in the past two decades. NMEs are compounds that contain novel moieties, i.e., they are not a version or a derivative of an existing substance. And they promise to provide critical new therapies against certain diseases. We construct a firm-level panel dataset and investigate how these firms’ strategic alliances in R&D are associated with the development of NMEs. Our empirical findings support our theoretical

[8] At very early stages, particularly when basic research is involved, high-tech and bio-tech R&D often receive government funding, such as the NSF, the NASA, and the NIH etc. These funding are important in dealing with market failure problems. However, if government funding alone is the key for disruptive innovation, socialism should prevail. Our contribution is to explain why VC financed start-up companies are crucial in disruptive innovation.

predictions.

5.1 NMEs as Measure of Disruptive Innovations

We believe NMEs approved by the FDA provide us objectively measured data of disruptive innovation in the industry, at least approximately, for the following reasons. First, most R&D investments in the pharmaceutical industry are infused to develop NMEs, the most significant part of innovation in this industry (PhRMA, 2018). Second, FDA, through its ex-post judgment, has rigorous regulations on the novelty, efficacy, and safety of the NMEs, entirely based on standardized sets of evidence. The ex-post role in judgment by FDA is important to notice, as the race for discovery is a free competition in which FDA does not play a role. The total amount of patents granted on the relevant drug research over the same sample period of 1998 to 2018 is 229 times bigger than the developments of NMEs, which are thus far more likely to lead to revolutionary inventions than patents.[9]

Inventing an NME is a highly tentative and costly process (Lendrem and Lendrem, 2013; McMeekin et al., 2019). Each new drug has to go through three phases of clinical trials for getting FDA approval into marketing. It is not until the end of phases III when it is certain whether a new drug is going to be granted for marketing. Moreover, even after getting the approval, a drug may be recalled during the post-approval phase IV. Without marketing approval, all R&D investment to a particular NME may be sunk. According to PhRMA, a trade group representing pharmaceutical companies in the US, on average, it takes 10 to 15 years to develop an NME drug; and 64.1% of the total costs of NME development are paid in the clinical trials. Furthermore, more than 88% of drugs entering a clinical trial eventually fail. For example, the failure rate of clinical trials for Alzheimer's drug candidates between 2002 and 2012 was 99.6%, with a 72% failure rate in Phase I, 92% in Phase II, and 98% in Phase III (Cummings et al., 2014). The average cost to develop an NME drug in the early 2010s was 2.6 billion, including the costs of failure (PhRMA 2019).

Between 1950 and 2008, among the 4,300 companies engaged in drug innovation, only 6% of them have obtained at least one NME approved by the FDA (Munos, 2009). According to the FDA, between 1998 and 2018, approximately 30 NMEs were approved per year.[10] That is, among thousands of firms doing R&D in drugs, only a handful number of them may successfully develop something. As such, the firm turnover rate in the pharmaceutical industry has been extremely high in the past decades. Among the 261 firms which have obtained NME approvals, i.e., the relatively successful firms, between 1950 and 2008, only 12% of them lasted for the entire period while 88% of them have either failed, or been merged or acquired, or were new entries during the period (Munos, 2009). Moreover, the firm turnover rate has increased dramatically in recent decades. For example, among NME developers, there were 38 entries and 21 exits in the 1980s; 85 new entries and 67 exits in the 1990s; while it further increased to 118 entries and 124 exits in the 2000s (Pinch et al., 2014).

Analyzing more than 1,222 NMEs granted between 1950 and 2008, Munos (2009) find that the share of the top 15 largest pharmaceutical firms in NME development has dropped substantially since the 1980s. Moreover, the costs of developing new drugs by small firms are

[9] Based on the US Patent and Trademark Office (https://www.uspto.gov/), the total number of patents granted to the class "Drug, bio-affecting and body treating compositions" (i.e. CCL/424 or CCL/514) between 1 Jan 1998 and 31 Dec 2018 is 144385, which implies that the average granted patents closely related to drug development per year during our examination period is 6875, 229 times of the NMEs approved per year. It is noted that some other CCLs, such as CCL/435 Chemistry: molecular biology and microbiology or CCL/436 Chemistry: analytical and immunological testing, are not included as sometimes those categories cover something else rather than drug development. Hence, we understate the total number of the drug development patents much in general.

[10] https://www.fda.gov/drugs/new-drugs-fda-cders-new-molecular-entities-and-new-therapeutic-biological-products/new-drug-therapy-approvals-2019

substantially lower than those of the large pharmaceutical firms. By 2008, 4,300 small biotechnology companies spend $28 billion annually on R&D (Buriall and Company, 2008), whereas a small number of large pharmaceutical firms spend $50 billion on R&D activities (PhRMA, 2009). And the total number of NMEs developed by small firms exceeded that of the large firms (Munos, 2009).

Although inventing NMEs is necessary for a pharma company to stay in the competitive market, being able to invent new drugs alone is not sufficient for a pharma company's survival as drug development and marketing, etc. all require a very large scale. Consequently, forming R&D strategic alliances between large pharma companies, which are good in scale economy, and independent small firms, which are good in dealing with highly uncertain discoveries and inventions, becomes a trend in recent decades. Applying our theory to disruptive innovation in the drug industry, we predict that facing high uncertainties, a larger number of parallel independent projects would improve the chance of success in inventing an NME.

5.2 Empirical Findings

To provide systematic evidence vis-à-vis our theory, we investigate the mechanisms responsible for all the NMEs granted by the FDA during 1998 and 2018. It is worth pointing out that during the last two decades, we witness a quiet medical revolution. The used-to-be incurable diseases, such as cancers and heart diseases, are no longer as deadly, and improvements have been steady due to the inventions of new drugs. According to the American Cancer Society (2010), between 1990 and 2006, mortality from cancer decreased by 21.0 percent for men and 12.3 percent for women in the US; between 1999 and 2006, new cases dropped continuously by about 1 percent annually. New drugs based on NMEs developed in the two decades played essential roles. As we have presented earlier, consistent with the findings of the Kornai Table, all the NMEs in this period were developed in capitalist market economies.

Data for the NME development comes from the FDA website, which discloses each NME's name, applicants, active ingredients, and the time of approval. In total, 271 firms were granted at least one NME between 1998 and 2018. Based on such information, we build up a firm-level panel dataset for the number of NMEs granted to the 271 firms per year. We construct two independent variables accordingly. *NME* is the total number of NMEs granted to a given firm in a given year. *NME_D* is a dummy variable which equals one if the firm is granted at least one NME in a given year and zero if otherwise.

To investigate R&D outsourcing of pharmaceutical firms in the process of NME development, we collect data of R&D strategic alliance deals built by the 271 firms, among which every firm has at least one NME developed in the past two decades. Our data comes from the Recap database. Recap provides information for the parties of R&D alliance agreements, the date of the agreements reached, the drug targets, and contract terms. An alliance agreement is between the "client companies", which outsource the R&D project, and the biotech agent firms, which take the R&D tasks. Specifically, we sort out the information for the number of alliance deals each year by each sampled firm, i.e., each client company. In the case that more than one "client company" firms are involved in one strategic R&D alliance deal, we count one deal for each client company. As it takes 10 to 15 years to develop a new drug, to capture the lagged effects of the strategic alliance and avoid being biased by any outlier of a specific year, we employ the total number of strategic alliance deals that a sampled firm builds between 5 years to 10 years before obtaining FDA approval of the NME (Denoted by *Alliance_10*) in a given year. For instance, for a firm whose NME approved by the FDA in 2018, we count the number of outsourcing deals led by this firm between 2008 and 2012. To check the robustness, we also extend the lag to between 5 years and 15 years before obtaining the FDA approval of the NME (Denoted by *Alliance_15*). For instance, for the NME

developed by the firm, which was approved by the FDA in 2018, we count the number of outsourcing deals led by this firm between 2003 and 2012.

In addition to the R&D alliance, some firm-specific factors such as size, financial performance, and R&D input may also affect the capability of firms in developing new drugs. But such information is only available for publicly traded firms. In our regression, we have a dummy variable (Denoted by *List*), which equals one if a firm is listed in the given year and zero if otherwise, to differentiate whether a firm is listed or not. In total, 119 out of the 271 firms in our sample are listed firms. We also obtain financial information for the listed firms from Wharton Research Data Services (WRDS). Firm size is measured by the total assets the firm has in a given year in natural logarithm format (Denoted by *Size*). Financial performance is measured by the return over the total assets of the firm (denoted by *ROA*) in a given year. R&D input is measured by the R&D expenditure of the firm over total sales in a given year (Denoted by *R&D*).

Table 4 presents the summary statistics for variables used in estimates. During 1998 and 2018, on average, each firm had 0.11 NME approved per year; makes approximately 8 outsourcing R&D deals within 5 years, and 15 such deals within 10 years. The average total assets of the listed firms are $30.46 billion, and by average, they invest 13.24% of their total sales to R&D. Moreover, the uncertainty of this kind of R&D is exceptionally high that the average return to total assets (ROA) for the listed pharmaceutical firms in this period is -21%; whereas, the maximum ROA is 175%, implying the majority of the firms were making losses, but a few successful made good fortunes.

All of the pharma firms have been active in forming R&D alliances. In total, the 271 firms outsourced 9,544 R&D projects between 1984 and 2009. By average, each firm closed at least 35 outsourcing deals (1.4 per year) between 1984 and 2009. The largest NME-developing pharma companies, such as GlaxoSmithKline, Merck, Schering, and Roche, did much more than the others that each of them outsourced more than 400 R&D projects during our sample period. The distribution of the NMEs is skewed. 182 (67%) out the 271 firms had only one approved NME during these 21 years, and only Pfizer, Johnson & Johnson, Merck, and Novartis were able to obtain more than 1 NME per year during this period.

Table 5 illustrates the summary statistics of the number of strategic R&D alliances formed and NMEs obtained by our sample firms in each year. Panel A and Panel B report the cases of Alliance_10 and Alliance_15, respectively. Firms that formed more R&D alliances had obtained more NMEs. Taking 2018 as an example, we observe that firms obtained no NME in that year, on average, formed 5.11 R&D alliances in the past (the case of Alliance_10). In contrast, firms obtained an NME or more NMEs in that year, by average formed 17.41 R&D alliances. Besides, the summary data seems also indicates a trend, particularly up to 2016, that pharma firms have been increasingly employ the R&D alliance strategy and this might increase the chances of obtaining NMEs.

As disruptive innovation is highly uncertain, its success is related to the number of parallel researches. Our theory predicts that institutions with a commitment to terminate bad projects ex-post facilitate a larger number of parallel R&D projects and are more efficient. In the context of developing NMEs, we expect firms with a larger number of R&D alliances have more chances to develop NMEs. To test our theory, we run regressions on the relationship between obtaining NMEs and the number of R&D alliances. Table 6 reports the regression results (in the case of Alliance_10). In Models (1) and (2), we use the full sample that includes both listed firms and unlisted firms. As financial information for unlisted firms is unavailable, we control only a handful of available variables, such as being listed or not (denoted by *List*), and the year and firm fixed effects. Model (1) presents the negative binomial regression results, in which the dependent variable is the number of approved NMEs that a firm obtains in a given year. Whereas the Model 2 reports the logit regression results, in which the dependent variable is whether a firm has obtained at least one approved NME in a given year. Both

models show that the number of R&D alliances outsourced by pharma firms is significantly and positively associated with their obtaining NMEs. Notably, if the number of R&D alliances outsourced increases by 10, it may lead to a 1.9% higher probability that the firm may obtain an NME. Meanwhile, on average, with ten more R&D alliances outsourced, a firm may obtain 0.16 more NMEs.

Similar to Models (1) and (2), Models (3) and (4) in Table 6 present the regression results for listed firms. In these two regression models, besides the year effects, stock exchange effects, and firm-fixed effects, we also control for the size, financial performance, and the R&D input of the firm. Again, the number of R&D alliances outsourced by pharma firms is significantly and positively correlated to the probability of obtaining an NME, and to the number of NMEs obtained. Specifically, if the number of R&D alliances outsourced increases by 10, the probability of obtaining an NME may be improved by 1.6%; or a firm may be able to obtain 0.06 more NMEs. Moreover, firm size is significantly and positively associated with the NME development. A plausible interpretation might be that larger firms are more affordable to form more R&D alliances than smaller firms, which give them better chances in developing NMEs and might lead to their expansion. A further study of the mechanism is beyond this paper.

To check the robustness of our results, we also conduct regressions with the R&D alliances outsourced for the case of Alliance_15. The results shown in Table 7 are fully consistent with our findings in Table 6.

6. Concluding Remarks

This paper revisits Kornai's dynamism of capitalism vs. failures in facing revolutionary technological changes in socialist economies (2013). Our theory is inspired by Kornai's idea of soft budget constraints (Kornai 1980, 1992). Concretely, we study why disruptive innovation occurs almost only in capitalist economies, and mostly in certain types of institutions there, e.g., VC financed startups in the recent half-century.

We analyze how the ownership structures of R&D projects in capitalist economies are purposely arranged differently in areas where innovation is exceptionally more uncertain than in other areas. The reason is that the ownership structure in R&D projects affects firms' commitment capacities in terminating failing R&D projects. Through this logic, our theory explains why disruptive innovation can hardly be created in a state-ownership-based socialist economy. The reason is that a state-ownership-based socialist economy can hardly imitate the HBC mechanism devised in a capitalist economy. The empirical findings based on a novel measure of disruption innovations in the pharmaceutical industry support our theoretical predictions.

Our findings provide a mirror image for the failure image of centralized economies in disruptive R&D. With the whole economy controlled by one owner, i.e., the state, R&D projects are always financed "internally" by the same owner. Moreover, we show that the optimal financing strategy for less uncertain R&D projects, such as in machine building, chemicals, steel, and other heavy industries, is to finance projects internally. Thus, we predict that there should be no substantial difference in R&D in those industries between a decentralized economy and a centralized economy. In reality, centralized economies indeed perform reasonably well in process innovations and product imitations for those industries.

In the pharmaceutical/biotech industry and other high-tech industries, such as computers and electronics, where R&D projects are often very uncertain, no-integration is more efficient. A high degree of integration in a centralized economy implies serious inefficiencies for R&D projects due to the lack of an ex-post screening mechanism. In fact, the most striking examples to support our insight are the devastating failures of serious efforts on the part of the Soviet Union to catch up with the West in computers and electronics, despite their strategic and

military importance.

Our theory also has implications for economic growth. The central role of financial institutions on technological change on economic growth has been recognized since Schumpeter (1934). In the new growth theory, the role of R&D in growth is endogenized through inputs to technological change and knowledge accumulation while the roles of financial institutions are ignored. Nevertheless, we observe financial institutions playing important roles to affect the efficiency of R&D and growth. Our theory has implications for the role of financial institutions on growth (Huang and Xu, 1999b).

Moreover, our theory provides a novel way to understand the financial crisis from an institutional perspective (Huang and Xu, 1999a). Due to the adverse effects of the soft budget constraint associated with project uncertainties, bad projects do not stop, and bad loans accumulate. Moreover, bank lending to bad projects is easily justified. Therefore, the prevailing soft budgeting in an economy distorts information, such that the inter-bank lending market faces a “lemon” problem.

Our theory sheds new light on the theory of the firm in different institutional environments. In a free market environment, the boundary of a firm is determined by the trade-off between the efficiency gain from solving the commitment problem --- gaining the capacity to make ex-post selections --- and the institutional cost of external financing. Here, the institutional cost of external financing refers to that of moral hazard and adverse selection problems, which have been extensively discussed in the literature. As a result of this trade-off, if a project is relatively certain, internal financing is more efficient; if a project is more uncertain, syndicated external venture financing is more efficient.

Finally, some remarks about our approach are in order. To keep our model simple, we have chosen to use a reduced form of the institutional cost of no-integration, which is a measurement of the imperfection of the capital market. It is related to another dimension of the informational asymmetry between the financiers and the entrepreneur, which may result in moral hazard and adverse selection problems for the entrepreneur. Depending on capital market development and other institutional settings, such as the legal system, the institutional cost may vary across countries and over time (La Porta et al., 1997). There exists extensive economic and finance literature that provides the rationale for such institutional costs (e.g., Arrow, 1962; Stiglitz and Weiss, 1981; and Myers and Majluf, 1984). We expect a model with fully endogenized institutional costs can generate richer results.

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Table 4 Summary statistics of the variables

Variable	Obs	Mean	Std. Dev.	Min	Max
NME	5,689	0.112322	0.389116	0	4
Alliance_10	5,542	7.989354	20.1718	0	215
Alliance_15	4,978	14.70912	36.20802	0	386
ROA	1,339	-0.21018	0.677135	-12.0275	1.745964
R&D (%)	1,198	13.2437	64.36018	0.015303	533.5354
Size (total asset) ($mil)	1,345	30459.86	156023.5	0	1736344
list	5,689	0.435577	0.495876	0	1

Table 5 Relationship between the Number of Strategic R&D Alliances and Obtaining NME Approval

Panel A: Cases based on Alliance_10				Panel B: Cases based on Alliance_15			
Year	NME=0	NME>=1	Diff	Year	NME=0	NME>=1	Diff
1998	1.45	7.35	5.9***				
1999	1.42	11	9.58***				
2000	2.27	8.96	6.68***	2000	3.02	13.45	10.43***
2001	2.74	15.28	12.54***	2001	3.81	20.39	16.58***
2002	3.82	10.8	6.98**	2002	5.41	15.07	9.66**
2003	4.08	23.29	19.22***	2003	5.69	31.63	25.94***
2004	5.31	13.19	7.88***	2004	7.39	18.06	10.67***
2005	6.11	21.83	15.73***	2005	8.57	29.72	21.15***
2006	5.75	24.05	18.30***	2006	8.74	34.95	26.21***
2007	6.7	28.3	21.60***	2007	10.12	41.75	31.63***
2008	7.81	24.27	16.46***	2008	12.28	38.36	26.08***
2009	8.57	24.41	15.83***	2009	14.3	38.1	23.80***
2010	9.54	21.43	11.89**	2010	16.14	35.4	19.26**
2011	7.75	45.21	37.47***	2011	12.95	66.86	53.91***
2012	9.21	28.64	19.43**	2012	15.92	48.31	32.39***
2013	9.88	38.95	29.07***	2013	17.51	65.95	48.44***
2014	7.45	48.34	40.89***	2014	14.56	80.89	66.33***
2015	6.57	50.71	44.14***	2015	13.63	86.6	21.97***
2016	8.92	57.58	48.66***	2016	18.15	99.83	81.68***
2017	6.18	33.79	27.61***	2017	14.28	66.14	51.86***
2018	5.11	17.41	12.30***	2018	13.31	43.73	30.42***
Full sample	6.03	26.81	20.78***	Full sample	11.31	48.14	36.83***

Table 6 Outsourcing and NME development (outsourcing activities between 5 and 10 years prior to NME development)

	(1)	(2)	(3)	(4)
	NME	NME_D	NME	NME_D
Alliance_10	0.0155***	0.0256***	0.00603**	0.0154***
	(9.98)	(11.01)	(2.63)	(3.84)
Size			0.339***	0.341***
			(5.05)	(4.36)
ROA			-0.246	-0.254
			(-1.47)	(-1.27)
R&D			0.000267	0.000775
			(0.16)	(0.43)
List	0.352**	0.277*		
	(3.10)	(2.29)		
Constant	0.217	-2.637***	-1.935	-4.904***
	(0.51)	(-11.33)	(-1.20)	(-3.83)
Year-fixed	Yes	Yes	Yes	Yes
Firm-fixed	Yes	Yes	Yes	Yes
Exchange-fixed			Yes	Yes
N	5542	5542	1197	1176

Note: T-statistics are shown in parenthese: * P,0.05, ** P,0.01, *** P,0.001

Table 7 Outsourcing and NME development (outsourcing activities between 5 and 15 years prior to NME development)

	(1)	(2)	(3)	(4)
	NME	NME_D	NME	NME_D
Alliance_15	0.00887***	0.0138***	0.00415**	0.0105***
	(9.62)	(10.01)	(3.09)	(4.17)
Size			0.333***	0.330***
			(4.70)	(3.89)
ROA			-0.238	-0.242
			(-1.42)	(-1.17)
R&D			0.000266	0.000857
			(0.16)	(0.48)
List	0.337**	0.279*		
	(2.76)	(2.10)		
Constant	0.812	-2.040***	-1.221	-4.522**
	(1.69)	(-10.78)	(-0.37)	(-3.28)
Year-fixed	Yes	Yes	Yes	Yes
Firm-fixed	Yes	Yes	Yes	Yes
Exchange-fixed			Yes	Yes
N	4978	4978	1093	1074

Note: T-statistics are shown in parenthese: * P,0.05, ** P,0.01, *** P,0.001