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Staged R&D Processes and Learning from Failure: Evidence from the U.S. Biotechnology Industry

Tao Wang
University College London
Management Science & Innovation
tao.wang.10@ucl.ac.uk

Abstract

In this paper, I explore boundary conditions of learning from failure in staged R&D projects. Based on data from American biotechnology industry, I find that failure experience from the downstream of R&D process enhances the learning capability more than failure experience from the upstream of the R&D process. I also identify the ratio of stage product development in a firm?s R&D portfolio as a moderator in determining learning from failure rates by serving as an antecedent of absorptive capacity. Furthermore, I highlight that the positive learning spill-over effects could not extend beyond the stage of R&D development, which gives credence to the limitation of knowledge applicability and explores the propensity of knowledge sharing and transfer inside organizations.

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Abstract: In this paper, I explore boundary conditions of learning from failure in staged R&D projects. Based on data from American biotechnology industry, I find that failure experience from the downstream of R&D process enhances the learning capability more than failure experience from the upstream of the R&D process. I also identify the ratio of stage product development in a firm's R&D portfolio as a moderator in determining learning from failure rates by serving as an antecedent of absorptive capacity. Furthermore, I highlight that the positive learning spill-over effects could not extend beyond the stage of R&D development, which gives credence to the limitation of knowledge applicability and explores the propensity of knowledge sharing and transfer inside organizations.

Introduction

Organizational learning is typically represented as a change in the organization's knowledge that occurs as a function of experience (Fiol&Lyles, 1985). Organizational learning theorists have long held that organizations learn primarily through processes of "problemistic search" that they engage in only after experiencing failure (Cyert&March, 1963; Lant, 1992). Existing evidence has shown that failure is more important than success for organizational learning (Cannon&Edmonson, 2001; Haunschild&Rhee, 2004; Baum&Dahlin, 2007; Madsen&Desai, 2010). There is, however, significant variation in firms' propensity to learn from failure and to build on failure experience in improving innovation capability in R&D process (e.g. Dutton&Thomas, 1984; Mihm et al., 2003; McGrath&Nerkar, 2004).

During the R&D process, firms reduce uncertainty associated with the R&D process through active learning, rather than through the mere passage of time. This collateral learning could cut across projects so that obstacles relating to one project can be resolved through learning that took place on another project (Childs and Triantis, 1999). Evidence suggests the collateral learning effect could be either sub-additive or super-additive depends on the relation among projects in single stage R&D projects (Vassolo et al., 2004).

On the other hand, many R&D projects are staged projects. Research shows that organizational information processing patterns differ across stages of the R&D process (Daft and Lengel, 1986) and learning from experience may occur in some phases but not in others (Van de Ven and Polley, 1992). There is fierce debate about the strategy of combining upstream and downstream to enhance learning effect in high-tech industries (Pisano, 2006): some argue that specialists which only focus either upstream or downstream R&D process enjoy higher financial returns; whereas, the U.S. equities markets of the 1960s arguably valued the synergies created by conglomerate mergers (Shleifer&Vishny, 1991). However, very few fine-grain research on the boundary conditions of learning from failure in staged R&D projects exists in the organizational learning literature.

The purpose of the current study is to fill this gap by disaggregating organizational failure experience into upstream and downstream failure experience and comparing each contribution to organizational performance. In essence, I attempt to determine whether the common finding of improved organizational outcomes with increasing organizational experience is driven by learning from upstream failure experience, learning from downstream failure experience, or some combination of the two.

Second, besides separating upstream and downstream failure experience, I directly test organizations with higher proportions of downstream R&D process projects could learn more efficiently from failure experience. I link the lower failure rates of these companies to their greater propensity to learn from failure experience. By highlighting how firms that are oriented towards either upstream- or downstream- R&D development are distinctive in terms of their ability to learn, I identify that the composition of the portfolio is a moderator in determining learning from failure rates by affecting organizations' absorptive capabilities (Cohen and Levinthal, 1990; Volberda et al, 2010).

Third, I find that positive learning spill-over effects resulting from failure do not extend beyond projects from a firm's R&D portfolio that are at the same stage as the failed project(s) from which these effects stem. Some have suggested that the benefits of learning-by-doing extend across a firm's R&D portfolio (Childs and Triantis, 1999). However, my findings provide credence to work that emphasizes limitations of the broader applicability of knowledge gained in a specific context (Meyer and Goes, 1988) and that knowledge management processes are distinctive across different stages of the R&D process (Madahavan and Grover, 1998).

To test my hypothesis, I generate a dataset of 738 R&D projects undertaken by the top 27 US biotechnology companies over the period 1992-2012. I choose this industry because the failure rate is sky-high in drug development (Henderson, 1994; Kola&Landis, 2004; Cannon&Edmonson, 2005), and learning from failure is not only essential but also highly possible in the R&D process. For example, Pfizer's Viagra is primarily designed to treat heart failure, but after the disappointing clinical trial and detailed analysis of failure, the researchers found that it is effective in treating asynodia. This learning from failure contributes billions of dollars to Pfizer's revenue.

Theory and Hypotheses

R&D Process and Organizational Learning

Reducing uncertainties and risks associated with new product development constitutes an important function of the improvement of innovative capabilities, which are a critical source of competitive advantage in many industries (e.g. Schilling and Hill, 1998; Utterback and Abernathy, 1975; Mansfield, 1981). Organisational learning, which encompasses processes through which firms create, retain, and transfer knowledge, plays a key role in the development of these innovative capabilities (e.g. Argote, 2013, Argote and Miron-Spektor, 2011; Cyert and March, 1963). For example, organisational learning has been found to be crucial in explaining efficiency improvements firms achieve in both manufacturing- (e.g. Argote and Epple, 1990) and service- sectors (Darr et al., 1995). Some firms learn more effectively than others however, and the shape of learning curves that empirically capture the development of firm innovative capabilities over time varies both across industries as well as across individual firms within industries (e.g. Dutton and Thomas, 1984).

As organisational challenges firms must confront in innovative processes vary along the development life cycle, firms must adapt strategies to deal with these strategies accordingly (e.g. Anderson and Tushman, 1990). Different stages of product development in technology ventures need different actions to acquire knowledge (Levinthal&March, 1993). In the early stages of products development, the companies undertake exploratory search in order to discover new things, which relates to new technical skills, market expertise, external relationships or radical

innovation(Lavie and Rosenkopf, 2006; Smith and Tushman, 2005). Whereas in the downstream of products development, business venture tends to exploit existing competence and refine existing knowledge (March, 1991).

Learning From Failure across Stages

One of the most potent mechanisms through which firms learn is through failure (Levitt and March, 1988; Edmondson, 2004) or "problematic search" (Cyert and March, 1963). Not all failures are of equal value in promoting learning though; Firms in the automobile industry learned more from voluntary products recalls than from involuntary recalls (Haunschild and Rhee, 2004). Moreover, major failures reduce the likelihood of future failures more than minor failures (Madsen and Desai, 2010).

I expect these mechanisms to be similar for downstream failures in the R&D process. First, failures that occur downstream in the R&D process tend to involve a greater loss of resources comparing to those happen in the upstream process. Defects discovered in the downstream of the software development process are approximately 100 times more costly than defects discovered early on (Thomke, 2003).

Second, even though organisations generally prefer upstream failures over downstream failures, the lack of investments in a project that is deemed to fail also diminishes the learning potential associated with that particular investment (Luehrman, 1998; McGrath and Nerkar, 2004). Downstream R&D can acquire knowledge from upstream product development to reduce uncertainty, and could also develop new knowledge which is not only relevant to existing project but also improve the capability which the firm develops for using in other new product development (McGrath, 1997).

Third, the magnitude of different stages of failure varies, affecting learning outcome. Although organization members tend to engage in problemistic search for new knowledge in response to failure, learning scholars argue that not all failures are of equal value in promoting organizational learning (Madsen&Desai, 2010). From organizational behaviour perspective, "small loses" is better for learning than big failures because for small failures the drive to determine the accountability is overwhelmed by uncovering the cause of the failure. Then the motivation to share and update knowledge is stronger than that of big failure (Sitkin,1992). However, empirical evidence by Madsen and Desai (2010) suggests that major failures reduce the likelihood of future failure more than the minor failures. They also propose two reasons for this: big failures have larger negative consequence and self-enhancement may lead organizations members ignore small failure. Comparing to upstream failure, downstream failure is more time and money consuming. Therefore, organizations learn more efficient from downstream failure because the reaction of organization members to upstream failures could prevent them from engaging in problemistic search for new knowledge and from making changes (Levinthal&March, 1981).

Last but not least, organizational myopia (Levinthal and March, 1993) and cognitive biases (Cannon and Edmondson, 2005; Watkins and Bazerman, 2003) lead individuals to ignore or underestimate the significance of failures in the upstream R&D. It is often more difficult to ignore downstream failures; as these tend to be more serious, there is a greater incentive to learn from these failures.

Hypothesis 1: Downstream innovation failures reduce subsequent R&D failures more than upstream innovation failures.

Learning from Failure and Absorptive Capacity

Although above I specify direct tests of the relative effects of upstream failure and downstream failure experience, I also extend theory in this domain by proposing and testing staged R&D as a moderator of learning from failure. Numerous researches have identified absorptive capacity as the facilitator to recognize and assimilate external information (Volberda et al., 2010); however, little work demonstrates that absorptive capacity could also moderate learning from failure and explain the variation of learning from failure.

Knowledge is the core competitiveness of organizations and critical knowledge acquisition through both internal resource and external resource depends on the organizations prior knowledge endowment, which is the absorptive capability (Cohen&Levinthal, 1990; Argote, 2013). Absorptive capacity is facilitated by R&D activities that provide organizations with the background knowledge necessary to recognize and exploit external information (Cohen&Levinthal, 1990). Investments in R&D not only facilitate learning from the experience of external sources, but also help learning from internal sources (Liberman, 1984).

Absorptive capacity is a portfolio-related characteristic of investments and a firm's absorptive capacity makes the assimilation of knowledge easier and reduces the uncertainty of other options in a portfolio (McGrath&Nerkar, 2004). As in sequential R&D projects, Lerner et al. (2003) report that the failure rate of R&D projects in the pharmaceuticals is lower for projects that involve alliances during the downstream of the drug development process than for other projects because upstream R&D need more financial capital and greater information asymmetries which associate with a significant transfer of control and loss of incentive. Therefore, as the development process moving forward, intra-organizational learning become more efficient due to the effective knowledge assimilation, and uncertainty declines because of the reduction of information asymmetries and retention of majority control right.

Organizational learning theorist proposes that learning from failure is more effective than learning from success because failure motives deeper search and richer understanding than success (Sitkin, 1992). Absorptive capacity is largely a function of the level of prior-related knowledge includes basic skills or even a shared language but may also include knowledge of the most recent scientific or technological development in a given field (Cohen&Levinthal, 1990). Thus, organizations with more downstream R&D projects have more knowledge endowment and ability to deeper recognize and assimilate the new information from the failure experience.

Hypothesis2. The relationship between subsequent failure and past failure experience is more negative for organizations with higher proportion of downstream R&D cases.

Learning Spill-Over Effects

Organizational Learning stands on the centre stage in organization theory and many scholars even believe that it is the only sustainable competitive advantage (Stata,1989). However, empirical

researches show that organizational learning may not always increase organization capabilities. For example, Van de Ven and Polley (1992) show that learning from experience may not occur in some phases of product development. Taking this point even further, organizations can learn from experience incorrectly such as superstitious learning, which may draw incorrectly conclusion, taking up resources for beneficial learning (Levitt&March, 1988). Furthermore, the worst learning may involve learning from bad thing, impeding organizational welfare and harming society (Baker&Faulkner, 1993). Since previous research has demonstrated that some organizations could not learn from failure due to potential bias (Denrell&March, 2001), I provide a more fine-grain investigation by disaggregating both organizational failure experience and organizational performance into upstream and downstream and comparing the contribution in the same stage or across stage. In essence, I attempt to determine the boundary of the stage-specific knowledge and positive learning spill-over effects.

The advancement of individual projects in a R&D portfolio generally benefits from resources and knowledge developed in the context of other projects in that portfolio. The advancement of downstream R&D projects can for example draw on a firm's experiences in upstream projects and has been found to reduce the overall uncertainty of a firm's R&D portfolio (McGrath, 1997). However, there are limitations to these learning effects across projects.

Organizational knowledge is shaped by organisational routines governing different networks that tie together the basic elements of organizations - members, tasks, tools and embedded in the interaction of these basic elements (Argote, 2013; Levitt and March, 1988; Starbuck, 1992; Stein, 1995). Therefore, organizational knowledge is created and retained in specific knowledge networks and only by choosing the right knowledge repository can the relevant knowledge be abstracted and transferred smoothly, in which learning occurs. For example, Cohen and Bacdayan (1994) demonstrate that knowledge acquired through performing a task can be embedded in supra-individual routines. Based on lab experiments, they find that in this task-task knowledge embedded network, task performance slows down significantly with the introduction of novelty. This could attribute to switching to slower declarative processing from routinized processing causing by novelty (Singley and Anderson, 1989). In drug development process, upstream innovation generates new knowledge and requires more novelty than downstream innovation. Therefore, knowledge repositories for these two stages are different and knowledge transfer across stage would not be as smooth as does in similar stage.

Knowledge can be categorized as universal knowledge and specialized knowledge (Grant, 1996). The characteristic of knowledge affects the knowledge sharing and knowledge transfer process. In other words, universal knowledge could be used in different situations but special knowledge requires a specific organizational context.

The characteristics of the knowledge being transferred could affect the efficiency of knowledge transfer across projects. Meyer and Goes (1988) reports that the innovation capability is more important than the characteristics of organizations in knowledge assimilation. Moreover, Madhavan and Grover (1998) speculate that different types of knowledge are reqired for different stages of product development process due to interpersonal trust. Similar innovation stages share a lot of universal knowledge such as development process and evaluation process but different stages have little common knowledge unless they share similar molecular mechanism, so the degree of transfer

is expected to be higher in the same stage knowledge transfer and across stage knowledge transfer, therefore affects organizational learning.

Hypothesis3: Learning effects from failure across projects at the same stage of development are greater than learning effects from experience across projects at different stages of development in a firm's R&D portfolio.

Method

Data and Sample

To test our hypotheses, we intend to use data of American base biotech companies which existed from 1992 onward based on the 2006 top 100 companies list ranked by revenue. Among these firms, 27 companies have their headquarters outside America, 3 firms' primary business is not new drug development, 31 firms were either acquired by other pharmaceutical companies or bankrupted during the period and 12 companies were established after 1992, which leaving only 27 firms in our dataset.

These firms account for a large proportion of drug development in the biotechnology sector (Pisano, 2006) and the other actors including smaller start-up, universities, independent institutes and some pharmaceutical companies. We only include the US firms because most of the new drugs are discovered and developed in America and many researches support that geographic distributed units face the challenges of exchanging and acquiring knowledge (Ingram&Baum, 1997; Argote, 2013). For the purpose of our study, we only include products already entered clinical trial development and registered drug since preclinical data in our database is not reliable.

We separate the product innovation into two stages: upstream stage and downstream stage. To produce a sequence of innovations, organizations need to cycle repeatly through a sequential phases (Brown and Eisenhardt, 1997; Puranam et al, 2006).The initial innovation is likely to involve the widest search of technology opportunities and scholars have conceptualized the notion of technology paradigm, which represents an upstream innovation that focuses on figuring out directions (Nelson and Winter, 1982). Following the initial innovation, further stages typically arise along the trajectory initialled by the upstream innovation (Dosi, 1988). In the drug development process, phase I clinical trial is mainly focus on evaluating the safety and identify side effects and phase II is to determine the effectiveness, both of them explore the efficiency and safety of the drug and are considered as upstream R&D. On the other hand, phase III clinical trial is to repeat phase I and phase II process and confirm the safety and effectiveness in large groups, which is considered as downstream R&D.

The unit of analysis is the individual drug development and its associated content, and the level of analysis is the firm. The sources for this information include the PharmaProject database and Combustion database.

Dependent variable

Project failure rates constitute our main dependent variables and we make a distinction between upstream and downstream failure rates. We calculated failure rates as the number of projects from a firm's R&D portfolio that failed divided over the total number of projects in that R&D portfolio over a 22 year period. This variable was calculated for each firm and updated annually.

Project failure rates are frequently used in empirical studies on organizational learning as a proxy for improved performance (Baum and Ingram, 1998; Haunschild and Suilivan, 2002; Haunschild and Rhee, 2004; Madsen and Desai, 2010). Moreover, in our specific context failure rates are a convenient proxy for performance for several reasons. First, project failures are a common occurrence in therapeutic product development (Henderson, 1994; Cannon and Edmonson, 2005). Second, given the significant resources involved in therapeutic product development projects (typically, firms spend in excess of US$ 500 Million to commercialise a new therapeutic product), failure rates represent a financially meaningful measure of a firm's R&D performance (Pisano, 2006). Third, although defining learning by fixed outcome could lead to an overly narrow representation of organizational learning (Kim and Miner,2007), it is well capture the knowledge from the product development process that operates to produce survival-enhancing learning in the biotech industry.

Independent variable

Failure experience The independent variable measuring failure experience was a count of the number of a firm's prior product development failure.

State-specific failure experience As introduced before, we divide the drug development process into two stages: Upstream stage includes both phase I and phase II clinical trial and downstream stage includes phase III clinical trial and drug registration. The upstream R&D cases proportion is defined as the number of phase I and phase II drug development divided by the total number of product development in the organization which is updated yearly. The downstream drug development proportion is defined in the same way.

Phase specific failure experience: To study the variation of phase specific learning, we measured two additional failure experience variables:

Upstream failure experience: Clinical phase I and phase II drug development cumulative failure experience

Downstream failure experience: Clinical phase III and FDA application cumulative failure experience

Control variables

Several control variables are also included:

Vicarious learning experience: Organizational learning theory suggests that organizations develop knowledge not only from their own experience, but also through observation of other companies' experience (Ingram and Baum, 1997; Madasen and Desai, 2010; Argote, 2013). In our setting, biotechnology companies can learn not only from their own R&D experience, but also from other pharmaceutical companies, universities and research institutes. Therefore, we include cumulative number of investigational new drug applications for FDA approval (IND) from FDA website as the proxy of industry experience.

Successful experience: Ingram and Baum (1997) find that firms can only learn from their own successful experience and from others' failure experience but not from their own failure experience and others' successful experience. They also explain that this is attributed to the reluctant of admitting own failure and over emphasize on own success. Moreover, Madsen and Desai (2010) claim that organizations learn more effectively from failure than success and knowledge from failure depreciates more slowly than that from successful experience. It seems that the effects of failure and success depend on organizational context. Since we already include failure experiences as our independent variable, we also include successful experience as control variable.

R&D expenditure and annual drug development: R&D expenditure may affect the investment in equipment, human capital, and management, which may have an effect on knowledge creation and retention, so we include annual R&D expense (indexed to 1992 dollars) in our model following the suggestion of others (Haunschild and Sullivan, 2002; Haunschild and Rhee, 2004; Stan and Vermeulen, 2013). Annual drug development is included because larger firms tend to have more product underdevelopment and it could also be a factor to reflect the size of the firm (Haunschild and Rhee, 2004; Stan and Vermeulen, 2013.

Firm age: Papers have examined the effect of ageing on the organizational performance (Tushman and Anderson 1986; Henderson 1994). So besides the control variable discussed above, we also include the age of the firm since it not only related to the technology advancement but also can indicate the knowledge endowment of an organization (Argote,2013).

Analysis

Because of our dependent variable takes a value between 0 and 1, we use logit models instead of OLS models. Moreover, we include both firm and time fixed effect in the analyses. The inclusion of firm and time fixed effect is critical since many characteristics of firms and technology change are unobservable. If not included, the organization heterogeneity could bias our result. Our data consist of a panel of 567 firm-years observations.

Result

Bivariate Correlations

Table 1 shows descriptive statistics and a bivariate correlation matrix for all our variables. The correlation table indicates that there are a few high correlations among independent variables. For example, upstream stage failure experience and downstream failure experience are highly correlated. This may be because they are sequential process and are interdependent with each other. Besides, the correlation between failure experience and general experience is high. One reason for this could be that the failure experience is part of the general experience and another reason could be both increase with the size of the firms increase and the time elapse (Madsen and Desai, 2010).

Hypothesis Testing

Table 2 shows the result from our fixed-effects logit regression. Model 1 contains only control variables and provides a baseline for our analyses. Model 1 highlights that the effect of annual drug development on future failure rate is positive and significant, indicating that organizations have

more drugs under development tend to experience more project failures. Model 1 also highlights that company age has a negative and significant effect on project failure rates, which means that older firms experience fewer failures. Moreover, industry experience has a weak positive effect on failure rates, indicating others' experience may not reduce organization's failure. This result is not in accordance with previous results (Ingram and Baum, 1997; Madsen and Desai, 2010). We can think of two explanations for this discrepancy. First, the IP appropriability regime in biotechnology is comparatively strong and most companies are not willing to share detailed process information with others due to the underlining financial benefit even if they have collaboration or have already formed alliances (Rothaermel and Deeds,2004; Pisano,2006) . Second, clinical trials information is usually strictly confidential and the knowledge acquired from drug development is usually tacit and not easy to articulate, so interorganization knowledge sharing and transfer would be much more difficult than in other industries.

In addition, the negative and statistically weak effect of R&D investment on future failure indicates that increased R&D investments may reduce drug development failure but that this effect is comparatively small. The only non-significant control variable is the successful experience. This may be explained by the low number of launched drugs comparing to failure ones.

In order to assess whether firms have different learning capability from different stage failure experience, we compare the learning effect on future failure between upstream and downstream innovation experience. In model 2, both upstream failure experience and downstream failure experience enter into the same regression. The coefficients of both variables are significant and negative, which means both of them can reduce subsequent failure. In addition, Wald test ($p<0.001$) shows that and downstream failure experience can reduce subsequent failure more effectively than upstream failure experience. Therefore, hypothesis 1 is supported.

To test H2, firstly, I added upstream drug development ratio and downstream drug development ratio in model 3 and model 4 separately. As shown by these two models, downstream drug development ratio has no obvious effect on future failure but upstream drug development ratio has a significantly positive effect on future failure. The reason for this may be that because there is a higher probability that a product will fail if it is in an upstream stage than if it is in a downstream stage (McGrath, 1997; Kola and Landis, 2004).

Then, I added the interaction term of upstream stage drug development ratio*failure experience and downstream drug development ratio*failure experience in model 5 and model 6. The results indicate that both upstream and downstream drug development ratio affect the relation of failure experience and subsequent failure negatively and significantly. Further t-tests show that organizations with a higher proportion of downstream drug development projects have steeper learning curves in terms of reducing future failure than organizations with a higher proportion of upstream drug development projects. Thus, we find confirmation for hypothesis 2.

Finally, I test whether same stage learning from accidents would be more efficient than cross stage learning (hypotheses). I use stage-specific failure rate instead of aggregated failure rate as independent variables and the results are shown in model 7 and model 8. Although upstream R&D failure experience has a negative and significant impact on upstream R&D subsequent failure likelihood in model 7, downstream R&D failure experience has no effect on upstream R&D subsequent failure likelihood. Wald test ($p<0.001$) suggests that the upstream R&D failure

experience coefficient is significantly more negative for reducing upstream subsequent failure than the downstream failure experience coefficient. Using downstream failure as the dependent variable, we get similar results. Thus, we find strong support for H3 and find that learning effects based on project failures are only positive for the advancement of projects from a firm's R&D portfolio that are at the same stage of the failed project.

Discussion and Conclusion

Our results indicate that failure experience from the downstream R&D process reduces subsequent drug failure and uncertainty more than the failure experience from upstream R&D process. Organizations with different ratio of downstream product development in their portfolio have different failure learning capabilities, which affect the decision making of the firms and also the performance. This variation of failure learning ability may be because of absorptive capacity and different knowledge acquiring from previous failure experience. Furthermore, we highlight that the positive learning spill-over effects could not extend beyond the stage of R&D development, which gives credent to the limitation of knowledge applicability and explores the propensity of knowledge sharing and transfer inside organizations.

Our results advance the existing literature in several respects. First, my findings improve our understanding of variations in organizational learning. Much progress has been made in organizational learning research but relatively little remains known about moderators of organizational learning (e.g. Stan and Vermeulen, 2013), especially learning from failure. Some studies find that the magnitude of failure and motivation could explain the learning variation and reconcile the disparity (Haunschild and Rhee, 2004; Gino et al., 2010; Madsen and Desai, 2010); however, more researches explaining the variations need further investigation. From my research, organizations with higher levels of downstream R&D projects in their portfolios seem to enjoy steeper learning curves than organizations with higher levels of upstream R&D projects in their portfolios. The absorptive capability of firms, which is oriented towards downstream R&D thus seems to be superior.

Second, I identify the product development portfolio as a new antecedent of absorptive capacity. Knowledge absorbing ability from external resource lies at the core of the ability to innovate and innovative firms tend to demonstrate higher profitability, greater market value and higher survival probabilities (Volberda et al, 2010). An organization's absorptive capacity depends on prior related knowledge (Lane et al, 2001), organizational structure (Anderson and Foss, 2005), individual knowledge development and sharing (Zahra and George, 2002) and interorganizational relationship (Argote, 2013). Besides these antecedents, we demonstrate that the product development portfolio, or the ratio of downstream product development, could also enhance organizations' absorptive capacity and in turn affect organizational learning rate.

Third, I extend the theory that absorptive capacity as the facilitator to recognize and assimilate external information from failure experience (Volberda et al., 2010). Dating back to the seminar work by Cohen and Levinthal (1990), absorptive capacity is regarded as a provider for background knowledge necessary to recognize and exploit external information, facilitated by R&D activities. Since cognitive bias has been recognized as the obstacle of learning from failure and recognition is the first step to learn from failure (Watkins and Bazerman, 2003), relatively little research has demonstrated how to avoid the ignorance of failure. According to my research, knowledge acquired

from failure experience serves as the core competitiveness of organizations depends on the organizations absorptive capability.

Fourth, my findings highlight novel boundary conditions for organizational learning. Organizations learn more effectively from downstream R&D failure experience. Although organizations can still learn from upstream R&D failure experience, the learning process is shallow and problematic. This proves and explains Lerner and his colleagues' finding (2003) that the likelihood of success alliance is contingent on the stage of the drug development process these alliances are forged.

Fifth, I demonstrate that knowledge created in upstream R&D failure experience is only useful for the same stage product development and cross stage knowledge transfer is much more difficult. In other words, the characteristics of the knowledge being transferred could affect the efficiency of knowledge transfer. In addition, we demonstrate that to accelerate knowledge sharing and knowledge transfer, organizations need to choose the appropriate knowledge repository. Furthermore, I empirically reject the assumption that investment in downstream R&D can draw experience from upstream firm-specific knowledge and prove that the knowledge can be utilized only on the same stage product development (McGrath, 1997). I propose that learning-by-doing could only happen in the same stage options but not across stage options in sequential R&D investment (Childs and Triantis, 1999).

Limitations, Direction for Future Work, and Conclusion

Our context of therapeutic product development offers a unique setting to examine staged R&D processes and learning effects across a firm's R&D portfolio. However, it also has limitations, which offer avenues for further research. First, therapeutic R&D projects are long-term projects and are capital intensive, often spanning more than 10 years and typically costing hundreds of millions of dollars. So the stage issue is more prominent than other industries. Therefore, the results given here may not suit to innovations with short term since learning process need time to retain and transfer knowledge (Argote, 2013). Thus, it would be interesting to see the learning effect of different stage in short term product development.

Second, no industry can bear such high failure rate as the biotech industry and this incredible attrition rate may affect the learning process. On the one hand, organizations learn more effectively from failure if the cost of failure is extremely high (Madsen and Desai, 2010). On the other hand, organizations may fall into the competence trap or myopia status due to failure information overload (Levinthal and March, 1993). So comparing the effect of learning from failure in different industries may find additional factors contributing to the variation of learning rates.

Third, though we controlled for the R&D expenditure, we did not have detailed capital investment data for each project and the level of capital investments in a project might affect learning effects firms enjoy as people tend to pay more attention to bigger investments (Watkins and Bazerman, 2003; Levinthal and Rerup, 2006). Thus, future research should address this issue.

This study compares the learning effect of downstream R&D failure experience and upstream R&D failure experience and demonstrates failure experience from downstream R&D process is more effective for learning. Organizations portfolio could explain the variation of learning ability, which because of absorptive capacity and different knowledge acquiring from previous failure experience.

In addition, the result shows that there is limitations of knowledge applicability and boundary of positive spill-over effects.

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Table 1 Descriptive Statistics and Correlations

Variables	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11
1 Company Age	18.98	0.577	1										
2 R&D Expense	116165.3	12061.55	0.1696	1									
3 Annual Drug Development	1.3	0.099	0.3646	0.6127	1								
4 Launched Experience	1.43	0.104	0.5173	0.5158	0.6519	1							
5 Industry Experience	183601.2	3122.2	0.4345	0.2937	0.4667	0.4446	1						
6 Failure experience	4.24	0.29	0.4309	0.5418	0.7835	0.7308	0.5712	1					
7 Upstream Drug Development Ratio	0.296	0.017	0.2228	0.2711	0.4973	0.2895	0.4755	0.4156	1				
8 Downstream Drug Development Ratio	0.16	0.013	0.3185	0.0868	0.2533	0.2791	0.1837	0.1687	-0.1107	1			
9 Upstream Failure Innovation Experience	3.8	0.301	0.3612	0.5901	0.8131	0.6818	0.5437	0.972	0.3956	0.1389	1		
10 Downstream Failure Innovation Experience	2.34	0.187	0.7235	0.3755	0.6298	0.8544	0.4328	0.7699	0.2795	0.2725	0.6835	1	
11 Annual Drug Failure Rate	0.245	0.0158	0.1963	0.1648	0.3584	0.2498	0.2774	0.2706	0.7268	0.1552	0.2389	0.229	1

Table 2 Regression

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Annual Drug Development	0.0658952***	0.0845081***	0.0857603***	0.0269251**	0.0890384***	0.0268419**	0.0715944***	0.0129137*
Industry Experience	0.0000152*	0.0000143*	0.0000148*	0.00000796	0.0000155*	0.00000785	0.00000952	0.00000477*
Founding History	-0.1727904*	-0.1556954*	-0.1639839*	-0.0981997	-0.1742448*	-0.0990044	-0.1020985	-0.0535968*
R&D Expense	-0.000000271**	-0.000000296***	-0.000000252**	-0.000000227***	-0.000000319***	-0.000000204***	-0.000000138+	-0.000000158***
Cumulative Launched Products	-0.0082884	0.0315322*	0.0259184+	0.027149**	0.0372429**	0.0255457**	0.0210678	0.0104644
Downstream Failure Experience		-0.0954304***					-0.0329887	-0.0624417***
Upstream Failure Experience		-0.018411**					-0.0207387***	0.0023277
Failure Experience			-0.0256421***	-0.0112426**	-0.0165087**	-0.0018266		
Downstream Drug Development Ratio			-0.0164682		0.1270956+			
FE*DDDR					-0.039882***			
Upstream Drug Development Ratio				0.6470498***		0.6989031***		
CDF*UDDR						-0.0132174+		
N	567	567	567	567	567	567	567	567
R-Square	0.346	0.3622	0.3518	0.6278	0.3736	0.6309	0.3238	0.15
DV	Annual Failure	Annual Failure	Annual Failure	Annual Failure	Annual Failure	Annual Failure	Upstream Failure	Downstream Failure

***p < 0.01; **p < 0.05; *p < 0.1