ORGANIZATIONAL CAPABILITIES, ORGANIZATIONAL STRUCTURE, AND THEIR DYNAMICS: THREE ESSAYS ON BOUNDARY CHOICE AND CAPABILITY DEVELOPMENT IN ENTRY DECISIONS

BY

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DISSERTATION

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ABSTRACT

One recent development in the organizational economics approach to strategy management concerns the integration of the organizational capabilities view and the transaction costs theory. My dissertation takes on this task focusing on transaction costs economics, dynamic capabilities, and temporal dimensions in the evolution of an industry. Essay one provides a constructive literature review on recent works and develops a framework to facilitate further integrative efforts in our inquiry into the firm boundary question. Essay two studies a firm's boundary choice for a given value-chain activity when entering a new industry, asking: what are the main and moderating effects of transaction hazards and pre-entry organizational capabilities on the choice between internalization and external development of a value-chain activity? Essay three examines a firm's technology management and industry entry strategies when facing an emerging radical technology, asking how non-redeployable complementary assets embedded in an incumbent's existing capabilities and boundaries affect managers' decision-making in the face of uncertainties.

I further enhance the theoretical coherence across the three essays by employing the same empirical setting for hypotheses testing: the nascent U.S. biofuels industry. I collect secondary data about boundary choice and primary data about managerial decision-making. I triangulate data from archival sources, surveys, and interviews to operationalize variables. The dissertation's research questions center on the non-redeployability of firm assets (specific asset and non-redeployable capabilities in essay one, specific asset and industry life cycle in essay two, and non-redeployable complementary assets and R&D investment as well as industry entry in essay three). Findings of the dissertation shed light on the fundamental implications of non-redeployability of firm assets on a range of strategic issues related to firm boundary choice, R&D investment, and industry entry, contributing to the evolving science of strategic organization.

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CHAPTER 1

INTRODUCTION

One recent development in the organizational economics approach to strategy management concerns the integration of the organizational capabilities view and the transaction costs theory. Along this line, great efforts have been made in pursuit of a better explanation of the firm boundary question (Langlois and Foss, 1999; Williamson, 1999; Madhok, 2002). Scholars have found empirical evidence for the important role of firm capabilities in its boundary choice, especially the comparative productive capabilities (Walker and Weber, 1984; Argyres, 1996; Leiblien and Miller, 2003; Hoetker, 2005; Jacobides and Hitt, 2005). Including simultaneously variables measuring transaction costs and comparative capabilities in an additive manner in one equation accounts for the comparative approach to a firm's boundary choice, but cannot capture the dynamic interactions between a firm's boundary choice and its capability development (Argyres and Zenger, 2008).

Dynamic interaction between a firm's capability development and its boundary choice can occur in a variety of ways, such as possible constraint by a firm's prior capability development on its current choice set of boundaries (Argyres and Liebeskind, 1999), possible real options value embedded in a certain boundary choice (Kang, Tan and Mahoney, 2009), and potential capability development facilitated by a chosen governance structure (Wang and Barney, 2006). To better understand these dynamic interactions is not only theoretically important, but also empirically relevant (Argyres and Zenger, 2008). My dissertation takes on this task by emphasizing the organizational economics approach to strategy management. More specifically, it focuses on transaction costs economics, dynamic capabilities, and temporal dimensions in the evolution of an industry.

Presence of dynamic interrelationships between a firm's boundary and capability development adds complexity to empirical testing on a firm's boundary choice, requiring a more complete theoretical framework that can capture these interrelationships. Essay one of my dissertation answers this call. This essay provides a constructive literature review on recent works that attempt to integrate the firm capability view and the transaction costs theory, and develops a framework to facilitate further integrative efforts in our inquiry into the firm boundary question. To this end, I first identify challenges in an effort to integrate the firm capability view and the transaction costs theory in explaining firm boundary, including issues related to unit of analysis, endogeneity, operationalization of theoretical constructs, and research design. To address these challenges, I further develop a theoretical framework that consists of two typologies of firm capabilities. The first typology emphasizes the functions of some firm capabilities (e.g., productive, transactional, and integrative capabilities) in reducing various costs (e.g., production, transaction, and organizational costs) involved in a transaction. The second typology focuses on characteristics (e.g., complementarity and specialization) of firm capabilities that may lead to value creation. I then illustrate how these two typologies of firm capabilities can help address the four challenges in empirical studies of firm boundary choice that strive to integrate the firm capability approach with the transaction costs theory.

As discussed in the first essay, a variety of attributes of firm capabilities (e.g., functions of firm capabilities and characteristics of firm capabilities related to value creation potential and value appropriation) can affect a firm's boundary choice. The sources of variations for these attributes can be both internal and external. While the strategy management literature focuses largely on the internal part, the industry evolution (Gort and Klepper, 1982) has made many observations about patterns of industry-level capability development over an industry's life cycle. Thus, the industry evolution literature provides a perspective that complements the existing organizational economics

approach to the firm boundary question, warranting integration among these multiple literature streams. The industry evolution literature helps to bring out the temporal dimensions in the firm boundary question and point our attention to the important implications of the interaction between firm evolution and industry evolution.

Building upon the typologies developed in essay one of this dissertation, essay two studies a firm's boundary choice for a given value-chain activity when entering a new industry, asking how the intertwined relationships among firm capabilities and transaction characteristics are moderated by industry evolution. The temporal dimensions highlighted in this study include the differential timings of entry as related to the evolution of an industry, as well as the associated comparative dynamics between a focal firm's capabilities and the suppliers'. In particular, I consider the impact of a firm's pre-entry experiences, industry evolution, and the transaction hazards, asking: what are the main and moderating effects of transaction hazards and pre-entry organizational capabilities on the choice between internalization and external development of a value-chain activity?

To answer this question, I classify transaction hazards into two types – transient and enduring – where the notion of transient transaction hazards is derived from the integration between the transaction costs theory and the industry evolution literature. Furthermore, I deconstruct a firm's pre-entry experience into two types – the firm and value-chain activity levels – where firm level pre-entry experience relates to a diversifying entrant that has routines and integrative capabilities; activity level pre-entry experience exists if a diversifying entrant or founders of a start-up had related experience in a given value-chain activity before entering the focal industry. This classification of firm capabilities is derived from the integration of the firm capability view and the industry evolution literature.

Not only will pre-entry capabilities matter for a firm's configuration of value-chain activities upon entering an industry, the firm's boundary choice at entry and capability development post-

entry will also impact its decision-making about choosing a future technology trajectory and entering an emerging industry. Essay three examines a firm's technology management and industry entry strategies when facing an emerging radical technology, asking how non-redeployable complementary assets embedded in an incumbent's existing capabilities and boundaries affect managers' decision-making in the face of uncertainties. The temporal dimensions here include the path-dependence of those strategic choices and the managerial decision-making when faced with uncertainty.

More specifically, the third essay of my dissertation proposes that the timing of R&D investment and that of industry entry are driven by related but differential incentives and constraints underpinning these two strategies (Conner, 1988). Building upon studies from the technology management literature (e.g., Rothaermel, 2001a, 2001b; Rothaermel and Hill, 2005; Schilling, 1998, 2002; Tripsas, 1997), the industry evolution literature (e.g., Klepper and Simon, 2000; Mitchell, 1991; Bayus and Agarwal, 2004), as well as works on technology evolution (e.g., Fleming and Sorenson, 2001; Fleming, 2002), I ask the following research question: how do an incumbent's non-redeployable complementary assets differentially affect managers' decisions about timing of R&D investment and industry entry. On the one hand, non-redeployable assets incur sunk costs and lead to value loss if the firm tries to redeploy such assets. Both investing in R&D of a radical technology and producing under the new technology regime are subject to potential profit loss due to the non-redeployability of an incumbent's current complementary assets. On the other hand, real options value embedded in these two strategic decisions tend to differ, in that R&D investment in a radical technology may provide greater flexibility but require less resource commitment than the industry entry. Thus, the trade-off between potential value loss due to non-redeployable assets and potential value creation due to real options plays out differently in these two strategic decisions, suggesting that an incumbent's non-redeployable complementary assets can exert different impacts on these two decisions.

Table 1.1 presents an overview of the three essays of my dissertation, highlighting the different but closely linked phenomena, theories, and constructs from each essay. One common theoretical construct throughout the dissertation is the redeployable or non-redeployable assets. When an exchange partner invests in assets that cannot be easily redeployed to alternative uses without losing economic value, this exchange partner incurs high asset specificity and is likely to be subject to high transaction costs (Williamson, 1985). When a firm configures its value-chain activities in a certain way upon entering an industry, it commits itself to a specific path of capability development, facilitating or constraining its future strategic choices by such commitment (Ghemawat, 1991). If a firm's prior investments are irreversible or non-redeployable, and external technological changes are likely to devalue these investments, then sunk costs occur and the firm's option to abandon will decrease (Dixit and Pindyck, 1994).

Whether an asset is generic or specific to a transaction influences an exchange partner's boundary choice (as emphasized in the transaction costs theory, Williamson, 1985); whether capability development is reversible or irreversible has implications for a firm's competitive advantage (as emphasized in the capability view of the firm, Ghemawat, 1991); and whether an uncertain investment has high or low real options value of abandonment affects managerial decision-making *ex ante* (as emphasized in the real options theory, Dixit and Pindyck, 1994). Though independently developed in three literature streams, these distinctions of firm assets (i.e., generic vs. specific, reversible vs. irreversible, and flexible vs. sunk costs) can be boiled down to one fundamental distinction: redeployable vs. non-redeployable assets, or the main construct of my dissertation. Table 1.2 summarizes these closely related but separately developed constructs.

I further enhance the theoretical coherence across the three essays by employing the same empirical setting for hypotheses testing: the nascent U.S. biofuels industry, which is currently undergoing development of new generational technologies. I collect secondary data about boundary

choice and primary data about managerial decision-making. I triangulate data from archival sources, surveys, and interviews to operationalize variables. In particular, for essay two, I examine a firm's boundary choice for four key value-chain activities that complement bioethanol production: (1) feedstock procurement, (2) technology development, (3) bioethanol marketing and distribution, and (4) co-product marketing and distribution. A firm's boundary choice is identified when it first starts bioethanol production. For essay three, I use a representative sample of the biofuels industry (bio-ethanol and biodiesel) in the U.S. I collect data through a large sample survey, asking managerial personnel in charge of the biofuels business to provide information about their anticipated R&D investment in the next generation production technology. I also ask them about their expectations regarding entry into the new industry defined by the new technology.

In conclusion, the next three essays of this dissertation build upon the organizational economics approach to strategy management, integrating transaction costs theory, dynamic capability view, real options theory, and industry evolution, as well as the technology management literature. The dissertation's research questions center on the non-redeployability of firm assets (specific asset and non-redeployable capabilities in essay one, specific asset and industry life cycle in essay two, and non-redeployable complementary assets and R&D investment as well as industry entry in essay three). Findings of the dissertation shed light on the fundamental implications of non-redeployability of firm assets on a range of strategic issues related to firm boundary choice, R&D investment, and industry entry, contributing to the evolving science of strategic organization.

TABLES AND FIGURES

Table 1.1 Overview of the Three Dissertation Essays: Phenomenon, Theory, and Key Constructs

	Phenomenon	Theory	Key Construct
Essay 1	Firm boundary choice	Transaction costs theory Firm capabilities view	Firm capabilities: productive, transactional, and integrative Firm capabilities: complementary capabilities, non-redeployable capabilities
Essay 2	Configuration of value-chain activities in the context of industry entry	Transaction costs theory Firm capabilities view Industry evolution	Pre-entry experience Enduring transaction hazard Transient transaction hazard
Essay 3	Managerial decision-making with uncertainty about the timing of R&D investment in radical technology and industry entry	Transaction costs theory Firm capabilities view Industry evolution Technology management	Non-redeployable complementary assets

Table 1.2 Redeployable vs. Non-redeployable Assets

Transaction Costs Theory	Capability View of the Firm	Real Options	Synthesis in My Dissertation
Generic asset	Reversible investment	Flexible assets	Redeployable assets
Specific asset	Irreversible investment	Sunk costs	Non-redeployable assets

CHAPTER 2

ESSAY 1: WHEN CAPABILITIES MEET TRANSACTION……

INTRODUCTION

Recently, the capability view of the firm has been used to address the firm boundary question that was predominantly studied with the transaction costs theory from both a theoretical perspective (e.g., Langlois and Foss, 1999; Madhok, 2002; Jacobides and Winter, 2005; Jacobides, 2008) and an empirical perspective (e.g., Walker and Weber, 1984; Argyres, 1996; Leiblein and Miller, 2003; Hoetker, 2005; Jacobides and Hitt, 2005). Revisiting the empirical findings from several of these works (Walker and Weber, 1984; Leiblein and Miller, 2003; Jacobides and Hitt, 2005), which have included both transaction costs variables and firm capabilities variables, shows surprisingly mixed empirical evidence for the transaction costs variables. Measuring transaction costs with demand volume uncertainty and technological uncertainty, Walker and Weber (1984) only received partial support for their predictions based upon the transaction costs theory. Leiblein and Miller (2003) did not find significant, direct effects of asset specificity on production integration; they even found a significantly negative effect between demand uncertainty and production integration. Jacobides and Hitt (2005) also found mixed support for their transaction costs-based hypotheses, and in some of their models, the predictions even became the opposite. Interestingly, however, measures of firm capabilities in these studies all turn out to be significant and consistent with their theoretical predictions: e.g., if a firm has strong productive capabilities, it is more likely to internalize production.

A puzzle then arises: compelling empirical evidence has been found for the effect of transaction costs or transaction-specific characteristics elsewhere in the research literature on firm boundary choice, but why do the variables measuring transaction costs only receive marginal or even

contradictory evidence when firm capabilities variables are also included in the same model? To put it more strongly, does it mean that the organizational capability perspective can substitute the transaction costs theory in predicting firm governance choice? Or does the former provide a better explanation of firm boundary choice than the latter? Less pointedly, do transaction costs and firm capabilities influence firm governance independently (Riordan and Williamson, 1985)? What are the possible boundary conditions for these two theoretical perspectives in predicting a firm's boundary choice? Under what conditions does the capability view provide better explanations? And under what conditions does transaction costs theory matter more?

Furthermore, the above-mentioned empirical studies (Walker and Weber, 1984; Leiblein and Miller, 2003; Hoetker, 2005; Jacobides and Hitt, 2005) on firm boundary choice have paid particular attention to productive capabilities (e.g., supplier production advantage derived from difference in manufacturing process, difference in scale of production and annual savings to make a component in Walker and Weber, 1984; production experience in related technologies in Leiblein and Miller, 2003; labor productivity and operating margin in Jacobides and Hitt, 2005). Other types of firm capabilities have been marginally referenced, such as transactional capabilities (Hoetker, 2005) and integrative capabilities (Helfat and Campo-Rembado, 2010), but empirical evidence on these other types of firm capabilities are rather limited. Therefore, compared to the ample evidence found for the transaction costs theory-based analysis, we have only found limited evidence on the role of firm capabilities in explaining and predicting firm boundary choice. Empirical studies with the firm capability perspective are still emerging, which further constrains efforts to develop a coherent theory. This insufficient work sparks the following research question: in what ways can the firm capability view and the transaction costs theory be complementary and congruent in providing better understanding about the firm boundary question?

This essay of the dissertation aims to address this question by more closely examining the intertwined relationships among firm capabilities, transaction costs, and governance choice. To this end, I will first discuss some challenges in our efforts to integrate the capability view and the transaction costs theory in explaining and predicting firm boundary. Then, I propose a theoretical framework in order to identify how the capability view can complement the transaction costs theory. This framework consists of two typologies of firm capabilities. The first typology emphasizes the functions of firm capabilities (e.g., productive, transactional and integrative capabilities) in reducing various costs involved in a transaction (e.g., production, transaction and organizational costs). The second typology focuses on characteristics of firms' capabilities (e.g., complementarity and specialization) that may lead to value creation and/or appropriation. I then make propositions on empirical implementations and theoretical interpretations for research inquiries into the firm boundary question.

CHALLENGES OF INTEGRATING CAPABILITY VIEW & TRANSACTION COSTS THEORY

Attempting to join the firm capability view and the transaction costs theory in order to explain and predict firm boundary is not without challenges. The first challenge relates to the unit of analysis. While the transaction costs theory treats individual transaction as the unit of analysis, the capability approach may involve different units of analysis. Measures of transaction costs are transaction-specific, but measures of firm capabilities often require consideration of multiple transactions or activities. A case in point is a firm's integrative capabilities, which reside in interfaces across activities, not within an individual transaction. This has two implications: one, empirical studies that try to integrate these two theoretical perspectives need to carefully design the methodology so as to capture the differential units of analysis. The second implication is that the

capability view can supplement the transaction costs theory in the analysis of firm governance by additionally considering those factors across transactions or activities.

A second challenge is related to the issue of endogeneity. Transaction costs are often measured with factors that are assumed to be exogenous to a firm's governance choice, such as technological and demand uncertainties. Firm capabilities, however, can be endogenous to the governance choice. For example, a firm can achieve economies of scope by integrating an activity, and thus enhancing productive capabilities. Thus, it is difficult to distinguish the firm's choice to integrate because of its high productive capabilities from the firm's choice to integrate in order to enhance productive capabilities. Therefore, differing from a transaction costs theory-based empirical study that can be done with a cross-sectional design, a capability view-based empirical study is supposed to account for potential endogeneity by designing a longitudinal dataset or using laggard measures of firm capabilities.

The endogeneity issue becomes even more complicated when a focal transaction itself is a capability-development activity. Such a transaction is influenced not only by characteristics of the transaction (e.g., level of uncertainty in acquiring capability from external providers), but also characteristics of firm capabilities (e.g., the discrepancy between a firm's extant capabilities and the targeted capabilities) (Capron and Mitchell, 2004, 2009). In this case, there is a need to distinguish between the extent to which the focal transaction pertains to capability development and the extent to which it is subject to transaction hazards.

As a matter of fact, any transaction may involve a certain level of capability development, though the degrees may differ. This poses a third challenge to the operationalization of transaction costs, especially the measurement of asset specificity, in an empirical study that attempts to integrate the transaction costs theory and the capability view. One needs to distinguish asset specificity from

the value-creation potential of the new capabilities to be developed with a certain governance structure. This challenge, however, has not yet been adequately addressed in extant empirical studies. Among the several empirical studies reviewed here (Walker and Weber, 1984; Leiblein and Miller, 2003; Hoetker, 2005; Jacobides and Hitt, 2005), only Leiblein and Miller (2003) specifically hypothesize and measure asset specificity as one of the explanatory variables. But even in this study, the main effect of asset specificity on firm integration decision is not found.

The non-significant result for asset specificity or non-inclusion of asset specificity variable at all in the abovementioned empirical studies suggest possible confounding effects between the construct of asset specificity and the construct of firm capabilities. These two constructs have been originally developed independently in two theoretical perspectives, and the intertwined relationships between these two can be set aside for use in different research questions. But when one construct is introduced to explain a question that is largely in the domain of the other construct, clarification of these two constructs is needed. This is particularly the case for the firm capability construct, as it is being introduced to the firm governance question that is traditionally studied with the transaction costs theory. This constitutes another challenge to such empirical studies.

I contend that there are conceptual overlaps between these two theoretical constructs, which further complicates empirical specifications, particularly the theoretical implications drawn from such empirical studies. For example, the "comparative advantage" argument developed in Jacobides and Hitt (2005) suggests that firms with comparatively stronger productive capabilities are more likely to integrate an associated production stage. The advantage derived from comparatively stronger productive capabilities may actually be the sources of asset specificity, as the focal firm can achieve greater economic value than the partners who do not possess comparative advantages. Thus, it is possible that the productive capabilities underpinning the comparative advantages are just one

special case of asset specificity.[12] Significant findings for the comparative productive capabilities variables in Jacobides and Hitt (2005) may reflect predictions based upon asset specificity.

The relationships between firm capabilities, transaction costs, and boundary choices become more complicated if we take a longitudinal perspective. Boundary choice at time T_0 can increase or decrease transaction costs for a boundary choice at time T_1. Argyres and Liebeskind (1999) point to the possibility of "governance inseparability" over time or across transactions, suggesting that boundary choice for one transaction is not only subject to concurrent transaction costs, but also constrained by previous commitments to transaction partners and relevant stakeholders. Breaking such commitments may impose unexpected costs not captured by transaction costs *per se*, but such costs are undoubtedly significant in a firm's decision calculus. Boundary choice at time T_0 may also increase or decrease production costs or productive capabilities at time T_1. For example, firms that choose to internalize a transaction at time T_0 are more likely to gain learning-by-doing benefits than firms that largely rely on external suppliers. Rational expectations about potential learning benefits and productive capabilities improvement in the long term may also influence a firm's boundary decision at T_0. Development of firm capabilities is also a longitudinal process, involving transaction costs and boundary choices. Mahoney and Qian (2010) further argue that heterogeneity in firm capabilities and transaction costs can be traced to the same origin, i.e., market frictions. Firms develop capabilities in an environment with positive transaction costs. Heterogeneity in firm capabilities depends on various market frictions (Itami and Roehl, 1987) and require long-term, path-dependent learning processes (Nelson and Winter, 1982), making them difficult to be imitated (Dierickx and Cool, 1989).

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[1] Argyres and Zenger (2008: 11) even suggest that the "notion of transaction-specific assets is very close to, if not identical to, the notion of firm-specific assets used in resource- and knowledge-based views of the firm."
[2] However, I do not argue here that these two constructs are equivalent. Some firm capabilities do not constitute asset specificity and vice versa.

Complexities among firm capabilities, transaction costs, and firm boundary choices have different implications for theoretical development and empirical studies. The following example illustrates these different implications. Suppose at time T_0 a newly established firm with zero stock of firm capabilities starts to develop its capabilities. This firm may choose a certain governance structure subject to the magnitude of transaction costs at time T_0. The process of capability development continues, and by time T_1, the firm has already accumulated a unique profile of capabilities, such as productive, integrative, and transactional capabilities. Suppose this firm needs to make a boundary choice at time T_1. To examine such a boundary decision, a typical empirical study that attempts to integrate the capability view and the transaction costs theory may treat firm capabilities and transaction-specific characteristics independently, adding corresponding variables into the regression model. This approach is valid for a cross-sectional study, but interpretations of results from such a research design for the purpose of theoretical advancement should be careful. Statistically significant findings for firm capability variables and insignificant transaction costs variables do not necessarily negate the explanatory power of the transaction costs theory, as the underpinning transaction costs might have already been captured by the firm capability variables.

In short, this section contends that the capability view complements the transaction costs theory when it comes to the firm boundary question, for the capability perspective can potentially extend beyond a single transaction as the unit of analysis, augment operationalization of asset specificity, and enrich finer-grained empirical testing. Empirical studies in this regard need to pay particular attention to two issues. One issue is the extent to which a measure of firm capabilities (e.g., comparative advantages) is different from a measure of asset specificity. The second issue is the longitudinal design of dataset or measurement that can tease out the intertwined relationships between firm capabilities and transaction costs.

Figure 2.1 presents a simplified illustration of the key takeaways of this section. It uses two time periods to depict the longitudinal aspects of the intertwined relationships between firm capabilities and transaction costs. Transaction costs are regarded as the fundamental driving forces of capability development and boundary choice. Both firm capabilities and transaction costs affect a firm's boundary decision. The oval with a solid line represents empirical studies that use the transaction costs theory as the primary tool. The oval with a dash reflects the relationships between firm capabilities and boundary choice that have been proposed by extant empirical studies reviewed in the beginning of this essay of the dissertation. These extant empirical studies often take an additive approach by placing the dashed oval on top of the solid oval--without explicitly addressing the interrelationships between firm capabilities and transaction-specific characteristics--or the bold double-head arrow in Figure 2.1. Some even go further and suggest the dashed oval can be independent of the solid oval.

As discussed above, a more productive approach is to integrate the constructs and relationships between each oval. Such an approach needs first to identify those mechanisms through which various firm capabilities and transaction-specific characteristics interact for the phenomenon under research. Once these mechanisms are identified and the potential confounding effects are teased out, then a cross-sectional study designed in an additive way is still valid, but interpretation of results from such an approach should not be overstated to the extent that the fundamental effects of transaction costs are neglected. These are challenging tasks. As a first step, the next section develops two typologies of firm capabilities that potentially interact with transaction specifics in determining firm boundary along two dimensions. The first typology emphasizes the functions of firm capabilities (e.g., productive, transactional and integrative capabilities) in cost minimization (e.g., production, transaction and organizational costs), and the second typology focuses on characteristics

(e.g., complementarities and specialization) of firm capabilities that may lead to value creation and/or appropriation[3].

TWO TYPOLOGIES OF FIRM CAPABILITIES RELATED TO BOUNDARY CHOICE

What are the key attributes that differentiate transactions and how do these attributes impact the governance structure reside at the centre of the transaction cost economics research (Williamson and Masten, 1999). Discriminating attributes of transactions and dimensions of governance structures, and achieving alignment between these two, is a general approach to the firm boundary question. This approach can be extended to situations where firm capabilities enable value creation / appropriation and cost minimization.

Matching Functions of Capability with Cost Minimization

"How should firm A, with its preexisting strengths and weaknesses, organize transaction X?" asks Williamson (1999: 1103). In Hoetker's (2005) answer, relational capability of a focal firm with its suppliers reduces the adverse impact of uncertainties on their transactional relationships and further reduces transaction costs. Using a resource-based approach, Leiblein and Miller (2003) maintain that vertical integration enables a firm to leverage firm-specific, valuable, and difficult-to-imitate capabilities. Jacobides and Hitt's (2005) answer weighs comparative productive capabilities of a focal firm against external specialized suppliers. They claim that firms are more likely to carry out a value chain activity internally if it possesses production cost advantages in that activity, even if the comparative advantages are potentially replicable or short-lived.

Just as in the case that there are various types of capabilities in a firm, answers to Williamson's (1999) call speak to different "preexisting strengths and weaknesses." While Hoetker

[3] Mahoney and Qian (2010) suggest that value creation and cost minimization are two intertwined aspects of the firm boundary question, and simultaneous consideration of these two objects is required for more complete understanding about a firm's boundary choice. This suggestion fits well with the purpose of this essay, as these two aspects align with the two typologies of firm capabilities developed here.

(2005) refers to relational capability that works towards reducing transaction costs more than production costs, Jacobides and Hitt (2005) explicitly address the influence of productive capability that leads to lower production costs. It is therefore important to identify those capabilities that are relevant to better explain and predict the mechanisms through which firm capabilities influence its boundary choice for a specific transaction. From an organizational economics view, boundary choice is a function of three sets of costs, i.e., production costs, transaction costs, and internal organization costs[4]. Each type of costs corresponds to a different set of firm capabilities, a typology of which will be developed in this section.

Production Costs and Productive Capabilities

Differences between a buyer's production costs and those of an external supplier indicate efficiency differentials between in-house production and market contracting mode. It is empirically difficult to directly compare the levels of production costs of a buyer and a supplier or to gauge the impact of production costs differences on the buyer's governance choice, especially when that choice can only be observed *ex post*.

There has been debate about the extent to which comparative production costs determine boundary choice, as well as the sources of production costs differentials. Stigler (1951) regards scale economies to be the source of production costs differentials, and develops a life-cycle theory of vertical integration. In this theory, firms in young industries tend to be vertically integrated, but as industry grows, specialized suppliers can be sustained by a large scale of output. Williamson (1975) submits that production costs differentials derived from scale economies are insufficient for vertical integration, as buyers can also achieve economies of scale by producing in-house and selling extras to customers, absent transaction costs (e.g., economic hold-up problems that might otherwise occur).

[4]Comparatively, transaction costs have been the most focused in the organizational economies. As Langlois and Foss (1999: 201) put it, "the field has indeed focused precisely on the comparative transaction costs of alternative organizational structures, including, paradigmatically, the choice between firms and markets".

Economies of scale, however, are only one potential source of production costs differentials. The resource-based view and the capability perspective extend beyond the scale economies, emphasizing the concept of firm-specific capabilities. With a shift of focus from scale economies to firm capabilities, Williamson's (1975) critique of Stigler (1951) is no longer applicable. It is not the economies of scale *per se*, but the productive capabilities underpinning scale economies and production costs that may affect a firm's vertical integration. Firms can improve productive capabilities by accumulating production experience, achieving scale economies, and coordinating with other complementary assets (Teece, 1982, 1986). Differentials along these multiple dimensions across firms represent their different levels of production costs. With the help of the micro-analytic lens provided by the capability approach, empirical studies examining effects of production costs on boundary choice become feasible.

Walker and Weber (1984) are among the earliest empirical studies that explicitly examine the influence of production costs on the make-or-buy decision, aside from transaction costs. This study overcomes the difficulty in directly comparing production costs by using a structural equation modeling approach, where three indicators (advantage in manufacturing process, advantage in scale of operations, and annual savings to make a component) represent the latent factor, the supplier's production advantages. Furthermore, to capture the comparative nature of production advantages between supplier and buyer, their model also includes the influence of buyer's production experience on the level of supplier production advantages. This experience is indicated by similarity of extant production equipments to those required by producing the new component, and buyer's production technology expertise. Walker and Weber (1984) find that comparative production costs are the strongest predictor of make-or-buy decisions. Transaction hazard measured by volume uncertainty and supplier competition have statistically significant but substantively small effects.

Argyres (1996) presents qualitative evidence that distinguishes the explanatory powers of these two perspectives in different contexts. Argyres (1996) examines the role of transaction characteristics and firm capabilities in several activities (e.g., product design, mold making, assembly, etc.) of a large firm, and finds that for some activities, asset specificity alone determines the make-or-buy decision, while for some other activities, firm capabilities or a combination of the two serve as the better explanation. This study further finds that the similarity of the knowledge base associated with different activities and the time required to develop knowledge are possible mechanisms through which capabilities operate. Firms tend to outsource an activity if suppliers have superior capabilities. However, when in-house development of capabilities is perceived to be value-creating in the long run, firms may choose to tolerate high in-house production costs in the short run, despite low transaction costs. It is easy to understand that high transaction costs coupled with strong in-house productive capabilities are most likely to lead to internalization, and low transaction costs with superior supplier productive capabilities lead to outsourcing. What makes it more interesting is the case where neither transaction costs nor productive costs advantage dominates the make-or-buy decision. Argyres (1996) finds that for one activity, the sample firm retains in-house production over time, but for different reasons at different time periods. Initially, transaction costs consideration determines the internalization choice, but later, capability differentials dominate the decision-making.

So far, we have seen evidence pointing to the role of productive capabilities in shaping firm governance. But this current evidence is based upon single-firm (Argyres, 1996) or single-corporate division analysis (Walker and Weber, 1984), and is derived from qualitative data. Whether these findings can be generalized to other contexts is still a question. More empirical evidence is needed.

Leiblein and Miller (2003) present an empirical study based upon a cross-sectional analysis of production decisions in a large sample pooled from the semiconductor industry. They find that firm-

specific capabilities have a statistically significant effect on firms' vertical integration decisions, independent of the effects of asset specificity, demand uncertainty and *ex ante* small number situations. This study uses previous production experience in similar products with similar process technology as the proxy for productive capabilities of a given firm, with an implication that previous production experience constitutes a firm's competence that can be leveraged across value chain activities (Quinn and Hilmer, 1994; Barney, 1999).

A firm's competence does not, however, necessarily lead to comparative efficiency. The outsourcing literature has provided many examples where firms may still choose to outsource activities at which they have accumulated substantial experiences (Quinn and Hilmer, 1994). One important reason for these outsourcing decisions is the comparative efficiency of the external suppliers. In order to more correctly examine the effect of firm capabilities on its integration decisions, a better-designed empirical study needs to go beyond absolute firm productive capabilities to include whether these capabilities are also better than potential external suppliers (Jacobides and Winter, 2005). A flipside to this argument is that even if a firm does not have much previous related experience in carrying out an activity, it may still choose to internalize production if the capabilities of potential external suppliers are even poorer.

To take into account the possible comparative efficiency, Jacobides and Hitt's (2005) study proposes a "comparative advantage" theory of vertical scope. Building upon the belief that there is variation in productive capabilities across firms, Jacobides and Hitt (2005) maintain that a firm's superior productive capability in one value chain activity is associated with more vertical integration of that activity, but less with vertical integration of a downstream activity. Superior productive capabilities of a firm are measured as labor productivity and operating margins in a focal value chain activity for a sample of mortgage banks. Although Jacobides and Hitt (2005) try to distinguish a

"comparative advantage" view of vertical integration from an "absolute advantage" or "unique and rare resource" view of vertical integration, the empirical measures for productive capabilities are actually similar to operationalization in Leiblein and Miller (2003). Also, empirical measures cannot capture the implications of comparative advantage of a firm in a focal value chain activity relative to potential external suppliers. To decide whether or to what extent a firm possesses comparative advantage in productive capabilities, information about potential external suppliers' productive capabilities is needed.

Hoetker (2005) addresses this issue by examining supplier selection strategies with a sample of notebook manufacturers and their sourcing decisions for innovative flat-panel displays. The unit of analysis in this study is not the focal firm that is making the sourcing decisions. Instead, a buyer-supplier dyad is created between every manufacturer and all potential suppliers, including internal suppliers. By doing so, this approach captures comparative productive capabilities between a given firm (represented by the indicator of internal supplier) and all potential suppliers, as well as comparative productive capabilities across external suppliers. Findings show that firms are more likely to choose a supplier if this supplier has greater technological capabilities. More explicit interpretation of this finding is that if the internal supplier of a manufacturer possesses stronger technological capabilities, then this manufacturer is likely to choose internal sourcing and, if otherwise, an external supplier. If a manufacturer chooses among several external suppliers, it is more likely to choose the supplier with greater technological capabilities.

In summary, these research efforts to incorporating productive capabilities have provided empirical evidence about firm boundary choice, in addition to the traditional theorizing based upon transaction costs. Statistically significant results for variables of productive capabilities in these empirical studies show that the capability view can contribute to better understanding about a firm's

boundary choice. Firms do take into account production costs in their decision-making calculus for integration choices. In making integration decisions, firms try to seek superior external resources and capabilities, or to leverage superior internal resources and capabilities, aside from the efforts to economize transaction costs. These empirical studies also have limitations, however, as the transaction costs variables and the productive capabilities variables are simply joined in an additive manner, assuming independent effects of these variables on firm boundary choice. This may not be the case due to possible endogenous interrelations between transaction costs and firm capabilities. The story of productive capability differentials is not sufficiently nuanced and misses the analytical complexity involved in a fuller understanding of the intertwined relationships between firm capabilities and transaction costs. Indeed, it is the high transaction costs due to contractual hazards and concerns about economic holdup that underpin the persistence of the differential productive capabilities (Riordan and Williamson, 1985; Williamson, 1975).

Transaction Costs and Transactional Capabilities

Not only are firms heterogeneous in productive capabilities, but also in their capabilities of governing transactions. In dealing with even the same type of transactions, firms may encounter different magnitudes of transaction costs. Underpinning such differentials are firm capabilities that pertain to transaction governance. Transactional capabilities are a firm's abilities to overcome transaction costs derived from asset specificity, uncertainty, or other factors that may lead to opportunistic tendencies. Initiating, negotiating, and implementing a transaction require a large set of firm capabilities, such as capabilities in selecting attractive external suppliers, specifying contractual conditions, and particularly enforcing and managing contract non-compliance (e.g., Doz and Hamel, 1998; Leiblein and Miller, 2003; Hoetker, 2005). Transactional capabilities exert impact on

integration decisions *ex ante* by reducing transaction costs or on transaction governance *ex post* by enabling communications, monitoring, and controls of transaction partners.

Several studies have incorporated the notion of transactional capabilities into the traditional transaction costs theory of the firm. Argyres and Mayer (2007) provide qualitative evidence about how firms may learn to contract with even the same partner over time. Mayer and Bercovitz (2008) find that prior relationships between two firms create an inter-organizational inertia lag that leads firms to use the same level of contingency planning in current exchanges as they used in prior contracts. These studies emphasize the constraining rather than enabling aspects of past governance choices, which reduce a firm's capabilities in economizing transaction costs related to current governance choices.

While Mayer and Bercovitz (2008) highlight a firm's *inabilities* to choose an optimal governance structure, Dyer's (1996) comparative study highlights the firm's capabilities in reducing transaction costs. Dyer (1996) finds significant difference between U.S. and Japanese automakers' usage of mixed governance structures. While U.S. automakers rely largely on markets and hierarchies to facilitate exchange, Japanese automakers rely on hybrid governance structures or alliances. Dyer (1996) attributes Japanese automakers' competitive advantages to their abilities in circumventing transaction costs with self-enforced safeguards, such as information sharing, reputation, trust, and credible commitment. Reducing transaction costs up front lowers the incurrence of transaction costs and changes the comparative dynamics among efficiencies of different governance structures. Such differences may be due to institutional settings of two different countries or firm-specific strategies, which we on focus here.

Findings from Mayer and Bercovitz (2008) and Dyer (1996) suggest there are at least two types of transactional capabilities. One is partner-specific transactional capabilities, which are

specifically developed through past transactions with that same partner. Partner-specific transactional capabilities are multifaceted. For example, there has been ample evidence[5] showing that inter-firm trust or past relationships with a specific partner facilitates *ex post* coordination if an unanticipated contingency occurs (Uzzi, 1997). Such relationships facilitate mutual understanding of each other (Gulati, 1995; Gulati and Singh, 1998), reduce the occurrence of opportunism (Parkhe, 1993), and enhance a firm's inter-firm coordination skills or relational capabilities (Dyer and Singh, 1998; Mitchell and Singh, 1996). Mayer and Argyres (2004) specifically study how firms may learn to contract with each other within repeated transactions, and suggest that firms with superior contract design capabilities (Argyres and Mayer, 2007) are more likely to use the market to organize a marginal transaction than those with weaker contract design capabilities. Contracts play an important role as repositories of knowledge about how to collaborate and contract. Learning from such repositories not only facilitates future transaction governance with the same exchange partner, but also exchange across transactions in which the focal firm may be engaged. This relates to the second type of transactional capabilities, i.e., general transactional capabilities.

General transactional capabilities are applicable to many transactions in which a firm is likely engaged For example, a firm experienced in risk management and price hedging strategies is less likely to be subject to the adverse effect of volume or price fluctuation uncertainties than a firm largely exposed to such uncertainties. Put differently, uncertainties in volume or demand impose less risk on firms equipped with such transactional capabilities, regardless of the transaction partners. General transactional capabilities can be developed from a firm's previous transaction experiences, which aid in the development of routine-based capabilities such as standard contractual safeguards, inter-firm coordination mechanisms, and contract enforcing schemes. Leiblein and Miller (2003)

[5] Given the extant ample evidence on the role of past transactions or experiences with a partner, I will skip literature review of individual papers that primarily examine the relationships between past relations and integration decisions, but provide summary findings based upon these studies.

find that a firm's general sourcing experience -- measured as the number of unique relationships with external suppliers over the last 5 years -- is negatively related to the likelihood of integration.

Both theoretical and empirical studies reviewed thus far in this section suggest that firms with strong transactional capabilities are more likely to choose external suppliers or partnerships than internal governance. In addition, conceptual distinction between partner-specific transactional capabilities and general transactional capabilities has only been partially operationalized in the empirical literature, where the lingering questions include: to what extent can transactional capabilities accumulated through repeated transactions with one exchange partner be transferred across partners?

A mirror concept of transactional capabilities is the organizational capabilities that enable communication and coordination within a firm, which will be discussed next.

Organizational Costs and Integrative Capabilities

Williamson's (1975) original organizational failures framework, including human factors (bounded rationality and opportunism) and environmental factors (uncertainty and small numbers), depicts key concepts concerned with comparative governance assessment. Factors leading to failures of market are also mirrored within an organization (Mahoney, 2005). While market exchanges are subject to transaction costs, internalization of these exchanges may also lead to greater bureaucracy and lower incentives. As integration decisions depend upon the comparative efficiency of different governance structures, the tradeoff between external market failures and internal organizational costs (Coase, 1988) plays an important role in assessment and decision-making. An even more intriguing question is whether and to what extent variations in internal organization costs are responsible for observed variations in organizational form (Masten, Meehan and Snyder, 1991: 5)?

Although the transaction costs theory relies on assessment of comparative efficiency of different governance choices, empirical studies on governance choice are constrained by data availability, as researchers cannot directly observe and measure transaction costs or internal organization costs of a sample of firms that have already chosen a certain governance structure (Masten *et al.*, 1991). The problem of measuring market transaction costs has been solved by using observable characteristics of the transaction (Williamson, 1979), such as asset specificity, uncertainty, and complexity. Predictions of organizational form are mostly based upon these observable transaction characteristics.

This large volume of empirical studies on governance forms, however, is mainly focused on market transaction costs; internal organizational costs are much less studied. Difficulties in directly observing or measuring organizational costs are a primary reason. But similar to the empirical studies on measuring transaction costs, a solution can be achieved by using observable characteristics of the internal organization of a transaction. Masten *et al.* (1991) develop a two-stage, regression estimation procedure to differentiate the effects of market organization costs and internal organization costs on governance choice, measuring organizational costs as the costs of planning, directing, and oversight of integrated tasks or components. Organizational costs are found to be decreasing with skilled human assets, which are also found to be positively related to the likelihood of a make decision. This empirical result provides indirect evidence showing that factors that reduce internal organizational costs are associated with internalization choice, and suggests the need as well as the feasibility to include those factors in empirical studies based upon the transaction costs theory. Though Masten *et al.*'s (1991) methodology has not been picked up widely in the transaction costs literature, their measures of internal organizational costs and related observable factors have broad implications for empirical studies. In order to obtain a better assessment of the comparative efficiency of governance

structures, factors leading to internal organizational costs need to be identified and distinguished from those associated with market transaction costs.

Firms differ in their capabilities in managing communication and coordination within the organization. This essay of the dissertation maintains that these firm capabilities are appropriate proxies for internal organizational costs of a potential transaction to be internalized. For example, the M-form elaborated in Williamson (1975) touches upon such heterogeneous firm capabilities, in that managerial capabilities residing in multi-division coordination and control economizes on bounded rationality and attenuates opportunistic behaviors across divisional managers. Other things being equal, when deciding whether to pull a transaction into the firm boundary, the expected costs of integrating that transaction with the firm's extant system of activities will be negatively related to the likelihood of integration. For example, Argyres and Liebeskind (1999: 49) coin the phrase "governance inseparability" to refer to the situation in which a firm's past governance choices significantly influence the range and types of governance mechanisms that it can adopt in future periods. Governance inseparability arises due to contractual commitment and/or changes in the bargaining power of the other parties, and imposes governance costs on the firm when it intakes a new transaction (Argyres and Liebeskind, 2002). Firms with different prior commitments face different governance choice constraints, which will further result in greater or lesser organizational costs for a new transaction.

In order to overcome such organizational costs, firm capabilities to smooth the integration process become important. The innovation and technology development literature has developed concepts that depict such firm capabilities. Henderson and Clark (1990) are among the first to distinguish architectural innovation from component innovation. Although this study is not directly related to the quest of firm boundary choice, the concept of architectural knowledge among product

components can be applied and actually has been extended to multiple contexts. Henderson (1994) defines internal integrative competence as a firm's ability to exchange information across boundaries within the firm, and suggests that such integrative capabilities cannot diffuse easily across an industry. Iansiti and Clark (1994: 565-566) further consider such capabilities as "skill in internal integration, such as the capability for coordination, leadership and organizational routines that ensure efficient communication between organizational subunits." Helfat and Raubitschek (2000) extend the component-architecture concept to the context of value chain activities, suggesting that firms can possess capabilities in integrating knowledge across different stages of a value chain[6]. Development of integrative capabilities, however, is costly and takes time (Nelson and Winter, 1982; Dierickx and Cool, 1989). Firms without such integrative capabilities are unable to develop them immediately before the integration of a targeted transaction. Therefore, possession of integrative capabilities constitutes advantages for firms by reducing internal organizational costs.

Despite the importance of a firm's integrative capabilities in its architectural structures (e.g., system of products, system of value chain activities), few empirical studies have examined the *ex ante* influence of these firm capabilities on the boundary choice of the firm. Available empirical evidence is limited, indirect, and mixed. Ohanian (1994) finds that established mills tend to remain vertically-integrated over time in the U.S. pulp and paper industry, which may imply that firms with capabilities in managing vertical integration are more likely to choose internalization for a transaction. In the early U.S. auto industry, Argyres and Bigelow (2007) observe that the number of firms that internalize standard components is nearly four times more than the number of firms that outsource unique components. Bigelow and Argyres (2008) distinguish *de alio* entrant from *de novo*

[6] Integrative capabilities in this essay of my dissertation are within a firm boundary, though firms may also develop skills in technology or knowledge transfer across firm boundaries (Mayer and Salomon, 2006). We relate a firm's capabilities in communication and coordination across firm boundaries to governance capabilities discussed in the previous section.

entrant in the auto industry and find that entrants with prior experience in other industries are less likely to choose internal engine production. If vertical integration itself can be a proxy for integrative capabilities, then these studies provide mixed findings. On the one hand, vertically-integrated firms are more likely to remain integrated as new transactions arise (Ohanian, 1994; Argyres and Bigelow, 2007). On the other hand, firms diversifying from prior related industries may choose external suppliers over internalization (Bigelow and Argyres, 2008).

Theoretical work on this topic is also scarce. Helfat and Campo-Rembado (2010) are among the first to theoretically explore the relationships between integrative capabilities and a firm's integration choice. Within an industry context with successive "systemic" innovations and inter-dependence across stages of production, Helfat and Campo-Rembado (2010) propose that firms with integrative capabilities are likely to integrate new production stages. Although in their model they argue that the reason firms should remain vertically integrated is to maintain innovative capabilities over multiple cycles of technological innovation, this proposal also has implications for the role of integrative capabilities by reducing internal organizational costs. Management of interfaces across successive innovations may incur lower costs within firm boundary if the firm possesses integrative capabilities.

In summary, empirical studies on the influence of internal organizational costs on a firm's integration decision are rather limited, largely due to difficulties in measuring such costs. The concept of integrative capabilities (e.g., Helfat and Raubitschek, 2000; Helfat and Campo-Rembado, 2010), which are able to facilitate communication and coordination across components, can be a partial solution. Current mixed empirical evidence (Ohanian, 1994; Argyres and Bigelow, 2007; Bigelow and Argyres 2008) challenges future studies to develop better measurement of integrative

capabilities and to identify contingencies for better understanding of the role of integrative capabilities.

Matching Characteristics of Firm Capability with Value Creation / Appropriation

Mahoney and Qian (2010) suggest that the firm boundary questions can be further examined from an economic value creation / appropriation view (Dyer, 1997; Zajac and Olsen, 1993), with an emphasis on learning, dynamic capabilities, and knowledge spill-in from exchange partners (Hoetker, 2005; Leiblein and Miller, 2003; Madhok, 2002). Value creation / appropriation is intertwined with cost minimization in a given firm boundary question, thus consideration of value creation / appropriation is necessary to better explain and predict the boundary decision.

Teece (1986) presents prescriptive discussions about the various scenarios of successful value creation and appropriation from innovations, and emphasizes that a firm's business strategy, as it relates to a decision to integrate and collaborate, is an important factor. Here, the integration or collaboration strategy primarily depends on the complementary assets required by successful commercialization of an innovation. Teece (1986: 289) classified complementary assets into three types: specialized assets (where there is unilateral dependence between the innovation and the complementary assets), generic assets (general purpose assets that do not need to be tailored to the innovation in question), and co-specialized assets (those for which there is bilateral dependence between the innovation and complementary assets). If we consider the complementary assets holder and the innovator or the innovation holder as two transaction partners, the interface between an innovation and the required complementary assets is a special case of the firm boundary question. Thus, Teece's (1986) thesis can be extended to more general scenarios concerning the firm boundary question, and the attributes of complementary assets can be extended to discussion about features of firm capabilities embedded in a given transaction (Jacobides, Knudsen and Augier, 2006). From the

focal firm's perspective, capabilities of the other transaction partner can be generic, specialized, or co-specialized. When the focal firm makes the boundary choice, one primary question is: to what extent the other party's capabilities are complementary and specialized to the focal firm's capabilities?

Extent of Complementarity of Firm Capabilities Involved in Transaction

Complementarity between two sets of firm capabilities refers to the situation where the marginal impact of one set of firm capabilities changes with the nature of the other set of firm capabilities (Milgrom and Roberts, 1990), or more specifically, when the marginal return to one set of firm capabilities increases in the presence of the other (Milgrom and Roberts, 1995). Existence of complementarity is the prerequisite for a transaction to occur, as both transaction partners pursue economic value created through the combination of two sets of firm capabilities. Put differently, the extent of complementarity between two sets of firm capabilities represents the potential value to be created from a transaction. Literature on strategic alliances and acquisitions has provided compelling evidence for the important role of resources and capability being complementary (e.g., Harrison, Hitt, Hoskisson and Ireland, 1991, 2001). There can be a variety of sources that can lead to complementarity between two sets of firm capabilities, and these sources can be very idiosyncratic in a given transaction. I will first explore a sample of them.

Complementarity needs to be distinguished from similarity or relatedness (Harrison, Hitt, Hoskisson and Ireland, 1991; Makri, Hitt and Lane, 2009; Wang and Zajac, 2007). Similarity or relatedness in resources and capabilities may lead to substitution rather than complementarity. Hess and Rothaermel (2011), for example, suggested that a resource combination focusing on the same parts of a value chain (e.g., two upstream activities) leads to knowledge redundancy and reduces innovative performance of a pharmaceutical company. But resource combination linking different parts of a value chain creates complementarity and enhances innovative performance. Measuring a

focal firm's resource complementarity in its alliance portfolio as the percentage of partners with SIC different from itself, Lin, Yang and Arya (2009) found that resource complementary interacts with a set of social and network factors to affect alliance formation and firm performance. These two studies indicate that diversity in capabilities of two transaction partners is likely to be positively associated with the extent of complementarity, or the value creation potential from the transaction.

Though it is impossible to exhaust factors that contribute to complementarity between two sets of firm capabilities, it is possible to identify some factors that can reduce complementarity. Dosi, Nelson, and Winter (2000) suggest that, in general, firm capabilities depend on routines that underpin the ability to accomplish tasks and perform activities in a repeated and reliable manner. When a transaction involves integrating two sets of firm capabilities from two transaction partners, routines are likely disrupted, which may hinder the realization of complementarity. Literature on post-acquisition performance provides empirical evidence. For example, based on 173 acquisitions in the U.S. manufacturing industry, Datta (1996) found that differences in top management styles, which could be considered a component of managerial capabilities, have a negative impact on firm performance after acquisitions.

Complementarity or the value creation potential can occur in the short or long term. Thus, in order to make a boundary choice that can maximize the value creation potential from complementarity, a firm needs to take into account both the short and long-term effects. To do so, the firm may focus on organizational learning, knowledge spill-over or spill-in, and the real option value that may result from the designed boundary choice. For example, Kang, Tan, and Mahoney (2009) found that OEM suppliers are willing to make unilateral, relationship-specific investment with buyers such as Dell. They also suggested that OEM firms make their decisions based not only upon economic benefits with their exchange partner, but also -- and more importantly -- the

potential benefits gained through established exchange relationships with these powerful buyers. If there are future -- dynamic capabilities and real options -- benefits to forming an exchange relationship, a transaction party may choose to tolerate the risks of opportunistic behaviors and actually make an organizational boundary decision that would be contrary to the cost-minimization prediction based on the single transaction as the unit of analysis (Argyres, 1996).

The extent of complementarity between two sets of firm capabilities is often evaluated in a dyad relationship. Such evaluations assume that both transaction parties are aware of the amount of value created because of complementarity and that each party can appropriate the value proportionally according to the contribution of each set of firm capability. The economic value accrued to each set of firm capabilities, however, may not equal the value appropriated by each transaction party, due to the differential extent of each set's specialization of firm capabilities towards the combined sets, to which I turn next.

Extent of Specialization of Firm Capabilities Involved in Transaction

Teece (1986) distinguished co-specialized complementary assets from specialized ones, though conceptually the former is a subset of the latter. This distinction can apply to a wide range of strategic phenomena beyond profiting from innovation, such as corporate diversification, technological evolution, and strategic alliance. For example, in the case of diversification strategy, Mahoney and Pandian (1992: 368) distinguished contestable synergy from idiosyncratic bilateral synergy, where "contestable synergy involves a combination of resources that create value but are competitively available… and idiosyncratic bilateral synergy is defined as the enhanced value that is idiosyncratic to the combined resources of the acquiring and target firm." The same logic can be applied to evaluating the extent of specialization of the firm capabilities involved in a transaction,

but extensions are required to be consistent with a dyadic relationship in a typical transaction. Table 2.1 presents a 2x2 matrix, where each axis represents one transaction partner.

Table 2.1 applies Teece's (1986) original classification of complementary assets to the dyadic relationship within a transaction between Firm A and B. Based upon the different answers to the question of whether or not one firm's capabilities are specialized to the other's, there are four possible combinations. Quadrant I depicts a scenario where either firm's capabilities are specialized to the other, though there are complementarities if the two sets of capabilities are combined. This is similar to the contestable synergy scenario in Mahoney and Pandian (1992), and market transaction is probably the most preferred mode of transaction. Quadrant IV represents the situation of co-specialization, where either firm's capabilities are not only complementary, but also specialized to the other firm's capabilities. This is in line with Mahoney and Pandian's (1992) definition of idiosyncratic bilateral synergy. Boundary choice under this situation may be integration through merging or strategic alliance with equity commitment. Quadrants II and III represent situations where unilateral specialization occurs; in other words, specialization is just for one of the two transaction parties (Klein, Crawford and Alchain, 1978). Quadrants I and IV do not make any directional implication for the two firms, as the implications are considered symmetrical. Quadrants II and III, however, have directional implications. Quadrant II can be described as *discretional specialization* for Firm A, but *committed specialization* for Firm B. For a firm, discretional specialization means that the value creation / appropriation potential from capability complementarity do not rely solely on the presence of one specific partner; thus the focal firm has more discretion than the partner, and is likely to be able to appropriate quasi-rent value (Klein, Crawford and Alchain, 1978). Correspondingly, committed specialization means that the value creation / appropriation potential from capability complementarity for one firm is dependent upon the presence of the other, though

it is not the case for the other party. Committed specialization can be regarded as an extreme form of asset specificity used in the transaction costs literature (Williamson, 1975).

While Quadrant I assumes a competitive market, or a large number of capability holders for both transaction parties, Quadrant IV assumes there is only a one-on-one match. Quadrant II and III present a one-to-many or many-to-one scenario, to which the design of value appropriation mechanism matters the most. Table 2.1 obviously presents four extreme cases of the distribution of specialized capabilities among the transaction partners in a dyadic relationship.

Embeddedness and mobility are two sides of the same coin and they are likely to affect the specialization of firm capabilities. Embeddedness entails both cross-sectional and longitudinal inter-connectedness of resources and capabilities (Dierickx and Cool, 1989). Consider the example of a university professor of chemistry who is tied to a university-owned research laboratory vis-à-vis a business school professor who has relatively less ties to the physical resources. In this example, the embeddedness logic suggests that ownership of the physical asset leads to *de facto* control over human resources (Grant, 1991; Hart, 1995). The owner of the physical resource (i.e., the university) is in the position to appropriate more of the value creation by the professor of chemistry than the relatively more mobile professor of business. This example is an illustration of the off-diagonal scenario depicted in Table 2.1. More generally, mobility of capabilities from one transaction partner can reduce her reliance on the other partner and is thus less subject to the co-specialization constraint.

In summary, this section highlights several aspects of firm capabilities within the context of a dyadic transactional relationship: the extent of complementarity, specialization, and embeddedness. I submit that the presence of complementarity or potential value creation is the prerequisite for a transaction to occur, that the differential extents / directions of specialization affects the regime of

value appropriation. Though challenging, simultaneously accounting for these aspects in empirical testing of a firm boundary question is needed for a more complete explanation and prediction of this fundamental question.

FIRM CAPABILITIES & BOUNDARY CHOICE: AN INTEGRATIVE PERSPECTIVE

The second section contends that the capability view can augment empirical studies based only upon the transaction costs theory by integrating value creation and value appropriation. Drawing upon the typologies developed above and the critiques presented in an earlier section, this section aims to offer some suggestions for future empirical studies that attempt to integrate the capability view and the transaction costs theory. In particular, I will focus on some of those aspects of empirical specifications that may enable the capability view to complement the transaction costs theory when it comes to the firm boundary question.

The previous section shows that empirical evidence on roles of firm capabilities, which are gleaned from independent testing of those various firm capabilities and based upon cross-sectional data, have limitations. First, the boundary choice of a firm is a function of internal organizational costs, transaction costs, and production costs (Williamson, 1975), which suggests managers account for potential tradeoffs or contingent relationships among these costs or associated capabilities. Tradeoffs arise, for example, when managers have to accept a higher level of transaction costs to achieve a low level of production costs. Contingencies occur, for example, when production costs matter only if transaction costs are extremely high. Second, given the path-dependent attributes of firm capability development (Dierickx and Cool, 1989; Nelson and Winter, 1982), firm capabilities evolve over time, each probably following its own life cycle depicted in Helfat and Peteraf (2004). It is possible that some firm capabilities are more enduring than others, or that some firm capabilities may transform from enabling factors to constraining factors for boundary choice over time. This

section reviews some recent works that have addressed these limitations one way or another and makes propositions with the purpose of encouraging further empirical studies.

First, do firms face the same transaction costs for similar transactions over time? Or more importantly, do transaction costs exert the same level of impact on a firm's boundary choice for firms with different levels of capabilities? Argyres and Bigelow (2007) examine the extent of negative effects on the survival of transaction misalignment across firms and over time. Transaction misalignment is defined as the occurrence when a unique engine was procured from outside suppliers or a standard engine was produced internally. 83% of misaligned transactions in their sample occur when standard engines were produced in-house; their findings show that a firm suffers more in survival if transaction misalignment happens in the shakeout stage. Taken together, this implies that some transaction costs decrease as industry evolves with increasing standardization, that managers pay more attention to transaction costs in the early stage of industry evolution than in later stage, and that firms tend to retain internal production despite decreasing transaction costs for standardized components.

Second, do firms face the same production costs over time? Or more importantly, do production costs exert the same level of impact on a firm's boundary choice at, for example, different stages of industry evolution? The answer to the first question is straightforward, given various factors such as economies of scale, learning curves, etc. The second question, however, requires consideration of comparative production costs of the focal firm versus external suppliers. Argyres and Bigelow (2007) find that large firms are less penalized by transaction misalignment during the shakeout stage, but firm size does not matter in pre-shakeout stage. Supposing that large firms incur comparatively lower production costs than external suppliers, this finding indicates that comparative production costs advantage exerts less impact on a firm's boundary choice in the pre-

shakeout stage than later. Also, firms with lower production costs pay less attention to transaction costs than firms with comparatively high production costs.

Though Argyres and Bigelow's (2007) study is not intended to examine firm boundary choice, they have shown some empirical evidence for the intertwined relationships between firm capabilities and transactions costs, proposed in the last two sections of this essay of the dissertation. In the following, this section will build upon these above questions and review extant empirical studies in order to develop a contingency framework.

Transactional Capabilities and Transaction Costs

Transactional capabilities affect boundary choice by reducing transaction costs, e.g., by circumventing abuses of inter-firm trust (e.g., Hoetker, 2005) and reducing technological uncertainties (e.g., Leiblein and Miller, 2003). As transaction costs are derived from asset specificity, uncertainty, frequency, or other factors, the importance of transactional capabilities depends upon the impact of these factors. In particular, when transaction costs are low, transactional capabilities become less relevant for a firm's boundary choice.

> *Proposition 1: Transactional capabilities have a larger effect on boundary choice when transaction costs are higher, and more so for partner specific transactional capabilities than for general transactional capabilities.*

To derive hypotheses and empirically test them, one can examine links between a firm's transactional capabilities and factors driving transaction costs. For example, Hoetker (2005) finds that prior relationships matter most when high technological uncertainties are involved in a transaction. When there are low uncertainties, benefits of having prior relationships with a supplier do not necessarily induce the focal firm to choose that supplier.

Productive Capabilities and Transaction Costs

Argyres (1996) finds that the firm chose to outsource mold-making to take advantage of suppliers' superior capabilities, despite significant transaction costs. For another activity known as

extrusion, this firm chose in-house in order to take advantage of its own differential capabilities, despite low transaction costs. Barney (1999) writes that firms in rapidly evolving high-technology industries will often prefer to gain access to capabilities through non-hierarchical forms of governance, despite the threat of partner opportunism by this decision. Without internal organizational costs, minimizing the sum of production costs and transaction costs is the key criteria for a firm's boundary choice (Williamson, 1985). Consistent with Williamson (1999), who suggests that make-or-buy decisions may be conditional on the state of a firm's productive capabilities vis-à-vis suppliers at a particular point in time, I propose

> *Proposition 2: Importance of transaction costs on firm boundary choice is contingent upon the firm's comparative productive capabilities; to the extent that when access to external superior capabilities or retaining of internal superior capabilities is preferred, transaction costs consideration becomes less relevant.*

There are two dimensions of comparative productive capabilities differentials: one is intra-temporal and the other is inter-temporal. Proposition 2 is derived from the intra-temporal dimension or the cross-sectional perspective, with the inter-temporal dimension excluded. In other words, comparative productive capabilities advantages or disadvantages are considered idiosyncratic to individual firms. However, a firm's comparative productive capabilities advantages may change over time due to structural change in the industry or different learning rates of the focal firm vis-à-vis external suppliers (Jacobides and Winter, 2005), which are further underpinned by the various transaction costs.

The industry evolution and technology management literature (Gort and Klepper, 1982; Abernathy and Utterback, 1978; Klepper and Graddy, 1990) has identified some consistent trends in the process of industry evolution. While the industry evolution literature depicts that industries go through stages such as growth with rapid entry, maturity with level entry rate, and shakeout through consolidation, the technology management literature identifies a technology trajectory from

production innovation to process innovation. Once can see convergent observations from these two related literatures. For example, during the pre-shakeout stage of an industry, uncertainties in demand and technology are high and the number of specialized suppliers is small. Or, while in the maturity or shakeout stage, firm competition focuses more on process innovation or cost reduction, so that the number of specialized suppliers increases. One simplified inference from these observations is that in early stages of an industry evolution life cycle, firms are more likely to possess comparative productive capabilities advantages vis-à-vis external suppliers; however, in later stages of an industry evolution life cycle, transaction costs tend to decrease along with increase standardization of technology and industry knowledge. In this scenario, external suppliers are more likely to obtain comparative productive advantage. Extending the last proposition, I suggest that

> *Proposition 3a: For firms without comparative productive capabilities advantage, transaction costs are less relevant in boundary choice in earlier stages of industry evolution.*
>
> *Proposition 3b: For firms with comparative productive capabilities advantage, transaction costs are less relevant in boundary choice in later stages of industry evolution.*

Integrative Capabilities and Organization Costs

Integrative capabilities, as defined, reduce internal organizational costs by enabling better communication, incentives, and control. Firms with stronger integrative capabilities are likely to incur lower internal organizational costs if a similar transaction is internalized. Because development of integrative capabilities is costly and takes time, firms may leverage integrative capabilities in boundary choice, with the purpose of appropriating values from previous investment in integrative capabilities (Helfat and Campo-Rembado, 2010). From an empirical perspective, one question

remains: supposing a marginal transaction is internalized by a firm's boundary, to what extent can the firm's integrative capabilities enable integration of this new transaction into its extant activities?[7]

To answer this question, we need to examine the interface between the focal transaction and the firm's extant activities. In particular, if this transaction is internalized, how much needs to be changed in extant activities in order to accommodate the new transaction? The modularity literature is particularly relevant here, which has been concerned with the relationships between product modularity and a firm's boundary choice (e.g., Sanchez and Mahoney, 1996; Schilling, 2000; Brusoni, Prencipe and Pavitt, 2001; Hoetker, 2006). Modularity in product architectures refers to the situation where the engineering interfaces defining the ways in which product components interact are standardized (e.g., Sanchez and Mahoney, 1996). An analogy can be drawn between the concept of modularity in product architecture and the modularity of transactional activities.

Two activities can be regarded as modular if interactions between two activities involve "thin crossing points" (Baldwin, 2008). Modularity between activities implies lower requirements for coordination and integration than if two activities are highly interdependent. For example, Monteverde (1995) finds that the need for "unstructured technical dialog" between product design and manufacturing stages with systemic underlying technology is positively related to the likelihood of vertical integration. Empirical studies testing the relationship between product modularity and organizational modularity, or the mirroring hypothesis that increasing modularity is associated with organizational decentralization (Henderson and Clark, 1990; Sanchez and Mahoney, 1996), have provided mixed evidence (Hoetker, 2006). For example, Bigelow and Argyres (2009) hypothesize that increasing the modularity of product architecture is associated with less vertical integration of

[7] One counter-argument about the role of integrative capabilities and vertical integration is the issue of tautology: vertically integrated firms are more likely to vertically integrate. This critique may not be relevant if we take a longitudinal perspective, i.e., a firm's integrative capabilities accumulated through previous integrations have an effect on the likelihood of internalization of a new transaction, which is the focus of an empirical study.

component production; they find support for this prediction from a sample of firms in the early U.S. auto industry. In contrast, Brusoni and Principe (2001) conducted case studies of the aircraft engine and chemical engineering industries, finding that modular product architectures actually require a certain information structure that can sustain interactive organizational coordination in production.

The firm level analysis of this mirroring hypothesis is often done with transaction costs reasoning, in which modularity reduces asset specificity and the hazard of leaking proprietary information. One possible explanation for mixed findings of this hypothesis is that the effect of integrative capabilities on boundary choice is not considered. For firms with low integrative capabilities, the likelihood of choosing internalization is low, especially when modular transactional activity is involved. For firms with high integrative capabilities, the likelihood to internalize is high, especially when non-modular transactional activity is involved. Firms with high integrative capabilities are also likely to choose integration for modular activity with the purpose of appropriating value from previous investment in developing integrative capabilities. Thus, integrative capabilities have a counter-effect on boundary choice regarding the effect of increasing modularity.

Hoetker (2006) finds that product modularity is positively correlated with supplier turnover, but not with the decision to outsource, suggesting that increased product modularity enhances re-configurability of organizations more quickly than it allows firms to move activities out of hierarchy. This interesting finding is actually consistent with the above-mentioned, opposite directional effects of increasing modularity and integrative capabilities on boundary choice. In this regard, prediction about the relationship between modularity and firm boundary needs to add one contingency, i.e., a firm's ability to integrate two activities beyond the need for integration.

> *Proposition 4: Importance of modularity between the focal transaction and the firm's extant system of activities on firm boundary choice is contingent upon a firm's strength of integrative capabilities: to the extent that integrative capabilities are high, modularity becomes less relevant.*

CONCLUSIONS

Starting with a review and critique of relevant works, this essay of the dissertation is motivated by the mixed empirical findings on the explanatory power of firm capabilities variables versus the transaction costs variables in recent studies that have tried to integrate the capability view of the firm and the transaction costs theory to explain a firm's boundary choice. I contend that the capability view constitutes a framework that complements the transaction costs theory in explaining and predicting firm governance choice, by augmenting both theoretical and empirical specifications. An empirical study with variables from both theoretical perspectives entered in an additive way is valid for a cross-sectional design. Interpreting the coefficient estimations for these variables independently is also valid if the researcher is only interested in the cross-sectional phenomenon, and if the possible confounding effects between asset specificity and value creation of firm capabilities are well addressed. Interpretation of results from a cross-sectional design shall not be directly extended to issues that are more appropriately examined with a longitudinal perspective, such as the capability development process, capability heterogeneity, and flexibility in governance.

This essay of the dissertation then develops two typologies of firm capabilities that are most relevant to a firm's integration decision by highlighting characteristics of firm capabilities that are associated with value creation / appropriation and cost minimization underpinning a firm boundary choice. It shows that these typologies enable us to identify contingent relationships across these different attributes of firm capabilities and costs in terms of their effect on a firm's boundary choice. Future work is needed to build upon the current paper and integrate the firm capability view into the firm boundary question in a more systemic way.

TABLES AND FIGURES

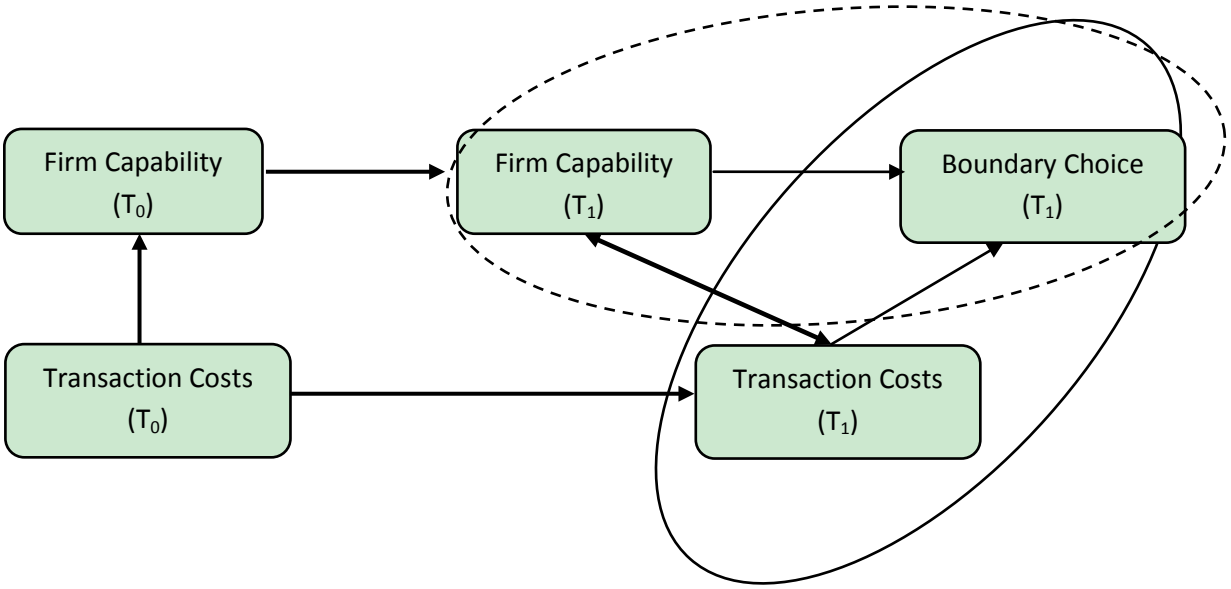

Figure 2.1: Firm capabilities, transaction costs, and boundary choice

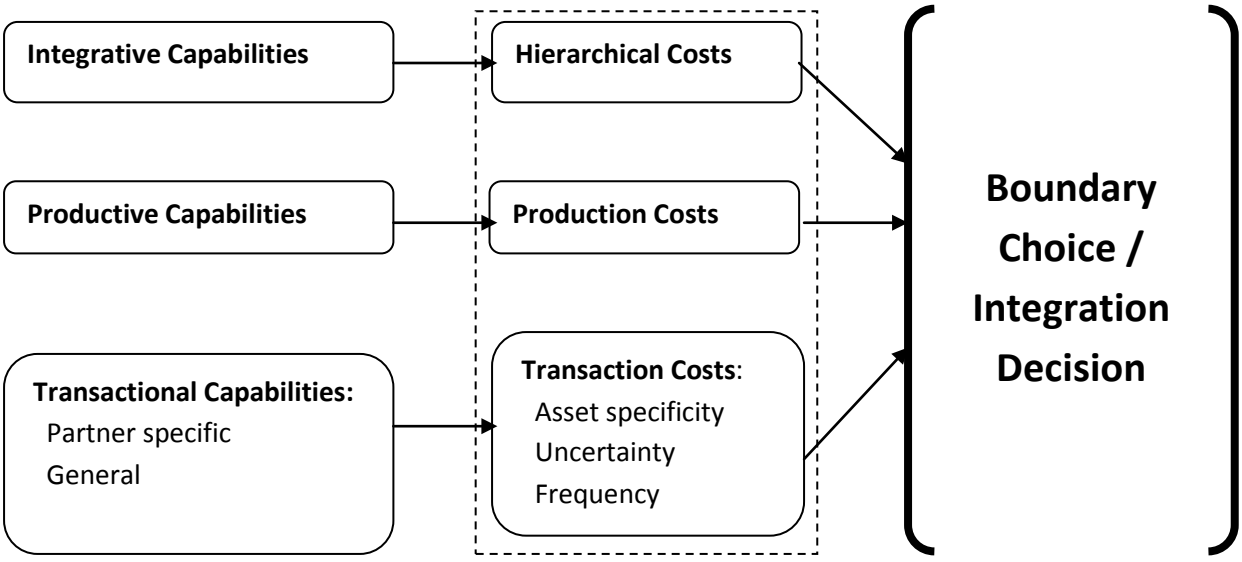

Figure 2.2: Firm capabilities, costs minimization and boundary choice

Capabilities from Firm A and Firm B are complementary, i.e., w/ value creation potential: what are the implications on bargaining power and transactional relationship?		Firm A: Whether Firm B's capabilities are specialized to Firm A?	
		Low	High
Firm B: Whether Firm A's capabilities are specialized to Firm B?	Low	I: Generic (contestable synergy; market transaction)	II: Discretional specialization for Firm A (Committed specialization for Firm B)
	High	III: Discretional specialization for Firm B (Committed specialization for Firm A)	IV: Co-specialization (idiosyncratic bilateral synergy; committed cooperation or integration)

Table 2.1: A dyadic view of specialization of asset (capability)

CHAPTER 3[8]

ESSAY 2: CONFIGURATION OF VALUE CHAIN ACTIVITIES: THE EFFECT OF PRE-ENTRY CAPABILITIES, TRANSACTION HAZARDS, AND INDUSTRY EVOLUTION ON DECISIONS TO INTERNALIZE

INTRODUCTION

Whether entry into an industry is undertaken by a diversifying entrant or a start-up,[9] a critical strategic question is the configuration of value chain activities, which include procurement, production, marketing and distribution, and technology development (Porter, 1985). Firms vary in the extent to which they choose to conduct these activities within organizational boundaries. Given trade-offs between incurring resource commitments for internalization and transaction hazards for external sourcing, organizational choices about value chain activities are of strategic importance to entrants that may lack experiential knowledge, either within or outside the focal industry context.

Balancing the trade-offs involved in optimal organizational choices about value chain activities at the time of entry is critical for several reasons. First, to ensure efficient production, a firm needs to design a system of activities that accounts for both complementarities and substitution effects (Milgrom and Roberts, 1995; Porter, 1991). Second, the firm's development of industry-specific bundles of resources and capabilities after entry is path-dependent (Dierickx and Cool, 1989), with the initial design setting the trajectory for long-term capability development (Helfat and Peteraf, 2003). Given the strategic importance of initial design of value chain activities, I examine the following research question: What factors determine how a firm configures value chain activities when entering a new industry? Specifically, what are the main and moderating effects of transaction

[8] A paper based upon this essay is forthcoming in the special issue of Organization Science, "Organizational Economics and Organizational Capabilities: From Opposition and Complementarity to Real Integration." Permission to use the working paper version in this dissertation has been granted by INFORMS.

[9] Prior research has defined diversifying entrants as pre-existing firms that enter a focal industry, and start-ups as firms that are born in the focal industry context (Helfat and Lieberman, 2002).

hazards and pre-entry organizational capabilities on the choice between internalization and external development of a value chain activity?

I draw upon the organizational economics, organizational capabilities, and industry evolution literatures to address the above question. In doing so, I build on an insightful set of studies that have started to integrate the three bodies of research. In organizational economics, a dynamic view of transaction costs enables examining a firm's boundary decisions while incorporating both firm (Argyres and Liebeskind, 1999) and industry evolution (Argyres and Bigelow, 2007, 2009; Bigelow and Argyres, 2008; Jacobides and Winter, 2005). Similarly, in the organizational capabilities literature, scholars have begun to examine how relational (Hoetker, 2005) or productive capabilities (Jacobides and Hitt, 2005; Leiblein and Miller, 2003; Walker and Weber, 1984) explain boundary choices. Empirical evidence from these two research streams shows that firm and industry evolution both matter, and that a firm's capabilities also play an important role in its boundary choices. No study has, however, examined all three sets of factors together.

The strategic importance of value chain organization for industry entrants and the potentially fruitful theoretical integration of organizational economics, organizational capabilities, and industry evolution literature motivate the current study. The make-or-buy logic from transaction costs theory (Coase, 1937; Williamson, 1975, 1985) is clearly applicable; substantial transaction costs cause firms to internalize an activity, other things being equal. Transaction hazards, however, may be either transient or enduring. Stigler (1951) argued that as industries mature, markets become increasingly efficient. Thus, as industries evolve, reductions in technological and demand uncertainty and in asset specificity can lower market frictions. Further, to the extent that capabilities and resources impact the above *ceteris paribus* assumption regarding the effect of transaction costs on internalization, insights from the resource-based approach (Barney, 1991; Penrose, 1959; Wernerfelt, 1984) and the

dynamic capabilities view (Helfat et al., 2007; Teece, Pisano and Shuen, 1997) are relevant. Indeed, acknowledging that firms' capabilities and transaction costs tend to intertwine and that the perspectives focusing on these phenomena can be complementary, Langlois and Foss (1999) called for more integrative efforts. Similarly, Williamson (1999: 1103) rephrased the original make-or-buy question as, "How should firm A – which has pre-existing strengths and weaknesses (core competence and disabilities) – organize X?" An unresolved question here is this: What types of firm capabilities may intertwine with transaction characteristics, and in what way?

Although the evolution of firm capabilities from inception and resulting firm have been the foci of the dynamic resource-based framework (Helfat and Peteraf, 2003), not all firms entering an industry are start-ups. Helfat and Lieberman (2002), drawing from the industry evolution literature (Agarwal, Sarkar, and Echambadi, 2002; Carroll, Bigelow, Seidel, and Tsai, 1996; Klepper and Simons, 2000), recommended that scholars use entry into a focal industry as a clear demarcation point to examine how pre-entry experience may impact subsequent choices, capability development, and firm performance. This research, however, has largely measured pre-entry experience as a dichotomous, firm-level variable (i.e., diversifying entrants versus start-ups), even though start-ups may benefit from their founders' pre-entry experience (Agarwal, Echambadi, Franco, and Sarkar, 2004; Helfat and Lieberman, 2002; Klepper, 2002). A dichotomous variable may not capture the rich heterogeneity in the types of experience an entrant brings into the new industry. Both diversifying and start-up entrants (through founder[s]) may have had experience in one or more value chain activities. Diversifying entrants may also be heterogeneous regarding specific experience in and capability for an activity. Furthermore, diversifying entrants may possess integrative firm-level capabilities that start-ups lack (Chen, Williams and Agarwal, 2010; Helfat and Campo-Rembado, 2010). To the best of our knowledge, no study has systematically compared differences in pre-entry

experience in an activity and in where that experience resides; whether in an individual founder (i.e., at "the founder level") or in firm routines (i.e., at "the firm level"). Our study addresses this gap.

Building on these theoretical perspectives, I derive the main and moderating effects of transaction hazards and pre-entry experience on a firm's decisions about configuring value chain activities. I hypothesize that transaction hazards, both transient and enduring, are positively related to internalization of an activity, as are pre-entry experience at the activity level and the firm level. Importantly, I predict that the influences of organizational capabilities on boundary choices vary over time, given the transience of some transaction hazards. I further predict that pre-entry activity experience at the firm rather than founder level will result in a higher likelihood of internalization, and that pre-entry activity experience positively moderates the relationship between enduring transaction hazards and decisions to internalize. I tested hypotheses in the evolving U.S. bioethanol industry over 1978 through 2009 and found support for most of them.

My study makes contributions to each theoretical perspective it draws upon. First, it extends the transactions costs literature beyond the few studies that have examined governance choice in start-ups and small firms (Bigelow and Argyres, 2008), by answering the (*rephrased*) call by Williamson (1999): Given their particular resources and capabilities at founding, how should a firm organize value chain activity X? Second, this study contributes to efforts to join the organizational capability and the transaction costs theory (Argyres, 1996; Hoetker, 2005; Jacobides and Winter, 2005; Leiblein and Miller, 2003; Madhok, 2002; Walker and Weber, 1984) to reveal how a firm's initial bundle of resources and capabilities may be the foundation for capability development and governance choice strategies after entry to an industry. Third, this study decomposes this initial bundle into activity- and firm-level capabilities to show their differential effects. Thus it enriches the construct of pre-entry experience developed in the industry evolution literature, further enabling

inquiries into the effect of pre-entry experience on post-entry strategies, complementing the often-studied relationships between pre-entry experience and firm performance or survival.

It is hoped that, taken together, these contributions position this study as the first of further inquiries about the coevolving relationships among governance choice, capability development, and industry evolution. This framework highlights the need for an integrative approach to theory development, emphasizing that organizational economics, organizational capability, and industry evolution explanations work in tandem rather than in isolation. Just as industry evolution reshapes boundary choices by reshaping governance costs, so do pre-entry experience and capabilities. Further, although transaction costs economics focuses on a firm's ability to "manage across activities" (to transact exchanges), and organizational capabilities theory focuses on managing a particular activity, they both seem to yield similar predictions about boundary choices. This parallel leads to an intriguing speculation that the capability for managing an activity and that for governing it are less distinct theoretically and empirically than they are commonly considered to be.

HYPOTHESIS DEVELOPMENT

Since I integrate several theoretical perspectives, I begin with an overview of the constructs derived from each theory and their potential interrelationships. Similar to Porter (1985), I describe a firm as engaging in various value chain activities that complement its core production activity and in particular differentiate four activities: raw material procurement, marketing and distribution for primary products, marketing and distribution for coproducts, and technology development. Each activity requires different sets of resources and capabilities and thus can be regarded as a sub-bundle of resources and capabilities. An underlying assumption is that differences in needed resources and capabilities are much larger between than within activities, thus permitting "activity-level" decomposition of capabilities.

Among various organizational capabilities, pre-entry experience is experience in related industries gained before entry into a focal industry. The term is comprehensive, including both functional and dynamic capabilities and both general and specialized resources (Helfat and Lieberman, 2002). Researchers have often bundled these together, largely assuming that start-ups lack pre-entry experience and have fewer resources and capabilities than diversifying entrants (Helfat and Lieberman, 2002; Teece, 1986). For example, as Teece (1986) pointed out, a lack of complementary assets (e.g., a marketing capability) puts start-ups at a disadvantage, even though they may have superior technological capabilities. However, other researchers have noted that start-ups can have pre-entry experience in the form of founder knowledge (cf. Agarwal et al., 2004; Helfat and Lieberman, 2002; Klepper, 2002), since founders convey resources (e.g., human capital, networks, status) and capabilities (e.g., marketing know-how; technological know-how). Here, I decompose a firm's pre-entry experience into activity-level pre-entry experience (for both diversifying entrants and start-ups) and firm-level integrative capabilities (for diversifying entrants only).

I define a *firm's pre-entry activity-level experience* as experience accrued by the firm, or the founder(s) of a start-up, that is related to a particular value chain activity and gained prior to entry in the focal industry. Pre-entry activity-level experience is thus possession of resources and capabilities related to that value chain activity. For example, in this empirical setting, the bioethanol industry, a pipeline company would have relevant pre-entry experience in fuel distribution, but not in feedstock procurement. In contrast, a farmer who is engaged in bioethanol production would likely have experience in feedstock procurement, but not in marketing and distribution of bioethanol. I note that the construct of activity-level pre-entry experience places diversifiers and start-ups on common ground, given both founders' and firms' prior capabilities.

Nonetheless, the distinction between diversifying entrants and start-ups is germane, since there may be systematic differences in how activity level capabilities affect boundary choices if these capabilities reside in founders (for start-ups) rather than in firms (for diversifiers). Theoretically, this relates to the presence of established firm-level routines or *integrative capabilities*, which Helfat and Raubitschek (2000) defined as knowledge of how to integrate activities, capabilities, and products in one or more vertical chains. Helfat and Campo-Rembado (2010) highlighted the role of such integrative capabilities in enabling communication and coordination across stages of value chain activities. By virtue of having existed in another industry prior to entry into a new one, diversifying entrants possess integrative capabilities relatively lacking in start-ups (Chen et al., 2010). I define firm-level or integrative pre-entry capabilities as present in diversifying entrants.

Following Capron and Mitchell (2009), I define the boundary choice for a value chain activity as the decision to undertake it either through internal (within firm boundaries) or external development (partnering with another firm through joint venture, licensing or strategic alliances, or outsourcing). External sourcing of a value chain activity exposes a firm to transaction hazards, defined as the costs incurred if an activity is carried out externally. Further, transaction hazards can be of two types: enduring and transient.

Transaction Costs and Economies of Scale: Organizational Economics Hypotheses

When it comes to vertical integration in an industry evolution context, Williamson (1975) and Stigler (1951) differ about the relative impact of production costs and transaction costs. Stigler (1951) regarded scale economies to be an independent source of production costs differentials, and developed an industry life-cycle theory of vertical integration. In this theory, firms in young industries tend to be vertically integrated, but as industries grow, specialized suppliers can be sustained by a larger scale of industry output. Williamson (1975) argued, however, that production

costs differentials derived from scale economies are not sufficient for vertical integration, as buyers can also achieve economies of scale by producing in-house and selling extras to customers, absent transaction costs. Put differently, it is high transaction cost, rather than low production cost, that leads to vertical integration (Riordan and Williamson, 1985).

These two views about vertical integration over an industry's life cycle can be synthesized via a decomposed view of transaction costs, however. Asset specificity, uncertainty, and transaction frequency are the primary drivers of transaction costs (Williamson, 1975). Some of these sources may be more enduring than others. The Stiglerian view highlights transient transaction hazards, which studies of industry evolution have associated with asset specificity and technological uncertainty (Agarwal et al., 2002; Argyres and Bigelow, 2009; Gort and Klepper, 1982). Knowledge accumulation and spillovers in an industry promote standardization of technology specifications (Abernathy and Utterback, 1978; Gort and Klepper, 1982), thus reducing the technological uncertainty, asset specificity, and potential economic hold-ups that drive high transactions costs (Argyres and Bigelow, 2009; Hoetker, 2004; Williamson, 1975). While asset specificity never vanishes completely, and aspects of asset specificity such as physical co-location and the learning costs engaged in switching partners remain significant even for higher standardized products (*cf* Klein, 1988), its relative importance declines over time. For instance, both technological uncertainty and asset specificity of the feedstock procurement activity have decreased as the bioethanol industry has evolved. Along with standardization of various value chain activities, specialized suppliers have emerged. Stigler's (1951) view is therefore conceptually aligned with the idea of transient transaction costs, in that decrease in uncertainties and asset specificity facilitates economies of scale.

However, other sources of costs, particularly as they relate to other types of uncertainty (e.g., demand and environmental, systemic technology shocks) and transaction frequency may endure

throughout an industry's life. Some industries and some activities may exhibit consistently higher transaction hazards than others, regardless of life cycle stage. Helfat and Campo-Rembado (2010) discussed how some industries (characterized by multiple overlapping markets) require more coordination and communication than other industries even as they mature, resulting in higher transaction costs. Further, variations in the transaction hazards related to value chain activities may persist. For instance, a bioethanol firm needs to transact to procure feedstock as often as production requires, and the transactions are subject to price fluctuations in the commodity market. Neither the frequency of transactions nor the price uncertainty is correlated with industry life stage. I note that this type of environmental uncertainty contrasts with technological uncertainty, which is likely to decrease as an industry evolves.

In all, as an industry evolves, transaction costs due to transient factors may decrease, but transaction costs due to enduring factors remain. Put differently, though the influence of transient transaction costs (e.g., asset specificity changes) on boundary choice for a given activity may vary as industry ages, the influence of enduring transaction costs (e.g., uncertainty and transaction frequency) is independent of industry evolution. Given this temporal dimension of transaction costs, timing of entry into the industry is an important determinant of the magnitude of transaction hazards an entrant experiences. Therefore, we maintain that both the Williamsonian transaction costs view and the Stiglerian view can be valid in the context of industry evolution, and put forward two baseline hypotheses.

H1a: An entrant is more likely to internalize a value chain activity if the enduring transaction hazards of carrying out that value chain activity are high.

H1b: A late entrant is less likely to internalize a value chain activity as transient transaction hazards are lower later in the industry life cycle.

Pre-entry Experience: Organizational Capability Hypotheses

The resource-based theory argues that firms pursue growth based on extant resources and capabilities (Wernerfelt, 1984; Chang, 1995). Extended use of resources and capabilities provides economies of scope (Teece, 1980)[10] and, thus production cost advantages for entrants in the focal industry who possess the relevant resources and capabilities. Generally, scholars have documented that pre-entry experience provides relevant resources and complementary assets, resulting in a performance and survival advantage, and such pre-entry experience can exist at both firm (Carroll et al., 1996; Helfat and Lieberman, 2002; Klepper, 2004; Klepper and Simons, 2000; Mitchell, 1991) and individual founder (Agarwal et al., 2004; Phillips, 2002) levels. Complementing the literature on diversification in corporate strategy regarding what industries or markets a firm should enter (Chatterjee and Wernerfelt, 1991; Montgomery and Hariharan, 1991; Montgomery and Wernerfelt, 1988; Silverman, 1999), industry evolution scholars have compared entrants' pre-entry experience (Bayus and Agarwal, 2007; Carroll et al., 1996; Klepper and Simons, 2000). These two theoretical perspectives convey the same message: relatedness of a potential entrant's resources and capabilities to those required by an industry is a driver of industry entry (Helfat and Lieberman, 2002).

Additionally, Helfat and Eisenhardt (2003) extended the concept of economies of scope to include a temporal dimension: a firm achieves inter-temporal economies of scope by transferring resources and capabilities from existing uses that may become obsolete to emerging and profitable new opportunities. Thus, whether firms with pre-entry experience pursue existing or inter-temporal economies of scope, production costs are likely to be lower for them than for entrants who lack such experience.

[10] The concept of economies of scope can be expressed as following: $C(X, Y) < C(X) + C(Y)$, where X, Y are two activities, and C is the cost of carrying out these activities. Economies of scope exist if the cost of jointly conducting X and Y is smaller than the sum of costs incurred when each is conducted separately (Carlton and Perloff, 2005).

Though governance choice is not a central topic of either the resource-based or the industry evolution literature, the formula for economies of scope suggests an integration strategy. To achieve economies of scope, a firm may choose to integrate two businesses within its boundaries. The same line of reasoning can be applied to value chain activities. If an entrant has experience in operations (either at the firm or founder level) that use resources and capabilities similar to those required by a value chain activity in the new industry, then this entrant is likely to have a cost advantage over entrants without such experience and is likely to carry out that activity itself. Therefore, I predict

> *H2a: An entrant is more likely to internalize a value chain activity if it possesses pre-entry experience related to that activity.*

A second important class of capabilities relates to integration of activities via communication and coordination across the components of a system or across value chain activities at different stages of production (Chen et al., 2010; Helfat and Campo-Rembado, 2010; Helfat and Raubitschek, 2000; Henderson, 1994; Parmigiani and Mitchell, 2009). Such integrative capabilities, which exist at the firm level, are important for product innovation (Helfat and Raubitschek, 2000), for firm growth (Chen et al., 2010), and for reducing the communication and coordination costs of conducting a transaction in-house (Poppo and Zenger, 1998).

Diversifying industry entrants have more integrative capabilities than start-ups. Development of these capabilities, however, is costly (Helfat and Campo-Rembado, 2010). Firms may choose to vertically integrate or de-integrate as an industry evolves but bear significant costs for such flexibility. The cost of setting up a vertically-integrated governance structure can be particularly high for specialized firms and start-ups (Leiblein and Miller, 2003). As a result, there is likely to be a tendency to maintain the initial boundary choice, for both vertically integrated and specialized firms. Helfat and Campo-Rembado (2010) found that firms may choose to remain vertically integrated in anticipation of new systemic changes in either their own or other industries, and Chen et al. (2010)

found that diversifying entrants navigate systemic change better than start-ups. Like systemic innovation (Helfat and Campo-Rembado, 2010), entry into a different industry represents systemic change for a firm and calls for integrative capabilities (Chen et al., 2010). Yet relative to diversifying entrants, start-ups may experience higher costs for integration of value chain activities, particularly in the absence of founder pre-entry capability in the activities. Given the greater levels of pre-entry integrative capabilities of diversifying entrants, I predict

H2b: A diversifying entrant is more likely to internalize a value chain activity than a start-up.

I now turn to an important distinction that relates to where pre-entry activity experience resides. Hypothesis 2a concerns the relatedness of pre-entry activity experience and not whether such experience is equally transferable to a new industry for both start-ups and diversifying entrants. Similarly, Hypothesis 2b focuses on the existence of an entrant's firm-level integrative capabilities, but not potential interactions with pre-entry activity-level capabilities. I now argue that a firm's integrative capabilities positively moderate the relationship between pre-entry experience in an activity and the decision to internalize that activity.

A diversifying entrant's integrative capabilities should help it transfer activity experience. Start-up founders with experience in an activity may possess the relevant knowledge, but firm-level routines that combine resources and capabilities for the ability to conduct the activity in-house are still needed. In contrast, even if activity experience acquired in related industries needs to be reconfigured to meet the new industry's requirements, diversifying entrants have already incurred much of the necessary cost (Helfat and Campo-Rembado, 2010), whereas start-ups have to incur these costs anew. A diversifying entrant's integrative capabilities should also enable it to leverage such experience better than a start-up can, since firm-level routines are more holistic and encompassing than knowledge residing in the mind of a founder that needs to be translated to the

firm level. This idea is consistent with Chen *et al.*'s (2010) finding that diversifying firms can deal with "growing pains" better than start-ups. Thus,

> *H2c: The positive relationship between a firm's likelihood of internalizing a value chain activity and the possession of pre-entry experience in that activity is stronger for diversifying entrants than for start-ups.*

Organizational Economics and Organizational Capabilities: An Integration Exercise

Transient Transaction Hazards (Entry Year) and Pre-Entry Experience

As industries evolve, entrants can rely on an increased stock of industry-specific knowledge (Gort and Klepper, 1982), which has important implications not only for changes in the relevance of pre-entry experience (Bayus and Agarwal, 2007; Klepper, 2002), but also for the availability of specialized external partners or suppliers (Jacobides and Winter, 2005). As discussed above, entry timing also relates to changes in asset specificity and uncertainty and thus should also have an important contingency effect on the relationship between pre-entry experience and boundary choices.

The industry evolution literature documents temporal changes in the technological and demand conditions in industries (Abernathy and Utterback, 1978; Agarwal and Bayus, 2004; Gort and Klepper, 1982). At the early stages, characterized by uncertainties in technology, demand, and government policy, resources and capabilities compete for value creation potential. Few, if any, supplier firms offer standard or easily customized applications for incumbent firms. Therefore, firms with transferable pre-entry activity experience are likely to be able to create competitive advantage. Given a small pool of suppliers, even imperfectly transferable pre-entry experience may make a firm the "least incapable" of the available suppliers (Hoetker, 2004). However, as the industry evolves, industry-specific knowledge develops (Gort and Klepper, 1982). Particularly after a dominant design is set, product features become largely predictable, and innovations are mainly add-ons to existing well-known production technologies (Abernathy and Utterback, 1978). Pre-entry resources and

capabilities from other industries, even if they are related, are less likely to fit the norms of the focal industry; hence, the value creation potential and relevance of pre-entry experience decrease over time (Bayus and Agarwal, 2007; Ganco and Agarwal, 2009). The increasing availability of capable suppliers means pre-entry experience loses value over time, and overall, pre-entry experience in an activity becomes less of a differentiator as an industry develops.

Similarly, interfaces between value chain activities simplify over time, because product features are gradually standardized. The organization of each value chain activity becomes more modular than it was early in industry evolution, which increases the pool of potential external partners specializing in various value chain aspects (Jacobides and Winter, 2005). Early in an industry's life, integrative capabilities allow diversifying entrants to gain competitive advantage by organizing transactions within their boundaries more efficiently than is possible in the nascent market. However, the standardization and modularization of the value chain over time increase the efficiency of organizing via the market and reduce the advantage of leveraging integrative experience to conduct activities in-house.[11] The above logic suggests a moderating effect of entry time on the relationships predicted in H2a and H2b.

> *H3a: The positive relationship between pre-entry experience in an activity and the decision to internalize that activity is weaker for later entrants.*
>
> *H3b: The positive relationship between being a diversifying entrant and the decision to internalize a value chain activity is weaker for later entrants.*

Enduring Transaction Hazards and Pre-entry Experience

The organizational capabilities hypotheses also imply that firms may differ in their ability to manage enduring transaction hazards. I now examine the impact of a firm's experience on its ability to manage transactions related to that activity in a new setting.

[11] In line with Hoetker (2006), I expect that although market efficacy will improve over time, integrative challenges will remain. Also, as noted above, certain aspects of asset specificity will remain non-trivial. Thus, while its marginal benefit will decrease as an industry evolves, prior experience may remain relevant for many transactions.

The nascent literature on dual governance—that is, the combination of making and buying similar inputs—suggests that organizations with internal capabilities deal with market transactions and manage external supplier relationships better (Mayer and Salomon, 2006). Firsthand experience with an activity helps a firm assess the performance of an outside supplier, reducing the risk of opportunism and hold-ups (Mayer and Salomon, 2006; Parmigiani, 2007). Knowledge about the activity also allows the firm to credibly threaten to internalize it, reducing the firm's vulnerability to external suppliers (Grant, 1996; Kogut and Zander, 1992).

Work on dual governance has generally examined simultaneous or near-simultaneous production of components in the same industry value-chain. However, to the degree that value chain activities are similar in an entrant's prior and new industries, a firm that internalized that stage in its prior industry or the founder of a start-up with similar prior experience should be able to apply lessons learned to management of external suppliers in the new industry. Accordingly, prior internal experience in a stage of the value chain will lower the cost of managing a given level of transaction hazards. In H2a, I argue pre-entry activity experience makes a firm more likely to integrate. Suppose two firms face a transaction hazard, and one has experience, but the other does not. If transaction hazard goes up by some degree of change, or "delta," the inexperienced firm is subject to that entire delta in additional hazard. But the experienced firm, because it has knowledge and capabilities relevant to the situation, is only subject to a fraction of the delta. The *marginal effect* of transaction hazards is therefore less for experienced firms. Given the lower marginal cost of dealing with an increase in transaction hazards, I predict that prior activity level experience will mitigate the transaction hazards posed by external sourcing of the activity, and thus negatively moderate the transaction hazards–internalization relationship.

Under the same logic, diversifying entrants' integrative experience provides knowledge about reducing communication and coordination costs that can be leveraged to manage the transaction costs of external sourcing. Firm-level experience in monitoring, identifying internal milestones, and creating routines to coordinate activities can also be leveraged to draw up contracts that safeguard against transaction hazards. Collectively, these factors make a diversified entrant's decisions about internalization of an activity less sensitive to the transaction hazards associated with that activity than the decisions of a start-up. Accordingly, I posit two moderating hypotheses.

> *H4a: The positive relationship between the enduring transaction hazards posed by an activity and the decision to internalize that activity is less for firms that have pre-entry experience in it.*
>
> *H4b: The positive relationship between the enduring transaction hazards posed by an activity and the decision to internalize that activity is less for diversifying entrants than for start-ups.*

To summarize, Figure 3.1 presents the theoretical framework. The first set of hypotheses examines the effects of enduring (H1a) and transient (H1b) transaction hazards on the decision to internalize a value chain activity, and the second set of hypotheses (H2a, H2b, and H2c) focuses on the role of organizational capabilities. The third (H3a and H3b) and fourth (H4a and H4b) sets integrate transaction hazards and firm capabilities to predict contingent effects on boundary choices.

DATA AND METHODOLOGY

Empirical Context: The U.S. Bioethanol Industry

I tested hypotheses with data from extant bioethanol producers that entered this evolving industry over 1978–2009. The industry dates back to the "oil shock" in the 1970s, which sparked interest in renewable energy sources. In 1978, President Jimmy Carter asked ADM (Archer Daniels Midland) to develop an alternative to OPEC oil. Subsequently, research funding, subsidies, and tax incentives from federal and state governments fueled growth of the bioethanol industry. Additional support stemmed from various agencies related to environment protection, agricultural development,

and economic development. Recently, societal attention to environmental and economic issues related to fossil fuels has provided an additional boost to the use of alternative energies (e.g. renewable fuels, solar energy, and wind). In the U.S., bioethanol is one of the two most important biofuels (bioethanol and biodiesel) and is made primarily from amylaceous grain plants (e.g., wheat, corn). The bioethanol industry is an ideal context for this study, given its clear demarcation of value chain activities and entrants' heterogeneous pre-entry experience.

Figure 3.2 reproduces the value-chain activities related to ethanol production as depicted by the U.S. Environmental Protection Agency (EPA), originating with feedstock production and ending with consumption. Entry into the industry requires incurring the capital costs of building a plant using one of two dominant technologies: dry or wet mill processing.[12] As Figure 3.2 shows, four key value chain activities complement ethanol production: (1) feedstock procurement, (2) technology development, (3) bioethanol marketing and distribution, and (4) coproduct marketing and distribution. Accordingly, I could identify whether producers chose to internalize any of these complementary activities.

Figures 3.3–3.5 depict the evolution of key industry variables. The industry has experienced rapid growth in both sales and number of firms and now ranks as the largest in the world in terms of total production (Renewable Fuels Association Report [RFA], 2008). Figure 3.3 shows a clear growth trend over the last three decades, with an annual rate of about 13.33 percent for the last 25 years, and acceleration since 2000 to about 17.4 percent. Furthermore, aggressive government incentives and policies have fostered entry by both diversifying entrants and start-ups (Figure 3.4). As befits the early and growth phases of the industry life cycle (Agarwal and Gort, 1996), not many

[12] Dry milling grinds the grain before water is added and produces distillers' dried grains as a coproduct along with ethanol. Wet milling separates the grain into separate components for a greater variety of coproducts (e.g., corn oil, corn gluten meal, and corn gluten feed).

exit events occurred in the industry in studied period. The pre-entry experience of industry entrants varies significantly. The firms and the founders of start-ups that entered the bioethanol industry came from a variety of backgrounds. For example, diversifying entrants included agricultural products companies that had engaged in grain processing and distribution (e.g., ADM, Bunge North America, Cargill), firms who had engaged in electricity or coal related production (e.g. Great River Energy, Headwaters, Inc.), and firms that had related production technology (e.g. ICM). Among the start-ups, founders' pre-entry experience varied considerably as well. Some were farmers (e.g., the founder of Central Indiana Ethanol Plant was a fourth-generation Hoosier farmer). Other start-ups' founders had been employed in incumbent firms but "spun out" to build new plants (e.g., a cofounder of Pacific Ethanol had managed a smaller-scale plant making bioethanol from beer and soft-drink syrup before he founded Pacific Ethanol, which has much larger scale and uses corn as primary feedstock).

Importantly, Figure 3.5 shows a declining trend in the number of internal activities per firm. Thus, the evolution of the U.S. bioethanol industry is also evident in a decrease in integrated firms over time, a trend that is consistent with Stigler (1951) and H1b in this paper.

Data Sources

My data represents all extant bioethanol producers[13] in the U.S. that entered from 1978 to 2009. I compiled information on the firms by cross-referencing information from the RFA and a consulting firm (BBI International) that specializes in renewable fuels and publishes the leading annual directory of the industry. Additional information regarding timing of entry, pre-entry experience, boundary choices for value chain activities, and production capacity was compiled from

[13] Currently, a few pioneers specialize in cellulosic ethanol production, testing technologies in pilot plants. I do not include such firms in our sample.

various resources, including SEC filings, firm websites, shareholder newsletters, press releases, industry magazines (*Ethanol Producer Magazine*), and various regional news reports on agriculture and biofuels.[14] These secondary data sources were complemented by interviews with managerial personnel who provided expert opinions on one of the key variables: enduring transaction hazards. The data contain 90 bioethanol producing companies and 360 firm-activity observations.

Estimation

The unit of analysis in this study is the internalization decision at the time of industry entry for each of four specific value chain activities. I report the results from probit estimation of the decision to internalize with clustering by firm to account for each firm's generation of four observations, one for each activity. Thus, the estimation technique used in this paper computes robust standard errors for the coefficients and accounts for inherent heteroskedasticity.

Variable Definition

The dependent variable, *Internalization*, indicates a firm's governance choice for feedstock procurement, technology development, bioethanol marketing and distribution, or coproduct marketing and distribution (1 = internalization, 0 = external development). I collected information on boundary choices at founding from a firm's first filed 10K (or 10K-SB), which have required sections for each of the four complementary activities. This information, checked against the firms' websites and industry publications, outlined whether these activities were conducted in-house or externally sourced through agreements with specialized suppliers or with other integrated ethanol producers. I also ensured from information for later years that these boundary choices remained

[14] More than 50 percent of the firms had 10K filings, and more than 90 percent maintained "history," "about us," and "partners" pages on their websites. For the few firms that do not have SEC fillings or websites, I used Lexis-Nexis to gather historical information from general and industry-specific news articles and releases.

unchanged and observed no switches between internal and external modes within my sample firms. Table 3.1 shows the internal/ external breakdown for each value chain activity in the sample.

Enduring transaction hazards: This variable, used to capture transaction hazards for each activity that endures throughout the industry's life, is based on six industry experts' responses to survey questions about perceived frequency and uncertainty (see Appendixes 3.1A and 3.1B).[15] The experts were randomly selected from among top managers in the industry. For each activity, the experts assigned a value from 1 (low) to 5 (high) for a typical bioethanol producer. I averaged these six responses, using the following procedure to ascertain inter-rater reliability and agreement.

I first checked the inter-rater reliability by calculating intra-class correlation coefficients (ICC).[16] For the 24 ratings of activity frequency (4 activities and 6 ratings for each activity), the ICC for average measures was 0.97. For the 24 ratings of activity uncertainty, the ICC for average measures was **0.93**. I then computed Fleiss's kappa statistics,[17]obtaining .54 for the frequency questions and .47 for the uncertainty questions on the four activities. These statistics show moderate agreement among respondents. For all eight questions together, the Fleiss's kappa is 0.61, showing substantial agreement. Thus, the six responses to my questions on the frequency and uncertainty of four value chain activities showed strong inter-rater reliability and moderate to substantial agreement among raters. Having established the reliability of the measures of frequency and uncertainty, I

[15] Responses by industry participants to questions presented in Appendix 1B showed that frequency and uncertainty were two of the most important parameters in evaluations of enduring transaction hazard, since their urgency had not declined over the years (in contrast, the industry experts agreed that the importance of asset specificity, availability of specialized suppliers, and competition had changed). The industry participants' consensus was that ethanol producers consistently faced substantial uncertainties related to market demand for ethanol, corn/feedstock prices, and government policies. One expert even said, "Our whole business is dealing with uncertainties." The frequency with which different value chain activities were done varied over time, but within each activity, frequency did not substantially change over the years.

[16] As both activity and respondent contributed to variations in ratings, I specify ICC (2, 6) for this calculation, where 2 represents two-way random effects and 6, the number of raters. I obtained ICC (2, 6) statistics for the ratings of frequency and uncertainty separately.

[17] Fleiss's kappa is more appropriate than Cohen's kappa if evaluations are provided by more than 2 judges.

compiled a single measure of each activity's transaction hazards, averaging the six experts' ratings on both variables. The measure for enduring transaction hazards is the sum of these two averages for each value chain activity.[18] Table 3.2 presents the four values. Robustness checks revealed no change in results when I used a rank order of the activities, rather than the values reported in Table 3.2.

Entry year (Transient transaction hazards) was defined as the year in which a firm started bioethanol production. For a firm with more than one plant, I used the founding year of its first operating plant, or the earliest available year. I subtracted 1977 from the chronological year of entry, so that 1 represents the earliest entry year in the sample. This measure captures the effect of transient transaction hazards, since industry experts agreed asset specificity had reduced over time (see Appendix 3.1B) .[19] Robustness checks confirmed that the results did not change when a logarithm of entry year was used.

Diversifying entrant: Following extant literature, I used a dichotomous measure for diversifying entrant (1 = firm was in another industry prior to bioethanol industry entry, 0 = founded as a bioethanol start-up). Joint ventures represent a hybrid organization structure between diversifying entrants and start-ups (Helfat and Lieberman, 2002). Four joint ventures were present in the sample, and were classified as diversifying entrants, given that they could benefit from their parents' firm-level experience and transfer of routines. Results remained largely similar when joint ventures were excluded from the analysis.

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[18] I note that this measure is based on questions asking for evaluation of a typical ethanol producer, not the ethanol producer to which the respondent was connected.

[19] Please refer to questions regarding changes in transaction frequency, uncertainty, and asset specificity over time in Appendix 1B. Though the managers did not use the term "asset specificity" *per se*, they all agreed that the availability of specialized suppliers, ease of setting up contractual agreements, and ability to verify quality had increased over time. Some excerpts from these responses follow. On the availability of specialized suppliers: "In the early years, most producers sourced their own grain, marketed their own product and the technology providers were few." On contractual agreements: "Now it is much easier to specify contracts with external service providers, and producers can evaluate various proposals from alternative service providers." And on evaluating the quality of external providers' services: "People running the plants are more knowledgeable and experienced to evaluate such contractual services."

Pre-entry activity level experience indicated whether a firm or its founder had pre-entry experience related to a given ethanol value chain activity (1 = related pre-entry experience, 0 = no related experience). Since both the diversifying entrants and founders of start-ups came from diverse industry settings and backgrounds, in coding this variable I relied on detailed information about their experience, particularly focusing on whether a firm or founder had prior experience in (1) handling grains (e.g., grain transportation, merchandizing, or trading); (2) R&D activities related to ethanol production (e.g., development of technology for corn milling, distiller grain drying, or corn oil extraction); (3) fuel sales, transportation, or storage; and (4) storage and transportation of agricultural processed goods (e.g., food and industrial starches, food ingredients, and animal feeds).[20] I combined key word and content searches of descriptions of firms' divisions, product offerings, services, histories, and so forth in the abovementioned various data sources to address these four primary inquires mapping onto the four value chain activities.

For diversifying entrants, I checked what businesses they had operated in prior to entry; and for start-ups, I ascertained the pre-entry work experience of the primary founders. For example, a firm with prior experience in petroleum distribution and marketing would be coded 1 for bioethanol marketing and distribution. For start-ups, I relied on company websites, news releases at founding, and trade journal accounts, which provided rich details on founding teams' prior expertise. For example, if a founder was a farmer, I coded 1 for the firm's procurement value chain activity and 0 for all others. Similarly, if a founder had oil refinery experience, I coded 1 for this firm's bioethanol distribution and 0 for all other activities. For firms with multiple founders, I compiled pre-entry

[20] None of the firms in our sample were active in these activities in the ethanol industry itself prior to beginning ethanol production. Showing a pattern that fits Stigler's (1951) conception, several specialized suppliers emerged later in the industry's life (e.g., ethanol marketing and distribution), but none of them backward-integrated into production.

experience by accounting for all the founders' experience; thus, a start-up could have related prior experience in multiple activities, even if any one of its founders had experience in only one.

Control variables included the following: *Production capacity,* a variable capturing firm size, representing the potential production of bioethanol in a firm's founding year, or the earliest available information about production capacity (in billion gallons/ year). Information was collected from the RFA's annual industry outlook, completed by other secondary sources described above. Robustness checks confirmed that the results were not sensitive to the use of a logarithm. I also controlled for differences in ownership structure. The RFA distinguishes three dominant types: public firm, locally owned producers, and other private. A "locally owned" ethanol firm is typically organized as a limited liability company (sometimes also as a limited partnership) and represents ownership by investors located in the region in which the plant operates. Investors are typically farmers, local businesspeople, and financial investors. These characteristics stem from the fact that most ethanol plants are in rural communities, and most of their economic impact is local. I followed the RFA's classification and controlled for potential structural effects of ownership types by creating dummy variables for *Public firm (*1 = public, 0 = other) and *Locally owned firm* (1 = locally owned, 0 = other). The omitted category thus included all other types of private ownership.

RESULTS

Descriptive statistics and correlations for all variables are in Table 3.3. Since I observed four distinct value-chain activities, simple cross-tabulations for each activity provide useful insight. Table 3.4 shows the percentage of firms that performed each activity internally or externally and reveals two important patterns. First, examining the row percentages shows that firms with pre-entry activity level experience are significantly more likely to internalize *each* of the four activities I examine (e.g., 85.7% versus 31.6% for ethanol marketing and distribution). Thus, no single activity is driving

the results of the formal analysis reported below. Second, comparing the column percentages shows that, combining those with and without prior experience, firms were most likely to internalize the activity identified as having the highest transaction hazards (procurement, 68.9% internalization) and least likely to internalize the activity identified as having the lowest hazard (technology development, 10% internalization). This finding is consistent with the expectations regarding internalization of activities with different levels of enduring transaction hazards.

Table 3.5 provides the results of the probit analysis of entrants' internalization decision for the four value chain activities. The "main effects" Model 1 includes the control variables, the baseline hypotheses (H1a and H1b) as they relate to both enduring and transient transaction hazards (year of industry entry is the proxy for the latter), and variables for organizational capability, pre-entry activity-level experience, and diversifying entrant (H2a and H2b). Models 2 and 3 add the interactions between (a) pre-entry activity-level experience and (b) diversifying entrant with transaction hazards (enduring and transient), respectively. The final, fully specified Model 4 reports all interactions among the variables of interest. The effects of the control variables are consistent and as expected in all the models reported in Table 3.5. Larger firms are more likely to internalize, as shown by the largely positive and significant coefficient of production capacity. Locally owned ethanol producers are less likely to choose internalization than are other private firms, while public firms are not significantly different from these private firms with other types of ownership structures.

I note that when testing interaction terms in probit models in which dummy variables were used to create groups, it is important to check for cross-group unobserved heterogeneity, which can lead to misleading results for interaction terms (Hoetker, 2007). Following the method proposed by Williams (2009), I were unable to reject the hypothesis of equal unobserved heterogeneity for either diversifying entrant (p = .287) or activity-level pre-entry experience (p=.657) and could therefore use

interaction terms with confidence. Further, Hoetker (2007) recommended appending reported coefficients with graphical analysis of predicted effects, both to assist in interpretation and to compute marginal effects for (nonmean) values of the explanatory variables of interest, preferably for values of explanatory variables one standard deviation above or below the mean. Accordingly, I refer to Table 3.5 and Figures 3.6 and 3.7 when discussing results. Figures 3.6 and 3.7 depict the probability of internalization (y-axis) against the x-axis of enduring transaction hazards and entry year (transient transaction hazards), respectively.

Both H1a and H1b, the baseline hypotheses derived from Williamson's (1975) transaction costs theory and Stigler's (1951) prediction on vertical integration over industry life cycle, are supported in Models 1 by statistically significant coefficient estimates for these variables. Firms are more likely to internalize value chain activities that are burdened with high enduring transaction hazards. Figure 3.6 reveals this to be the case, regardless of whether a firm has pre-entry activity-level experience and of whether it is a diversifying entrant or start-up. Similarly, firms are less likely to internalize value chain activities if they entered later. Figure 3.7 depicts the likelihood of internalization for firms entering at different times in the industry's life cycle: though the slopes vary with differences in pre-entry activity- or firm-level experience (i.e., for diversifying entrants), they are consistently negative over time.

Hypotheses 2a is also supported, as shown in Model 1: firms are more likely to internalize a value chain activity if they have pre-entry experience in that activity. In both Figures 3.6 and 3.7, firms that have pre-entry experience in an activity (solid lines) are more likely to internalize that activity than their counterparts (dashed lines). Model 5 supports this finding for the subsample of start-ups. The coefficient for pre-entry activity-level experience remains positive and significant even

when it is a founder rather than a firm that has the experience, indicating the impact of activity-level experience on boundary choice is independent of the presence of firm-level integrative capabilities.

Hypothesis 2b is also supported: diversifying entrants are more likely than start-ups to internalize any given value chain activity. This is seen more clearly in Figures 3.6 and 3.7, as multiple interactions complicate interpretation of the coefficients in Table 3.5.[21] Figures 3.6 and 3.7 account for all statistically significant interaction effects and treat the simple effect of diversifying entrants as null, since it is consistently not statistically significantly different from zero. As seen in Figure 3.6, diversifying entrants with experience in an activity are more likely to internalize that activity at any level of transaction hazards than are start-ups with such experience, a pattern repeated for diversifying entrants and start-ups without activity-level experience. In Figure 3.7, I see that all firms become less likely to internalize later in the industry's life cycle. Diversifying entrants are more likely to internalize an activity than are equivalent start-ups, a difference that increases as the industry ages. Thus, overall, I find support for H2b.

Turning to the interaction effects hypotheses tested in Models 2 through 4, I note that multicollinearity causes some of the coefficients to lose statistical significance when all interaction terms are entered in Model 4.[22] A test of the interaction items reveals them to be jointly significant at the 5% level. Thus, below I utilize Models 2 and 3 for interpretation of results, with reference to Model 4.

I find support for H2c, regarding the enabling role of integrative capabilities in transferring pre-entry activity level experience, with a positive and significant coefficient estimate from Model 3.

[21] Both figures report the mean value of the independent variable, plus and minus one standard deviation.
[22]In model 4, the variance inflation factor (VIF) for pre-entry activity-level experience is 65, and the VIF for the interaction between pre-entry activity-level experience and enduring transaction hazard is 61, both much higher than the threshold value of 10. Similarly, the condition number for this model is 37.6, higher than the threshold value of 30. I follow recent advice against mean centering as a solution for multicollinearity (Echambadi and Hess, 2007).

I also find support for the hypotheses related to pre-entry activity experience and transient hazards related to industry life cycle effects. As predicted in H3a, the coefficients in Models 2 and 4 show a statistically significant, negative interaction effect of entry year and pre-entry activity-level experience. This support for H3a is further evident in Figure 3.7, showing that whether a firm is a diversifying entrant or a start-up, the slope is steeper (more negative) over time given pre-entry activity-level experience. Put differently, I find that such experience has a weaker positive impact on the decision to internalize an activity for later entrants. However, contrary to hypothesis H3b, though diversifying entrants who entered early are no more likely to internalize value chain activities than start-ups, later diversifying entrants are significantly *more* likely to internalize than later start-ups. Given the non-significant simple effect of diversifying entrant and the negative, significant simple effect of entry year, an alternative interpretation is that later start-ups are much less likely to internalize activities than early start-ups, but this pattern is not true for diversifying entrants. Thus, the lack of support for H3b shows that start-ups are much more sensitive to transient transaction hazards than diversifying entrants: as outside options for external development of a value chain activity become more available, start-ups—with or without experience in an activity—are much less likely to internalize it than late-entering diversifying entrant.

As predicted in H4a, the role of enduring transaction hazards in promoting internalization of an activity is weaker when firms have pre-entry experience in that activity. The coefficients of the relevant explanatory variables in Models 2 and 4 and the predicted likelihood of internalization in Figure 3.6 strongly support this hypothesis. For both diversifying entrant and start-ups, the slope is steeper (more positive) for firms that lack pre-entry activity-level experience as enduring transaction hazards increase; that is, firms with pre-entry experience in an activity are generally more likely to

internalize that activity (as predicted in H2a), and the differential is higher at lower levels of enduring transaction hazards than at higher levels.

Finally, I find support for H4b. Figure 3.6 shows that firm-level experience possessed by diversifying entrants causes them to be less sensitive to increases in enduring transaction hazards across activities. Even though diversifying entrants are more likely to internalize (as predicted in H2b), the differential is lower for higher levels of enduring transaction hazards.

Robustness Checks

I perform several robustness checks to ensure that my results are not sensitive to the type of firms comprising the sample, and the measure of enduring transaction hazard. As noted above, the empirical setting includes a distinctive ownership structure that the Renewable Fuels Association refers to as "locally owned." A locally owned ethanol firms is typically organized as a limited liability company or a limited partnership and represents ownership by investors (e.g. farmers, local businesspeople, and financial investors) located in the region in which the plant operates. Many of these locally owned producers have complex governance structures and may be responding to different incentives than other firms. There are important and interesting questions regarding why farmers sometimes organize into these cooperative structures, including as a means of diversifying into the ethanol production industry. In the context of this study, an important robustness check thus relates to confirming that these firms are not driving the results.

To do so, I replicated my analysis on a sample that omitted all locally owned firms. As shown in Table 3.6, the estimated coefficients relating to the hypotheses are *all* in the anticipated direction and of similar magnitude to the coefficients for the entire sample (Table 3.5). All of the main effect hypotheses, and three of the five interaction terms remain statistically significant in models 2 and 3 (the others take on *p*-values in the .20 range), despite the exacerbated

multicollinearity issue due to reduced sample size (max VIF for models 2-4 are 50.6, 46.4, and 75.0, respectively). I note, however, that the interaction items involving enduring transaction hazards remain significant and consistent with my hypotheses. The interaction items involving entry year lose statistical significance but retain the same direction. Furthermore, the four interaction terms are jointly significant in model 4 at the p=.025 level. In all, I find strong support for seven of the nine hypothesized relationship when excluding locally owned producers (as opposed to eight of nine for the full sample).

In additional analysis (available from the authors upon request), I also ran the main effects regression on several subsets(startups, diversifying firms, locally owned producers, non locally owned producers). I found support for the hypothesized relationship for all subsets, as is also implicit from the comparisons of the main results in Table 3.5 and the analysis reported in Table 3.6 (excluding locally owned), and in column 5, Table 3.5 (for the startup sub sample). In particular, I found that the results for locally owned producers were similar to those estimated for the sample with no locally owned producers.

Further, I conducted robustness checks on the measure of enduring transaction. The analysis, available upon request, used (1) dummy variables for each of the value chain activities, and (2) a simple ordinal variable running from 1 (lowest hazards) to 4 (highest). Both robustness checks provided results that are significant and in the expected direction. In the dummy variable regression, relative to the omitted activity (Technology development, the lowest transaction hazards), I found that the other activities are all significantly more likely to be integrated, with Procurement (the highest transaction hazard) having the highest coefficient. In the regression using ordinal measures, I found a positive and significant coefficient for enduring transaction hazard, as hypothesized.

Taken together, these results show that the main results, as reported in Table 3.5, are a fair representation of the entire sample and are not driven by any single type of firm, in particular, locally owned producers. They also show that the locally owned producers and other firms respond similarly to the theoretical variables. They confirm that firms are less likely to internalize activities that have higher enduring transaction hazards, regardless of how these are measured.

DISCUSSION AND CONCLUSION

This essay builds on work in organizational economics, organizational capabilities, and industry evolution to examine firms' boundary choices at the time of their entering an industry. Specifically, I argued that these factors are intertwined and developed an integrative framework. The empirical testing in the U.S. bioethanol industry provided strong empirical support for my theoretical framework.

Notwithstanding the differences in the views of Stigler (1951) and Williamson (1975) about the role of economies of scale and transaction costs in explaining vertical integration choice, I found support for both views. On the one hand, I found that firms are more likely to internalize value chain activities with high transaction costs. The activity-specific measure derived from industry expert opinions shows that the uncertainty surrounding the key activities may differ, as may their frequency. In this setting, uncertainty and frequency are enduring factors that lead to enduring transaction costs. On the other hand, the asset specificity of a transaction may vary over an industry's life. Knowledge accumulation and spillovers promote emergence of specialized suppliers for various value chain activities and may reduce, but not eliminate, overall asset specificity over time (Gort and Klepper, 1982; Stigler, 1951). Therefore, the results support a long-standing tenet of the literature on industry evolution: Later entrants are less likely to internalize any given stage of a value chain and can take advantage of a more fully developed market to avoid internalization.

Argyres and Bigelow (2007) found that misalignment of governance structure penalizes firms more at later stage than at early stages of an industry's life cycle, pointing out that it can be misleading to assume uniformly severe selection pressures over an industry's life while applying transaction costs theory. My results corroborate this argument, showing that firms encounter varying degrees of transaction costs at different industry life stages. This variation is especially notable if I take into account firms' historical commitment (Argyres and Liebeskind, 1999) or experience in a focal industry (Bigelow and Argyres, 2008), since the findings are based on a sample of new entrants into the bioethanol industry.

The findings on organizational capabilities show that a firm's experience prior to entry shapes the scope of its activities in the focal industry, and that different types of pre-entry experience have different impacts on decisions to internalize. The logic is broadly consistent with the large literature on the advantages possessed by diversifying entrants (Helfat and Lieberman, 2002; Wernerfelt, 1984), in that I find that firms are more likely to internalize an activity if they or their founders have had experience related to it. Further, I advance this literature by distinguishing pre-entry experience with a given activity from broad firm-level pre-entry experience related to integrative capabilities. I separate underlying mechanisms previously bundled together via the diversifying entrant/start-up dichotomy. This distinction recognizes that both start-ups and diversifying entrants can have pre-entry activity-level experience and permits us to isolate the effects of firm level integrative capabilities. In doing so, I show that both pre-entry experience with an activity and integrative capabilities can and do transfer across value chains to shape decisions about firm scope. Further, firm-level experience possessed by diversifying entrants enhances the effect of activity level experience.

The support for H3a (effect of pre-entry activity-level experience on transient transaction hazards, proxied by entry year), but lack of support for H3b (similar effect of diversifying entry) has interesting implications. The relevance of *activity* experience to the decision to internalize attenuates as more specialized outside options become available with industry maturity, which is consistent with Bigelow and Argyres' (2008) study showing a weak trend toward vertical disintegration in an industry over time. In contrast, *if one controls for activity-level experience*, as I did here, diversifying entrants are less influenced by the availability of specialized suppliers of value chain activities when they enter the industry later. Thus, integrative capabilities (Chen et al., 2010; Helfat and Campo-Rembado, 2010; Helfat and Raubitschek, 2000) appear to be a different or higher-order construct than activity-level experience and may act in a different way on boundary choice. Integrative capabilities are related to communication and coordination of activities, and this may be the reason that their effect on the probability of internalization persisted even as the industry matured, given that later diversifying entrants are much more likely to choose internalization than later start-up entrants.

My findings also highlight the value of pre-entry experience for managing relationships with external suppliers or related partners (Hoetker, 2005), and they add to the growing body of research on dual governance (Mayer and Salomon, 2006; Parmigiani, 2007). By examining a firm's choice of organization of boundaries for value chain activities as it leverages *pre-entry* experience, either in a given activity level or in the firm, I add to this literature by examining the effect of transfer or spillover of capabilities from one industry to another, and the concomitant ability to buffer the effect of transaction costs. I find that the benefits of such experience or associated capabilities can transfer across value chains under conditions of high transaction hazards, whether enduring or transient.

Integrating organizational capabilities and organizational economics and exploring contingent conditions also permit us to contribute to the dynamic perspective on the role of boundary choice in capability formation, as distinct from the role of superior capabilities in the boundary choice for an asset or activity (Argyres and Zenger, 2008). The empirical results underscore the importance of both transaction costs and capability stocks for boundary choices at a time of entry and point to the importance of initial boundary choice to a firm's capability development over time (Helfat and Peteraf, 2003). This further has implications for entrepreneurial start-ups' industry entry decisions, as it relates to entry timing, structure design, and capability development.

I are cognizant of limitations in this study. First, I assumed that the transferability of pre-entry experience is the same for different value chain activities. Value chains are more or less related overall, which will affect the transferability of pre-entry experience. Even in a pair of value chains, the degree to which each activity is related may vary systematically. Future work might try to quantify such transferability in a more refined way, rather than with a dummy variable. Secondly, though the distinction between pre-entry activity- and firm-level experience provided more insights than a dichotomous measure (diversifying entrant vs. start-up), and my results also show that integrative capabilities enable transferring activity-level experience across value chains, further explorations along these dimensions would provide insights into the more specific advantages and disadvantages of diversifying entrants. Thirdly, this study is based on an industry that is approaching maturity but has not yet arrived at the shake-out stage. Ideally, an examination of the theoretical predictions in the entire life of an industry would make for a more complete story. Replicating this study in other industries would indeed be even more useful than usual.

Notwithstanding the above-mentioned limitations, this essay contributes to understanding of the intertwined relationships between organizational economics and organizational capabilities factors in an evolving industry. It is among the first that theorizes and empirically examines interactions of these factors. I hope to have answered Williamson's (1999) question as to how, given certain initial resources and capabilities, a firm should organize a given activity. The findings indicate that firms can leverage pre-entry activity-level experience, which helps reduce the impacts of both enduring and transient transaction hazards. In contrast, though I found some evidence that firm-level integrative capabilities help reduce the impact of enduring transaction hazards, causing firms to prefer internalization, these capabilities cause them to internalize even when transaction hazards related to availability of specialized suppliers and/or knowledge have been mitigated. By doing so, I contribute to transaction costs economics literature by highlighting the differences in strategies undertaken by firms with heterogeneous capabilities, in response to similar hazards encountered within or across time periods. Similarly, I contribute to the capability development literature by adding to recent efforts to join organizational capability and transaction costs (Hoetker, 2005; Leiblein and Miller, 2003; Madhok, 2002), revealing how a firm's initial bundle of resources and capabilities may lay the foundation for capability development and governance choice strategies after entry into an industry. Further, I contribute to the industry evolution and entrepreneurship literatures (Helfat and Lieberman, 2002; Klepper and Simons, 2000) by enriching the construct of pre-entry experience to distinguish specific activity-related capabilities (e.g., marketing, technology) that both diversifying firms and founders of start-ups may have (Agarwal et al., 2004; Helfat and Lieberman, 2002) from a firm's integrative capabilities (Chen *et al.*, 2010; Helfat and Campo-Rembado, 2010). By examining the effect of pre-entry experience on value chain configuration at industry entry, I also complement the often-studied relationships between pre-entry experience and

firm performance (growth and survival). Thus, this study is a first step for further inquires about the coevolving relationships among governance choice, capability development, and industry evolution. My framework highlights the need for an integrative approach to theory development, emphasizing that organizational capability, organizational economics, and industry evolution explanations work in tandem rather than in isolation. Further work along these dimensions would help disentangle the complex web of relationships among firm capabilities and firm scope in a constellation of evolving industries.

TABLES AND FIGURES

FIGURE 3.1: THEORETICAL FRAMEWORK OF HYPOTHESES

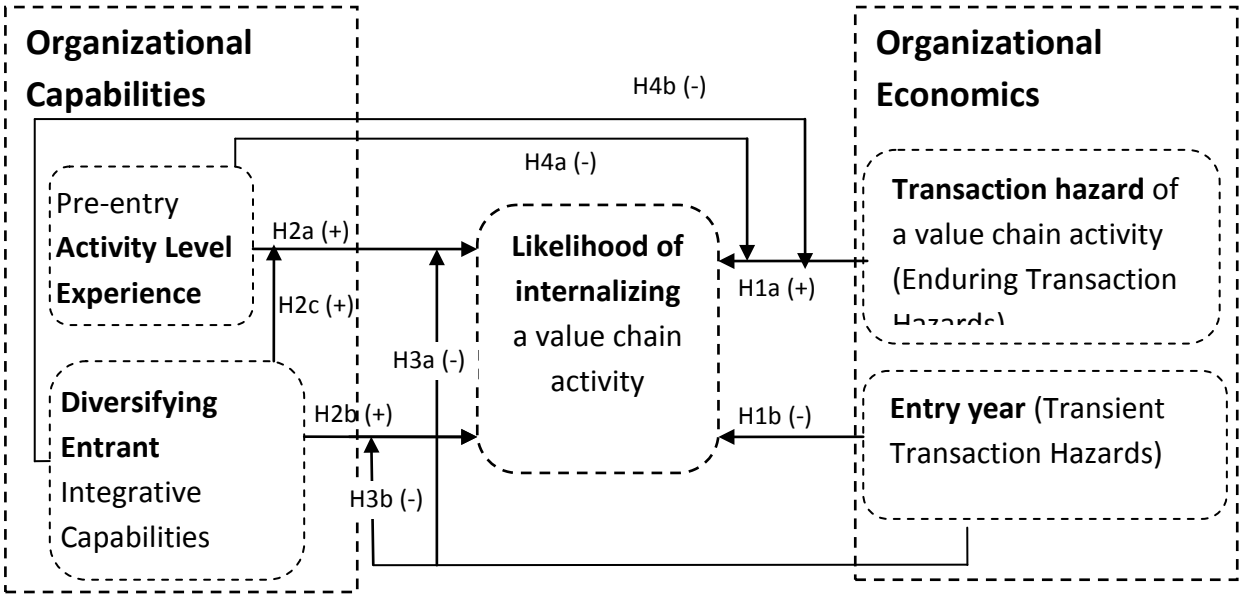


FIGURE 3.2: VALUE CHAIN ACTIVITIES RELATED TO ETHANOL PRODUCTION

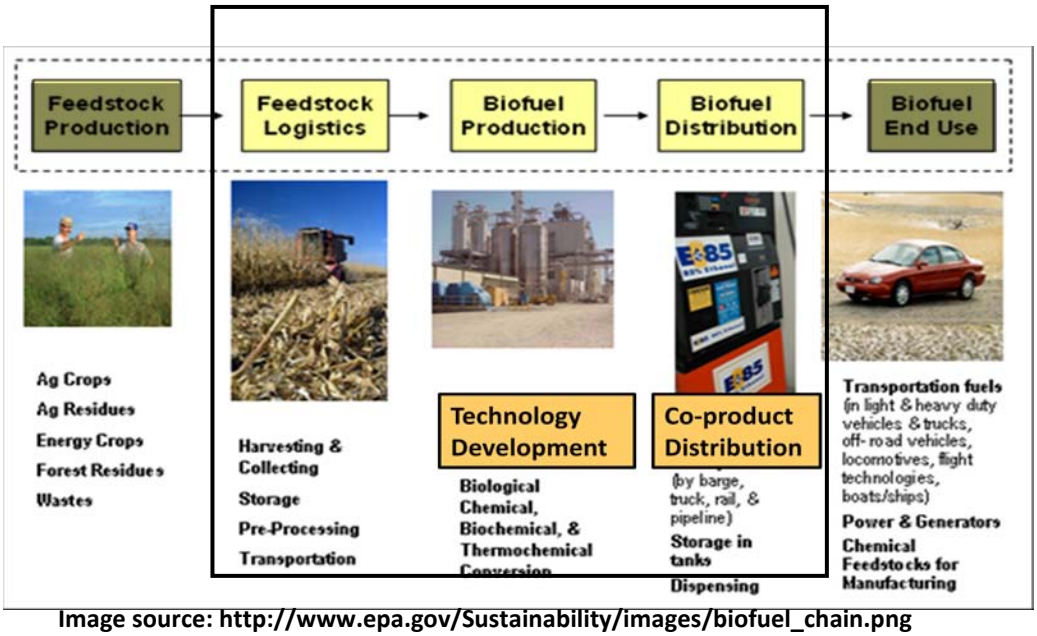
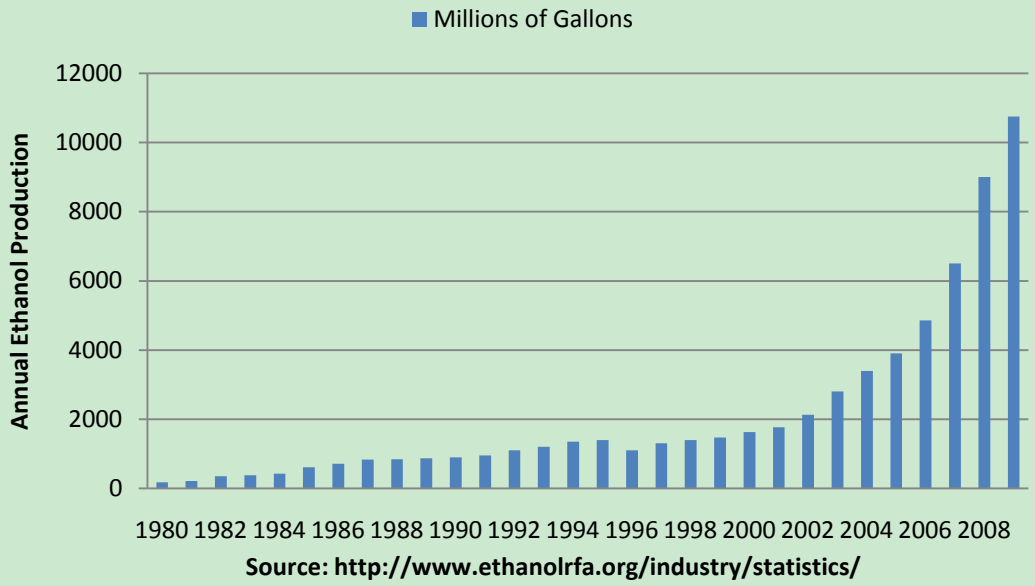


Image source: http://www.epa.gov/Sustainability/images/biofuel_chain.png

FIGURE 3.3: HISTORICAL U.S. FUEL ETHANOL PRODUCTION



Source: http://www.ethanolrfa.org/industry/statistics/

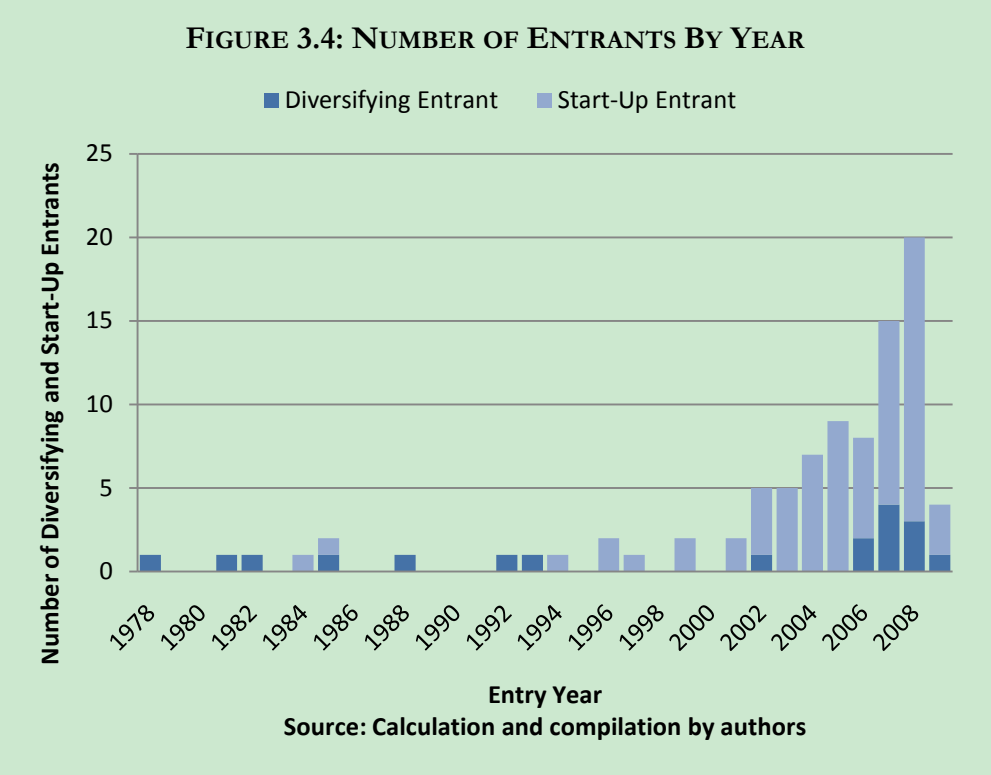


Figure 3.5: Number of Internalization divided by Number of Entrants

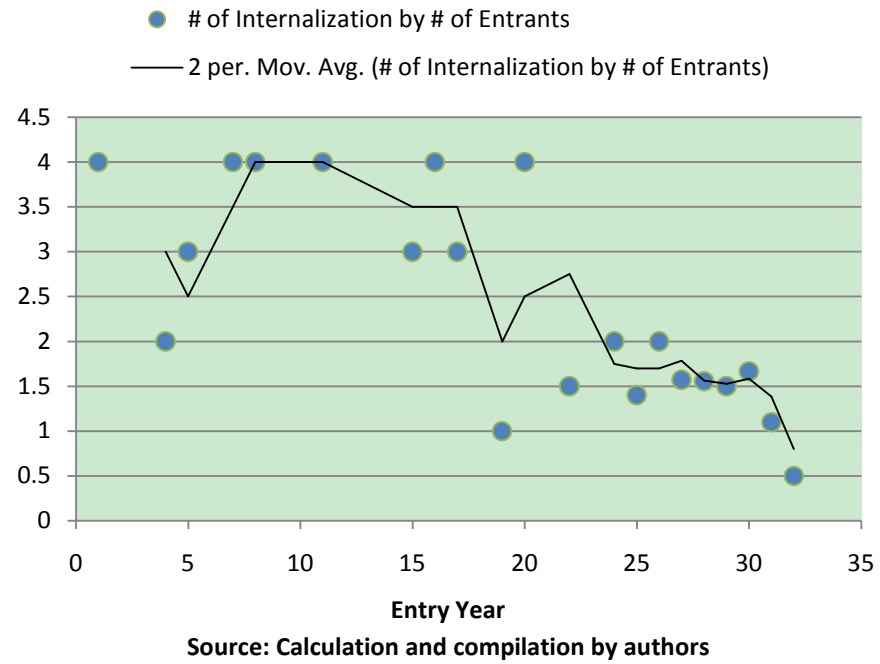


FIGURE 3.6: ENDURING TRANSACTION HAZARDS AND PROBABILITY OF INTERNALIZATION

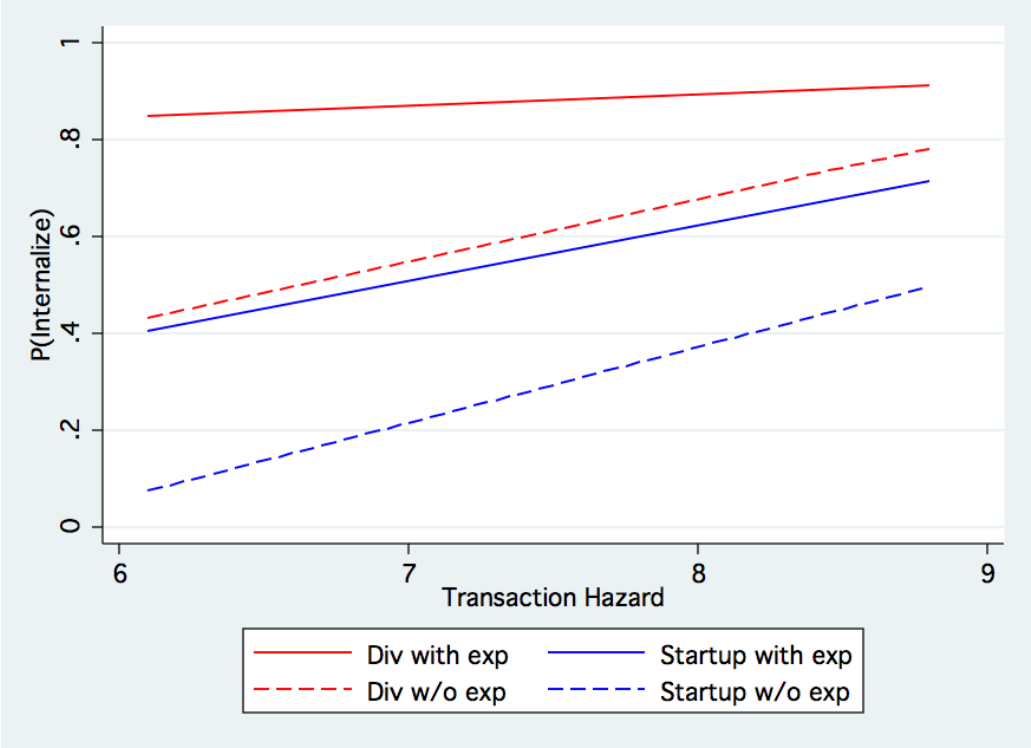


FIGURE 3.7: ENTRY YEAR AND PROBABILITY OF INTERNALIZATION

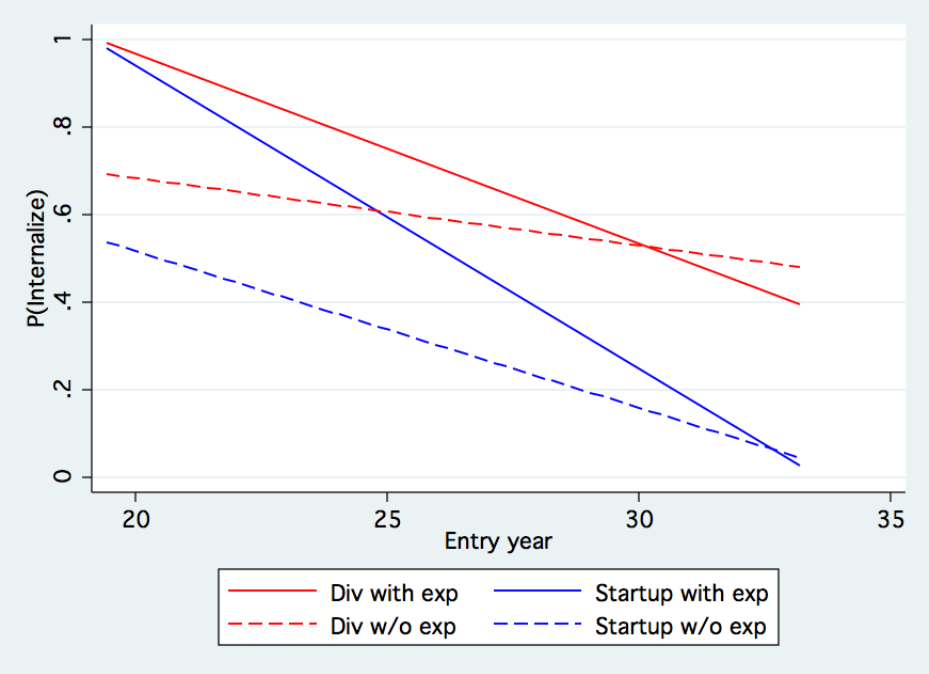


TABLE 3.1: FREQUENCY OF INTERNALIZATION (1) AND EXTERNAL DEVELOPMENT (0) BY ACTIVITY

	Internal	External
1. Feedstock procurement	62	28
2. Technology development	19	71
3. Ethanol marketing & distribution	36	54
4. Co-product marketing & distribution	44	46

TABLE 3.2: ENDURING TRANSACTION HAZARDS BY ACTIVITY

Activity	Feedstock Procurement	Technology Development	Ethanol Marketing	Co-product Marketing
Enduring Transaction Hazards	**9.16**	**5.5**	**8**	**7**

TABLE 3.3: DESCRIPTIVE STATISTICS AND PEARSON CORRELATIONS

	Mean	St. Dev.	Min.	Max.	1	2	3	4	5	6	7
1. Production Capacity	127000	229000	5000	1400000	1						
2. Locally Owned	.46	.50	0	1	-.27***	1					
3. Public Firm	.12	.33	0	1	.46***	-.34***	1				
4. Entry Year (Transient Transaction Hazards)	26	6.9	1	32	-.36***	.00	-.25***	1			
5. Enduring Transaction Hazards	7.42	1.35	5.5	9.16	.00	.00	-.00	.00	1		
6. Pre-entry Activity Level Experience	.29	.45	0	1	.16***	-.10*	.12**	-.24***	.46***	1	
7. Diversifying Entrant	.17	.37	0	1	.14***	-.29***	.41***	-.35***	-.00	.25***	1

NOTE: *** p<=0.01; ** p<=0.05; * p<=0.1

TABLE 3.4: CROSS-TABS BY PRE-ENTRY ACTIVITY LEVEL EXPERIENCE AND BOUNDARY CHOICE FOR ACTIVITY

	Boundary Choice	
Pre-entry Activity Level Experience in Procurement	**External %**	**Internal %**
No	**37.5**	**62.5**
Yes	**28.8**	**71.2**
All firms	**31.1**	**68.9**

Pre-entry Activity Level Experience in Technology development	**External %**	**Internal %**
No	**95.1**	**4.9**
Yes	**37.5**	**62.5**
All firms	**90**	**10**

Pre-entry Activity Level Experience in Ethanol marketing and distribution	**External %**	**Internal %**
No	**68.4**	**31.6**
Yes	**14.3**	**85.7**
All firms	**60**	**40**

Pre-entry Activity Level Experience in Co-product marketing and distribution	**External %**	**Internal %**
No	**60.8**	**39.2**
Yes	**6.2**	**93.8**
All firms	**51.1**	**48.9**

TABLE 3.5: PROBIT REGRESSIONS - INTERNALIZATION (1) OR EXTERNAL DEVELOPMENT (0) OF AN ACTIVITY

	Full Sample				Start-up Only
Control Variables	(1)	(2)	(3)	(4)	(5)
Constant	-0.98	-1.98**	0.03	-0.60	-0.67
	(0.68)	(0.78)	(1.13)	(1.14)	(1.23)
Production Capacity	1.10**	1.15**	0.79	0.80	0.61
	(0.51)	(0.57)	(0.55)	(0.61)	(0.66)
Locally Owned	-0.49**	-0.51**	-0.66***	-0.69***	-0.78***
	(0.21)	(0.22)	(0.23)	(0.24)	(0.27)
Public Firm	-0.48	-0.58	-0.32	-0.39	-0.08
	(0.42)	(0.46)	(0.41)	(0.44)	(0.59)
Explanatory Variables					
Enduring Transaction Hazards	0.37***	0.46***	0.50***	0.52***	0.58***
	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)
Entry Year (Transient Transaction Hazards)	-0.08***	-0.07**	-0.14***	-0.13***	-0.14***
	(0.02)	(0.03)	(0.04)	(0.04)	(0.04)
Pre-entry Activity Level Experience	0.71***	8.36***	0.34	6.81**	9.24**
	(0.22)	(2.79)	(0.27)	(2.81)	(3.63)
Diversifying Entrant	0.18	0.14	-0.98	-1.32	
	(0.26)	(0.28)	(1.46)	(1.60)	
Interactions					
Pre-entry Activity Level Experience *		-0.16**		-0.16*	-0.16*
Entry year		(0.07)		(0.08)	(0.09)
Pre-entry Activity Level Experience *		-0.38**		-0.23	-0.51*
Enduring Transaction Hazards		(0.19)		(0.22)	(0.30)
Diversifying Entrant *			0.10**	0.09**	
Entry Year			(0.04)	(0.05)	
Diversifying Entrant *			-0.25*	-0.18	
Enduring Transaction Hazards			(0.14)	(0.16)	
Diversifying Entrant *			1.11**	0.79	
Pre-entry Activity Level Experience			(0.49)	(0.63)	
Regression Statistics					
Log Likelihood	-174.27	-167.83	-166.63	-162.58	-129.79
N	360	360	360	360	288
Correctly classified	75.28%	77.50%	77.22%	75.83%	77.43%
Adjusted Count R2	.41	.46	.46	.42	.39
McFadden's Adjusted R2	.26	.27	.27	.28	.27
p>Chi2	.000	.000	.000	.000	.000

Note: *** p<=0.01; ** p<=0.05; * p<=0.1; Robust standard errors in parentheses;

Firm fixed effects controlled with cluster adjust standard errors for intra-group correlation, where firm is a group.

TABLE 3.6: PROBIT REGRESSIONS - INTERNALIZATION (1) OR EXTERNAL DEVELOPMENT (0) OF AN ACTIVITY: ROBUSTNESS CHECK OMITTING LOCALLY-OWNED FIRMS

	(1)	(2)	(3)	(4)
Control Variables				
Constant	-0.98	-2.17**	1.97	1.27
	(0.71)	(0.89)	(3.91)	(3.69)
Production capacity	1.02**	1.03*	0.28	0.30
	(0.50)	(0.60)	(0.61)	(0.667)
Public firm	-0.35	-0.42	-0.10	-0.15
	(0.39)	(0.46)	(0.39)	(0.727)
Explanatory Variables				
Enduring Transaction Hazard	0.31***	0.45***	0.47***	0.53***
	(0.07)	(0.08)	(0.10)	(0.000)
Entry Year (Transient Transaction Hazards)	-0.06***	-0.06**	-0.20	-0.19
	(0.02)	(0.03)	(0.14)	(0.141)
Pre-entry Activity Level Experience	0.76**	6.88***	0.17	4.85*
	(0.30)	(2.35)	(0.41)	(0.057)
Diversifying Entrant	0.10	-0.04	-2.64	-3.32
	(0.33)	(0.35)	(3.99)	(0.380)
Interactions				
Pre-entry Activity Level Experience * Entry Year		-0.07		-0.05
		(0.06)		(0.259)
Pre-entry Activity Level Experience * Transaction Hazard		-0.51**		-0.36
		(0.22)		(0.151)
Diversifying Entrant * Entry Year			0.15	0.15
			(0.14)	(0.243)
Diversifying Entrant * Transaction Hazard			-0.30*	-0.20
			(0.16)	(0.258)
Diversifying Entrant * Pre-entry Activity Level Experience			1.36**	0.83
			(0.65)	(0.74)
Regression Statistics				
Log Likelihood	-101.39	-96.85	-94.84	-92.87
N	196	196	196	196
Correctly classified	72.96%	73.47%	74.49%	75%
Adjusted Count R2	0.45	0.46	0.49	0.50
McFadden's Adjusted R2	0.20	0.21	0.22	0.22
p>Chi2	.000	.000	.000	.000

Note: *** p<=0.01; ** p<=0.05; * p<=0.1; Robust standard errors in parentheses;
Firm fixed effects controlled with cluster adjust standard errors for intra-group correlation, where firm is a group.

CHAPTER 4

ESSAY 3: R&D INVESTMENT AND INDUSTRY ENTRY: INCUMBENT'S NON-REDEPLOYABLE COMPLEMENTARY ASSETS

INTRODUCTION

When facing an emerging radical technology, incumbents need to decide whether to invest in R&D of the new technology and whether to enter the new ensuing industry.[23] More critically, the timing of engaging in each of these two activities is of strategic importance to an incumbent, who is likely to face potential challenging attackers from among the existing incumbents and new entrants (Conner, 1988). The technology management literature has observed that incumbents, particularly those dominant firms in many industries, did not react swiftly to emerging radical technologies and lost market share to new entrants after entry to the new industry (Abernathy and Utterback, 1976; Henderson and Clark, 1990; Rosenbloom and Christensen, 1994; Tripsas and Gavetti, 2000; Tushman and Anderson, 1986). Scholars are also puzzled that these incumbents might have invested substantially in the radical technology as early as those new entrants. For example, in transition from chemical to digital imaging, Kodak (Gavetti, Henderson and Giorgi, 2005) experienced substantial loss in market shares, though it had put enormous amount of investment in the digital imaging products early on, comparable to the investment made by Sony. Apparently, first mover in R&D investment of a radical technology does not equal the first mover of industry entry. What factors may have led to an incumbent's pioneering R&D investment in the radical technology but laggard entry to the digital imaging product markets?

Existing literature has shown that entry timing matters for firm success in terms of financial performance (Lieberman and Montgomery, 1988), technology success (Schilling, 2002), and survival

[23] R&D in emerging radical technology in this paper refers to investment in development of a pre-commercialization technology that has the potential to give rise to the new dominant design; industry entry refers to the commencement of production based upon the post-commercialized technology.

(Agarwal and Bayus, 2004; Bayus and Agarwal, 2007; Chen, Williams and Agarwal, 2011; Dowell and Swaminathan, 2006). Entry timing also matters for a firm's inventive performance (Ahuja and Lampert, 2001; Fleming and Sorenson, 2001; Jiang, Tan and Thursby, 2011). Mechanisms leading to these beneficial outcomes are considered motivating factors for a firm to enter early or late; the motivating factors for choosing entry timing for each of these two strategic maneuvers may differ (Conner, 1988). Existing studies on entry timing are largely based upon *ex post* observations, thus evidence that can distinguish motivating factors for early R&D of emerging radical technology and those of early industry entry are still lacking. An *ex post* approach is useful when only successful new technologies are considered and value judgments about a new technology concerns only successful entrants. This approach, however, is inadequate for the purpose of studying differences in incentives and constraints underpinning managers' strategic decision-making *ex ante*. To understand the strategic intent of incumbents to invest in R&D or to enter a new industry while facing substantial uncertainties, an *ex ante* approach is needed.

This essay of my dissertation answers this call by examining the differential effects of heterogeneous firm capabilities of incumbents on their intention to engage in R&D of an emerging radical technology early or to enter the ensuing industry early. To this end, I draw upon studies that have examined factors associated with post-entry performance differentials in the technology management literature (e.g., Rothaermel, 2001a, 2001b; Rothaermel and Hill, 2005; Schilling, 1998, 2002; Tripsas, 1997), the industry evolution literature (e.g., Agarwal and Bayus, 2004; Bayus and Agarwal, 2007; Klepper and Simon, 2000; Mitchell, 1991), as well as works on technology evolution (e.g., Fleming and Sorenson, 2001; Fleming, 2002). One important factor has been recurrently highlighted in these studies: an entrant's complementary assets (Teece, 1986), which may be redeployable or non-redeployable under the new technology regime. The effect of a given set of complementary assets on a firm's strategic intent is determined by not only whether the

complementary assets are redeployable, but also how much the incumbent has invested in these complementary assets. Accordingly, this essay of my dissertation suggests that complementary assets are an important, differentiating parameter in a firm's decision calculus regarding R&D investment and industry entry. It asks: how do an incumbent's complementary assets, particularly the non-redeployable complementary assets, impact its decision-making about the timing of R&D investment and industry entry?

I hypothesize that firms with stronger non-redeployable complementary assets, whether at the function level or at the firm level, are less likely to invest in R&D of emerging radical technology early or to enter a new industry early, but the overall negative impact is stronger for the industry entry decision. I test these hypotheses with a dataset compiled from a representative sample from the biofuels industry (bio-ethanol and biodiesel) in the U.S., which currently is developing a new generation of technologies. I collect data through a large sample survey, asking managerial personnel in charge of the biofuels business as informants about their R&D investment in the next generation production technology, and also their expectations about entry to the new industry defined by the new technology. I further complement the survey with archival sources to create a dataset combinative of primary and secondary data. Empirical findings corroborate the importance of a decomposed view of complementary assets in particular. More generally, findings corroborate the different incentives and constraints underpinning the two strategic maneuvers of incumbents, R&D investment and industry entry, when facing an emerging radical technology.

This essay of my dissertation makes three sets of contributions to the industry evolution and technology management literature. First, it studies the underlying incentives and constraints of an incumbent's decision to invest in emerging radical technology and to enter the new industry, which have been studied as largely indistinguishable. Thus, empirical findings can be used to address the puzzling observation described in the beginning of this essay. Second, this essay reveals the

facilitating and/or constraining roles of non-redeployable, complementary assets at both function and firm levels, advancing our understanding about this important theoretical construct. Third, by studying the factors that differentially impact an incumbent's decision to engage in R&D of an emerging radical technology or to enter a new industry, this study further extends our understanding about the interaction between technology evolution and industry evolution to the firm level. This approach complements existing studies that largely focus on the industry level.

Findings from the current essay also provide managerial and public policy implications. Given the potential negative consequences of a failed technology strategy or lock-out of a new industry (Schilling, 1998, 2002), managers need suggestions that can improve their foresight when evaluating an emerging technology and when navigating through technological changes. For policymakers, because investment in new and uncertain technologies from private sectors may often be hindered by uncertainties and risks despite potential positive social benefits, incentives and cooperative initiatives are needed to encourage initiative efforts by firms. Understanding firms' decision-making process in technology adoption will facilitate such policymaking.

The remainder of the essay provides more detailed report of this study, and has four sections: section two reviews relevant literature and develops hypotheses; section three discusses empirical setting, data collection procedures, variable definition, and estimation methodology; and the final section presents empirical results, followed by discussions and conclusions.

THEORY DEVELOPMENT

Non-redeployability of Complementary Assets across Technology Regimes

Teece (1986) highlights the importance of complementary assets as related to a firm's ability to appropriate value from innovation. Complementary assets include manufacturing, marketing, service, and other assets needed for commercialization of an innovation. Analyzing their importance for successful commercialization of an innovation, Teece (1986: 289) classified complementary

assets into three types: *specialized assets* (where there is unilateral dependence between the innovation and the complementary assets), *generic assets* (general purpose assets which do not need to be tailored to the innovation in question), and *co-specialized assets* (those for which there is bilateral dependence between the innovation and complementary assets).[24]

Complementary assets are not only indispensable for innovation commercialization, but also for other strategic maneuvers related to firm strategies, such as diversification into a related industry by leveraging existing complementary assets, R&D investment in an emerging technology, and adaptation to a new technology regime. First, empirical evidence has been found illustrating that incumbents with redeployable complementary assets are likely to perform better than new entrants after the technology change (Rothaermel, 2001a, 2001b). Secondly, compelling evidence has also been found in the industry evolution literature that prior experiences in related industry confers performance and survival advantage to diversifying entrants as compared to start-up entrants (Helfat and Lieberman, 2002; Klepper, 2004; Klepper and Simons, 2000; Mitchell, 1991). For instance, Mitchell (1989) defined reputations, distribution systems, and service network as valuable specialized assets for the medical imaging industry; they found that possession of these specialized assets is positively associated with an incumbent's likelihood of entry into a technology subfield. Furthermore, complementary assets are found to affect an incumbent's technology trajectory choices *ex ante* (Wu, Wan and Levinthal, 2011).

The above-mentioned findings showing that incumbents are able to appropriate greater value or achieve better post-entry performance rests on an important premise: that their complementary assets under the previous technology regime are specialized to the focal industry and are not devalued under the new technology regime. However, this premise may not always hold. Some complementary assets can be transferred from the current technology regime to the new one

[24] For the research purpose of this paper, unless specified otherwise, I use specialized complementary assets to include co-specialized complementary assets, as the latter is a special form of the former.

easily without losing value, while other assets may stick to the current technology regime. For instance, Tripsas (1997) identified three types of redeployable complementary assets in the typesetter industry: specialized manufacturing capacity, sales and service network, and proprietary font library. She found evidence for the important role of these redeployable complementary assets in buffering incumbents with inferior technologies. Some complementary assets may even become an obstacle to technological change and create inter-technology-regime diseconomies. For example, Christensen (1997) pointed out a possible downside of some complementary assets (e.g., marketing capabilities developed through close attention to current customers), in that these complementary assets actually became an obstacle to an incumbent's development of new disruptive technology. Put differently, complementary assets can be value-creating under one technology regime, but with low redeployability in the other regime, or flexible in usage under two technology regimes with high redeployability. Accordingly, I define redeployable complementary assets as those that can be redeployed from the current to the new technology regime without being devalued, and non-redeployable complementary assets are those that create greater value in the current technology regime than in the new one. I further suggest here that redeployability of existing complementary assets is likely to be a differentiator in incumbents' heterogeneous decisions regarding R&D investment and industry entry.

The distinction between re-redeployable and non-reredeployable complementary assets in existing literature is often made at the industry level (e.g., Rothaermel and Hill, 2005; Tripsas, 1997), rather than the firm level. To what extent complementary assets are redeployable depends on the radical technology itself and is exogenous to an individual firm. This approach is appropriate and adequate for comparison between incumbent entrants as a group and new entrants as another group, but is inadequate for the purpose of comparing among individual incumbents. This essay suggests the need to consider the extent to which an incumbent possesses competitive strength in those

assets. In the case of non-redeployable complementary assets, incumbents with substantial investment in such assets may incur great costs if they choose to enter a new technology regime.

In all, it is expected that the role of complementary assets in these two strategic decisions is contingent upon whether or not the complementary assets are redeployable under the new technology regime, and to what extent an incumbent's competitive advantages lie in these complementary assets.

R&D Investment vs. Industry Entry

When an emerging radical technology will potentially displace the current technology, a shift from the existing technology regime to a new one is likely to occur. Such a regime shift impacts not only the core technology of incumbents, but also the operation of and coordination across the upstream and downstream activities. It is possible to assume that the impact on core technology is similar across incumbents, as they are currently using the same dominant design. Then the variations largely come from firms' upstream and downstream activities, as well as the links across these activities. While industry entry represents a complete shift from the old to the new regime, engagement in R&D prior to commercialization can happen in the interim of this shift.

When an incumbent responds to a radical technology, it may exhibit one of the following behavioral patterns: early R&D investment but laggard industry entry; early R&D investment and pioneering industry entry; laggard R&D investment but early industry entry; and laggard R&D investment and laggard industry entry. What could be the underlying mechanisms for such variations in entry timing? These two strategies impose different requirements on firm resource and capability, thus demanding different levels of resource commitment and triggering different decision-making calculus of incumbents. While early engagement in R&D of a radical technology may create flexibility of technological trajectory choices, early industry entry represents a credible commitment to the new industry. Different timings of R&D investment and industry entry also have different

implications for competition. As Conner (1988) suggested, a leading firm may develop early, but then "shelve" its new product until its current product is challenged successfully by the rival, thereby deliberately deciding to forgo being first-mover in the new market. In other words, a firm may rationally defer industry entry under high uncertainty, in which case the real options value of waiting suggests a second-mover strategy may be chosen even if the firm was a first mover in R&D. More generally, this essay suggests these two strategic maneuvers, i.e., R&D investment in emerging technology and entry to the ensuing industry, are subject to related, but distinct sets of incentives and constraints. Hypotheses developed below will focus on the effect of non-redeployable complementary assets of an incumbent on its strategic intent to engage in each of these two strategies.

Non-redeployability of Complementary Assets, R&D Investment, and Industry Entry

Engaging in R&D of the emerging radical technology before its potential commercialization offers a variety of benefits when an incumbent possesses strong complementary assets that can be redeployed in the post-commercialization stage. Such complementary assets increase a firm's ability to appropriate value from an innovation (Teece, 1986) and to provide benefits for incumbents who engage in early research related to the radical technology. First, these firms can develop and accumulate an early, tacit knowledge about the radical technology, which is time-consuming and path-dependent (Dierickx and Cool, 1989). Such tacit knowledge will facilitate an incumbent's internal development for the purpose of commercialization of the radical technology, or enable the firm to better evaluate and grasp external opportunities, such as technology acquisition or alliances after the commercialization has occurred. Second, as the radical technology is still at its infancy stage, specifications of various features of the dominant design are not yet known and have to be established (Tushman and Anderson, 1986). By participating in early technology development, firms can get ahead of their competitors for specifications of the next dominant design of the industry,

pre-empting the technological spaces. In the meantime, firms can also influence the development processes to maximize the potential value yielded from their complementary assets. Third, tacit knowledge about the new technology, the extended use of complementary assets, and the links between technological specifications and the complementary assets are likely to create a strong strategic position for these firms if they enter the new technology regime (Porter, 1996).

When these above-mentioned complementary assets are specialized for the current technology regime, or are non-redeployable in the next technology regime, possession of such complementary assets becomes a disincentive for R&D in radical technology, especially when an incumbent has competitive strength in such complementary assets. With anticipation of potential losses on these complementary assets, an incumbent is more likely to wait than become a pioneer. If an activity and associated capabilities will experience substantial loss under the new technology regime, investment commitment (Chandy, Prabhu and Antia, 2003) to a prior development path is likely to become the very obstacle to a firm's technical change (Christensen and Rosenbloom, 1995). Capabilities and competencies developed under the previous technology regime may evolve into rigidities (Leonard-Barton, 1992) when radical changes are needed. Prior commitment to unique firm resources and capabilities leads to low redeployability under the new technology regime, and managers are less willing to cannibalize if the existing investments have low redeployability (Chandy and Tellis, 1998). For instance, focused managerial attention on current customer demand and value poses a difficult dilemma to managers of successful incumbent firms, rendering these managers unable or unwilling to invest in the new disruptive technology (Christensen, 1997).

Non-redeployable complementary assets may reside in at least two levels: function-level and organization-level complementary assets. Function-level complementary assets are emphasized in studies including Teece (1986), Tripsas (1997), and Rothaermel and Hill (2005), and are in a variety of forms, such as specialized manufacturing capacity, sales or downstream activities, and services.

Organization-level complementary assets are also multi-faceted, including efficient business processes, appropriate distribution of decision-making authority, a supportive business culture, and managerial capabilities. For example, Helfat and Campo-Rembado (2010) described a firm's abilities to efficiently communicate and coordinate across different stages of production that encompass organizational routines of communication and coordination, governance structure, and managerial leadership. As organization-level complementary assets tend to become embedded in the structure and information-processing procedures of established firms, they can be context-specific and exhibit different extents of redeployability across different technology regimes. Henderson and Clark (1990) described such a case of non-redeployable organization-level complementary assets: when the usefulness of a firm's architectural knowledge is destroyed by an innovation, it is difficult for that firm to recognize or to correct this destruction. Leonard-Barton (1992) developed a four-dimensional system of a firm's core capabilities (distinct technical system, skills, managerial systems, and values), and suggested that each capability component can cause rigidity on innovation. More importantly, the system-wise interconnectedness among these capability components makes it even more difficult for managers to recognize and cope with the core rigidities.

The negative effect of non-redeployable complementary assets is further supported by the findings on managers' loss-aversion tendency when making strategic decisions in the face of uncertainties (Kahneman and Tversky, 1979). Due to prior commitment to unique firm resources and capabilities that are not redeployable under the new technology regime, managers exhibit strong aversion to losses and thus are less willing to cannibalize if the existing investments have low redeployability (Chandy and Tellis, 1998).

Thus, consistent with these studies on both organization- and function-level complementary assets, I predict that

H1a: Strength in non-redeployable function-level complementary assets is negatively associated with an incumbent's likelihood of early R&D investment.

H1b: Strength in non-redeployable organization-level complementary assets is negatively associated with an incumbent's likelihood of early R&D investment.

A firm's resources and capabilities affect the timing of industry entry as well (Lieberman and Montgomery, 1988, 1998). Analyzed benefits leading to prediction of H1a and H1b are mostly applicable to the prediction on industry entry as well. Let us start the reasoning with redeployable complementary assets. Helfat and Lieberman (2002: 725) examined the birth of firm capabilities and resources at the time of market entry and found a consistent theme that "the greater the similarity between pre-entry firm resources and the required resources in an industry, the greater the likelihood that a firm will enter that particular industry, and the greater the likelihood that the firm will survive and prosper." Redeployability is a strong form of similarity of resources and capabilities; thus incumbents possessing stronger redeployable complementary assets are likely to hold optimistic perceptions of the new industry and to enter the industry earlier. Tushman and Anderson (1986) suggested that if a new technology enhances a firm's capabilities, the firm will enter early. Tripsas (1997) found that incumbents with redeployable assets in the typesetter industry are more likely to enter into a new product generation. Though not of primary interest in his testing, Mitchell (1989) found that an incumbent's timing of entry into new technical subfields is impacted by its complementary assets (e.g., direct distribution system in the medical diagnostic imaging industry). These effects can occur to incumbents even when they are not early technology developers, as these firms can leverage their redeployable complementary assets through alternative modes of entry, such as joint venture and acquisition (Helfat and Lieberman, 2002) with start-up entrants that have strong technical know-how (Teece, 1986). Competition among incumbents will further speed up an incumbent's intention to enter the new industry when the commercialization is ready.

The above analysis applies to both function- and organization-level complementary assets. Entering a new industry is more than a simple addition of a new technology to the firm (Taylor and Helfat, 2009). Instead, it also induces reconfiguration of multiple levels of firm structure, such as the level of a value chain consisting of multiple activities. Firms with stronger organization-level complementary assets, which are derived from an underlying system of knowledge and systems of learning, may incur lower costs in technological changes. For example, when an incumbent with redeployable downstream complementary assets intends to leverage technical know-how of a start-up entrant by allying with it, the incumbent's integrative capabilities will facilitate the process (Helfat and Campo-Rembado, 2010).

The flip side of the above reasoning about redeployable complementary assets suggests that if a firm possesses competitive strength in non-redeployable complementary assets, then its intent to enter a new industry early will be negated. The loss-aversion tendency of managers facing uncertainties is similarly applicable here (Kahneman and Tversky, 1979). Therefore, I predict that

> *H2a: Strength in non-redeployable function-level complementary assets is negatively associated with an incumbent's likelihood of early industry entry.*
>
> *H2b: Strength in non-redeployable organization-level complementary assets is negatively associated with an incumbent's likelihood of early industry entry.*

The negative effect of non-redeployable complementary assets on R&D investment, however, may differ from that on industry entry. First, when the emerging radical technology is filled with uncertainties, an incumbent firm may rationally take into account the real option value in its strategy decision-making. Engagement in R&D provides different real-option values than immediately entering an industry. On the one hand, in the infancy stage of a radical technology, different technological specifications compete to become the dominant design (Tushman and Anderson, 1986). Earlier technology developers can engage in establishing future technology

standards that are most compatible with their existing resources and capabilities, which provides the real options of growing or abandoning the technology, depending upon the success of the new technology trajectory. On the other hand, as discussed before, industry entry represents a much stronger resource commitment than R&D investment, thus leading to lower flexibility once implemented. Firms may spend more than challengers on R&D of emerging radical technology, but deliberately choose not to be the first-mover in introducing the product to market (Conner, 1988). In other words, firms may defer industry entry because of high uncertainty, in which case the real-options value of waiting suggests a second-mover strategy may be chosen even if the firm was a first mover in R&D. If commercialization of the radical technology proves to be successful, incumbents can speed up industry entry by quickly engaging in acquisition or strategic alliances later (Helfat and Lieberman, 2002).

Second, these differences in real-options values may be exacerbated in the presence of non-redeployable complementary assets. An incumbent may still be incentivized to engage in R&D of the emerging radical technology in anticipation of value loss due to the non-redeployability of assets. On the one hand, early investment in R&D may act as a credible threat to competitors or potential challengers and deter the latter's investment in the new radical technology. By doing so, the focal incumbent may be able to create a shield for its non-redeployable complementary assets and elongate the use of these assets under the current technological regime. On the other hand, by engaging in R&D early, firms can compete for development of technological specifications or standards for the next generation of technology that can minimize the value loss to their non-redeployable assets. Furthermore, accumulation and learning of tacit knowledge of the radical technology through early engagement in R&D also provides firms with better information needed for execution of the real options of waiting, abandoning, or growing, as uncertainties involved in market development and technology commercialization get resolved over time. For instance, when

an incumbent is equipped with knowledge or learning capabilities about the new technology, it is better able to identify candidates for acquisitions or strategic alliance later if it decides to enter the new industry. These potential benefits of engaging in R&D early despite the presence of non-redeployable complementary assets are likely to enhance the real option values accrued to this early-mover strategy.

In all, the above analysis suggests that despite the negative effect of non-redeployable complementary assets on both strategic maneuvers, the relative effect may be weaker for R&D investment than for the industry entry decision. Therefore, I predict that

> *H3a: The negative effects of non-redeployable function-level complementary assets on an incumbent's likelihood of early industry entry are stronger than on its likelihood of early R&D investment.*
>
> *H3b: The negative effects of non-redeployable organization-level complementary assets on an incumbent's likelihood of early industry entry are stronger than on its likelihood of early R&D investment.*

DATA AND METHODOLOGY

Empirical Context: The U.S. Bio-fuel Industry – Bio-ethanol and Biodiesel

The current study is situated in the U.S. bio-fuels industry, including the bio-ethanol sector and the bio-diesel sector. Both sectors have seen rapid growth in terms of the number of firms and industry production capacity in the last decade. According to the Renewable Fuels Association (RFA), there are about 125 ethanol-producing companies with total production capacity estimated to be 11.7 billion gallons annually in 2009. According to the National Biodiesel Board (NBB), there are about 140 bio-diesel producing firms with total capacity estimated at 2.41 billion gallons annually. These bio-fuels producers use primarily grain-based feedstock, such as corn and soy oil, and the corresponding so-called first generation production technologies. Due to the commodity nature of feedstock and fuel products, bio-fuel producers face substantial price fluctuations and compete

particularly on production costs. The rapidly growing number of competitors in the industry further imposes strong pressures on cost reductions.

Alternative non-food feedstock and alternative production technologies are being pursued to address these concerns about cost reductions and fuel sustainability. Government has set up a series of regulations and laws to stipulate bio-fuels development. For example, Section 942 of the Energy Policy Act of 2005 (EPA) authorizes the establishment of incentives to ensure that the annual production of one billion gallons of cellulosic bio-fuels is achieved by 2015. The Energy Independence and Security Act of 2007 (H.R. 6), which was signed into law in December 2007, contains a number of incentives designed to spur cellulosic ethanol production. The farm bill, the Food, Conservation, and Energy Act of 2008 (H.R. 2419) also includes a new income tax credit for the producers of cellulosic alcohol and other cellulosic bio-fuels, estimated at $1.01 per gallon[25]. Both private sectors and government agencies are conducting R&D activities in projects that are set to validate alternative feedstock (e.g., agricultural residues, forestry residue, and grass) and to develop alternative technologies (e.g., enzymatic conversion, acid hydrolysis, and gasification).

Development of these alternative feedstock and technologies poses both opportunities and challenges to bio-fuels producers using first generation technologies with grain-based feedstock. On the one hand, if these new technologies and feedstock are proved to be commercially viable, bio-fuels producers continuing with first generation bio-fuels production may become cost disadvantaged. On the other hand, bio-fuels producers may also bear substantial costs when switching from first generation production to the new generation of technologies and feedstock. In particular, transitioning from the first generation production to the second generation requires changes in at the minimum the following aspects: substitution of grain-based feedstock to non-grain feedstock; addition to and/or replacement of first generation production facilities, processes, and

[25] http://www.ethanolrfa.org/resource/cellulosic/

equipment; replacement of production and distribution facilities for co-products derived from grain-based feedstock with facilities that cater to newer co-products derived from non-grain based biomass feedstock; and importantly, managerial capabilities appropriate for the new technology regime. These changes, among others, engender the need for reconfigurations of capabilities and structures of the bio-fuels producers, and the associated changes in managerial perceptions.

The potential benefits coupled with the potential costs of adopting the second generation bio-fuels technologies and the fact that development for the second generation technology still involves substantial uncertainties make the bio-fuels industry an ideal empirical setting for my research purpose: to examine the differential impacts of an incumbent's non-redeployable complementary assets on the managerial decision making *ex ante*, regarding the decision to engage in R&D investment before the emerging radical technology is commercialized, and to enter the new industry after successful commercialization of the new technology.

Data Sources

This essay of my dissertation combined secondary and survey methods for data collection. I conducted two surveys on the two bio-fuel sectors in the U.S.: one among ethanol producers, and the other among biodiesel producers. Questions in the two surveys are nearly identical, except that questions are modified with phrases and language to match the industry-specific knowledge, while the theoretical constructs remain the same.

The study of ethanol producers employed a multi-modal design, using both mailings and online surveys to elicit responses. The survey ran from January 2009 to August 2009. I attended two consecutive industry-wide annual conferences organized by the Renewable Fuels Association in 2008 and 2009. The purpose for my first conference attendance in early 2008 was to learn about the industry's general perception of the new technology, to identity ethanol-producing companies in the U.S., and to conduct a pilot study for my survey questions. In January 2009, I mailed questionnaires

to 105 companies with identifiable executive personnel, including a cover letter providing information about the source and purpose of the study, as well as alternative ways of responding through a Web version of the survey questionnaire. In February 2009, I attended the industry conference for the second time, with the purpose of informally interviewing executives from ethanol-producing companies. Afterwards, in late February, I sent out reminder postcards to all those who had not yet returned a completed questionnaire via mail or Web, and e-mail invitations to the survey to executives who I met at the industry annual conference. By early March, I had received a total of 37 completed questionnaires: 24 via mail and 13 via Web. A second mailing including a cover letter and the questionnaire was sent in mid-March 2009. The final total number of completed and usable questionnaires from the ethanol sector is 41, representing a 40% response rate.

The study of bio-diesel producers used online surveys to elicit responses. I obtained a representative list of biodiesel producers in the U.S. from the National Biodiesel Board (NBB), and compiled email addresses of about 135 executives, with one executive from each firm. Invitations to the Web-based questionnaire were sent in early June, followed by two rounds of email reminders. The first round of reminders was sent out in late June, and the second round in mid-July. The survey was closed with a total of 34 completed and usable responses, representing a 25% response rate.

I also resorted to secondary sources for data collection, including industrial associations (the Renewable Fuels Association; the National Biodiesel Board), government agencies (the Department of Energy; the Department of Agriculture), industry-specific magazines (Ethanol Producer Magazine; Biodiesel Magazine), firm webpages, newsletters, and SEC filings if available. The archival data mainly serve two roles: to confirm or complement survey responses, and to generate variables unavailable from survey data. I triangulated information from different sources for variable measurement. The combination of archival and survey data provides a solid base for this study.

Variable Definition

I use both secondary data and survey questions to develop measures of explanatory variables for this essay. For each variable that is measured with survey questions, I provide a brief description of these questions, and the procedures used to construct the measure. Notably, questions for these variables are designed with 5-point Likert-scale items, unless specified otherwise.

Dependent Variables

The first dependent variable is an indicator of whether a firm is and will be soon investing in R&D of the next generation of technology for producing bio-fuels. Based upon survey responses, I assigned a value 1 to those who indicated their firms are currently or will start investing in such R&D activities in the next 2-3 years, and 0 otherwise.

The second dependent variable is also an indicator variable derived from survey responses. If the survey respondents indicated that their firms intend to be early or pioneer entrants into the next generation of biofuels production in the next 3-5 years, I assigned a value of 1; if the respondents indicated their firms will not produce next generation biofuels until the majority have started producing, or will be laggard entrant, I assigned a value of 0.

Independent Variables

To identify the function-level complementary assets, I look at two value-chain activities of a typical biofuels producer: upstream feedstock procurement activity, and downstream biofuels marketing and distribution activity. In order to evaluate the redeployability of complementary assets associated with a given value-chain activity, I resorted to industry experts. As described in the empirical context section, the second generation technology in both the ethanol sector and the biodiesel sector will alter the value-chain activities of existing biofuels producers. In particular, the current feedstock procurement activity needs the most reconfiguration among all value-chain activities, as the next generation technology will be using totally different feedstock for biofuels production and is thus the least redeployable.

I used two survey questions to measure a firm's strength in its feedstock procurement: how difficult is it for other biofuels producers to imitate your company's feedstock procurement activity? How difficult is it for other biofuels producers to achieve the same level of efficiency and effectiveness in feedstock procurement as your firm? I then conducted principal component analysis on these two survey questions, and retained the primary component as the final measure for a firm's strength in non-redeployable assets: *strength in non-redeployable, function-level complementary assets*.

Strength in non-redeployable organization-level complementary assets: secondary data or established measures from prior literature are not available for this variable. I used two survey questions to establish a proxy for it. The first question asks: to what extent a firm's *overall* investment in current biofuels business can be recouped under the technology regime of the next generation biofuels (reverse coded). The second question asks: to what extent does the development of next generation technology create uncertainties and complexities on the firm's existing managerial resources? I then conducted principal component analysis on these two questions and extracted one component to be the measure: *non-redeployable, organization-level complementary assets*.

Control Variables

While independent variables in this essay are aimed to capture the role of non-redeployable complementary assets, an incumbent's strategic intent to invest in R&D and industry entry may also be affected by its possession of redeployable complementary assets. Therefore, empirical testing is supposed to control for such effects. To this end, I include two additional measures as proxies for redeployable complementary assets.

The first is an incumbent's strength in redeployable, function-level complementary assets. Contrary to the upstream feedstock procurement activity, a typical biofuels producer's downstream activity will experience much less reconfiguration, as the end product (biofuels) from different types of feedstock is of similar attributes. Moreover, the marketing/distribution assets from the current

technology regime can be largely usable in the next generation of technology. Accordingly, I used two survey questions to measure a firm's strength in its marketing and distribution activity: how difficult is it for other biofuels producers to imitate your company's marketing and distribution activity? How difficult is it for other biofuels producers to achieve the same level of efficiency and effectiveness in marketing and distribution as your firm? I then conducted principal component analysis on these two survey questions and retained the primary component as the final measure for a firm's strength in redeployable complementary assets.

The second is an incumbent's strength in redeployable, organization-level complementary assets. When an innovation requires alignment and coordinated adjustment at different stages of value-chain activities in a value chain (Teece, 1986), firms with stronger redeployable integrative capabilities have cost advantages when they engage in innovation with their vertical boundary (Helfat and Campo-Rembado, 2010). These integrative capabilities facilitate better communication across the new technology development efforts and the upstream or downstream value-chain activities. Accordingly, I measured this variable as the number of value chain activities (i.e., procurement, operation management, technology development, marketing and distribution of biofuels, and marketing and distribution of co-products) that are internalized by a firm. I first identified whether a firm conducts an activity internally or externally, where internal mode was assigned a value of 1 and external mode with a value of 0. I then computed the sum of these values of the five value-chain activities for each firm. With this calculation, the variable ranges from 1 to 5, where 5 indicates a firm integrates all five activities, and 1 means the firm conducts plant operation by itself and outsources all other activities. This measure is intended to capture a firm's ability in communication and coordination across these different activities, or its integrative capabilities (Helfat and Campo-Rembado, 2010). Integrative capabilities manifested in the extent of vertical

integration is considered redeployable from the grain-based biofuels to the next generation biofuels, primarily because the similarity in links *across* these activities within these two technology regimes.

In addition, I also control for firm size (measured by a firm's nameplate production capacity in million gallons per year), firm age (measured as the years in which the firm has been producing ethanol/biodiesel), entry type (diversifying entrant versus start-up entrant when the firm started the grain-based biofuels production), and industry sector (indicator variable where 1 represents the ethanol sector, and 0 is the biodiesel sector).

Appendix 4.A has survey questions used for measures in this essay.

Estimation Methodology

As the hypotheses here address two related decisions by the same actor, errors in the two equations that predict each decision are related, and the dichotomous variables representing two decisions are likely to be jointly distributed (Greene, 2000). Further, H3a and H3b intend to compare the magnitude of coefficient estimates in two models; thus, a system of equations that can address the correlated error terms is needed. I conducted bivariate probit models to estimate the parameters via maximum likelihood approach, using the --biprobit-- command in STATA. I further conducted Wald tests of simple hypotheses testing, and computed marginal effects for each equation with the purpose of testing H3a and H3b. Table 4.1 presents statistics and pair-wise correlations. VIF test shows that no significant multi-collinearity is detected.

RESULTS

Table 4.2 has the results, with two sets of bivariate probit regressions: Model 1 presents the results with only the constant and the control variables; Model 2 includes the two explanatory variables. Under each model, two equations are estimated: one for early R&D investment decision, and the other for the early industry entry decision. Results in Model 2 will be used for interpretation.

The correlation of errors of two equations, rho, in Model 2 is 0.29, but is not statistically significant. One interpretation of the insignificant correlation is that after accounting for the right-hand-sided variables, the decision to engage in R&D investment and that to enter industry early is affected by unknown and uncorrelated effects.

In the "early R&D investment" equation in Model 2, the estimated coefficient for an incumbent's *strength in non-redeployable, function-level complementary assets* is positive and statistically significant, opposite to what H1a predicts. The coefficient estimated for an incumbent's *strength in non-redeployable, organization-level complementary assets* is negative and significant, consistent with H1b. In the "early industry entry" equation in Model 2, both coefficients estimated for *strength in non-redeployable, function-level complementary assets* and *strength in non-redeployable, organization-level complementary assets* are negative and significant, supporting H2a and H2b.

H3a and H3b concern the relative effect of a firm's *strength in non-redeployable function-level and organization-level complementary assets* on the two strategic decisions: early R&D investment and early industry entry. In particular, I conjectured that the negative effects predicted in H2 would be greater than those predicted in H1. To test H3, I first conducted two Wald tests to check whether the coefficients for a given explanatory variable in the two equations are jointly zero or are the same. With this, I then examined the significance level and sign of that explanatory variable across two models. Lastly, I used the marginal effects of these two variables in two equations to make further comparison. As the rho, or the correlation of error terms in two equations, is found to be insignificant, I computed the unconditional marginal effects for each right hand side variables based upon Model 2, holding the rest variables at the mean level. Table 4.3 presents the computed unconditional marginal effects for Model 2.

For the variable *strength in non-redeployable, function-level complementary assets*, both Wald tests are rejected, suggesting that the coefficient for the R&D investment is statistically different from that

for the industry entry decision. Furthermore, as can be seen in Model 2, the coefficient for *strength in non-redeployable, function-level complementary assets* is positive in the R&D investment equation, but is negative in the industry entry equation, providing evidence that an incumbent is less likely to enter an industry earlier if it has competitive strength in non-redeployable, function-level complementary assets than to engage in R&D investment of the radical technology. Additional evidence can be found in Table 3 regarding the marginal effects. The unconditional marginal effect of an incumbent's *strength in non-redeployable, function-level complementary assets* when all other variables are held at their means, is 0.06 and significant for the R&D investment equation; the marginal effect of this variable for the industry entry question is -0.10 and significant. The comparison can be interpreted this way: one unit change in the variable *strength in non-redeployable, function-level complementary assets*, other things being constant, increases the probability of early R&D investment by 6%, but decreases the probability of early industry entry by 10%. Given this evidence, it can be concluded that H3a is supported.

I followed a similar procedure to check empirical evidence for H3b, which predicts that the negative effect of an incumbent's *strength in non-redeployable, organization-level complementary assets* is stronger for its intent to enter an industry early rather than invest in R&D of the radical technology. Wald tests show that the two coefficients for this variable in two equations are statistically different and not jointly equal to zero. Given that both coefficients estimated are negative and significant, testing of H3b may be done by comparing the magnitude of these two negative coefficients. From Model 2, the estimated coefficient is -0.56 for the R&D investment question, and -1.1 for the early industry entry equation. This provides preliminary indication that the negative effect is stronger for the industry entry decision, consistent with the prediction of H3b. Additional check of the marginal effects in Table 3 shows that one unit of change in the variable of an incumbent's *strength in non-*

redeployable, organization-level complementary assets reduces the probability of early R&D investment by 12% and early industry entry by 30%. Thus, H3b is also supported.

It should be noted as a caveat that it is difficult to assign quantitatively meaningful value to a one-unit-change in either of the two explanatory variables, as they are measured as the principal components extracted from survey questions. However, as the survey questions are all 5-item likert scale, and the method for extraction is the same for two variables, it is still possible to assess the relative effect of each variable on the two dependent variables, which is sufficient for the purpose of testing H3a and H3b.

Results on control variables are worth noting. First, the coefficient estimates for an incumbent's *strength in redeployable, function-level complementary assets* are positive and significant in both equations of Model 2, which is consistent with empirical findings from the technology management and industry evolution literature showing that if an incumbent possesses such assets, it is more likely to appropriate value from engaging in R&D early and to achieve performance advantage than other entrants. However, the coefficients of an incumbent's *strength in redeployable organization-level complementary assets* are significant in neither equation of Model 2. Coefficient estimates for the other control variables -- firm size, age, entry type, and industry sector affiliation -- are found to be insignificant in either equation.

DISCUSSION AND CONCLUSION

This essay of my dissertation is set to study how incumbents decide when to invest in R&D of an emerging radical technology and when to enter the new ensuing industry early. It is motivated by an empirical puzzle that some incumbents did invest heavily in R&D of the new technology but was delayed in securing market share after commercialization of the technology. The essay is further motivated by the possible differential roles of complementary assets, which are found to impact an incumbent's technology trajectory choice *ex ante* (Wu *et al*, 2011), but are understudied in the

technology management literature. Existing literature focuses primarily on the influence of complementary assets after the commercialization of a radical technology has happened, and only distinguishes between specialized and generic complementary assets at the level of industry (Teece, 1986; Christensen, 1997; Tripsas, 1997; Rothaermel, 2001a, 2001b; Rothaermel and Hill, 2005). This essay of my dissertation departs from existing literature by integrating the industry-level distinction between specialized and generic complementary assets with the firm-level heterogeneous competencies. I first distinguished whether or not a set of complementary assets are redeployable at the industry level, and then accounted for the strength of a given incumbent with respect to that set of complementary assets. By doing so, I avoided using the sweeping assumption that all incumbents are equally strong in possessing the same set of specialized complementary assets, and highlighted the importance of an incumbent's competence in those complementary assets. More specifically, I emphasized the redeployability of complementary assets across two technology regimes and distinguished between function-level and organization-level complementary assets. I further contended that an incumbent's decision to engage in R&D investment and the decision to enter a new industry are subject to related but different incentives and constraints; the firm's strength in non-redeployable complementary assets can be a differentiator for these two strategic maneuvers. Empirical findings from a sample of biofuels producing companies largely support this conjecture.

One interesting finding is that non-redeployable, function-level complementary assets play different and even opposite roles in decision-making of the two strategic maneuvers. In particular, if a firm is currently strong in these assets, the non-redeployability of these assets reduces the firm's intention to enter the new industry earlier, but actually induces the firm to engage in R&D early. In developing H1a, I suggested that an incumbent can engage in R&D earlier in order to compete for technical specifications of the next dominant design that can minimize value-destroying to its current complementary assets. This effect is found to be even stronger than predicted, in the case of

non-redeployable, function-level complementary assets. Indeed, the case of Kodak exemplifies this finding. Kodak possessed superior complementary assets in the chemical film industry, such as the marketing and distribution of the film products. These assets, however, would be devalued under the regime of digital imaging technology. At the early stage of the development of digital imaging technology, Kodak made substantial investment in R&D of the new radical technology, but its development was mainly focused on product designs that could be integrated with its existing complementary assets. For example, the early exploration of digital imaging technology in Kodak had a focus on "film-based digital imaging" (Gavetti, Henderson, and Giorgi, 2005), in the sense that product development projects were scattered over many divisions designed for the chemical film businesses, and that product innovations (e.g., digital print station, thermal printers, and paper to make prints from the cameras) were aimed to extend use of its film products. Consistent with the finding in this essay, Kodak engaged in early R&D of the digital imaging technology, not because it planned an early transition from chemical to digital imaging, but because it attempted to build off its existing assets that are likely to be devalued.

Existing works studying the influence of complementary assets on incumbents' post-entry performance in a new industry or subfields often use dichotomous measures, such as specialized versus generic complementary assets (e.g., Rothaermel and Hill, 2005), and devalued versus non-devalued complementary assets (e.g., Tripsas, 1997). Significant findings of various measures of complementary assets in this essay indicate the necessity to unpack the construct of complementary assets along multiple dimensions (e.g., redeployability and level in this essay). This approach enables deeper understanding about their roles. First, consistent with existing studies in technological change and industry entry (e.g., Helfat and Lieberman, 2002; Rothaermel, 2001a, 2001b), this essay finds a facilitating role of redeployable, functional complementary assets, but not the redeployable, organizational complementary assets. This suggests that it is helpful for future studies to not lump

together different levels of complementary assets, which may actually play different or even opposite roles. Second, results for hypotheses testing in this essay show that in a firm's decision of R&D investment and industry entry under high uncertainties, non-redeployable complementary assets play a larger role than redeployable complementary assets. Incumbents seem to pay more attention to the non-redeployability or likelihood of value-destroying of their complementary assets, which can be interpreted as important sources of rigidity in technological changes (Leonard-Barton, 1992). Third, the supportive evidence for H3, which predicts that the constraining effect of non-redeployable complementary assets is stronger with an incumbent's intent to enter industry early than its intent to invest in R&D, suggesting that the industry entry decision requires a more complicated calculus than the R&D investment decision. This is likely because possession of complementary assets is not indispensable for conducting R&D *per se*, but entering an industry does demand a full set of complementary assets in order to ensure efficient operations of and interactions among the various value-chain activities associated with a given business. The various real options available only to the R&D investment as well as the associated differential real options values become an important differentiator in the decision calculus.

Furthermore, findings from this essay provide complementary evidence to research literature on the success or failure of adopting technology with an *ex post* approach (Tripsas, 1997; Tripsas and Gavetti, 2000; Schilling, 2002; Hill and Rothaemel, 2003; Rothaermel and Hill, 2005) and industry evolution literature on post-entry performance (Helfat and Lieberman, 2002; Klepper and Simons, 2000; Mitchell, 1991), by examining how the different attributes of a firm's complementary assets enter its decision-making calculus. My findings from an *ex ante* perspective suggest a microscopic view is useful to better understand the differential roles of complementary assets on a firm's R&D investment and industry entry decision. We need to identify the specific type of complementary assets in order to disentangle mechanisms facilitating or constraining these two strategic maneuvers.

More research in this direction is needed to address the following limitations of this study. First, empirically, this study is based on a single industry context, so one needs to be cautious when generalizing findings from this essay of my dissertation to other industry contexts, where impact of technology regime shift may impact the redeployability of complementary assets in a rather different manner. Second, this study examines and compares a firm's R&D investment and industry entry when the decisions are still being made. Thus, the likelihood of R&D investment and that of industry entry are measured based upon managerial perception, rather than actual occurrences observed *ex post*. Though such a measure is necessary and appropriate for the current essay, it may encompass manager's cognitive bias in terms of accuracy of prediction. Future study, for example, can complement this study with a longitudinal approach to compare firms that actually enter the new industry with those that decide not to enter later. Third, theoretically, this essay considers primarily internal factors of a firm and the managerial interpretation of these factors in forming the managerial decisions. External factors in environmental change are also important and may interact with internal firm factors in inducing strategic action. Thus, a more complete research design that examines both internal and external factors will be a useful extension.

Notwithstanding these limitations, this essay of my dissertation contributes to the technology management and industry evolution literature. It is among the first few empirical studies that explore both facilitating and hindering roles of complementary assets on an incumbent's R&D investment and industry entry decisions *ex ante*. Thus, it unpacks the heterogeneities in entry decisions of firms that are often neglected in studies with *ex post* approach. It offers both managerial and policy implications for parties concerned with new technology promotion and industry policy by suggesting that policymakers, for example, consider the idiosyncratic attributes of different types of firms in their decision-making in order to make the policy more effective.

TABLES AND FIGURES

Table 4.1 - Descriptive Statistics and Correlations

	Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8
1. Strength in non-redeployable function-level complementary assets	-0.03	1.35	-1.93	2.84	1							
2. Strength in non-redeployable organization-level complementary assets	0.03	0.97	-1.92	1.78	-0.24**	1						
3. Strength in redeployable function-level complementary assets	0.01	1.34	-3.36	8.20	-0.03	0.08	1					
4. Strength in redeployable organization-level complementary assets	3.22	1.29	1	5	0.18	-0.25**	0.11	1				
5. Firm size	2.60	2.43	-6.21	6.40	0.03	-0.06	0.05	-0.18	1			
6. Firm age	4.67	3.91	1.00	28.0	0.17	-0.24**	0.03	0.09	-0.01	1		
7. Diversifying entrant	0.20	0.40	0.00	1.00	0.15	-0.13	0.04	0.15	0.00	0.21*	1	
8. Ethanol sector	0.55	0.50	0.00	1.00	-0.06	0.02	-0.10	-0.53***	0.48***	0.14	-0.15	1

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

Table 4.2: Bivariate Probit Regression on "Early R&D Investment" and "Early Industry Entry"

	Model 1		Model 2	
Dependent variable =	**Early R&D Investment**	**Early Industry Entry**	**Early R&D Investment**	**Early Industry Entry**
Constant	**-0.84**	**-0.67**	**0.21**	**-0.02**
	(0.71)	(0.81)	(0.88)	(1.03)
Firm size	**0.002**	**-0.001**	**0.002**	**-0.001**
	(0.002)	(0.002)	(0.002)	(0.003)
Firm age	**0.09****	**0.06**	**0.05**	**0.07**
	(0.04)	(0.07)	(0.04)	(0.07)
Diversifying entrant	**0.47**	**-0.50**	**0.57**	**-0.95***
	(0.43)	(0.45)	(0.44)	(0.58)
Ethanol sector	**-1.16****	**1.28****	**-1.41****	**0.99**
	(0.51)	(0.52)	(0.58)	(0.63)
Strength in redeployable function-level complementary assets	**0.14**	**0.64*****	**0.23****	**0.88*****
	(0.11)	(0.23)	(0.11)	(0.32)
Strength in redeployable organization-level complementary assets	**-0.04**	**0.44****	**-0.32**	**0.50**
	(0.17)	(0.22)	(0.24)	(0.32)
Strength in non-redeployable function-level complementary assets			**0.31****	**-0.36****
			(0.15)	(0.18)
Strength in non-redeployable organization-level complementary assets			**-0.59*****	**-1.10*****
			(0.23)	(0.31)
N	**75**		**75**	
Log pseudolikelihood	**-53.88**		**-41.94**	
AIC	**137.75**		**121.88**	
BIC	**172.52**		**165.92**	
Correlation between disturbances in "Early R&D Investment" and "Early Industry Entry" equations	**0.36**		**0.29**	
Standard error of the correlation above	**0.30**		**(0.34)**	

1. * p<0.1; ** p<0.05; *** p<0.01;
2. Standard errors robust to heteroskedasticity of unknown form in parenthesis.

Table 4.3: Impact of one-unit change in the determinants of "Early R&D Investment" and "Early Industry Entry" on marginal unconditional response probabilities

	Model 2	
Prediction for dependent variable of:	**Early R&D Investment**	**Early Industry Entry**
	dy/dx	**dy/dx**
Firm size	**0.00**	**-0.00**
	(0.00)	(0.00)
Firm age	**0.01**	**0.02**
	(0.01)	(0.02)
Diversifying entrant	**0.14**	**-0.16**
	(0.13)	(0.11)
Ethanol sector	**-0.32****	**0.16**
	(0.13)	(0.12)
Strength in redeployable function-level complementary assets	**0.05****	**0.23***
	(0.02)	(0.13)
Strength in redeployable organization-level complementary assets	**-0.07**	**0.14**
	(0.05)	(0.11)
Strength in non-redeployable function-level complementary assets	**0.06****	**-0.10***
	(0.03)	(0.06)
Strength in non-redeployable organization-level complementary assets	**-0.12*****	**-.30****
	(0.05)	(0.12)

1. * p<0.1; ** p<0.05; *** p<0.01;

2. Parameters are based on Model 2 in Table 2

3. Standard errors in parenthesis.

4. For variables "diversifying entrant" and "ethanol sector", dy/dx is for discrete change of dummy variable from 0 to 1

CHAPTER 5

CONCLUSION

The objective of my dissertation is to examine the relationships among transaction costs, firm capabilities, and industry evolution, with a focus on the temporal dimensions of these relationships. This dissertation shows the applicability of the organizational economics approach to a range of strategic issues, such as boundary choice at industry entry, investment decision about R&D of radical technology, and timing of industry entry. I theorize the fundamental implications of non-redeployablity of firm assets on these various strategic issues, and empirically test my hypotheses within the context of a nascent industry, the U.S. biofuels industry. I summarize findings, main questions addressed, and future questions raised in each of the essays in Table 5.1.

Essay one starts from the mixed findings of recent efforts to join the capability view and the transaction costs theory in the study of firm boundary choice, suggesting possible reasons. Then I propose two typologies of firm capabilities relevant to value creation and cost minimization, illustrating how the two typologies (i.e., characteristics of firm capabilities, and functions of firm capabilities) provide useful tools for addressing the challenges of joining the capability approach with the transaction costs theory. These tools hopefully can facilitate our more complete understanding of the firm boundary question.

This essay has important implications for the following two essays. It shows the usefulness of taking an integrative approach to the firm boundary question and it suggests the necessity to account for various contingencies involved in a firm's boundary choice. One important contingency comes from the temporal dimensions in the evolution of an industry, which I specifically focus on in essay two. It also informs the theory in essay three by suggesting that the interactions between firm capabilities and firm boundary are indeed two-way. While essay two examines the effect of a firm's

prior capabilities on its future boundary choice, essay three studies the effect of a firm's prior capabilities and boundary choice on its future capability development and boundary expansion.

In the second essay, I build on the typologies developed in the first essay and propose an integrative theoretical model connecting transaction hazards, firm capabilities, and industry evolution. It studies a special type of firm boundary question – boundary choice for a value chain activity when a firm enters a new industry – connecting organizational capabilities, organizational economics, and industry evolution literature. I deconstruct a firm's pre-entry capabilities into those residing in organizational routines and structural integration, and those residing in individual founders. I further divide transactional hazards into enduring ones and transient ones over the course of industry evolution. I further connect these constructs by differentiating roles of firm capabilities in lowering production costs or better managing transactions.

The findings of essay two are multifaceted. First, notwithstanding the differences in the views of Stigler (1951) and Williamson (1975) about the role of economies of scale and transaction costs in explaining vertical integration, I find support for both views. On the one hand, the results show that firms are more likely to internalize value-chain activities with high transaction costs. On the other hand, the asset specificity of a transaction may vary over an industry's life cycle. Knowledge accumulation and spillovers promote occurrence of specialized suppliers for various value-chain activities and may reduce, but not eliminate, overall asset specificity over time (Gort and Klepper, 1982; Stigler, 1951). Therefore, the results of this paper support a long-standing tenet of the literature on industry evolution: later entrants are less likely to internalize any given stage of a value chain and can take advantage of a more fully developed market to avoid internalization.

Second, the findings on organizational capabilities show that a firm's experience prior to entry shapes the scope of its activities in the focal industry and that different types of pre-entry experience have different impacts on decisions to internalize. This finding further advances the

industry evolution literature by distinguishing pre-entry experience with a given activity from broad firm-level, pre-entry experience related to integrative capabilities.

Third, I further find that the relevance of *activity level* experience to the decision to internalize attenuates as more specialized outside options become available with industry maturity, which is consistent with Bigelow and Argyres' (2008) study that shows a weak trend toward vertical de-integration in an industry over time. In contrast, diversifying entrants are less influenced by the availability of specialized suppliers of value-chain activities when they enter the industry later. Thus, integrative capabilities appear to be a different or higher-order construct than activity-level experience and may act in a different way on boundary choice.

And finally, findings of essay two highlight the value of pre-entry experience for managing relationships with external suppliers or related partners (Hoetker, 2005), adding to the growing body of research on dual governance (Mayer and Salomon, 2006; Parmigiani, 2007). By examining a firm's boundary choice for value-chain activities as it leverages *pre-entry* experience, this essay adds to this literature by examining the effect of transfer or spillover of capabilities from one industry to another, and the concomitant ability to buffer the effect of transaction costs.

Essay three studies a special type of capability development and boundary expansion: R&D investment and industry entry. I examine the hindering roles of non-redeployable complementary assets on an incumbent's decision-making in regard to early R&D investment and early industry entry. One interesting finding is that non-redeployable, function-level complementary assets play different and even opposite roles in decision-making of the two strategic maneuvers. More specifically, if a firm is currently strong in these assets, the non-redeployability of these assets reduces the firm's intention to enter the new industry earlier, but actually induces the firm to engage in R&D investment early. One possible explanation for this finding is that an incumbent can engage in R&D earlier so as to compete for technological specifications of the next dominant design,

thereby minimizing value-destroying to its current complementary assets. This effect is found to be even stronger in the case of non-redeployable, function-level complementary assets than non-redeployable, organization-level complementary assets. Another explanation for this effect is that the real options values embedded in early R&D are higher than those embedded in early industry entry. The trade-off between real options value (e.g., options of abandonment, growth, and wait) and non-redeployability of complementary assets influences incumbents to engage more likely in early R&D investment than in early industry entry.

LIMITATIONS AND FUTURE RESEARCH

This dissertation builds on the organizational economics approach to strategy management, while incorporating industry evolution and technology management literature. Such an integrative framework enables deeper understanding of the key issues related to firm boundary choice and capability development, opening up plentiful opportunities for future research.

First, the organizational economics theories discussed in this dissertation include the transaction costs theory, the capability view of the firm, and the real options theory. Other organizational economics theories can be further incorporated, such as the property rights theory. Although I focus only on the characteristics of firm capabilities related to value creation in essay one, consideration of value appropriation as well as value creation also plays an important role in a firm's boundary choice (Jensen & Meckling, 1976; Kim & Mahoney, 2005). If the contractual party contemplating firm-specific investment *ex ante* is not afforded residual control rights *ex post*, then a far-sighted decision-maker will foresee the contractual hazards of potentially having at least part of their investment appropriated; and consequently, there will likely be a rational under-investment in firm-specific capabilities (Mahoney and Qian, 2010). Therefore, future work is needed to complete the explanatory framework for the firm boundary question by taking into account the characteristics of firm capabilities related to value appropriation.

Second, the dissertation studies the antecedents of a firm's boundary choice and a manager's decision about engagement in a nascent industry through R&D investment or production. Future work is needed to understand these strategic decisions and examine the performance implications of these strategies. For example, in essay two, I find that diversifying entrants are more likely to remain vertically integrated than start-up entrants when they enter an industry at a later stage. I interpret this tendency as a rational decision of firms, for diversifying entrants possess integrative capabilities (Helfat and Campo-Rembado, 2011) and are more able to handle external suppliers. By this way of interpretation, I propose that diversifying entrants can also have performance benefits by remaining vertically integrated. Whether this proposition holds depends upon the extent to which these firms experience rigidities (Leonard-Barton, 1992) or inertia in their organizational changes. Further examination of the actual performance is able to verify this proposition.

Examination of performance implications is also an important next step for the third essay because of the *ex ante* approach it takes. In this essay, I study the antecedents of managerial decision-making of biofuels-producing companies in regard to their R&D investment and industry entry while the decisions are still being made. It will be interesting to follow through these firms by comparing their current action intentions and their actual decisions in the future. Such comparison sheds light on a set of questions: what organizational factors may contribute to the discrepancy between the intended and the actual strategy? Will the statistically significant relationships between explanatory variables (i.e., non-redeployable complementary assets) and dependent variables (i.e., the managerial decision to be early mover in R&D investment or industry entry) still hold at a later stage immediately before the actual decision? How can a firm deal with non-redeployability of its assets by engaging in alternative resource reallocation methods? What types of firms are more able to overcome the constraints by non-redeployable assets? To understand these and other related issues, a data collection method involving longitudinal surveys will be helpful.

The *ex ante* method used in essay three enables me to examine the decision-making process of managers facing high uncertainties. Aside from the manager's perception of a firm's strength in given value-chain activities, the decision-making process involves much more complicated dynamics among managerial perception, organizational factors, and external environment. To better unpack the managerial decision-making in the face of uncertainties, a simulation approach will be helpful. With a simulation method, researchers are able to manipulate different dynamics among variables of interest. For example, the third essay assumes a unitary-actor decision-making framework, in which the same manager is asked to predict R&D investment decision and industry entry decision. This may not be true in many cases, where R&D managers oversee the R&D investment decision and marketing managers are responsible for the market entry decision. When asked to advise the two investment decisions, there can be conflicts in incentives and interests of these managers. Thus, it is valuable to study the dynamics of these agents with divergent interests.

CONTRIBUTIONS

With the first essay, I develop a more complete framework for our enhanced understanding of the firm boundary question, contributing to recent development in literature that examines the role of firm capabilities in this strategic choice (Walker and Weber, 1984; Argyres, 1996; Madhok, 2002; Leiblein and Miller, 2003; Jacobides and Winter, 2005; Jacobides and Hitt, 2005). By identifying the types and attributes of firm capabilities involved in a given transaction, we are able to study the main and moderating effects of these firm capabilities, improving explanations and predictions of the empirical question in inquiry.

Essay two makes contributions to the multiple literatures it draws upon and engages. First, to the transaction costs literature: (1) it extends beyond the few studies that have examined governance choice in start-ups and small firms (Bigelow and Argyres, 2008) by answering the (*rephrased*) call by Williamson (1999): given their particular resources and capabilities at founding,

how should a firm organize value-chain activity X? (2) Although the unit of analysis in this study is an individual activity or a transaction, it goes beyond these by simultaneously considering multiple value-chain activities within a firm. (3) This study sees transaction costs with an evolutionary lens, proposing a categorization of transaction hazard – enduring and transient – and distinguishes their effects on boundary choice empirically. Second, this essay contributes to recent efforts to join the organizational capability view and the transaction costs theory (Argyres, 1996; Hoetker, 2005; Jacobides and Winter, 2005; Leiblein and Miller, 2003; Madhok, 2002; Walker and Weber, 1984) in explaining vertical integration. It not only incorporates the production efficiency into the inquiry of boundary choice, but also emphasizes the sources of the differences in production efficiency. It further examines how a firm's initial bundle of resources and capabilities may be the foundation for capability development and governance choice strategies after entry to an industry. Finally, essay two breaks down this initial bundle of firm resources and capabilities into activity- and firm-level capabilities in order to examine their differential effects. Thus, it enriches the construct of pre-entry experience developed in the extant industry evolution literature, which has often used an inadequate *de novo - de alio* dichotomous indicator. This enriched construct will hopefully enable further inquiries into the rich connections between pre-entry experience and post-entry strategies, as well as firm performance and survival.

In the third essay, I contribute to the industry evolution and technology management literature. First, it studies the underlying incentives and constraints of an incumbent's decision to invest in emerging radical technology and to enter the new industry, which have been studied largely as discrete phenomena. Second, with a deconstructed view of complementary assets, this paper is able to reveal the facilitating and/or constraining roles of deployable and non-deployable specialized complementary assets that have not been systematically studied, thus advancing our understanding about this important theoretical construct. Third, by studying the factors that differentially impact an

incumbent's decision to engage in R&D of an emerging radical technology or to enter a new industry, this study extends our understanding of the interaction between technology evolution and industry evolution further to the firm level. This approach is complementary to existing studies that mostly focus on the industry level.

As a whole, this dissertation makes broad contributions to the evolving science of strategic organization. First, it empirically tests two important questions in the strategy field (i.e., the firm boundary question and the sustainable competitive advantage question), which map onto the two phenomena studied (i.e., configuration of value-chain activities at industry entry, and timing of investment in R&D and industry entry). Second, it shows the utility of studying both the content and the process of firm strategies (e.g., the firm boundary choice of value-chain activities are observed *ex post*, while the R&D investment and industry entry decisions are primarily observed *ex ante*). Third, it also shows the benefits of combining quantitative and qualitative methodologies in empirical studies, encouraging future research modeled from this manner.

TABLES AND FIGURES

Table 5.1 Dissertation Summary: Questions, Findings and Future Research

	Main Question	Main Proposition / Finding	Questions for Future Research
Essay 1	How to integrate the capability view with the transaction costs theory so as to better explain the firm boundary question?	A more complete framework for explaining the firm boundary question consists of constructs related to functions of firm capabilities in cost minimization, and characteristics of firm capabilities in value creation.	1. What characteristics of firm capabilities that can affect value appropriation also have implications for a firm's boundary choice? 2. What factors may lead to changes in functions or characteristics of firm capabilities, and how to account for them in theory development?
Essay 2	What are the main and moderating effects of transaction hazards and pre-entry organizational capabilities on the choice between internalization and external development of a value-chain activity?	Entrants facing lower transaction hazard (enduring or transient), or with great pre-entry capabilities (firm level or activity level) are more likely to choose internal mode for a value chain activity; decrease in transient transaction hazard and capability to manage transactions moderate these main effects.	1. What are the performance implications of the boundary choice upon industry entry? Does the boundary choice intermediate the relationships between pre-entry firm capabilities and post-entry performance? 2. Given the moderating role of a firm's pre-entry capabilities, and that of the transient transaction hazard, how to tease out the potential trade-off between transaction costs and firm capabilities in the firm boundary question?
Essay 3	How do an incumbent's non-redeployable complementary assets differentially affect a manager's decision about timing of R&D investment and that of industry entry?	An incumbent's strength in non-redeployable complementary assets is negatively associated with its decision to enter a new industry early, but the strength may actually induce the firm to engage in R&D of a radical technology early.	1. Is there discrepancy between a firm's intended strategy and the actual strategy? If yes, what firm level factors contribute to such discrepancy? 2. How can a firm proactively use alternative resource allocation methods to negate the effects of non-redeployability of assets on its strategic choices? 3. How to unpack the process of managerial decision-making to capture the different incentives and interests underpinning the decision of R&D & industry entry?

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APPENDIX

Appendix 3.1A: Questions on measuring transaction hazards for an activity

Based upon your industrial knowledge, with a scale from 1 to 5, where 5 means a great deal, and 1 means not much, how would you rate the following aspects for a typical ethanol producer?

1. How frequent does an ethanol producer need to conduct feedstock procurement? (Please give a number between 1 to 5, and the same for the rest)
2. How frequent does an ethanol producer need to conduct technology development?
3. How frequent does an ethanol producer need to conduct ethanol distribution?
4. How frequent does an ethanol producer need to conduct co-product distribution?

5. To what extent is the feedstock procurement uncertain to an ethanol producer? (Please give a number between 1 to 5, and the same for the rest)
6. To what extent is the technology development uncertain to an ethanol producer?
7. To what extent is ethanol distribution operation uncertain to an ethanol producer?
8. To what extent is co-product distribution operation uncertain to an ethanol producer?

APPENDIX 3.1B: QUESTIONS ON ENDURING/TRANSIENT ASPECTS OF TRANSACTION HAZARDS FOR AN ACTIVITY

Please provide a response to the following questions, stating whether you agree or disagree with the statements. It would also be helpful if you could provide us with reasons substantiating your assessment.

1. Compared to the early years of the ethanol industry, ethanol producers can now rely more on external service providers to conduct activities, such as feedstock procurement, technology development, and marketing/distribution of products.

2. Compared to the early years of the ethanol industry, it is much easier to specify contract with external service providers, because the knowledge of conducting an activity has become more understandable.

3. Compared to the early years of the ethanol industry, it has also become much easier to evaluate the service quality by the external providers.

4. Over the years, ethanol producers keep facing substantial uncertainties in market demand for ethanol, fluctuations in corn/feedstock prices, and government policies.

5. Due to the nature of seasonal harvest of feedstock, ethanol producers need to conduct feedstock procurement, ethanol distribution and co-product distribution in a certain frequency. And the typical frequency for conducting an activity has largely remained the same, ever since the early years of the ethanol industry.

6. Aside from the recent development of cellulosic technology, the grain ethanol processing technology has followed a rather steady progress over the years. There have not been dramatic changes in the processing technology in the last two decades.

APPENDIX 4.A

1. Dependent variable:

- R&D investment -: ***For firms that choose answer (a) in both questions below, I assigned a value of 0; for all other firms, I assigned a value of 1.***

Which of the following better describes your company's current strategy in the next generation technology development? (check all that apply)

a) We currently are not investing in R&D on the next generation technology
b) We have developed the next generation technology on our own
c) We have set up a joint venture to do R&D on the next generation technology
d) We have acquired a firm that has R&D capabilities in the next generation technology

Which of the following better describes your company's likely investment strategy in the next generation technology development in the next 2-3 years? (check all that apply)

a) We will not invest in R&D on the next generation technology
b) We will develop the next generation technology on our own
c) We will set up a joint venture to do R&D on the next generation technology
d) We will acquire a firm that has R&D capabilities in the next generation technology

- Industry entry -: ***For firms that choose answers (c), (d), or (e), I assigned a value of 1; for all other firms, I assigned a value of 0.***

How soon after the technology is commercially viable will your company start to produce the 2nd generation ethanol/biodiesel?

a) We will not produce the 2nd generation ethanol/biodiesel
b) We will be laggards in producing the 2nd generation ethanol/biodiesel
c) We will produce the 2nd generation ethanol/biodiesel along with the industry majority
d) We will be among the early producers of the 2nd generation ethanol/biodiesel
e) We will be pioneers in producing the 2nd generation ethanol/biodiesel

2. Independent variable (5-item likert scale questions):

- Strength in non-deployable function-level complementary assets -:

a) How difficult is it for other ethanol/biodiesel producers to imitate your company's **(biofuels) marketing and distribution** activity?
b) How difficult is it for other ethanol/biodiesel producers to achieve the same level of efficiency and effectiveness in **(biofuels) marketing and distribution** as your company's?

- Strength in non-deployable organization-level complementary assets -:

a) Overall, our current investment in ethanol/biodiesel can be recouped if we were to produce the next generation ethanol/biodiesel
b) Development of the next generation technology is too complex and uncertain for our management team to pursue

3. Control variable (5-item likert scale question):

- Strength in deployable function-level complementary assets -:

a) How difficult is it for other ethanol/biodiesel producers to imitate your company's **feedstock procurement** activity?
b) How difficult is it for other ethanol/biodiesel producers to achieve the same level of efficiency and effectiveness in **feedstock procurement** as your company's?