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Bio Energy Entry Timing from a Resource Based View and Organizational Ecology Perspective

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Abstract

Recent changes in U.S. energy policy have prompted the growth of the bio energy market. The ability to quickly enter and respond to the opportunities of this market is critical to an agribusiness' success. Understanding entry into this rapidly growing bio energy market, however, is not well understood. In drawing on management theories of the Resource Based View (RBV) and that of Organizational Ecology, this study develops a conceptual and dynamic programming model to explain the entry behaviors of different types of bio energy businesses. A contribution of this study is it demonstrates that bio energy entry decisions emphasize a basic trade-off involving gains from a commitment to specialized, and correspondingly higher cost assets, and gains from remaining flexible with lower levels of fixed and less specific assets. This commitment-flexibility trade-off not only underlies entry, but such a trade-off is argued to be influenced by the population and uncertain conditions of the market. Importantly our work also sheds light on the implicit risks of the ethanol industry, and in part explains how corn-based dry mills and cellulosic-ethanol conversion technologies may be ideal depending on the type of market conditions upon entry.

Keywords: management theory, resource based view, bio fuels, ethanol, and organizational ecology entry timing.

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Introduction

Through various considerations relating to the U.S. Clean Air Act, rising energy prices, increasing green house gas emissions, and heightened concerns for national security, U.S. energy policy has focused its efforts on reducing its energy dependence from foreign supplies. Such a policy environment has contributed to a significant growth in the U.S. production of ethanol from 175 million gallons in 1980 to 4.85 billion gallons in 2006 (Rendleman and Shapouri, 2007); (Renewable Fuels Association 2008). Furthermore, five year forecasts made in 2007 predicted ethanol supply to exceed 7.5 billion gallons before 2012 (Mosier 2007). These estimates are already dated as U.S. supply has already breached 10 billion gallons in 2009 and is expected to rise substantially if the gasoline blend level is increased by 50% (RFA 2010). These market conditions have subsequently attracted the entry of many agri- and bio-related businesses. Ethanol plants alone have increased from 50 in 1999 to 170 in 2009 (Renewable Fuels Association 2009).

With this increasing growth and entry into the ethanol market, a basic challenge facing managers and investors is knowing when and how to enter this dynamic sector. On the question of when, earlier entrants into ethanol processing had gained significant first mover advantages from not only more favorable processing margins, but it also yielded pre-emptory benefits of lower construction and facility operation costs (Hurt, et al. 2006). While, later entrants face higher corn prices, higher construction costs, and, in particular, uncertainty about policy commitments to bio fuels. For instance, U.S. policy makers have questioned the use of corn for fuel and have contemplated the importation of lower cost sugarcane-based ethanol from Brazil. Enacted policy could thereby undermine the continued profitability of the corn-based ethanol market; causing pause for entry into the industry.

The emergence of alternative ethanol technologies also complicates the business environment for bio fuels. For example, there may be second mover advantages for firms to enter directly into second generation technologies, such as cellulosic. Relative to corn dry milling, cellulosic models are viewed as a more environmental friendly technology. They use a feedstock that does not directly compete for food production, has the potential to yield more ethanol per acre, and is thought to have a more favorable carbon footprint.

As the industry deals with the issue of when and how to enter the ethanol sector, management theories offer insights into this entry problem. One theory of management is the Resource Based View (RBV). It finds specialized assets create an incentive to enter early (King and Tucci 2002); (Mitchell 1989, 1991). This is because although specialized assets can yield a firm a differential or efficiency advantage over rivals (Lee et al., 2000; (Ghemawat and Del Sol 1998); (Mitchell 1989, 1991), the returns from such specialized are "eventually" imitated or replicated by new entrants (Lee et al., 2000); (Ghemawat and Del Sol 1998); (Mitchell 1989, 1991), Hence, specialized assets create an incentive to enter so as to gain first move advantage in securing the value of such assets (King and Tucci, 2001); (Mitchell, 1989,1991). For instance, empirical studies have found early entry can increase with the presence of specialized assets, such as in the U.S. Medical Diagnostic Imaging Industry (e.g., Mitchell, 1989, 1991). We explore in this research how this line of RBV reasoning although useful to understanding other industries, may not be applicable to the case of ethanol. This is because new entrants that produce corn-based ethanol by in large do not employ specialized assets, while the later entrants employing second generation cellulosic technologies do. This is because amongst other factors involving logistics, pretreatment activities etc, cellulose conversion to fermentable sugars is significantly more complex, and requires substantial R&D investments, either directly or indirectly, in specialized enzymes not used for corn or sugarcane.

Alternatively, theory from Organizational Ecology holds more promise to explaining the bio energy entry problem. Critics have maintained, and we find as well, that the firm level focus of the RBV leads to insufficient attention to the conditions of the market (e.g., Priem and Butler 2001). Organizational Ecology holds that in order to remain nimble and adaptive, the uncertainties associated with the emergence of new industries, bio energy in our case, require firms to not over invest in specialized assets. Such uncertainties however evolve with industry development and therefore different firm typologies are required to compete and survive at different stages of industry growth. We explore this theory and juxtapose it with the RBV within a dynamic simulation model of business entry and survival within the bio energy sector.

The objective of this study is to thereby integrate the specialized asset arguments of the RBV with the typologies and market level focus of Organizational Ecology. Through this integration, this study introduces a conceptual and analytical model that helps managers, investors, and analysts assess the entry decisions, especially as it relates to the dry milling and cellulosic conversion technologies of the ethanol market. This application to the bio energy sector also provides a novel context to advance the theoretical integration of RBV and Organizational Ecology perspectives to understanding a firm's entry decisions. Specifically, in this conceptual model, our contribution is that we demonstrate a bio energy firm's entry decisions depend on a basic trade-off between gains from a commitment to specialized, and correspondingly higher cost assets and gains from remaining flexible with lower levels of fixed and less specific assets. This commitment-flexibility trade-off not only underlies entry, but such a trade-off is argued to be influenced by the population and uncertain conditions of the market. Importantly our work also sheds light on the implicit risks of the ethanol industry, and in part explains how corn-based dry mills and cellulosic-ethanol conversion technologies may be ideal depending on the type of market conditions upon entry. To explore the implications of this basic trade-off for both managers and investors, a dynamic programming (DP) model is constructed that jointly accounts for this flexibility-commitment tradeoff and the market dynamics of the ethanol market.

In the development of this study's theoretical and simulation model, it is important to recognize that such a model is based on the authors' "best knowledge to date" of the ethanol industry. In particular, as the ethanol industry is a relatively young industry, much remains unknown and further analysis is needed as better information is developed. Hence, as understanding of this industry develops, our assumptions of this model will likely change and thus would need to re-evaluate the conclusions of our model (e.g. McGrath and MacMillan 2000). Our observations of this industry and the subsequent assumptions used in the development of our model thereby reflect but one possible view of the ethanol industry. Nevertheless, in spite of the changing and highly uncertain nature of this industry, we believe our study offers an "experimental" approach – a novel theoretical and simulation approach- that can help better understand some of the key risks factors impacting bio energy entry. Such an approach follows a "disciplined entrepreneurship" approach ascribed by Sull (2004) in which reduction of uncertainty can arise from not only the "experimentation of something new" but in doing so help identify the key variables that influence their possible payoffs (see also McGrath and MacMillan, 2000). The study's theoretical and empirical model is developed with this spirit in mind in which the integration of the RBV and Organizational Ecology perspectives into a DP context not only offers a unique approach to understanding ethanol entry decisions, but in doing so identify new variables of interest for manager and investors to consider when evaluating their bio-energy firm's possible payoffs.

Conceptual Model

Model Assumptions and Entry Characteristics of the Ethanol Industry

Some key assumptions and definitions are thereby first outlined before reviewing the associated literature. As the focus of this study is on the firm's entry into the ethanol market, this study assumes that the bio energy firm only produces ethanol fuel. This study's setting is stylized as we assume first generation ethanol conversion technologies only involve dry milling and second generation technologies involve cellulosic. Although there are numerous other possible forms of bio-conversion technologies, such as algae, entry into the ethanol market has been largely fueled by debates between these two technologies (e.g. McAloon et al. 2000); (Mosier 2007); (Robertson et al. 2000). Furthermore, this study does not examine wet milling technologies. Wet milling technologies can be used to process corn into ethanol as well as many other non ethanol products, such as high fructose corn syrup, corn oil, lysine, corn meal, plastics, and dyes. This study focuses only on dry milling technologies because relative to wet milling, it remains as the dominant ethanol conversion technology for new entrants due to its lower capital costs (Dale and Tyner 2006). Given these assumption, we examine the entry arguments underlying the RBV and Organizational ecology.

A basic assertion of the RBV is that a firm's performance or profitability stems from the characteristics of its resources. In terms of dynamic entry decisions, specialized assets are of particular interest to the RBV. The RBV argues that since specialized assets promote efficiency, specialized assets offer a firm a differential or efficiency advantage over rivals (Lee et al., 2000; (Ghemawat and Del Sol 1998); (Mitchell 1989, 1991). However, as specialized assets can "eventually" be imitated or replicated by new entrants (Lee et al., 2000); (Ghemawat and Del Sol 1998); (Mitchell 1989, 1991), specialized assets create an incentive to enter early because early entry enables a firm to gain a "head start" in securing the value of such assets (King and Tucci 2002); Mitchell, 1989, 1991). In the context of the ethanol market and as argued further, this RBV explanation suggests firms with specialized assets, such as cellulosic, should enter quickly. Waiting exposes the underlying technology to competitive imitation and thus eroding the economic rents associated with the investments in the specialized technology (i.e. development of feedstock specific cellulosic enzymes). This also suggests that firms with less specific or flexible assets, such as dry milling, do not face such risks from entering early.

This RBV logic, however, does not fit well with the market entry of first generation dry mill technologies. Entry into ethanol in the late 1990s was broad and rapid with few technological barriers to entry (Renewable Fuels Association 2004). As dry mill technologies were not specific, but available to all, the lower capital requirements of this non-specialized technology allowed for easy entry. This ease of entry subsequently led to a rapid increase in production capacity. While, as the second-generation technology, cellulosic involves significantly more specialized and as a result higher cost assets, cellulosic models have been adopted at a much slower pace. Hence, although the RBV provides some direction for explaining firm entry, the specific technology entry argument appears inconsistent or incomplete for explaining this pattern of entry in the U.S. ethanol industry.

Such inconsistencies can be attributed to limitations of the RBV. As the RBV has been criticized for its lack of attention to market conditions (Priem and Butler, 2001), entry timing research has called for a greater integration of the logic of the RBV with Organizational Ecology (Lieberman and Montgomery 1998). This is because Organizational Ecology argues that market conditions not only have a decisive influence on the entry and survival of firms, but also different stages of market development can have a distinct influence on the survival of different types of firms. For instance, during the early stages of market development, the market is commonly characterized by a high level of uncertainty and a low degree of competition (Lambkin and Day 1989). During this stage, Organizational Ecology argues that the market favors the entry and survival of flexible businesses because these firms, termed as R types, are suited to capitalizing on the emerging opportunities of early market development (Lambkin and Day 1989). Yet, as markets mature with greater certainty and competition, these market conditions favor the entry and survival of more efficient businesses characterized by K types. As a result, a shortcoming of RBV explanations is that entry decisions are not only influenced by a firm's specialized assets, but can also be influenced by the typologies and market conditions described by Organizational Ecology. However, absent in Organizational Ecology theory is it fails to provide sufficient attention to the specialized assets ascribed by the RBV. Hence, in order to develop an integrated RBV and Organizational ecology model of bio energy firm entry, the nature of a bio energy firm's specialized assets is explained in the context of the market conditions ascribed by Organizational Ecology.

Resource Based View Perspective on Entry Order: Specialized Assets

To advance this development, specialized assets are defined by a commitment to a course of action that is costly to reverse (Ghemawat and Del Sol 1998: 28). In other words, specialized assets involve significant investments upon entry and thus involve a high cost of abandonment (Ghemawat and Del. Sol 1998). In a bio energy context, dry milling firms generally face a lower commitment of resources and are associated with a lower degree of asset specificity than cellulosic. For instance, the capital cost for a typical dry mill ethanol plant is about $1 per gallon of capacity while cellulosic ethanol has capital costs 400 times greater (Renewable Fuels Association 2004); (McDermott 2009). While, more conservative estimates have found that second generation cellulosic production of ethanol from wood chips would still require $5 of capital per gallon of ethanol capacity (Mascoma Corp. 2008). Such differences in cost structure stem from bio-chemical reasons because dry milling technologies that convert starch are significantly simpler than those converting cellulose. While, cellulose conversion to fermentable sugars is significantly more complex, and requires substantial R&D investments, either directly or indirectly, in specialized enzymes not used for corn or sugarcane. Furthermore, dry milling technologies also have a long history producing industrial and food grade alcohols which has benefitted from learning curve and scale related cost efficiencies. While cellulosic is a second generation technology and has yet to be fully commercialized and thus does not benefit from the specialized efficiencies of dry milling. Lastly, as corn is the primary feedstock for dry milling, the transportation and storage of corn can be supported by existing assets of the market. On the other hand the primary feedstock for cellulosic plants, agricultural, industrial, and municipal wastes require novel collection logistic, storage, and pre-processing configurations and specific investments (Goldsmith et al. 2009). In fact, collection logistic, storage and pre-processing treatments tend to designed for the specific feedstock being used. For instance, due to the greater composition of liquids in municipal waste, the transportation of municipal waste requires different logistics, handling and pre-treatments than that of wood chips. As a result of these factors, the dry miller faces lower entry and abandonment costs due to a lower degree of asset specialization.

This concept of specialized assets not only underscores differences in commitment between that of the dry millers and cellulosic, but the concept also exhibits heterogeneous and imperfectly immobile properties that can impact a firm's entry decision. Specialized assets are heterogeneous resources in so far as they provide an efficiency differential between the firm and that of its rivals (Isobe et al. 2000); (Peteraf 1993); (Wernerfelt 1984). Hence, although specialized assets may require greater investment, they are a source of competitive advantage (Ghemawat and Del Sol 1998); (Peteraf 1993). For instance, though cellulosic faces higher capital requirements and fixed costs, there may be economies not present in dry milling. For example, cellulosic's reliance on agricultural, forestry, or municipal solid waste – as a primary feedstock- would result in lower feedstock costs than dry millers (Lin and Tanaka 2006). Such cost advantages are important as feedstock costs are more than 60% of operating expenses.

Finally RBV argues that firms with specialized assets should enter earlier, not later as in the case of cellulosic models. Early entry promotes learning curve effects that reinforce the efficiencies of a firm's specialized assets (Carow et al. 2004); (King and Tucci 2002); (Lee et al. 2000); (Lieberman and Montgomery 1998); (Mitchell 1989). Competitive advantages from learning are much less or nonexistent with old technologies such as sugar and starch conversion because much of the dry milling technology has been readily available over the past half of the century. . While, since cellulosic is yet to be a fully commercialized technology, early entrant cellulose plant managers could gain significant advantages over competitors from "learning-by-doing."

Entry decisions also need to consider that specialized assets are imperfectly immobile (Ghemawat and Del Sol 1998), (Peteraf 1993). Imperfectly immobile assets are assets that are specific to the needs of the firm and thus tend to be "sticky" resources (Ghemawat and Del Sol 1998). For instance, because cellulosic requires a considerable commitment of resources that can lead to a potentially high abandonment cost, cellulosic involves high levels of immobile assets. Although this immobility preserves a firm's efficiency differential and thus competitive rents, markets can nevertheless shifts and thus render immobile assets useless (Ghemawat and Del Sol 1998). Furthermore, because immobile assets are "imperfect", they can "eventually" be imitated or replicated by later entrants (Mitchell, 1989, 1991); (Ghemawat and Del Sol 1998); (Lee et al. 2000). With imperfectly immobile assets, there is, therefore, an incentive to enter early.

Due to the heterogeneous and imperfectly mobile properties, specialized assets create an inherent tension for managers and investors. The first mover advantages of entering early to stay ahead of imitation and exploit gains from specialization come at a risk to the underlying investment in the specialized assets. This because early and specialized investment in large scale facilities may be misplaced as market conditions change. In that, this line of reasoning suggests cellulosic firms, such as Mascoma, Iogen, CERES, Novozymes and Genecor International, have an incentive to enter early because early entry pre-empts the influences of competitive imitation and provides a means to exploit the temporary cost advantages of their firm's specific assets. But they can be rightly hesitant to such early mover advantages, if the market and policy environments for ethanol are too uncertain. For example the U.S. government could chose not to protect the higher cost infant cellulose-based ethanol industry in favor of free market policies that would allow entry to low cost first generation sugarcane ethanol from Brazil or Cuba. The biodiesel industry directly faces such uncertainties as extension of government subsidization has recently been allowed to lapse (Abuelsamid 2010).

While, in contrast to specialized resources, non-specialized or flexible resources are neither heterogeneous nor imperfectly immobile. Flexible resources, such as dry milling, are not a source of competitive advantage (Ghemawat and Del Sol 1998). This is because non-specialized assets do not involve significant commitments in which earlier decisions can be reversed with minimal cost (Ghemawat and Del Sol 1998). Flexible assets thereby not only reduce the cost of entry and exit into a market, but as consequence create highly competitive or contestable market conditions that erodes gains from such assets (Ghemawat and Del Sol 1998). As Ghemawat and Del Sol (1998) describes:

> "Thus, while companies may invest in firm-flexible resources to reduce their exit barriers [i.e. low abandonment costs], the trouble is that this kind of investment is also likely to reduce entry barriers. In a hypothetical situation where there are no entry or exit barriers – a situation described by economists as perfectly contestable – any advantage would be ironed out in the twinkling of an eye" (Ghemawat and Del Sol 1998: 32)

With flexible assets, there is an incentive to delay entry. This is because, due to the mobile nature of non-specific assets, the returns from these assets can be readily appropriated by a firm's rivals (Ghemawat and Del Sol 1998). As a result, unlike that of the specialized asset case, early entry would not enable the firm to secure the value of these flexible assets and thus favoring later entry. Yet, since entry into the bio energy industry is predominantly driven by the early entry of dry milling firms, such a RBV explanation thereby cannot readily explain this type of entry behavior.

Organizational Ecology Explanations of Entry Order Effects: R and K type Firms

Entry timing decisions are not only influenced by a firm's specialized or flexibility assets, but are also influenced by market conditions surrounding entry. In particular, a basic premise of Organizational Ecology is that the market is the primary determinant of a firm's life cycle. Organizational Ecology argues that markets support the entry and thus growth and survival of a population of firms (Carroll and Hannan, 1989); (Hannan and Freeman 1977). For instance, in the case of ethanol, the growth in the number of ethanol plants is attributed to the market opportunities created by the Toxic Substances control act of 2000. The act called for the elimination of MTBE additives in fuel because of its potential risks to public health and the environment. The act created a standard of utilizing ethanol as a fuel additive replacement.

Consequently through this act, a large market for ethanol was created. The creation of this market subsequently supported the rapid entry and growth of ethanol processors.
As markets support the growth of a population of firms, Organization Ecology also argues that this growth yields competitive influences that favor the survival of distinct organizational forms (Brittain and Freeman 1980); (Brittain and Wholey 1988); (Lambkin and Day 1989); (Zammuto 1988). Organizational Ecology argues that as markets evolve through various stages of the product-life cycle, each stage favors the entry and survival of two archetype firms - R and K types. R types are characterized by small and flexible entrepreneurial firms that have simple organizational structures (i.e. less developed bureaucracies) (Ebben and Johnson 2005); (Zammuto 1988). These characteristics enable the R type to quickly capitalize on the newfound opportunities of an emerging market niche (Brittain and Freeman1980); (Lambkin and Day 1989) and thus the R type is proficient in exploiting first mover advantages (FMA) (Brittain and Freeman 1980); (Lambkin and Day 1989); (Zammuto 1988). That is, due to R types' speed and flexibility, R types favor early entry into the initial or formative stages of the product-market life cycle (Brittain and Freeman 1980); (Lambkin and Day 1989); (Wholey and Brittain 1986); (Zammuto 1988).

However, gains from FMA dissipate with the increasing maturity of the product-market lifecycle (Lambkin and Day 1989); (Lieberman and Montgomery 1998). With increasing market maturity, selection no longer favors the speed and flexibility of R types, but rather favors K types that compete on scale efficiencies (Brittain and Freeman 1980); (Lambkin and Day 1989). Such efficiencies stem from K types' types higher fixed investments (i.e. scale economies) and bureaucratic organizational structures (Brittain and Freeman 1980); (Lambkin and Day 1989); (Zammuto 1988). As these efficiencies enable the K type to compete in highly populated markets, K types favor entry into the mature stage of the product-life cycle (Brittain and Freeman 1980); (Lambkin and Day 1989); (Zammuto 1988).

Integrating the Resource Based View and Organizational Ecology

However, as Organizational Ecology focuses on a population level of analysis, it tends to overlook the underlying assets that contribute to R and K types' entry behavior (see Hannan and Freeman 1977). Our study argues that due to R types' smaller size, the R type lacks specialized assets. This is because with its smaller size, the R type does not have the same access to financial resources as larger firms and, as a result, lacks the commitment that is necessary for investing into fixed and specialized assets (Ebben and Johnson 2005). Yet in spite of this lack of specialized assets, the R type firm can shift tactics and goals as environmental circumstances change and thus can better respond to new and emerging market opportunities. This is consistent with Miles et al. (1978) and Zammuto (1988) who contend R type's flexibility stems from minimizing their long-term commitment to any single technology or market.

However, unlike the R type, the K type exhibits considerably greater specialization of assets. This is because with its larger size and more certain business environment, the K type can attract larger amounts of financial resources which enable the K type to invest in fixed and dedicated production assets. With such investments, the K type benefits from scale efficiencies and other related learning economies that serve to further K type's specialization of tasks (e.g. Brittain and Freeman 1980); (Ebben and Johnson 2005); (Miles et al. 1978); (Zammuto 1988). This is consistent with Miles et al. (1978) who find that K type's efficiencies stems from its specialization to a single core technology. However, as specialized assets are costly to reverse (Ghemawat and del Sol. 1998), this specialization limits K type's flexibility to adapt to changing market conditions (e.g. Brittain and Freeman 1980); (Zammuto 1988).

In a bio energy context, differences in the R and K types' specialization of assets are thus argued to be analogous to the assets used by the dry mill and cellulosic firms. Namely, the flexibility of R types is argued to be analogous to the versatility of the dry milling firm. This is because since dry mill firms do not require a significant commitment of resources, dry mill firms face a lower entry / exit costs than the cellulosic firm. With these lower costs, the dry milling firm, like the R type firm, can thereby quickly respond to the emerging opportunities of the market. This is because due to the relative absence of a significant commitment of resources, it minimizes the cost of reversing earlier decisions and thus enables the R type firm to respond quickly to changes in the market (Ghemawat and Del Sol 1998). However, since such flexibility is gained at the expense of a lack of specialization, the dry milling firm – like the R type- cannot compete on low cost. Costs are higher but entry is quicker and easier, and abandonment costs are lower if markets change. With such lower abandonment costs, the dry milling firm can thereby exhibit the flexible properties of the R type firm.

While, unlike the flexibility of the R type dry milling firm, the efficiencies of the K type are analogous to the specializations of the cellulosic firm. Namely, as cellulosic requires significant commitments in R&D (Lamonica 2008); (Verenium Corp. 2010) that can span over multiple years, such investments are not only costly, but are also costly to reverse. This commitment to R&D though not only gives rise to the specialized nature of the cellulosic firm but such commitment raises costs and limits the cellulosic firm's flexibility to the changing conditions of the ethanol market. Therefore, due to this specialization of assets, the cellulosic firm exhibits the limited flexibility of the K type. However, as a commitment to specialized assets yields gains in efficiency, the cellulosic firm exhibits the scale efficiencies of the K type. For instance, key commercial challenges facing cellulosic firms are improving the efficiency of plant operations; gallons ethanol/ton of feedstock, enzymes/gallon of ethanol; ethanol/unit of time; and ethanol/ unit of capital cellulose (Knauf and Moniruzzaman 2004); (Rendleman and Shapouri 2007); (Goldsmith 2009) and(Goldsmith et al. 2010). As these costs largely stem from the firm's commitment to, or acquisition of R&D, such fixed investments can yield opportunities to exploit significant scale related economies. For example, investment in efficient enzyme technologies would yield access to new large, abundant, and low cost biomass feedstocks. In particular, dry milling technologies have a predicted maximum capacity of 15 billion gallons / year due to limited corn availability. Cellulose mills could produce upwards of 70 billion gallons of ethanol just from agricultural wastes (Mosier 2007); (Grainnet 2010). This potential to access a larger volume of cheap feedstock by the K type cellulose mills can thereby yield scale efficiencies that lower the cost of processing ethanol as compared with the R type dry milling approach (Graf and Koehler 2000); (Hammelinck et al. 2005). Some studies have suggested that once cellulosic enzymes become successfully commercialized, cellulose mills will have significantly lower operating costs when compared with dry milling (Lin and Tanaka 2006). Hence, due to the specialized nature of the cellulosic, the cellulosic firm is thereby analogous to the large scale efficiencies of the K type firm.

Based on these R and K type distinctions, Table 1 summarizes the essential features of the R and K type bio energy firms and relates their features to differences in their specialized assets.

Table 1. R and K type Bio Energy Firm Characteristics

Firm Type	Flexibility	Productive Efficiency	Specialized Assets	Bio Energy Firm Equivalent
R Type	High	High	Low	Dry Miller
K Type	Low	High	High	Cellulosic

Theoretical Propositions

Specialized Assets and Density Dependence

Differences in the specialization of assets between the R type dry milling and K type cellulosic firm not only provide Organizational Ecology a greater firm level orientation, but also yield a RBV explanation that is consistent with Organizational Ecology's theory of density dependence. Density dependence suggests that under low density environments, there is an abundance of market opportunities that favor the flexibility and speed of the R type dry milling firm. Such a view might partially explain the early and rapid entry of dry milling firms during the 1990s. During this period, early entry was motivated by a lack of investments in specialized assets because this provided the dry milling firm the flexibility to quickly enter and exploit the opportunities of the emerging ethanol market. As this early entry into the ethanol market has been largely dominated by dry milling technologies (Renewable Fuels Association 2004); (Dale and Tyner 2006), this density dependent selection of the R type firm is offered as one explanation of the early entry of the dry milling firm.

Alternatively, under highly dense populations, density dependence argues the competition for scarce market opportunities favors firms that can compete on efficiency (Brittain and Freeman 1980); (Lambkin and Day 1989); (Zammuto 1988). Since K types have specialized assets that yields scale economies, such assets thereby enable the K type to compete in highly competitive conditions. Hence, according to density dependence, competitive conditions will favor the entry of the K type cellulosic firm. In drawing on the logic of density dependence, the R type dry milling firm and K type cellulosic entry behaviors can, thereby, be explained by the following proposition:

Proposition (1): Given differences in their specialization of assets, an R and K types' entry timing is density dependent whereby low (high) population densities at founding favor R type dry milling firm (K type cellulosic firm) type entrance.

Asset Specificity and Market Uncertainty

In addition to such density dependent effects, Organizational Ecologists contend uncertainties over the various stages of the product-market life cycle can also affect an R and K types' entry timing. During the early stages of the product life cycle, consumer preferences are typically ill defined and product attributes such as price, quality, function and other demand attributes are largely unknown (Kerin et al. 1992); (Lambkin and Day 1989); (Shankar et al. 1998). With such uncertainty, the R type's lack of specialized assets minimizes their exposure to risk because by avoiding a significant commitment of resources, changes in market conditions incur a minimal cost to R type's investments (Ghemawat and Del Sol, 1998). In addition, since R types lack of specialized assets result in a smaller scale of operations, R types are better able to with stand down turns during the early stages of market development. However, as markets mature, the greater certainty of market favors the selection of the K type firm (Lambkin and Day1989); (Zammuto 1988). With greater market certainty, customer needs become better identified to which allows marketing efforts to be precisely targeted. Input requirements also become better defined. Hence, as markets mature, markets favor K types' specializations of skills (Lambkin and Day 1989); (Robinson et al. 1992). Moreover, the K type is favored in certain markets because the reduction of market uncertainty minimizes the risk to K type's specialized assets to which enables the K type to focus on developing further improvements in their production efficiencies (Lambkin and Day 1989). With this reduction of market uncertainty, this promotes the entry by the K type firm.

Such "uncertainty" dependent predictions have parallels to the uncertainties faced by bio energy firms. There are various sources of uncertainty that can impact the demand for ethanol. Currently, the demand for ethanol is limited by an "ethanol-blend wall" in which a maximum of a 10% ethanol-fuel blend is permitted for transportation fuels. However Growth Energy has recently proposed to the EPA raising the amount to 15%. Such potential changes in fuel blend mixture are therefore one important sources of demand uncertainty. Demand uncertainties can also arise from the threat of low cost exporters of ethanol, such as Brazil. Furthermore, there have been increasing concerns by critics about the social and environmental benefits of corn-ethanol production (Roberts et al. 2000). Critics have argued that the production of fuel from corn directly competes with human consumption. Furthermore, the increasing use of chemicals and fertilizers in the production of corn-ethanol has led to increasing skepticism about the environment benefits of corn-ethanol (Roberts et al. 2000). Such debates create considerable uncertainty about the continued viability and thus demand for the US corn-ethanol industry. Such demand uncertainties also places considerable uncertainty in the underlying technologies that will define this market. Namely, will the market by defined by cellulosic or by dry milling technology?

Under such uncertain demand conditions, Organizational Ecology suggests that the R type dry milling firm is better able to tolerate the uncertainties of this market. This is because due to the absence of a significant commitment of resources, the R type dry milling firm is least exposed to the uncertainties of this market. That is, in the absence of a significant investment in specialized processing assets (i.e. minimal investments in R&D in feedstock specific enzymes); the R type dry milling faces a relatively low cost of entry / exit whereby under conditions of uncertainty, an incorrect entry decision can be reversed at minimal cost. Furthermore, as R type's lack of commitment to specialized assets leads to a smaller scale of operations, this smaller scale is suited to capitalizing on the nascent yet uncertain demands of this market.

On the other hand, under stable market conditions, the K type cellulosic firm is favored over that of the R type dry milling firm because stable ethanol markets reduce the risk to K type's specialized assets. In particular, since scale and processing efficiencies are dependent upon stable market conditions (Lambkin and Day 1989), limited disruptions in demand enable the K type cellulosic firm to not only exploit potential scale economies but also limits its exposure to the risk associated with their investments in R&D. These "uncertainty" dependent arguments are thus proposed by the following:

Proposition (2): Given differences in R and K type's specialization of assets, entry-timing effects are uncertainty dependent whereby uncertain (stable) market conditions at founding favors the entrance of R (K) types.

R and K type Entry Decision Making

Differences in the specialization of assets by R and K types thereby yield a distinct trade-off between those gains from a commitment to specialized assets and the flexibility afforded by non-specialized assets (e.g. Ebben and Johnson 2005); (Ghemawat and Del Sol 1998); (Lieberman and Montgomery 1998); (Miller and Folta 2002). For instance, early commitments to specialized assets yield advantages from "exploiting" gains associated with efficiency. By committing to specialized assets, it promotes a firm's ability to "exploit" or build upon its existing technical competence. Yet, such a commitment reduces a firm's flexibility from "exploring" new market opportunities (Levinthal and March 1993). Exploration, nevertheless, has its costs because a firm fails to develop a distinct area of competence (March 1991). This study argues that this commitment (exploitation)-flexibility (exploration) trade-off not only drives an R and K type's entry decisions, but subsequently determines the entry timing effects of density dependence and market uncertainty.

To elaborate, an R type's entry decision involves distinctly trading off gains from a commitment to exploit the efficiencies of specialized assets for the explorative benefits of flexible assets. Since the R type lacks a commitment to specialized resources, the R type - relative to the K type – has an inherent cost disadvantage. Yet, as the lack of specialized assets reduces a firm's commitment to any particular set of assets, the R type benefits from being able to adapt and explore the changing opportunities of an emerging market. This is consistent with Zammuto (1988) who contends R types are adept at competing for first mover advantages, but fail to capitalize on efficiencies in leveraging a distinct area of expertise. This reasoning suggests that the early and rapid entry by dry milling firms in the 1990s was not due to efficiencies from the dry milling technology, but rather due to their low capital commitments. Stated differently, since dry milling involves a relatively low commitment of resources, this technology provided a low cost of entry as well as exit into this market. Yet, since the R type dry milling firm cannot compete on efficiency, this low cost of entry / exit, therefore, requires that the R type dry milling compete strictly on the first mover advantages of early entry. As a result of this trade-off, an R type dry milling firm enters early into the market in which markets are characterized by a low population and a high degree of uncertainty. This trade-off is proposed by the follow decision heuristic:

Proposition (3): Driven by non-specialized assets, an R type's early entry is the result of trading off its lack of production efficiencies for first mover advantages to which such a trade-off favors an R type's early entry into low populated and uncertain markets.

While, the K type firm's entry decision emphasizes trading off the flexibility of non-specialized assets for its commitment to exploit the production efficiencies of its specialized assets.

However, since these production efficiencies involve an irreversible commitment of resources or at the minimum involve high entry and abandonment cost, this commitment to specialize limits K type's flexibility from exploring the opportunities of emerging markets. Therefore, unlike the R type, the K type's entry decision involves trading off the first mover advantages of non-specialized assets for the gains in production efficiency that arise from a commitment to specialization. With this decision trade-off, this suggests the K type cellulosic firm distinctly favors late entrance for two reasons. First, as ethanol demand in maturing markets become well defined, late entry reduces the risk to K type's investments in cellulosic. That is, such reductions in uncertainty provide justification for cellulosic firms to not only invest in costly R&D but also enable the K type to raise capital from external investors. Second, with relatively stable market conditions, output variations are minimized to which promotes the exploitation and thus specialization of tasks (e.g. Levinthal and March 1993). This enables the K type cellulosic firm to exploit its scale efficiencies and thus compete in high-density environments. This trade-off is proposed by the follow decision heuristic:

Proposition (4): Driven by specialized assets, K type's late entry decision is a result of trading off gains from first mover advantage for production efficiency rents to which such a trade-off favors a K type's entry into highly populated and certain markets.

R and K type Learning Effects

A consequence of such decision heuristics is that an R and K types' entry decisions distinctly affect their ability to exploit learning curve advantages. Since the R type competes through an early entry of the market, the R type dry milling firm thereby affords a "head start" in developing experiences that can reduce its cost. This head start yields learning curve advantages that can create a relative cost advantage to later entrants (Kerin et al. 1992); (Lieberman and Montgomery 1998). This can be important for the R type dry milling firm because by leveraging such learning curve effects, the firm can compete with the scale efficiencies of the K type cellulosic firm. However, since the K type cellulosic firm has specialized assets, the K type should, thus, be better at exploiting such learning curve effects than the R type. This is because a firm's specialization of experiences reinforces learning curve effects (Levinthal and March 1993); (March 1991). Hence, this suggests that since the cellulosic firm largely competes through their ability to exploit scale economies, learning curve effects should have a greater impact on the cellulosic firm's performance than that of the dry milling firm. The following is proposed:

Proposition (5): Given the specialization of assets of the R and K type, learning curve effects have a more pronounced effect on K type's performance than the R type.

Method

To integrate the insights of the Resource Based View with Organizational Ecology, a dynamic programming (DP) simulation model was developed. DP models are suited to examining systems where there are a series or a sequence of decisions that are being made with respect to a number of changing state variables. Specifically, DP programming involves determining a sequence of optimal decisions that maximizes a given function for any given changes in future states of nature (Kennedy 1986). DP also involves decisions that involve trade-offs in which there are explicit benefits and costs associated with each decision (Kennedy 1986).

This study argues that a firm's entry into the ethanol market exhibits these DP characteristics. As the product-life cycle evolves through various states of competition and uncertainty, the entry problem facing the manager is one of deciding over these changes in market states, a sequence of entry decisions that will maximize their firm's profits. Moreover, since a DP approach is suited to examining trade-offs, such an approach is thereby suited to examining the firm's commitment vs. flexibility trade-off (Ghemawat and Del Sol 1998).

Formulating a DP Model

DP involves deriving an optimal policy of interrelated optimal decisions that maximize an objective function over time. Founded on Bellman's (1957) principle of optimality, an optimal policy "has the property that whatever the initial state decisions are, the remaining decisions must constitute an optimal policy with regard to the stage resulting from the first decision" (Bellman 1957: 83). Stated in mathematical terms, DP involves solving for a sequence of decisions or an optimal policy, $\{U_1, U_2, U_3, ... U_{T-1}\}$ that maximizes a specified objective function, V_t (S_t, U_t), given a series of states $(S_1, S_2, S_3 ... S_{t-1})$ for a finite period of t to T-1 simulation periods (T = end of the product life cycle). Optimal decisions and state conditions are related through a state transformation function, S_{t+1} (S_t, U_t), in which a current decision, U_t and state, S_t, impacts a future state, S_{t+1}

To solve such a DP programming problem, backward induction is a commonly used algorithm (Kennedy 1986). Backward induction is a process of solving a sequence of optimal decisions by solving them backwards in time. Backward induction proceeds by first considering the decision being made in the last period and then choosing the optimal decision for the states associated with this period. Using the optimal decision made in this last period, one then determines the next optimal decision for the second-to-last period. This process continues backwards until the optimal decision has been determined for every possible state at every point in time. This backward induction algorithm is typically suited to solving problems with a finite time horizon and for problems involving discrete choice (i.e., enter or exit). Optimal solutions to such a problem are computed numerically.

This backward induction algorithm is used to solve the bio energy firm's (R and K types) optimal entry. This is because a bio energy firm's entry decision is based on a discrete entry choice that occurs over various market states. Furthermore, since a firm's decision to enter and remain within this bio energy sector is not indefinite, the entry decision is, thus, based on a finite planning horizon. That is, a finite horizon was chosen because a manager's planning horizon is typically based on returns over a finite period. Moreover, a finite horizon was chosen because optimal policy decisions are easier to compute and requires less computational resources.

To illustrate the firm's entry decision, equations 1 and 2 translate a firm's entry behavior into a DP structure. A firm – such as an R or K type - for each time period, t, faces an entry or exit decision, U_t (1 = enter, 0 = not to enter / exit), that maximizes its profits, V_t (S_t, U_t) over t=0 to T-1 simulation periods. For a given period t, a firm's profits – equation 1– is comprised of gains from early entry or first mover advantage (FMA), X_t (U_t), and gains from its production efficiencies, P_t (U_t, S_t). Since a firm's specialized assets impacts a firm's entry timing, a specialized asset parameter, SA_t, is included into this profit equation. This specialized asset parameter, SA_t, reflects a firm's commitment to the ethanol industry. Larger values denote greater specificity and thus reflect a greater commitment to the industry than firms with less specialized assets. This characterization is also consistent with Ghemawat and Del Sols' (1998) characterization of specialized assets. As the principle of optimality requires that future decisions must be optimal to earlier decisions, a firm's profit must also include a one period future discounted profit value, $V_{t+1}(S_{t+1},U_t)$. β denotes a fixed discount rate.

$$(1)\quad V_t(U_t,S_t)=\underset{U_t}{Max}\sum_{t=0}^{T-1}X_t(U_t)+P_t(U_t,S_t)-SA_t+\beta\cdot V_{t+1}(U_{t+1},S_{t+1})$$

$$(2)\quad S_{t+1}=S_t+U_t,\ S_0=0$$

The dynamic optimization of Equation 1 is constrained by a state transformation function, Equation 2. Given a firm's (1) entry / (0) exit decision, U_t, Equation 2 shows a firm's one period future experience, S_{t+1}, is the sum of the firm's accumulated experience, S_t, and its optimal decision, U_t, at period t. Since a newly entering firm has no prior experience, its initial experience is equated to zero, S_0=0 (e.g. Stinchcombe 1965).

Innovation or FMA Rent: X_t (U_t)

As entry decisions involve evaluating competing gains in FMA against gains in production efficiency, FMA, X_t (U_t), are the expected returns to a firm from bringing a new product or service to an emerging market (equation 3). The new product here is fuel ethanol. The expected returns are described by equation 3 whereby Pr_t (N_{t-1}), reflects the price of the ethanol produced by the firm. However, as witnessed in the ethanol market when there has been active investment and subsequent expansion of industry capacity, the price of ethanol declined[1]. In this study, we attribute this decline in price to increases in direct and indirect competition, N_{t-1} (see also equation 8) in the ethanol market (Renewable Fuels Association 2008, 2009). Furthermore, W represents the expected returns from introducing ethanol to the market at time t = 0 (i.e. initial period of the simulation). As the gains from dry milling technologies are subject to obsolescence by newer technologies[2], such as cellulosic, this expected return should thus decline with increasing market maturity. As a result, with increasing market maturity, t, returns, W, are modeled by a non-linear function that declines at an exponential rate, δ. The level of innovation rents or FMA returns secured by a firm is then derived by the product of a firm's entry decision, U_t, (0 or 1) at time, t, price, Pr_t (N_{t-1}) and the declining value of the expected returns, W.

$$(3)\, X_t(U_t)=\Pr_t(N_{t-1})\cdot W\cdot \exp^{\delta\cdot t}\cdot U_t$$

Gains from Production Efficiencies, P_t (U_t, S_t):

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[1] Alternatively, such declines in ethanol prices can be similarly observed by declines in the corn-ethanol spread.

[2] A reviewer correctly points out that our model is a stylized view of the industry. Nobody knows for sure whether cellulosic technology will replace dry mill derived ethanol. One can surely imagine settings with excess corn with few market alternatives and poor infrastructure, e.g. Mato Grosso, Brazil (See Goldsmith et al. 2010), where low-capital cost dry milling might be competitive.

Gains from production efficiencies, $P_t\,(U_t\,,\,S_t)$ are returns from better utilizing the productive capacity of a firm's specialized or non-specialized assets. A firm's capacity utilization is determined by comparing the size of the market demand for ethanol, MS_t , with the productive capacity, Q_t^* , of a firm's assets (see also Kerin et al. 1992). When the market demand or market size (MS_t) exceeds the firm's productive capacity, Q_t^* , the firm's volume of output, Q_t , is maximized at the level of its production capacity, Q_t^* . However, when market demand falls short of a firm's production capacity, such as the initial stages of market development, the firm would not fully utilize its production capacity. The firm produces a level of ethanol output, Q_t , that is determined by the current level of market demand, MS_t. A firm's volume of ethanol output, Q_t , and production efficiencies are described by the following inequalities:

$$(4)\quad if\ Q_t^* > MS_t^*, then\ 0 < Q_t = MS_t^* < Q_t^*$$
$$Else,\ if\ \ Q_t^* < MS_t^*,\ then\ Q_t^* = Q_t < MS_t^*$$

Market Size

The market demand or market size of ethanol, MS_t , is expressed as the product of a market growth parameter, s, and a time trend variable, t (Equation 5). To capture mature market conditions, this growth in demand has an upper limit of $\overline{M}$. This upper limit can be interpreted as the "ethanol-blend wall" in which a maximum 10% ethanol-fuel blend is currently permitted by law.

$$(5)\quad MS_t = Min\left[s \cdot t^3, \overline{M}\right]$$

In addition, as markets mature, the demand for ethanol should become increasingly stable or certain. Market size, MS_t^*, is, thus, adjusted by a market uncertainty function, UNC_t.

$$(6)\quad MS_t^* = MS_t \cdot UNC_t \quad where \quad UNC_t = -\left(v \cdot RND\right) \cdot \left(1 - \frac{t}{T}\right) \quad RND = Random \in \left[-1, 0\right]$$

Market uncertainty, UNC_t , is driven by a random number generator, RND, with values that range between -1 and 0. Negative values were used to capture the downside risk that can arise from entry into the ethanol market. This downside risk is used to capture the uncertainties about the continued viability of the ethanol market. However, as markets mature, this uncertainty declines. Uncertainty in the demand for ethanol is, therefore, modeled as a declining function of market maturity, t. This decline in market uncertainty is consistent with Organizational Ecology depictions of the product life cycle (Lambkin and Day 1989). To model this uncertainty, it is multiplied by the second term, $\left(1 - \frac{t}{T}\right)$. By taking the product of market size, MS_t (equation 5) with this uncertainty parameter, UNC_t , it generates an increasing trend in market size with reductions in downside variability. To examine the effects of such market uncertainty on an R and K type firms' entry timing, this equation is adjusted by a scalar parameter, v.

Density Dependence

Density dependence effects are captured by the Lotka-Voltera population growth function (Hannan and Freeman, 1989) (equation 7)

$$(7)\quad N_{t+1} = N_t + \alpha \cdot N_t\left(1 - \frac{N_t}{\eta}\right)$$

The market's population, N_{t+1}, of ethanol firms in period *t+1*, grows at an intrinsic population growth rate of, α. The intrinsic population growth rate of, α, refers to the rate of new ethanol firms entering the market. This growth rate was set at a rate of 0.5 units / simulation time to reflect highly but not purely competitive markets[3]. Entry is also limited by the market's carrying capacity parameter, η. The carrying capacity parameter, η, refers to the maximum population of firms that can be supported by the market. Through the population dynamics expressed in equation 7, density dependence effects are captured through downward pressures on price. Specifically through equation 8, increases in population from equation 7 reduces the firm's product price, $Pr_t(N_{t-1})$, by an exponential rate of μ from an initial price of $\Pr_0 + \Pr_1$ to an asymptotic terminal price level of $\Pr_0$. In particular, as a firm cannot influence the entry decisions of others, an individual firm, thereby, cannot influence population and thus price. Equation 8, thereby, assumes that ethanol firms have very limited market power.

$$(8)\quad \Pr_t(N_{t-1}) = \Pr_0 + \Pr_1 \cdot \exp^{-\mu \cdot N_{t-1}}$$

R and K Type Learning

Learning curve effects are captured by equation 9 which models a declining relationship between a firm's Marginal Cost, $MC_t(S_t)$, and a firm's accumulated experience, S_t. An ethanol firm's accumulated experiences, S_t, reduces its marginal cost, $MC_t(S_t)$, at a learning rate of γ from an initial value of $\rho + \phi$ to an asymptotic marginal cost value of ρ that is strictly positive. The initial value $\rho + \phi$ corresponds to the marginal cost of a firm with zero experience ($S_t = 0$). This reflects the high costs associated with "liabilities of newness" (e.g. Stinchcombe 1965). As the firm accumulates greater experiences, S_t, its marginal cost declines to an asymptotic marginal cost value of ρ.

$$(9)\ MC(S_t) = \rho + \phi \cdot \exp^{(-\gamma \cdot S_t)}$$

Based on the entry order effects of population density, market uncertainty, and learning, a firm's returns from its production efficiencies is represented in full by equation 10. These returns are computed as the product of a firm's price, $Pr_t(N_{t-1})$, its level of sales Q_t, – as determined by inequality 5 – and its entry decision, U_t, less the sum of the product of its marginal cost, $MC_t(S_t)$ and its fixed level of production capacity, Q_t^* and its entry decision, U_t. and the product of its Fixed cost and entry decision, U_t. A fixed cost parameter was used to account for startup

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[3] Under perfectly competitive conditions, free entry / exit would suggest a greater rate of entry, such as a value greater or equal to 1. However, since R type dry milling firms requires a minimum amount of investment, there are some positive entry and exit costs. Hence, a value of less than one was set.

and shut down costs. That is, in addition to our specialized asset parameter, SA_t, this Fixed Cost, parameter was included to reflect the cost of entry and exit to the industry[4].

$$(10)\quad P_t(U_t, S_t) = \left(\Pr_t(N_{t-1}) \cdot Q_t\right) \cdot U_t - \left(MC_t(S_t) \cdot Q_t^* + FC\right) \cdot U_t$$

To include, a firm's FMA rents, X_t (U_t), the full specification of a firm's profits is shown by the following.

$$(11)\quad V_t(U_t, S_t) = \underset{U_t}{Max} \sum_{t=0}^{T-1} \Pr_t(N_{t-1}) \cdot W \cdot \exp^{\delta \cdot t} \cdot U_t + \left(\Pr_t(N_{t-1}) \cdot Q_t^*\right) \cdot U_t - \left(MC_t(S_t) \cdot Q + FC\right) \cdot U_t - SA_t$$
$$+ \beta \cdot V_{t+1}(U_{t+1}, S_{t+1})$$

$$(2)\quad S_{t+1} = S_t + U_t,\ S_0 = 0$$

In drawing on equations 11 and 2, the R and K type firm is distinguished by differences in their specialized asset parameter, SA_t, as well as differences in Fixed Costs. In parameterizing these firms, the R type has a lower value for this specialized asset parameter, SA_t, than the K type. Furthermore, since the R type dry milling firm procures corn as a key input to their ethanol process, the R type dry milling firm faces a higher marginal cost, MC, than the K type cellulosic firm. Furthermore, since the R type dry milling firm has access to relatively smaller volumes of feedstock (i.e. corn) than the K type cellulosic firm (i.e. agricultural waste, wood chips, etc), the R type dry milling firm has a lower fixed productive capacity, Q_t^*, than the K type cellulosic firm. Critical will be whether the K-Type firm, with its higher capital cost, can balance its need for large scale processing with a well-matched feedstock collection model with high spatial density. Moreover, since the R type dry milling firm has fewer specialized assets (i.e. lack of R&D and lack of other supporting assets in transportation and distribution), the R type dry milling firm has a lower Fixed Cost, FC, than the K type cellulosic firm.

Model Validation

Validation of simulation models, amongst other factors, depends on the desired objectives of the research (Sargent 1999). Although simulations have varied uses, simulations have been used in management research as a means for theory development (e.g. Cyert and March 1963); (Nelson and Winter 1982). For instance, in studies of firm and market evolution, Nelson and Winter's (1982) seminal work had drew on simulation modeling to examine the dynamic behavior of firms and markets. This study follows a similar approach in which the DP simulation is used to examine the theoretical validity of this paper. As a result, the focus of this study is not one of validating the empirical results of the DP simulation, but rather the DP simulation is used to examine the logical consistency of this study's theoretical arguments. This is not to say that empirical validation is not important but this paper argues that the "empirical validation" of simulation results raises some methodological concerns.

For instance, one common method for validating simulation results is the "historical friendly" approach (Sargent 1999). This involves comparing the outputs of the simulation with a detailed

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[4] For instance, since cellulosic firms require investments in R&D, such commitments, however, occur over multiple periods. These R&D investments are, thus, treated as fixed costs that accrue over time.

history of the economic system (Sargent 1999); (Windrum et al. 2007). For this study, a historically friendly approach is, however, problematic. This is because although key market concepts such as competition and uncertainty can be empirically measured, a key focus of this research is on the examination of the entry behaviors of the R and K type firms. Yet, with the possible exception of Goldsmith and Dissart (1998), there have been very limited empirical estimates of R and K type organizations in agribusiness research. In fact, to our knowledge, there have been no empirical estimates of R and K bio energy firms. As a result, even though other estimates relating to population (i.e. firm entries) and uncertainty could be drawn from prior studies, estimates of the parameters of the R and K type firm are not available. Validation, especially through comparisons with past studies, thereby, becomes difficult because there is no prior basis for comparison. The estimation of these key parameters is, thus, called for in future studies.

Furthermore, a “historical” approach also faces some deep seated methodological problems. A historical approach only shows that the underlying model is “capable” of producing the observed empirical phenomena because multiple combinations of parameter settings, initial conditions, and structural assumptions can lead to the same simulated output (Windrum et al. 2007). Nevertheless, although there are numerous possible parameter settings, the logic of our conceptual model dictates that the entry behaviors of R and K types can be still examined by relative differences in their firm level parameters, such as asset specificity, MC, Output, Fixed Costs. These parameter settings are shown in Appendix 1. Based on these settings, this study’s DP simulation model was programmed with the Fortran 77 compiler. Based on this code, various simulation runs with randomized initial values were also conducted. The findings were robust across these simulations.

Results and Discussions

Density Dependence

To examine Proposition 1, the initial population conditions were varied to examine the effect of population densities on R and K types’ entrance. In addition, since initial population densities impact the population densities of later periods, such variations in the initial population impact the population densities confronted by the later entrant, K type. The carrying capacity of this market is artificially limited to 100 competitors. Similar entry patterns were observed with increases in this carrying capacity. Lastly, since density effects are reflected through reductions in price, the price is reduced at a rate of -0.05 per unit increase in the population. Changes in this parameter did not appreciable affect R and K types’ pattern of entry.

Given these specifications, increases in population densities prompted earlier exit by the R type and reduced R type’s profits (Table 2). For instance, at a population density of 2 other competitors, R types entered in the first period and exited in period 4 with profits of $257. However, with increasing densities (e.g. initial population = 20), the R type exited in period 2 with a significant reduction in profits to $15. With further increases in population density of 25 other competitors, R types no longer entered the market. While, K type’s entry and exit periods remained largely robust to these changes in population. In fact, by increasing the initial population density to the market’s carrying capacity (100 competitors), the K type still remained in the market (entry in period 8 and exited in period 15). However, K type's profits dramatically declined from $89,697 to $107. Nevertheless, the K type was more resilient to increases in population densities than the R type. This is consistent with Proposition 1.

One implication of these results is that density conditions at founding have differential effects on the survival of R and K type firms. This suggests that as competition increases, dry mill firms are not likely to enter the industry and are likely to be displaced by the efficiencies of the cellulosic firm. This result appears to be consistent with the view that cellulosic is a more efficient source of ethanol than dry milling (e.g. Robertson et al. 2000)[5]. In particular, this result is consistent with some of the realities faced by dry milling firms. For instance, the increasing competition among dry milling firms has lead to an increase in the input price of corn which resulted in a decline in the price margins for dry millers. This reflects a decline in market opportunities to which favor more efficient conversion technologies. Hence, under highly dense population conditions, the K type cellulosic firms maybe favored for their efficiencies in gaining access to low cost feedstock. This lower cost of cellulosic feedstock not only lowers K type's input costs but also provides significant scale efficiencies for the K type cellulosic firm (Lin and Tanaka, 2006). However, such scale economies depend on the firm's ability commercially employ effective cellulosic enzymes (e.g. Knauf and Moniruzzaman 2004); (Tiffany and Eidman 2004); (Rendleman and Shapouri 2007).

Table 2. Density Dependence

	R Type			**K Type**		
Initial Population	*Entry*	*Exit*	*Fitness*	*Entry*	*Exit*	*Fitness*
2	1	4	257.4	7	No Exit	89697.3
3	1	3	221	7	No Exit	46004.5
4	1	3	192.2	8	No Exit	23141
5	1	3	165.5	8	No Exit	16824.8
10	1	2	87.1	8	No Exit	4579.6
15	1	2	46.8	8	No Exit	2115.1
20	1	2	15.4	8	No Exit	1229
25	No Entry	No Entry	0	8	No Exit	810.9
50	No Entry	No Entry	0	8	No Exit	241.4
75	No Entry	No Entry	0	8	No Exit	138.3
100	No Entry	No Entry	0	8	No Exit	107.1

Market Volatility

To examine Proposition 2, market uncertainty was varied from a value of v = 1 (low uncertainty) to a value of v = 10 (high uncertainty)[6]. When uncertainty was low (v = 1), the R type firm entered in period 1 and exited in period 9 with profits of $1,926 and the K type entered in period 7 and remained until period 15 with profits of $934,870 (Table 3). With increases in uncertainty (v = 10), the R type still enters in period 1, but exits in period 3 and its profits are reduced by 61% to $754. K type's entry was significantly delayed to period 13 and its profits fell by 56% to $414,723. This pattern of entry is consistent with Proposition 2.

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[5] This a point that is not only raised by a reviewer but also is commonly understood by those involved in comparing the advantages between these energy conversion technologies (e.g. Robertson et al., 2000).

[6] Population effects are removed by setting the price decline parameter to 0.

The implication of these results is that the uncertainties in ethanol demand favor the entry of the dry milling firm, while delaying the entry of the cellulosic firm. Hence, unlike RBV explanations (e.g. Ghemawat and Del. Sol 1998), this suggests that under conditions of uncertainty, the R type dry milling firm's lack of specialized assets may promote earlier entrance or at the minimum reduces R type's exposure to risk than when compared to the K type. This appears to be consistent with the pattern of entry in the ethanol industry.

This result also has related implications to U.S. energy policy. Uncertainty declines when commitment to ethanol tax credits, import tariffs, and subsidies are strengthened. With reductions in uncertainty, greater specialized investments can be made. For instance, ADM who has long experienced with dry and wet milling technologies (ADM News release, 2007), and British Petroleum, long experienced in fossil fuel technologies, both have expanded, albeit slowly, into cellulosic ethanol production research and development.

Table 3. Market Uncertainty

	R Type			**K Type**		
*Uncertainty, V**	*Entry*	*Exit*	*Fitness*	*Entry*	*Exit*	*Fitness*
1	1	9	1926.2	7	No Exit	934870.3
2	1	4	1466.7	7	No Exit	922611.1
3	1	3	880.7	7	No Exit	801919.4
4	1	3	754	7	No Exit	674460.6
5	1	3	754	11	No Exit	642550.8
6	1	3	754	11	No Exit	567595.2
7	1	3	754	12	No Exit	435335
8	1	3	754	13	No Exit	414723
9	1	3	754	13	No Exit	414723
10						

Joint Density and Volatility Effects

In order to evaluate Propositions 3 and 4, density dependence and market uncertainty effects were jointly examined[7] (Table 4). Under conditions of low (2) density and highly uncertain market conditions, the R type firm enters in period 1 and exits in period 3 with profits of $2.6. R type's entry behavior is, thus, consistent with the conditions described by Proposition 3. Furthermore, as indicated by Proposition 3, R type's competition for first mover advantage (FMA) rents in periods 1 and 2 yields respective gains of $320 and $214. These FMA rents are, however, offset by respective losses in production efficiency of $-450 and $-72. This trade-off is consistent with Proposition 3.

The K type firm enters in period 7 and remains until period 15 with profits of $219,690[8] (Table 4). The K type enters into the market with a population of 20 other competing firms and in a market with reduced uncertainty. K type's entry into such founding conditions is, thus,

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[7] To provide a suitable balance of population density effects and market uncertainty, the price decline parameter was set to -0.025, and the market uncertainty parameter, v, was set to a value of 2.5. Through comparisons with other combination of values, we felt that this set of values yields the greatest balance of these effects.

[8] Profits is calculated through equation 11 in which fitness is determined by the sum of the period's innovation rents and production efficiency rents and the one period discounted value of the one period future fitness.

consistent with Proposition 4. Furthermore, K type's entry into such founding conditions was attributed to K type's decision to compete for production efficiency rents. For instance, in period 7, K type's production efficiency rents are $42,291, while its FMA rents are only $29. For the remaining periods, the average production efficiency and FMA rents were, respectively, $29,889 and $10.

Table 4. Density Dependence and Market Uncertainty

		R Type				**K Type**			
Time	*Population*	*Entry 1 Exit 0*	*Fitness*	*Innovation Rents*	*Production Efficiency*	*Entry 1 Exit 0*	*Fitness*	*Innovation Rents*	*Production Efficiency*
1	2	1	2.6	320.1	-450	0	0	0	0
2	3	1	143.1	214.6	-71.5	0	0	0	0
3	4.4	0	0	0	0	0	0	0	0
4	6.5	0	0	0	0	0	0	0	0
5	9.6	0	0	0	0	0	0	0	0
6	13.9	0	0	0	0	0	0	0	0
7	19.9	0	0	0	0	1	219690	29	42291
8	27.9	0	0	0	0	1	191560	19.5	59369.2
9	38	0	0	0	0	1	142745	13	49122.4
10	49.7	0	0	0	0	1	101098	8.7	19793.9
11	62.2	0	0	0	0	1	87799.2	5.9	30641.2
12	74	0	0	0	0	1	61724.3	3.9	22587.3
13	83.6	0	0	0	0	1	42263.7	2.6	17544.8
14	90.5	0	0	0	0	1	26693.5	1.8	14626.4
15	94.8	0	0	0	0	1	13030.6	1.2	13029.4

R and K type Learning

This simulation draws on the parameters of the previous simulation with the exception that learning curve effects are enabled (Table 5). The R and K types' learning rates were both set at a value of -0.4 (i.e. $\gamma^{r} = \gamma^{k} = -0.4$). Such a rate is set so that the effects of each firm's non-specialized or specialized assets can be independently examined of this learning rate. The R type firm enters in period 1 and exits in period 3, while the K type enters in period 7 and remains until period 15 (Table 5). Relative to the results of the previous simulation (Table 4), learning does not alter R and K type entry and exit periods. However, learning significantly improves both R and K type's profits. In particular, R type's profits improved more dramatically than the K type. R type's profits increased by 2350% from $2.6 to $63.7, while K type's profits improved by 47% from $219,690 to $323,352.

Table 5. Density Dependence and Market Uncertainty with Learning

Learning	**R Type**			**K Type Learning rate = -0.4**		
Rate	*Entry*	*Exit*	*Fitness*	*Entry*	*Exit*	*Fitness*
0.1	1	3	20.2	7	No Exit	323351.9
0.2	1	3	36.2	7	No Exit	323351.9
0.3	1	3	50.6	7	No Exit	323351.9
0.4	1	3	63.7	7	No Exit	323351.9

The learning rate was then varied to determine the robustness of these findings (Table 5). R type's profits were examined with learning rates that ranged from -0.1 to -0.4. Lower rates of learning were used to reflect R type's lack of specialized assets. However, even with such lower learning rates, the R type firm still experienced a larger percentage growth in profits than the K type[9]. Proposition 5 is, therefore, not supported. This suggests early entry by the R type dry milling firm can benefit from learning curve economies. For instance, ADM, which has utilized both dry and wet milling processes, has been an early entrant into the corn-ethanol industry and remains as one of the lowest cost processors of corn ethanol.

The broader implication of this result is that it suggests learning curve effects may significantly affect an R type dry milling firm's ability to compete with the efficiencies of the K type cellulosic firm. Namely, although the high R&D costs of cellulosic remains a key commercial barrier, cellulosic firms nevertheless face lower feedstock costs than dry millers. Yet, despite such cost advantages, early entry by the R type dry milling firm can leverage learning curve effects from being first movers to offset their higher input corn costs, and will compete aggressively against later entering cellulosic firms. Learning curve economies may in part explain the viability and logic of the dry mill corn model in the early phase on the bio energy movement.

However, shifts in U.S. energy policy can reduce the high costs of producing effective cellulosic enzymes. For instance, expansion of tax credits and subsidies to the cellulosic ethanol sector could overcome the high R&D costs of enzyme research and development. Specifically, shifts in U.S. energy policy towards investments in R&D as opposed to fuel would benefit the cellulosic industry. Such a policy shift would reduce uncertainty and allow K types to further commit to its specialized assets and exploit the scale efficiencies of specialization.

Conclusions

Amidst rapid technological changes and shifting competing landscapes, understanding when and how firms enter into the bio energy market can be instrumental to a firm's competitive survival. Although there are various considerations that affect a firm's entry timing, the insights of the RBV and Organizational Ecology can be particularly instructive to explaining a firm's entry into the ethanol market. In drawing on these approaches, a central tenet of this study is that a firm's entry timing is dependent on the specialization of their assets to which such specializations introduce a "commitment-flexibility" trade-off that influences a firm's entry into distinct stages of the product market life cycle. This basic argument offers four implications and contributions. First of significant importance is this study's unique application of density dependence theory to the entry of bio energy firms. As the government has multiple objectives in supporting bio energy incubation, public technologies and ethanol subsidies, such objectives can lead to a more dense population, which in turn will affect the capital commitment-flexibility calculus facing bio energy managers and investors. This study shows that entry into the bio energy market can be density dependent in which the R type dry milling firm may be better able to survive in relatively low population conditions than K type cellulosic operations. While, under highly dense environments, the K type cellulosic firm is more likely to enter than the R type dry milling firm. As such density dependence effects can influence the composition of bio energy firms in the

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[9] Results are available on request.

market, determining the "optimal" composition of bio energy firms is important. This is because the growth of the bio energy market requires not only innovations by cellulosic firms, but must also be commercially viable (i.e. dry milling). Policies that focus on the development of one (i.e. ethanol subsidies to dry milling) may lead to population conditions that drive out the entry of the other (i.e. cellulosic). Since cellulosic reflects a potentially important technology that can significantly reduce U.S. dependence on foreign oil as well as being more environmentally friendly, such density dependence explanations should, therefore, be considered.

Second, as bio energy entry decisions involve a basic "commitment-flexibility trade-off", such a decision framework can help bio energy managers and investors better understand the trade-offs between that of being a cost efficient processor of cellulosic biomass and that of being an early mover to the uncertainties of an emerging market. The tradeoff problem for managers and investors also in part explains why new technologies, such as cellulosic, often are by-passed in favor of older or "lesser" technologies, such as dry milling. Understanding such a trade-off not only introduces to bio energy managers and investors the distinct rent streams associated with such activities, but understanding such a trade-off can extend more traditional capital budgeting approaches, such as Net Present Value (NPV). In particular, NPV methods have been used to examine the long term profitability of market entry decisions (Briggeman et al. 2006). However, NPV approaches do not account for this commitment-flexibility trade-off nor account for changes in investment value that can arise from different states of nature. The study's DP approach allows bio energy managers and investors to examine such trade-offs in a dynamic context.

Third, from a broader research standpoint, agribusiness and agricultural economists have traditionally drawn on the concept of specialized assets or asset specificity to explain the vertical coordination of markets (e.g. Barry, 1999); (Barry et al. 1992); (Cook and Barry 2004). This study extends the concept of specialized assets to not only explain a bio energy firm's commitment-flexibility trade-off, but also their entry timing. This linking of a firm's specialized asset / asset specificity to such a trade-off has not been recognized by the Resource Based View or by Organizational Ecology explanations of market entry. The significance of this linkage is that this study provides a greater understanding of how specialized assets impact a firm's internal decision processes to which have been absent in both these perspectives.

Lastly, this study suggests entry strategies need to jointly account for a firm's specialized assets with the contingencies of the market environment (i.e. population and uncertainty). Although the RBV has been one of the key influences to the field of strategic management, the RBV has, nevertheless, been criticized for its lack of attention to market conditions (e.g. Priem and Butler 2001). This study extends RBV explanations of entry timing by attributing entry to both the specialized nature of a firm's assets as well as to the uncertain and population conditions of the market. Such an extension argues that firms with specialized assets will favor late as opposed to early entrance. A delayed entry not only leverages greater market certainty and thus reducing risks to a firm's specialized asset, but late entry enables the firm to benefit from the efficiencies of its specialized assets. Such an argument offers one explanation of the entry behaviors of bio energy firms.

On a related note, this explanation also extends more traditional "barrier to entry" explanations. Namely, as barriers to entry stem from exploiting scale economies, it typically involves investments in specialized or dedicated production assets. Hence, Industrial Organizational economic explanations would suggest first mover advantages can arise in the presence of such barriers to entry. Yet, as firms with specialized assets favor late as oppose to early entrance, this specialized asset argument is, thus, not accounted for in barriers to entry explanations.

There are nevertheless theoretical and methodological limitations to our study. Theoretically, Organizational Ecology contends "organizational inertia" limits a firm's ability to change. This is also consistent with RBV reasoning (Priem and Butler 2001). As there has been greater attention to examining organizational change processes (e.g. Ng 2007), changes in a firm's asset profiles can subsequently alter their entry behavior. Thus examination of such change processes is called for in future research.

Another limitation of this study is the DP simulation was constructed for the primary purpose of theory building. Our DP simulation results can only be interpreted as an extension to the logic of our theoretical arguments. A direction for future research is therefore to empirically test the arguments of this model. Lastly, our DP model is based on entry decisions involving discrete entry / exit choices and is based on a finite planning horizon. A limitation of a finite planning horizon is that political interests (i.e. job creation and perceived energy independence) may favor a long term government commitment to U.S. corn-ethanol. In this context, an infinite planning horizon may be a more appropriate representation of the DP model.

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References

ADM. 2007. News Release: Joint ADM and Purdue University Cellulosic Ethanol Project Selected for Funding by U.S. Department of Energy. http://www.adm.com/en-Aus/news/_layouts/PressReleaseDetail.aspx?ID=185. (accessed January 2010).

Abuelsamid, S. 2010. Expiration of biodiesel subsidy ends bad year for industry. A utobloggreen.com. http://green.autoblog.com/2010/01/03/expiration-of-biodiesel-subsidy-ends-bad-year-for-industry/. (accessed January, 2010).

Barry, P. 1999. Where next for agribusiness research and education? An organizational economics perspective. *American Journal of Agricultural Economics* 81(5):1061-1065.

Barry, P., Sonka, T., and K. Lajili, 1992. Vertical coordination, financial structure and the changing theory of the firm. *American Journal of Agricultural Economics* 74:1219-1225.

Bellman, R. Dynamic Programming. 1957. Princeton: Princeton University Press.

Briggeman, B.C., et al. 2006. Protecting your turf: first-mover advantages as a barrier to competitor innovation. *International Food and Agribusiness Management Review* 9(1):53-70.

Brittain, J. W. and J. H. Freeman. 1980. *Organizational proliferation and density dependent selection.* In John Kimberly and Robert H. Miles (eds.), The Organizational Life Cycles: Issues in the Creation, Transformation and Decline of Organizations. San Francisco: Jossey-Bass.

Brittain, J. W. and D. R. Wholey. 1988. Competition and coexistence in organizational communities: population dynamics in electronic components manufacturing. In G. R. Carroll (ed.) *Ecological Models of Organizations*: 195-222. Cambridge, MA: Ballinger Publishing Co.

CERES. Website (http://www.ceres.net/)

Carow, K., Heron, R. and T. Saxton. 2004. Do early birds get the returns? An empirical investigation of early-mover advantages in acquisitions. *Strategic Management Journal* 25:563-585.

Carroll, G.R. and M.T. Hannan. 1989. Density delay in the evolution of organizational populations: a model and five Empirical tests. Administrative Science Quarterly 34(3): 411-430.

Cook, M., and P. Barry. 2004. Organizational economics in the food, agribusiness, and agriculture Sectors. *American Journal of Agricultural Economics* 86(3):740-743.

Cyert, R.M. and J.G. March. 1963. A Behavioral Theory of the Firm. Englewood Cliff: NJ: Prentice Hall.

Dale, R.T. and W.E. Tyner. 2006. Economic and technical analysis of ethanol dry milling. Dept. of Agricultural Economics, Purdue University, Staff Paper 06-04.

Ebben, J and A. C. Johnson. 2005. Efficiency, flexibility, or both? Evidence linking strategy to Performance in Small Firms. *Strategic Management Journal* 26(13): 1249-1259.

Ghemawat, P. and P. del Sol. 1998. Commitment vs. flexibility. *California Management Review*, 40(4): 26-42.

Goldsmith, P.D. and J.C. Dissart. 1998. Computer-based scenario modeling: application to swine Industry 14(4): 281-298.

Goldsmith, P.D., R. Rasmussen, and C. Guimares. 2009. The capital efficiency challenge of bio energy models: The case of flex mills in Brazil." The Handbook of Bio energy and Policy, M. Khanna, J. Scheffran and D. Silberman eds. (December): 175-194.

Goldsmith, P.D., G. Signorini, J. Martines, and R. Rassmussen. 2010. Bio energy efficiency and a flex-mill simulation in Mato Grosso. Bioenergy Issues: Studies from Brazil and the United States; In Print. W. Baer, E. Amann, and D. Coes, editors; Routledge Press.

Graf, A. and T. Koehler. 2000. Oregon Cellulose-Ethanol Study. Oregon Office of Energy. June.

Grainnet. 2010. http://www.grainnet.com/pdf/cellulosemap.pdf . (accessed April).

Hamelinck, C.N., G.V. Hooijdonk, and A.P.C. Faaij. 2005. Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle- and long-term. Biomass and Bioenergy. 28(4) April 2005: 384-410.

Hannan, M. T. and J. Freeman. 1977. The population ecology of organizations. *American Journal of Sociology,* 82(5):929-964.

Hannan, M.T. and J. Freeman. 1989. Organizational Ecology, Cambridge, MA: Harvard University Press.

Hurt, C., Tyner, W., and O. Doering. 2006. Economics of ethanol. Purdue extension Bio Energy Series. ID-339.

Isobe, T., Makino, S. and D.B. Montgomery. 2000. Resource commitment, entry timing, and market performance of Foreign Direct Investments in Emerging Economies: The case of Japanese International Joint Ventures in China. *Academy of Management Journal* 43(3): 468-484.

Kennedy, J. Dynamic Programming: Application to Agriculture and Natural resources. Barking, England: Elsevier Applied Science Publishers.

Kerin, R.A., R.P.Varadarajan, and R.A. Peterson. 1992. First Mover advantage: a synthesis, conceptual framework, and research propositions. *Journal of Marketing* 56:33-52.

King, A.A. and C.L. Tucci. 2002. Incumbent entry into new market niches: The role of experience and managerial choice in the creation of dynamic capabilities. *Management Science* 48(2):171-186.

Knauf, M. and M. Moniruzzaman. 2004. Lignocellulosic biomass processing: A perspective. *International Sugar Journal* 106(1263):147-150.

Lamonica, M. 2008. Inside Mascoma's Ethanol-Making Bug Lab. http://news.cnet.com/8301-11128_3-10047209-54.html. (accessed 2010).

Lambkin, M. and G.S. Day. 1989. Evolutionary processes in competitive markets: beyond the product life cycle. *Journal of Marketing* 53:4-20.

Lee, H., K.G. Smith, C.M. Grimm and A. Schomburg. 2000. Timing, order and durability of new product advantages with imitation. *Strategic Management Journal* (21)23-20.

Levinthal, D.A. and J. G. March. 1993. The myopia of learning. *Strategic Management Journal* 14:95-112.

Lieberman, M.B. and D.B. Montgomery. 1998. First mover (dis)advantages: retrospective and link with the resource based view. *Strategic Management Journal,* 19:1111-1125.

Lin, Y. and S. Tanaka. 2006. Ethanol fermentation form biomass resources: current state and prospects, Appl. Microbiol. Biotechnol 69:627-642.

March, J.G. 1991. Exploration and exploitation in organizational learning. Organization Science, 2(1):71-87.

Mascoma Corporation. 2008. http://www.mascoma.com/pages/index.php. (accessed November, 2009).

McAloon, A., F. Taylor and W. Yee. 2000. Determining the cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks. National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy01osti/28893.pdf

McDermott, M. 2009. 20,000 Gallon Per Year Cellulosic Ethanol Pilot Project Opens in South Dakota. http://www.treehugger.com/files/2009/01/20000-gallon-per-year-cellulosic-ethanol-plant-southdakota.php. (accessed April, 2010).

McGrath, R.G. and I.C. MacMillan. 2007. Discovery-Driven Planning. *Harvard Business Review* 1-12.

Miles, R.E., C.C. Snow, A.D. Meyer and H. J. Coleman. 1978. Organizational strategy, structure and Process. *Academy of Management Review* 3(3):546-562.

Miller, K. D. and T. B. Folta. 2002. Option value and entry timing. *Strategic Management Journal* 23:655-665.

Mitchell, W. 1989. Whether and when probability and timing of incumbents' entry into emerging industrial subfields. *Administrative Science Quarterly* 34:208-230.

Mitchell W. 1991. Dual Clocks: entry order influences on incumbent and newcomer market share and survival when specialized assets retain their value. *Strategic Management Journal* 12:85-100.

Mosier, N.S. 2007. Cellulosic Ethanol – BioFuel Beyond Corn. ID-335. Purdue University Cooperative Extension Service. http://www.ces.purdue.edu/extmedia/ID/ID-335.pdf

Nelson, R. R. and S. G. Winter. 1982. An Evolutionary Theory of Economic Change. Cambridge, MA: Belknap Press of Harvard University Press.

Ng, D. 2007. A Modern Resource Based Approach to Unrelated Diversification. *Journal of Management Studies.* 44(8):1481-1502.

Peteraf, M.A. 1993. The cornerstones of competitive advantage: a resource based view. *Strategic Management Journal* 14(3):179-191.

Priem, R.L. and J. E. Butler. 2001. Is the Resource-Based "View" a useful Perspective for Strategic Management Research? *Academy of Management Review* 26(1):22-40.

Renewable Fuels Association. 2010. www.ethanolrfa.org. (accessed April).

Renewable Fuels Association. 2009. Ethanol Industry Outlook, http://www.ethanolrfa.org/objects/pdf/outlook/RFA_Outlook_2009.pdf

Renewable Fuels Association. 2008. Changing the Climate: Ethanol Industry Outlook, http://www.ethanolrfa.org/objects/pdf/outlook/RFA_Outlook_2008.pdf

Renewable Fuels Association. 2004. Synergy in Energy: Ethanol Industry outlook, 2004. http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2004.pdf

Rendleman, C.M and H. Shapouri. 2007. New Technologies in Ethanol Production. USDA, Office of the Chief Economics and Office of Energy Policy and New Uses. *Agricultural Economic Report* 842 (Feb).

Robertson, G.P. et al. 2000. Sustainable Bio fuels Redux *Science* 322(3): October 49-50.

Robinson, W.T., C. Fornell and M. Sullivan. 1992. Are market pioneers intrinsically stronger than later entrants? *Strategic Management Journal* 13(8):609-624.

Shankar, V., G.S. Carpenter and L. Krishnamurthi. 1998. Late mover advantage: How innovative late entrants outsell pioneers. *Journal of Marketing Research* 35(1):54-70.

Sargent, R. G. 1999. Validation and verification of simulation models. Proceedings from the 1999 Winter Simulation Conference, 39-48.

Stinchcombe, A. 1965. Social Structure and Organization. In James March (ed.), Handbook of Organizations. Chicago: Rand McNally.

Sull, D. N. 2004. Disciplined Entrepreneurship. *Sloan Management Review*. Fall: 71-77.

Tiffany, D.G. and R. Eidman. 2004. U.S. Dry-Grind Ethanol Production: Economic Competitiveness in the Face of Emerging Technologies. Paper presented at 9th Joint Conference on Food, Agriculture and Environment.

Verenium. 2010. Form 10-K annual report. Filed 3/16/2010 for the period ending 12/31/2009.

Windrum, P., Fagiolo, G., and Moneta, A. 2007. Empirical validation of agent-based models: alternatives and Prospects. *Journal of Artificial Societies and Social Simulation*, 10(2):8. http://jasss.soc.surrey.ac.uk/10/2/8.html : 1-35.

Wholey, D. R. and J. W. Brittain. 1986. Organizational ecology: findings and implications. *Academy of Management Review* 11(3): 513-533.

Zammuto, R. F. 1988. Organizational adaptation: some implications of organizational ecology for strategic choice. *Journal of Management Studies* 25(2):105-120.

Appendix 1

Market Selection Parameters

Parameter Name	Parameter description	Assigned Value
α	Intrinsic growth rate of pop.	0.5/unit time
η	Carrying capacity of environment	100 firms
N_1	Initial population levels at period 1.	2 firms
N_{15}	Max population levels in period 15.	100 firms
μ	Rate of decline in prices	-0.05 /unit time
Pr_0	Terminal industry price at high population densities.	MC^K (S_t) (MC for K type)
Pr_1	Potential price reduction associated with competitive markets.	MC^R (S_t)-MC^K (S_t) (Differential MC between R type and K types.)

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Pr_1	Potential price reduction associated with competitive markets.	MC^R (S_t)-MC^K (S_t) (Differential MC between R type and K types.)

Firm Asset Specificity Parameters

Parameter Name	Parameter Description	Assigned Value
γ	Organizational learning rate for both R- and K- types	γ =0.0 (simulation one)
B	Discount rate on objective value function	8%
ρ^r (for R type)	Asymptotic marginal cost level.	20/unit
φ^r (for R type)	Potential reductions in marginal cost	20/unit

Firm Asset Specificity Parameters

Strategy Type	Marginal Cost MC(S_t) (Constant)	Fixed Cost FC (Constant)	Firm productive output U.P (Constant)
R-Type	40/unit	50	10 units
K-Type	10/unit	1000	5000 units