A Real Options Approach for Deciding What Opportunities to Pursue

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Abstract

Systems Engineering and Management (SEM) are not only about doing things right; SEM is also about doing the right things. Choosing the right opportunities to pursue is a central aspect of doing the right things; for example, an ill-conceived vehicle that is engineered well is nevertheless still a failure – see Hanawalt and Rouse (2009). We present an investment valuation model that describes how firms make market entry decisions in competitive, dynamic markets. We apply real options theory from finance/decision science to determine the optimal time that a firm should pursue an opportunity in a dynamic market. We determine the entry/pursuit criterion as a function of differing firm cost characteristics and state of the competition – whether another player has already pursued the opportunity, i.e., whether there is an incumbent, which may be acceptable if the size of the opportunity has grown. Our proposed real options model has several features that make it different from existing market entry models. We treat the firm’s opportunity to enter a new market as an investment option whose success enhances the financial position of the firm. Our model also considers that entering a new market is a risky business since future market conditions are unpredictable. In addition, our investment model treats competition in the market endogenously to describe investment behaviors of large and small firms in developing markets. One of the most important theoretical results of our market entry model is about identifying the differences in investment behaviors of small and large firms in dynamic markets. It is explained why small firms enter developing markets at lower market sizes compared to big firms. We find supportive evidence for the differences between investment behaviors of small and large firms in the retail industry – this choice being driven by the need for situations where large number of entry decisions have been made and documented, and the nature of the conditions prompting entry are available.

1. Introduction

Systems Engineering (SE) addresses the design, development and deployment of systems and products. As such, SE firms intending to create these systems or products eventually face decisions on when to pursue opportunities; for instance, when to enter new markets or market segments for selling their products and services or when to acquire rights for bidding on projects in special business environments. These decisions are complicated by the possible need to develop new offerings for these emerging opportunities, e.g., airplanes, new vehicles, petrochemical facilities, buildings, retail stores, etc. Table 1 summarizes different types of decisions about pursuing opportunities by 4 types of firms in different industries: aerospace manufacturers, automobile manufacturers, international construction firms, and retail firms. The nature of decision making about these opportunities is different in each industry. In the aerospace industry, the decision is when a giant manufacturer should start selling airplanes in a region in the world like South America or Eastern Europe or a specific country. This decision is not frequent, i.e., once or twice in a decade, while the competition level is substantially low since few giant firms compete for these opportunities. In the automobile industry, the decision type is
slightly different from the aerospace industry. Although the opportunity is to sell new cars in a region/country the level of competition is higher than the aerospace industry since there are several firms that produce cars. Also the decision to pursue opportunity in the automotive industry is more frequent that the aerospace industry; once or twice in several years compared to once or twice in a decade. The decision in the international construction industry is when a large firm should acquire the right to bid in a host country like in one of the developing countries in Asia or Middle East. A large international firm must first establish a strong tie with local firms, pay initial fees, and open a local office in a host country before it gets the right to bid on upcoming projects. The level of competition is higher than aerospace and automobile manufacturing industries since there are many large contractors compete in international markets. Also the decision to enter international construction markets occurs once or twice a year for a contractor, which is more frequent than the similar decision for aerospace and automobile manufacturers. Finally, the decision in the retail industry is when a retail firm should launch a new store in an emerging market. Of all industries, retailing is the most competitive industry since there are a lot of small, medium, or large companies that can enter the market. Also a retailer makes market entry decision perhaps many times a year and therefore, the frequency of pursuing opportunities is the highest in retailing.

Table 1. Decision-Making about Pursuing Opportunities in 4 Industry Settings

<table>
<thead>
<tr>
<th>Decision Type</th>
<th>Aerospace Manufacturers</th>
<th>Automobile Manufacturers</th>
<th>International Construction Firms</th>
<th>Retail Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of Decision-Making</td>
<td>Once or twice in a decade</td>
<td>Once or twice in several years</td>
<td>Once or twice a year</td>
<td>Many times a year</td>
</tr>
<tr>
<td>Competition Level</td>
<td>Very few giant international players</td>
<td>Several giant international players</td>
<td>Many large international players</td>
<td>A lot of small, medium, and large local and international players</td>
</tr>
<tr>
<td>Investment Costs ($)</td>
<td>Initial capital required to purchase land, build a distribution center and a maintenance service facility, etc.</td>
<td>Initial capital required to expand global supply chain network, purchase land, build an assembly factory and a distribution center, establish a local dealership network, etc.</td>
<td>Initial capital required to pay mandatory fees to get the right to bid on projects in a country, establish partnerships with local contractors/suppliers, open an office in the host country, etc.</td>
<td>Initial capital required to expand existing supply chain network, build a distribution center, purchase land and build a store or lease space, etc.</td>
</tr>
<tr>
<td>Fixed Costs ($/Year)</td>
<td>Annual expenses to operate facilities, pay employees, etc.</td>
<td>Annual expenses to operate facilities, pay employees, etc.</td>
<td>Annual expenses to pay mandatory fees to local government and partners, run the host-country office, pay employees, etc.</td>
<td>Annual expenses to run a store and respective facilities in the supply chain network, pay employees, etc.</td>
</tr>
<tr>
<td>Variable Costs ($/Sold Unit)</td>
<td>Costs of a sold airplane</td>
<td>Costs of a sold car</td>
<td>Costs of a construction project at development, design, and/or construction phase</td>
<td>Costs of a sold unit of goods or services</td>
</tr>
</tbody>
</table>
Opportunities to pursue in each industry differ in size and in terms of numbers of units sold or, more generally, revenues. In this perspective, an opportunity to pursue is an investment option for a firm in that industry that must be carefully evaluated; future revenue streams should be compared to costs of pursuing an opportunity to determine whether a market opportunity is financially attractive from an investment standpoint. Firms – that are competing to pursue these opportunities in each industry – are different in their investment capacities as well as their cost structures. There are three kinds of cost components that form a firm’s cost structure: investment costs, fixed costs, and variable costs.

*Investment costs* are one-time expenses that a firm must pay to pursue a market opportunity; an aerospace manufacturer must outlay initial capital to purchase land, build a distribution center and a maintenance service facility, etc. before it could start selling airplanes in a potential market. Similarly, an automobile manufacturer must outlay initial capital to expand its global supply chain network, purchase land, build an assembly factory and a distribution center, establish a local dealership network, etc. before it starts to sell cars in a region or a country. An international construction firm, on the other hand, outlay initial capitals to pay all fees required to get the right to bid on construction projects in a country, establish partnerships with local contractors and suppliers, open an office in the host country, etc. before it starts bidding and working on construction projects in the host country. Finally, a retailer must outlay initial capital to expand its supply chain network, build a distribution center, purchase land and build a store or lease space, etc. before it starts selling goods and services to customers in a new geographic location.

*Fixed costs* are expenses that a firm must pay annually to take advantage of a market opportunity and continue operations; in aerospace and automobile industries, fixed costs are annual expenses to operate facilities, pay employees, etc. Fixed costs for an international construction firm are expenses to pay mandatory fees to local government and partners, run the host-country office, pay employees, etc. In retailing, fixed costs are expenses to operate a store and respective facilities in the supply chain network, pay employees, etc.

*Variables costs* are expenses that a firm must pay to produce and sell goods and services in a potential market; in the aerospace industry, variables costs are costs of a sold airplane. In the automobile industry, fixed costs are costs of a sold car. Variable costs for an international construction firm are costs of a construction project at development, design, and/or construction phase. In retailing, variable costs are costs of a sold unit of goods or services in the store.

Firms in each industry are different in terms of their cost structures. This, in turn, impacts firms’ investment behaviors; larger firms have higher level of initial investments and fixed costs to pursue a market opportunity compared to smaller firms, which typically operate on smaller scales. The differences between firms’ costs structures impact the firm’s decision that is seeking to pursue an opportunity in a competitive market. Several factors are important in a firm’s decision about the optimal time to pursue an opportunity in a dynamic market: (a) uncertainty about how an emerging opportunity in a dynamic market evolves over time; (b) the state of competition in the market (i.e., whether there is an incumbent firm in the market or whether another firm has also pursued the opportunity); and (c) the firm’s cost structures as well as expected cost structures of competitive firms in the prospective market. An appropriate
investment analysis method is required to evaluate a firm’s market opportunity considering above factors and decide when it is optimal to pursue an opportunity.

Conventionally, the evaluation of a firm’s opportunity in a developing market is conducted by the Net Present Value (NPV) analysis approach; the NPV approach has been used in a variety of systems engineering applications. This approach calculates the firm’s NPV given cash flows summarizing the entire costs and benefits of the firm’s investment in a new market. The NPV approach is, however, based on the implicit assumption that the firm must enter the new market now or it can never enter the market. This approach does not consider the value of waiting to receive more information in the valuation process of the firm’s investment opportunity. In this paper, this limitation will be overcome by using a different perspective on investment valuation under uncertainty recognized as the real options theory, which has been applied to systems engineering problems in recent years.

We present an investment valuation model that describes how firms make market entry decisions in competitive, dynamic markets. Our research objective is to apply real options theory from finance/decision science to determine the optimal time that a firm should pursue an opportunity in a dynamic market. We determine the entry/pursuit criterion as a function of differing firm cost characteristics and state of the competition – whether another player has already pursued the opportunity, i.e., whether there is an incumbent, which may be acceptable if the size of the opportunity has grown. To achieve this objective, the rest of this paper is structured, as follows. Research backgrounds on market entry models are presented in section two. The differences between the traditional valuation approach and the real options valuation approach are discussed with a simple example in this section. The model to determine the firm's optimal entry time into a developing market is described in section three. Results and model characteristics are summarized in section four. In section five, we provide supportive evidences for our market entry model in retail markets – this choice being driven by the need for situations where large number of entry decisions have been made and documented, and the nature of the conditions prompting entry are available. Conclusions and future works are provided in section six.

2. Research Background

2.1. Traditional Valuation: Applicability and Limitations

The traditional valuation of a firm’s investment opportunity in a new market is typically conducted by the NPV analysis approach. This approach calculates the NPV of an investment given future cash flows, summarizing life cycle costs and benefits of the firm’s investment in the new market. All relevant cash flows in periods $t_0$ through $t_N$ are discounted to period $t_0$ with a discount factor $k$ per period, as follows:

$$\text{NPV} = \sum_{i=0}^{N} \frac{C_{t_i}}{(1+k)^i}$$

(1)

A positive cash flow $C_{t_i} > 0$ indicates a cash inflow in period $t_i$; a negative cash flow $C_{t_i} < 0$ indicates a cash outflow in period $t_i$. The firm’s investment is assumed to have $N+1$ cash in- and outflows and $t_N$ is the time horizon of the firm’s investment in the new market. The firm’s investment in the new market may, however, be subject to uncertainty due to the future market conditions for the firm’s products or services, competition, operation and maintenance costs, government regulations, etc. Techniques such as probabilistic analysis and Monte Carlo
simulation can be used to determine the distribution of the investment’s NPV as well as its expected NPV in uncertain business environment.

Many managers, however, believe that the assumptions of the NPV analysis approach do not properly represent their real world decision making problems and its findings do not seem to match their own experience. Empirical evidence overwhelmingly contradicts usefulness of NPV approach. Although the NPV approach recommends investment in the market with greater than zero NPV managers often require the expected benefit of an investment to be at least three to four times greater than its costs before considering that opportunity for investment (Amram and Kulatilaka 1999; Dixit and Pindyck 1994; Ellingham and Fawcett 2006; Myers 1987; Smit and Trigeorgis 2004). In the uncertain investment environment, managers prefer to wait and receive more information about the market and then decide whether to enter. This way the management can avoid or limit the downside of the investment by deferring the market entry and waiting for new information about the market conditions. The NPV approach does not consider the value of waiting to receive more information in the valuation process of the firm’s investment opportunity in the new market. The NPV approach is based on the implicit assumption that the firm must enter the new market now or it can never enter the market. This limitation can be overcome by using a different perspective on investment valuation under uncertainty recognized as the real options theory.

2.2. Real Options Valuation Method

The term ‘real options’ was first introduced by Myers (1977). It referred to the application of financial option pricing in finance and banking, such as Black and Scholes (1973) formula to the assessment of non-financial or “real” investments with strategic management flexibility like multi-stage development or modular plant expansion. The real options methodology is an emerging state-of-the-art capital budgeting paradigm that addresses managerial flexibility and strategic behaviors of decision-makers under dynamic uncertainty (Amram and Kulatilaka 1999; Dixit and Pindyck 1994; Smit and Trigeorgis 2004). It also provides an analytical framework to evaluate management flexibility in decision making regarding whether and how to proceed with business investments while it considers the dynamic uncertainty of the investment underlying factors. We explain the difference between these two investment analysis approaches, the NPV approach and the real options approach, with a simple example that is taken from chapter 2 of Dixit and Pindyck (1994).

2.2.1. Example

Suppose a firm is trying to decide whether to invest in a widget factory. The investment is completely irreversible – the factory can only be used to make widgets, and should the market for widgets evaporate, the firm cannot uninvest and recover its expenditure. To keep things as simple as possible, we will assume that the factory can be built instantly, at a cost $I = $1600, and will produce one widget per year forever, with zero operating cost. Currently the price of a widget is $200, but next year the price will change. With probability $q = 0.5$, it will rise to $300, and with probability $(1 – q = 0.5)$, it will fall to $100. The price will then remain at this new level forever (see Figure 1).
The firm’s problem is that given these values, is this a good investment? Should the firm invest now, or would it be better to wait a year and see whether the price of widgets goes up or down? Suppose the firm’s discount rate for this investment is \( r = 10\% / \text{year} \). There are two ways to treat uncertainty for this investment situation.

The first approach is *simple (naïve) NPV approach*. In this approach, we assume that the firm pays \( I = $1600 \) at time 0 and immediately opens the factory in this market. This factory remains open forever. This factory sells one widget at time 0 with \( P_0 = $200 \). The factory will sell one widget at any time in future. The expected price of the widget in time 1,2,… will be $200, i.e., \( E(P) = (0.5)(300) + (0.5)(100) = $200 \). Therefore, this investment’s cash flow consists of – $1,600 at time 0 and a perpetual revenue of $200. The NPV of this investment is the present worth of this time series of cash flow. The cash flow at each period will be discounted back to the period before at the rate of \( \frac{1}{1+r} = \frac{1}{1+0.1} \). The NPV calculation is summarized below.

\[
\text{NPV}_0 = -1600 + \sum_{t=0}^{\infty} \frac{E(P)}{(1+r)^t} = -1600 + \sum_{t=0}^{\infty} \frac{200}{(1+0.1)^t} = $600 > 0
\]

This approach yields the NPV of $600 for this investment and therefore, recommends investment. This approach, however, is based on an implicit assumption that the firm has to invest today or never at all. Hence, the NPV of this investment opportunity is $600 if the firm opens a factory at time 0, i.e., \( \text{NPV}_0 = $600 \).

The second approach is the *real options approach*. The above calculation is not correct since it ignores a cost – the opportunity cost of investing now, rather than waiting and keeping open the possibility of not investing should the price fall. To see this, we first calculate the value of investment under both states of the price at time 1. If the bad market condition is realized, and the firm can invest at period 1 instead of period 0, then the value of the investment at time \( t = 1 \) is:

\[
-1600 + \sum_{t=0}^{\infty} \frac{100}{(1+0.1)^t} = -$500 < 0
\]

Therefore, if the firm waits for period 1 and then in period 1, the bad state is being realized, then the firm will not invest. Although the firm looses an immediate sale of $200 at period 0 the firm benefits from this flexibility option in the long run and limits its downturn to zero if the bad state occurs.

If the good state, however, is realized, then the value will be:
The value of this investment strategy with deferral option can be calculated based on the firm’s investment values in good and bad market conditions at period 1, as computed above. This calculation considers that the firm will just invest in the good market condition at period 1, i.e., the deferral option limits the firm’s loss at period 1 by not investing at period 0. It also considers the opportunity cost of selling one unit at the current price of $200 in period 0. The value of the firm’s investment at period 0 can be calculated, as follows.

\[
NPV_1 = \left( -1600 + \sum_{t=0}^{\infty} \frac{300}{(1 + 0.1)^t} \right) \times \frac{1}{1.1} + \frac{1}{2} \times (0) \times \frac{1}{1.1} = $773
\]

This is the NPV of this investment opportunity if the firm waits for one period to receive information about the widget price and then, decides whether to open a factory or not, i.e., NPV1 = $773. Therefore, given the option between investing in period 0 or 1, the NPV of investment in period 1 is higher than the NPV of investment in period 0, i.e., NPV1 = $773 > NPV0 = $600. The difference $773 – $600 = $173 shows the value of waiting or the value of receiving more information about the widget price. Thus, the optimal investment time under the real options approach is period 1.

Now, suppose next year with probability \( q = 0.5 \), the widget price will rise to $250, and with probability \( 1 - q = 0.5 \), it will fall to $150. The price will then remain at this new level forever. The expected price will not change from the previous example. Therefore, the NPV of this investment will remain at $600 if the firm decides to open a factory in period 0. The NPV of this investment, however, will change if the firm decides to wait for a period, and decides whether to open a factory or not, as follows.

\[
NPV_1 = \frac{1}{2} \left( -1600 + \sum_{t=0}^{\infty} \frac{250}{(1 + 0.1)^t} \right) \times \frac{1}{1.1} + \frac{1}{2} \times \left( -1600 + \sum_{t=0}^{\infty} \frac{150}{(1 + 0.1)^t} \right) \times \frac{1}{1.1} = $545
\]

Therefore, given the option between investing in period 0 or 1, the NPV of investment in period 0 is higher than the NPV of investment in period 1, i.e., NPV0 = $600 > NPV1 = $545. Under this new price configuring, the firm should invest immediately and open a factory in this market. The firm does not benefit from waiting and delaying its investment in this market since the value of waiting or the value of receiving more information about the widget price is negative $545 – $600 = –$55. Thus, the optimal investment time under the real options approach is period 0. Therefore, unlike the NPV approach the real options approach considers the value of waiting in the valuation process of the firm’s investment in this developing market.

The above example shows how the real options valuation procedure is different from the conventional NPV analysis. The major difference between these two approaches is that in the real options approach, it is not predetermined when and how to go with an investment opportunity; it should be determined as part of the evaluation process. The field of real options analysis, however, has gone through a massive transition from a topic of modest academic interest in 1980’s and 90’s to considerable, active academic and industry attention (Borison 2005). The real options methodology has been applied in several investment valuations in various domains such as technology assessment (Shishko et al. 2004), research and development (Bodner and Rouse 2007), mining (Mayer and Kazakidis 2007), manufacturing (Bengtsson 2007).
This broad range of applications indicates that the real options methodology has been used to value real-world investment opportunities, for which there is no underlying traded security. A variety of analytical procedures have been developed in independent disciplines of management science/decision analysis and finance for real options analysis (see Borison (2005) for a comprehensive review of real options analysis methods). Real options analysis has already been applied to market entry problems; Dixit (1989) describes a model to determine a firm’s optimal entry and exit decisions in an uncertain business environment. However, the competitive interaction between firms in developing markets and the effect of one firm’s entry on other firm’s behavior were not considered in this model. Smit and Trigeorgis (2004) used a real options and game theoretic approach to study corporate investment strategies under competition. The competitive interaction between firms to enter new markets was considered in their model but the firms’ different cost structures and its impact on firms’ optimal investment time were not addressed in their work.

Our proposed real options model has several features that make it different from the above research. We treat the firm’s opportunity to enter a new market as an investment option whose success enhances the financial position of the firm. Entering a developing market is an example of an investment activity since it has three important features of an investment as outlined by Dixit and Pindyck (1994). It is partially irreversible, it is subject to uncertainty, and management has the flexibility to choose the investment time. This decision is partially irreversible since the firm cannot recover the majority of its initial expenses (required initial capital to purchase land, build a distribution center and a maintenance service facility, build a store or lease space, etc.) when it enters the market; the degree of irreversibility increases as the size of the firm’s investment increases in the new market. Our model also considers that entering a new market is a risky business since future market conditions are unpredictable. In addition to the above features, our investment model treats competition in the market endogenously to describe investment behaviors of large and small firms in developing markets. It is explained why small firms enter developing markets at lower market sizes compared to big firms. Our real options model is described below.

3. Model

Suppose there are two firms, firm 1 and firm 2 that have investment opportunities in a developing market. These firms provide identical products or services to customers in this market. We denote firm 1’s and firm 2’s quantity of the product or the service at time t by $Q_1(t)$ and $Q_2(t)$, respectively. The price of this product or service will be determined in the market according to the total quantity of the product or the service in the market. In this paper, we use a linear demand function (Varian 2003) to characterize the relationship between the price of a product or a service and its total quantity in the market. This demand function is based on the
assumption that both firms provide homogenous products or services to customers in the market. Equation (1) summarizes this linear demand function, as follows.

\[ P(t) = -\gamma \times TQ(t) + X(t) \]  

(2)

where \( P(t) \) is the unit price of the product or the service in time \( t \) and is measured in $/quantity and \( TQ(t) \) is the total quantity of products or services that are supplied to the market by these two firms in time \( t \) and is measured in quantity/time unit. This linear demand model captures the negative relationship between the price of the product or the service and its total quantity in the market. It is chosen since it simplifies the computational process. So even though they are important questions on their own, how good the actual demand is represented here, product differentiation (why all the products are considered the same) and/or how good we fit the data for demand estimation are not central to the problem discussed in this paper.

Higher \( \gamma \) in the demand model of Equation (2) means that changes in price has little to no effect on the quantity demanded by people and low \( \gamma \) means that the quantity demanded by consumers is very sensitive to the price. Also variable \( X(t) \) in Equation (2) identifies the maximum price of this product or service that customers are willing to pay in this market. \( X(t) \) can be interpreted as an indicator of the market size (say market population). People are different in their willingness to pay for goods, therefore, higher population means higher likelihood of finding people with higher willingness to pay for a product or a service. Therefore, the value of \( X(t) \) increases (decreases) as the market size increases (decreases). Figure 2 shows how the relationship between the price of the product or the service and its total quantity in the market changes as \( X(t) \) changes over time. As the market size enlarges \( X(t) \) increases and thus, the demand line shifts up. As the market size contracts \( X(t) \) decreases and hence, the demand line shifts down.

These firms consider this demand model in their decision making process. The timing of their decisions is summarized below.

3.1. Timing of firms’ decisions
These two firms have investment opportunities to provide a product or service to the market. This product or service follows the linear demand function of Equation (2). At time $t$, each firm has two decisions to make. The first decision is whether to enter the market or not. Once a firm is in the market it stays in the market forever. Given the firm is in the market at time $t$, the second decision is about the optimal quantity of the product or the service that the firm should provide to the market. The sequence of information revelation and firms’ decision making are, as follows.

- **The incumbent firm**: at time $t$, the incumbent firm observes the value of $X(t)$ and after considering whether the other firm would be in the market at time $t$, decides about the optimal quantity that it should provide to the market.
- **The new entrant firm**: at time $t$, the new entrant firm observes the value of $X(t)$ and the previous entry decision of the other firm, and after considering whether the other firm would be in the market at time $t$, decides to enter the market or not. If the firm decides to enter the market it has to decide about the optimal quantity that it should offer in the market at time $t$.

### 3.2. Market structures

Considering these two firms’ entry decisions, we have three possible market structures, in which the number of firms in the market could be zero, one, or two. Figure 3 shows these market structures. Suppose at time $t$ firm $i$ ($i = 1,2$) is not in the market. If firm $j$ ($j \neq i$) is not in the market either then the market structure becomes the market with no firm in. If firm $j$ ($j \neq i$) is in the market then market becomes monopoly with one firm. Now suppose at time $t$, both firms $i$ ($i = 1,2$) and $j$ ($j \neq i$) are in the market. Then, market becomes duopoly with two firms in.

![Figure 3. Market structures](image)

Given a specific market structure, firms make decisions about their quantities such that they maximize their profits.

### 3.3. Firms’ optimal quantities and profits

In any of the above market structure, each firm seeks to maximize its profit. The firm’s profit is equal to its revenue minus its cost. Firms’ costs are different from each other since these two firms are different in many aspects of their operations including supply chain management, service levels, negotiations with suppliers, and etc. In this paper, we summarize these firms’ differences at higher level of abstraction in terms of their cost structures specified by the following three cost variables for firm $i$ ($i = 1,2$).

- **Investment Cost** ($IC_i$) to enter a market measured in dollars: These costs are one-time sunk costs and irreversible and therefore, delay firms’ investments in the market.
• Fixed cost (FC) to conduct business in a market measured in $/time unit: The firm should pay these costs every period in order to continue its operations in the market regardless of the quantity it offers in the market that period.

• Variable cost (VC) to provide one unit of the product or the service to the market measured in $/quantity

The firms’ investment costs are just important in their decisions about optimal time to enter a market. The firms’ fixed and variable costs are also important in finding their optimal quantities and their respective profits after they entered the market. Both firms’ profits are zero at time t when there is no firm in the market. Suppose at time t firm i (i = either 1 or 2) already paid its investment cost (IC) and therefore, is in the market while firm j (j ≠ i) is not in the market. Thus, firm j’s profit is zero but firm i’s profit follows equation (3), as summarized below.

\[ \Pi_i(t) = (P(t) - VC_i) \times Q_i(t) - FC_i \quad i = \text{either 1 or 2} \]  

where \( \Pi_i(t) \) represents firm i’s profit function that is measured in $/time unit and \( Q_i(t) \) is firm i’s quantity in this market structure at time t. \( Q_i(t) \) is also a decision variable for firm i since it seeks to maximize its profit by providing the optimal quantity of the product or the service in this monopoly market. The unit price of the product or the service in this monopoly market (P(t) in Equation 2) is calculated by substituting \( Q_i(t) \) for \( TQ(t) \) in Equation (1).

The objective of firm i is to find its optimal quantity of the product or the service that maximizes its profit at time t. The following formulation determines firm i’s optimal quantity in the monopoly market at time t. This optimal quantity is denoted by \( Q_i^M(t) \) and maximizes firm i’s profit \( \Pi_i(t) \) described in Equation (3).

\[ Q_i^M(t) = \begin{cases} \frac{X(t) - VC_i}{2\gamma} & \text{if } (X(t) - VC_i) \geq 0 \\ 0 & \text{Otherwise} \end{cases} \quad i = \text{either 1 or 2} \]  

(4)

It can be seen that \( Q_i^M(t) \) does not depend on firm i’s fixed and investment costs. This optimal value, however, depends on firm i’s variable costs and \( X(t) \). Therefore, firm i’s optimal quantity of the product or the service in the monopoly market depends on the market size \( X(t) \). Based on this optimal quantity, firm i’s optimal profit in the monopoly market at time t – denoted by \( \Pi_i^M(t) \) – is summarized below.

\[ \Pi_i^M(t) = \begin{cases} \frac{(X(t)^2 - X(t) \cdot VC_i)}{4\gamma} + \frac{(VC_i)^2}{4\gamma} - FC_i & \text{if } (X(t) - VC_i) \geq 0 \\ -FC_i & \text{Otherwise} \end{cases} \quad i = \text{either 1 or 2} \]  

(5)

Now suppose both firms already paid their investment costs and therefore, are in the market at time t. Firm i’s (i = 1,2) profit in this duopoly market at time t is denoted by \( \Pi_i(t) \) as described earlier in Equation (2). The unit price of the product or the service in this duopoly market (P(t) in Equation 2) is calculated by substituting \( Q_i(t) + Q_2(t) \) for \( TQ(t) \) in Equation (1).

These two firms decide on their optimal quantities such that maximize their profits. Conditional on both firms being in the market, no firm has informational or first mover advantage over the other firm. This type of competition is known as Cournot competition. Therefore, firm i’s (i = 1,2) optimal quantity in this duopoly market is:
\[ Q_i^D(t) = \begin{cases} \frac{(X(t) - 2VC_i + VC_j)}{3\gamma} & \text{if } (X(t) - 2VC_i + VC_j) \geq 0 \quad i = 1,2 \text{ and } j \neq i \\ 0 & \text{Otherwise} \end{cases} \] (6)

It can also be seen that firm i’s optimal quantity in the duopoly market at time t – denoted by \( Q_i^D(t) \) – does not depend on firm i’s fixed and investment costs. This optimal value, however, depends on this firm’s variable costs and \( X(t) \). Therefore, firm i’s optimal quantity of the product or the service in the duopoly market depends on the market size \( X(t) \). Based on this optimal quantity, firm i’s optimal profit in the duopoly market at time t – denoted by \( \Pi_i^D(t) \) – is summarized below.

\[
\begin{align*}
\Pi_i^D(t) &= \frac{(X(t))^2}{9\gamma} + \frac{X(t)(VC_j - 2VC_i)}{9\gamma} + \frac{(VC_j - 2VC_i)^2}{9\gamma} - FC_i \\
&\quad \text{if } \begin{cases} (X(t) - 2VC_i + VC_j) \geq 0 \quad i = 1,2 \text{ and } j \neq i \\
&\quad (X(t) - 2VC_j + VC_i) \geq 0 \quad i = 1,2 \text{ and } j \neq i \end{cases} \\
\Pi_j^D(t) &= -FC_j \\
&\quad \text{if } \begin{cases} (X(t) - 2VC_i + VC_j) < 0 \quad i = 1,2 \text{ and } j \neq i \\
&\quad (X(t) - 2VC_j + VC_i) < 0 \quad i = 1,2 \text{ and } j \neq i \end{cases} \\
\Pi_i^D(t) &= -FC_i \\
&\quad \text{if } \begin{cases} (X(t) - 2VC_i + VC_j) < 0 \quad i = 1,2 \text{ and } j \neq i \\
&\quad (X(t) - 2VC_j + VC_i) < 0 \quad i = 1,2 \text{ and } j \neq i \end{cases} \\
\end{align*}
\] (7)

These two firms’ optimal quantities and their respective profits at time t depend on variable \( X(t) \). The timing of firms’ decisions to enter the market, which defines the market structure, also depends on variable \( X(t) \). The value of variable \( X(t) \) changes as the market size changes over time. We capture incremental variations of variable \( X(t) \) with a random walk model.

### 3.4. Binomial lattice for modeling incremental variations of \( X(t) \)

We use a specific random walk formulation referred to as the binomial lattice (Cox et al. 1979; Kamrad and Ritchken 1991) to describe the variation of \( X(t) \), as follow. Suppose the current value of variable \( X \) is \( X_0 \). After time increment \( \Delta t \), the value of this variable may increase to \( X_{1u} = u \times X_0 \) with probability \( p_1 \) or decrease to \( X_{1d} = d \times X_0 \) with probability \( p_2 = 1 - p_1 \), where \( u > 0 \) and \( d = 1/d \). This variation trend will continue in subsequent time increments as shown in Figure 4.
Figure 4. Binomial lattice

The firm facing this dynamic variation in market size needs to determine when it is optimal to enter the market. The described binomial lattice will be used as a decision tree to solve the firm’s optimal investment timing problem.

3.5. Firms’ optimal entry time

The firms’ decisions about optimal time to enter a developing market depends on the current market size or the value of $X(t)$ in our model. Firms’ profits are functions of $X(t)$ – as described in section 3.2 – and therefore, $X(t)$ becomes the state variable in firms’ decision space. Suppose the variation of $X(t)$ in time has been characterized by a binomial lattice similar to the one shown in Figure 4 consisting of $N$ time increments. This lattice is used as a decision tree to solve the firms’ optimal time to enter the market. Every node in this lattice is a decision node for firms, at which they should decide between one of these two alternatives considering the current value of $X(t)$: invest and enter the market or wait and defer investment decision making to the next time period when more information about the market size becomes available. A standard backward induction procedure is applied to solve this decision tree and find the optimal firms’ decisions, as follows.

Backward induction proceeds by first considering the last time firms can make decision and choose whether to enter the market at that time. Using this information, firms can then determine what to do at the second-to-last time of decision. This process continues backwards until firms have determined firms’ optimal investment time for every possible situation at every point in time. This way firms’ optimal market entries will be determined endogenously in our valuation model. The decision rule for firms’ market entry at every node in this lattice is, as follows. Each firm should enter the market if the firm’s expected NPV of investment exceed the expected value of waiting and deferring investment to the next time step. The Firm’s expected NPV at any node
in the lattice is equal to expected, discounted future firm’s profits in subsequent nodes – which can be possibly linked to the current node – minus its investment cost. Both firms will behave optimally according to the market structure at any future node in this lattice. Optimal firms’ profit in various market structures (shown in Figure 3) were be based on our formulations in Section 3.1. Expected values of these optimal profits will be computed and discounted back to the current node. Then, firms’ investment costs will be subtracted from these expected discounted profits to calculate firms’ expected NPVs of entering the market at the current node. A common discount rate $\rho$ will be used for both firms. This external discount rate shows firms’ belief about the riskiness of a specific investment in a new market.

Expected values of waiting for these two firms at the current node can be computed in a similar fashion. Expected values of firms’ investment at two future nodes in the subsequent time step will be discounted back to the current time step to determine firms’ values of waiting. Firms should enter the market when expected NPVs of investment at the current node exceed expected values of waiting and deferring market entry decision to the next period. We use a notional example to illustrate the characteristics of our theoretical market entry model.

4. Results

Suppose the first firm (firm 1) is a big enterprise, which has low variable costs to provide products or services to a market but high fixed and investment costs to enter and operate in the market. The second firm (firm 2) is a small enterprise that has high variable costs to provide products or services to the market but low fixed and investment costs to enter and operate in the market. We assign numerical values to these firm’s cost parameters to investigate how firms’ differences in cost structures impact their optimal investment strategies. These values are $IC_1 = \$400,000 > IC_2 = \$200,000$, $FC_1 = 200,000 \$/year > FC_2 = 100,000 \$/year$, and $VC_1 = \$80 < VC_2 = \$100$. The values of the other model parameters are $\rho = 8 \%/year$, $\gamma = 1$, $X_0 = \$700$, $u = 1/d = 1.03$, $\Delta t = 1/12$ year, and $N = 120$ time increments (i.e., months). The firms’ optimal investment thresholds will be calculated at four levels of probability of up-movement in the market size lattice $p_1 = 1 - p_2 = 0.52, 0.55, 0.58, \text{and } 0.61$.

The above two firms’ investment strategies in this developing market will be investigated under two situations. First, we assume that each firm decides to enter this market without considering the competition effect from the other firm. Next, we assume that each firm makes decision to enter this market considering the competition effect from the other firm.

Figure 5 shows these two firms’ optimal investment thresholds under the above two market situations. The vertical axis represents market sizes, at which it is optimal for firms to exercise their investment opportunities and enter the market. The horizontal axis defines various levels of probability of up-movement in the market size ($p_1$), for which these optimal investment thresholds are computed. It can be seen that the small firm’s optimal investment threshold in the monopoly and the duopoly market is lower than the big firm’s optimal investment threshold in the monopoly and the duopoly market, respectively. This result is expected since the small firm has the overall cost advantage, which puts it at the better position than the big firm to enter the developing market at the relatively lower market size.
The competition effect can also be observed in Figure 5. The big firm’s optimal investment threshold in the duopoly market is greater than this firm’s optimal investment threshold in the monopoly market because the small firm had already entered the duopoly market and hence, the big firm should wait longer to exercise its investment opportunity. However, the small firm’s optimal investment threshold in the monopoly market is the same as this firm’s optimal investment threshold in the duopoly market since the small firm is the first firm that can enter this developing market. Thus, our option valuation model indicates the strategic aspect of early investment by the small firm in the competitive market.

We conduct two sensitivity analyses to assess our model characteristics with respect to changes in values of two important model parameters that impact the firms’ optimal investment thresholds. The first sensitivity analysis is conducted to explore how changes in the probability of up-movement in the market size lattice (p₁) impact the firm’s optimal investment threshold. Figure 5 shows that firms’ optimal investment thresholds decrease as p₁ increases from 52% to 61%. As the value of p₁ increases the likelihood of market growth increases, and consequently, expected values of firms’ investments in this market increase. This motivates firms to invest earlier and at lower market sizes.

The second sensitivity analysis is conducted to investigate how changes in the ratio of up-movement in the market size lattice (u) impact firms’ optimal investment thresholds. Figure 6 shows the small and big firms’ optimal investment thresholds in dynamic, competitive markets. It can be seen that these firms’ optimal investment thresholds increase as the value of parameter u increases from 1.03 to 1.09. Parameter u describes the dispersion of possible market size values, i.e., the higher the ratio of up-movement in the market size lattice the wider the range of
possible market size. Therefore, the riskiness of firms’ investments increases as the value of parameter \( u \) increases. This further raises critical firms’ investment thresholds in volatile markets.

![Sensitivity analysis for the ratio of up-movement in market size lattice (\( u \))](image)

**Figure 6. Sensitivity analysis for the ratio of up-movement in market size lattice (\( u \))**

5. Supportive Evidences from the Retail Industry

One of the most important features of our investment valuation model is its ability to explain the contrast in market entry behaviors of small and large firms in dynamic markets; our real options model for pursuing opportunities shows that smaller firms can pursue smaller opportunities than larger firms, in part because they can be profitable with smaller opportunities while larger firms cannot. Also there may be relatively less intense competition for smaller opportunities, at least not deep-pocketed competition. Not surprisingly, larger firms prefer larger opportunities – however, they will pursue smaller opportunities but are hesitant if smaller firms are already pursuing these opportunities. We provide supportive empirical evidences from the actual investment behaviors of small and large firms in the retail industry.

We study actual market entry decisions by considering investments in retail markets to find supportive empirical evidences for our real options model – this choice being driven by the need for situations where large number of entry decisions have been made and documented, and the nature of the conditions prompting entry are available. The earlier work of the authors (Ashuri 2008; Ashuri et al. 2008) motivates the current research with an example from retail, a sector in which significant amounts of data exist for empirical studies. Studying the market entry behavior of the large retail firm Wal-Mart and the small retail firm Dollar General across various geographic markets in the state of Georgia shows that on average Dollar General enters
developing markets at lower populations compared to Wal-Mart. In Georgia, the average market population for a typical Dollar General store is approximately 22,000. This number is approximately 300,000 for a typical Wal-Mart store. Joint percentile histograms of market populations for Dollar General and Wal-Mart stores in Georgia are also shown in Figure 7. It can be seen that the majority of Wal-Mart stores are opened at higher market populations compared to Dollar General stores; Note that population is just a surrogate for pursuing an opportunity in a retail market (i.e., number of people × average expenditure).

Therefore, the observed market entry behaviors of Wal-Mart and Dollar General in the State of Georgia confirm what we would expect from the theoretical results of our real options model. In fact, our model provides economic explanation of why small firms enter developing markets at lower market sizes (i.e., populations) compared to big firms.

Figure 7. Joint percentile histogram of market populations for Dollar General and Wal-Mart stores

6. Conclusions and Future Work

Systems Engineering and Management (SEM) are not only about doing things right; SEM is also about doing the right things. Choosing the right opportunities to pursue is a central aspect of doing the right things; for example, an ill-conceived vehicle that is engineered well is nevertheless still a failure – see Hanawalt and Rouse (2009). We present an investment valuation model that describes how firms make market entry decisions in competitive, dynamic markets. We apply real options theory from finance/decision science to determine the optimal time that a
firm should pursue an opportunity in a dynamic market. We determine the entry/pursuit criterion as a function of differing firm cost characteristics and state of the competition – whether another player has already pursued the opportunity, i.e., whether there is an incumbent, which may be acceptable if the size of the opportunity has grown.

Our proposed real options model has several features that make it different from existing market entry models. We treat the firm’s opportunity to enter a new market as an investment option whose success enhances the financial position of the firm. Our model also considers that entering a new market is a risky business since future market conditions are unpredictable. In addition, our investment model treats competition in the market endogenously to describe investment behaviors of large and small firms in developing markets.

One of the most important theoretical results of our market entry model is about identifying the differences in investment behaviors of small and large firms in dynamic markets. It is explained why small firms enter developing markets at lower market sizes compared to big firms; smaller firms can pursue smaller opportunities than larger firms, in part because they can be profitable with smaller opportunities while larger firms cannot. Also there may be relatively less intense competition for smaller opportunities. On the other hand, larger firms prefer larger opportunities – however, they will pursue smaller opportunities but are hesitant if smaller firms are already pursuing these opportunities. We find supportive evidence for the differences between investment behaviors of small and large firms in the retail industry – this choice being driven by the need for situations where large number of entry decisions have been made and documented, and the nature of the conditions prompting entry are available. Through studying actual market entry decisions by Wal-Mart (large firm) and Dollar General (small firm) in the state of Georgia, we find empirical evidences to support our theoretical findings that larger firms enter greater market sizes compared to smaller firms.

Our valuation model is based on many assumptions that are used for simplifying the investment evaluation procedure. Relaxing any of these assumptions may provide opportunities for further research. We used a simple demand function, which is exogenous to our investment analysis model to characterize the inverse relationship between price and quantity in product or service markets. This model is based on an important assumption that firms provide products or services at the same price to consumer markets. We also assume that customers only consider the price of a product or service at their decision of choosing a firm for shopping. Future research is needed to develop more appropriate demand models that describe the relationship between price, quantity, and quality in different product or service industries. Perhaps, Betancourt and Gautschi (1988) and Betancourt et al. (2004) researches could provide a good start to understand the economics of firms.

Last but not least, our real options model should be empirically validated in other industry sectors in addition to the retail industry. One might question how the market entry of retail chains relates to decisions by aerospace firms or automobile companies to enter new markets. Certainly the sales transaction differs significantly between retail and aerospace – less so between retail and automotive. Further, the demographic characteristics of a market differ between retail and aerospace – again, less so between retail and automotive. The simple fact is that this model had to be validated in a domain where a large number of market entry decisions
are made. The result was an initial focus on retail where data was available for thousands of market entry decisions by two major competitors. Similar studies should be conducted to investigate investment behaviors of firms of different sizes in other sectors.

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