Effects of Contractors' Risk Attitude on Competition in Construction

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Abstract: Competitive bidding is the major mechanism of competition. Bidding is risky because the actual cost of the job is unknown. Thus, the bid should be high enough to make a profit but low enough to win the bidding. The result of competition depends on the competitor's risk-taking behaviors, which are affected by the organization's risk attitudes. A contractor's risk-taking is an essential element of the construction business. The current study explores the domain of competition at the aggregate market level. An evolutionary simulation model was developed to investigate the effects of risk attitude on a contractor's success and on the market structure. The analysis accounts for different risk-taking behaviors in competition, different performances by contractors, corresponding organizational changes, and aggregate patterns in the form of the market structure. The study finds that risk attitude is a competitive characteristic of contractors. The results provide new insight on competition in the market place, and explanations are given for a contractor's competitive success. **DOI: 10.1061/(ASCE)CO.1943-7862.0000284.** *© 2011 American Society of Civil Engineers.*

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Introduction

Competition and risk are two of the most frequently used terms to describe the construction business. Competition in a market is developed by multiple competitors, who may behave differently under uncertain environments depending on their own risk attitudes. Over time, organizations develop their own cultures. A firm's culture, especially its risk culture, defines its own approach to dealing with uncertainty (Hillson and Murray-Webster 2005). Winners and losers are determined through their competition in the market. A market model based on risk raises some interesting questions. Is there an appropriate level of risk attitude for contractors to achieve survival and growth? Organizations can affect their own environment, as well as their own selection regimes (Erwin and Krakauer 2004) and how they compete defines the structure of a market (Besanko et al. 1996). Could contractors with various risk attitudes, as a universal trait, evolve or affect characteristics of the market through competition among themselves? What effects or patterns would evolve externally reflecting these internal states, such as risk-aversion? This study investigates these questions using a simulated evolutionary approach, which considers contractors as individual entities competing with each other for common job opportunities in a market, and analyzes their competition as an evolutionary process. This approach replicates the structure of the U.S. construction industry, as represented *The Top 400 Contractors* by the *Engineering News-Record* (ENR) (1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008).

This study focuses on the fundamental aspect of competition in construction, risk attitude, as the latent basis of individual contractors' risk-taking behavior. Competitive, fixed price, and winner-take-all bidding is represented as the paradigm for competition among contractors in the market place. The objective of this study is to answer the following questions:

- Are contractors risk-neutral, risk-averse, or risk-tolerant?
- Are there relationships between risk attitude and firm performance?
- Is there an appropriate level of risk aversion or risk tolerance that maximizes the profitability, survival, and growth?

The research described in this paper deals with the following tasks: (1) review competition studies in construction and other areas, (2) identify missing concepts and propose better approaches, (3) analyze construction industry data to identify aggregate patterns as the result of competition, (4) propose hypotheses to identify the effects of risk attitude on competition and the relationships between risk attitude and firm financial performance, (5) develop an efficient method to represent contractors' risk-taking behaviors and an evolutionary model to simulate competition among contractors, and (6) test the proposed hypotheses using the model and make recommendations for construction contractors.

Literature Review

Competition Studies in Construction

Since Friedman's model (1956), a probabilistic model to find the optimum markup to maximize the expected profit from a specific job, there has been a significant number of studies about competitive bidding in construction. Advancements have been obtained by

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applying new and different ideas. For example, Mayo (1992) showed, by extending Friedman's model, that a contractor's bidding decisions depend on each firm's current workload and backlog, as well as general business climate for construction projects. Other researchers, such as Skimore and Pemberton (1994), investigated different strategies for markups used by different contractors. Kim and Reinschmidt (2006) developed a dynamic simulation model to investigate the interactions between competing construction firms over time. Moselhi et al. (1993) developed a decision support system to assist contractors in setting bid markups. Chen (1991) applied portfolio analysis to develop decision strategies at the firm level for bidding. Cagno et al. (2001) developed a multicriteria model for the probability of winning a bid. Nevertheless, most competitive bidding models follow Friedman's original model with some modifications or extensions.

Competitive bidding studies develop general bidding strategies that can be applied in many bidding situations. These strategies are quantitative so that the bid decision process is made clearly and objectively, rather than subjectively. However, in real situations, subjective assessment is the most commonly used method by contractors (Shash 1995; Mochtar and Arditi 2001). Competitive bidding models for calculating optimum bid markups have also been difficult to implement in real business situations owing to the lack of data for analysis, lack of acceptance by senior management, and other practical reasons (Christodoulou 1998). Many researchers agree that the study of bidding and competition is not a mature field, as there are broad gaps between the proposed theoretical approaches and applications in real situations. There are important points that have not been fully considered in previous competition studies, even though they can have significant effects on competition among contractors. These points include:

- Risk-taking under competition is an essential element in the construction business.
- Contractors may have their own individual risk attitudes, as part of their organizational culture, which affect organizational behavior.
- Competition is developed by the interaction of multiple competitors. Ultimately, different risk attitudes among contractors could affect competition among themselves.
- A contractor's financial performance may be affected by competition.
- The goal of contractors is not to maximize profit in the short term on specific projects, but to survive and grow over the long-term.

Among previous competitive bidding models, utility theory models have considered a contractors's risk attitude (Dozzi et al. 1996; Marzouk and Moselhi 2003). However, these models have considered risk attitude simply as a single decision factor contributing to an individual contractor's bid decision. Less attention has been paid to a contractor's risk-taking behavior in competition and the effects on the structure of the market (the distribution of the number of firms with different sizes), even though risk attitude is a universal trait for all industry entities.

Competition Studies in Biology, Ecology, Economics, and Industries Other than Construction

Various competition studies can be found in such fields as biology, ecology, economics, and others. The studies in biology and ecology discuss competition within a species or between species as the relationship between individuals who compete for common living requirements, such as energy or space (Carbone and Gittleman 2002; Marquet 2002). An individual's energy consumption and limited resources are considered as basic elements of competition and the environment evolves through competition and selection. Researchers have found a ubiquitous phenomenon in a variety of systems, the power law. Regression analysis of empirical data regarding the relationship between population density (D) and body size (mass, M), for a variety of organisms finds that the best-fitting model is the exponential relationship or power function, $D = \alpha M^{\beta}$. This universal relationship, which can also be expressed as $\log D = \alpha + \beta \log M$, is linear on a logarithmic (log-log) scale. The value of β is negative, indicating an inverse proportionality; population density decreases as body size increases. Many studies in biology and ecology have reported β values around $-3/4$, but there are differences of opinion and different values have been found (White and Seymour 2005).

In market ecology and economics, researchers have applied the biological competitive relationship to the population of business organizations in the market place to identify mechanisms that lead to some aggregate pattern or phenomenon in different industries, such as the skewed size distribution of firms (Singh 1990). The size distributions of business organizations are usually highly skewed but economic theory does not explain much about these observations (Simon and Bonini 1958). Different approaches and explanations for the underlying mechanism have been proposed. They include long-run average cost curves (Viner 1932), Gibrat's law of proportionate effect (Simon and Bonini 1958), equilibrium approaches (Jovanovic 1982), and evolutionary processes among heterogeneous organizations (Kwaśnicki 1998). Recent studies have applied evolutionary approaches that better describe competition in a market. In these approaches, entities having better traits (fitness) survive and others disappear in a competitive market. The current study tests the effects of contractors' risk attitudes as their own traits, and analyzes how the industry structural patterns are affected by their competition.

Industry Pattern in Construction

The current study analyzes U.S. construction industry data to determine industry patterns as a result of competition, i.e., the size distribution of construction organizations. The analysis reveals that there is an apparent industry pattern, which can be explained by the competitive process.

Size Distribution of Construction Firms—ENR Top 400 Contractors

Engineering News-Record (ENR) publishes annual summary data about the top 400 U.S. contractors. The data rank firms by previous year gross revenues. The data used in this study cover 14 years from 1994 to 2007 ENR (1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008). Fig. 1 shows the size distribution of the 400 contractors by gross revenue on a logarithmic scale (log-log plot). The linear average trend line of $R^2 = 0.98$ indicates the strong presence of the power law in construction; statistically, the linear regression explains 98% of the variance in the data. This large number means that the power law model has an excellent fit to the observations; hence, the power law can be used to represent the data. This empirical finding links construction to ecology, biology, and evolutionary economics: the power law governs the population of construction contractors. The pattern of the power law is the aggregate effect evolved through contractors' competition for job opportunities, analogous to the competitive, evolutionary forces that generate power law distributions for biological, ecological, and economic systems. (Note: The distributions have been normalized to account for the increases in the total volume of revenues over the data period.)

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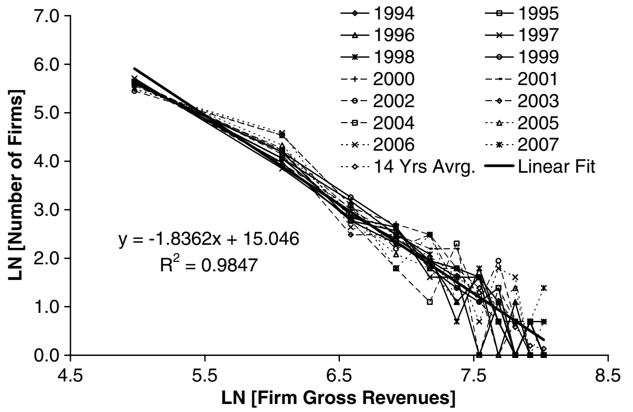

Fig. 1. Size distribution of ENR 400 contractors

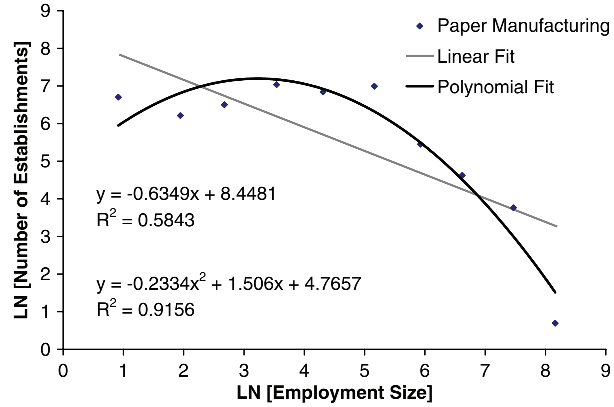

Fig. 3. Size distribution in paper manufacturing

Size Distribution of Construction Establishments—2002 Economic Census

The U.S. Census Bureau (2002) data is another source of data to identify the market structure of the U.S. construction industry. Fig. 2 shows the size distributions of establishments (measured by the number of employees) for all general contractors and for each sector: building contractors, heavy construction contractors, and specialty trade contractors. An establishment is defined by the Census Bureau as a single physical location where business is performed. Thus, one firm may have many establishments distributed geographically. The power law is observed again in the log-log plot for each of the contractor groups. The linear trend lines have negative slopes and high R^2, indicating very good statistical fit to the data.

The slopes of the linear trend lines in Fig. 2, derived from the Economic Census data, are lower than the slope in Fig. 1, derived from the ENR 400 data because of the differences in the size measurement and the level of data between the two data sets. The ENR data account for only the 400 largest firms and the size is measured by a firm's gross revenues. The U.S. Census data (2002 Economic Census) count all establishments (710,307) in the construction industry and the size of an establishment is measured by the number of its employees. The differences can be resolved by using the Economic Census data. A slope of -1.74, similar to the slope of -1.83 in Fig. 1, is found by restricting the Economic Census data to only large establishments (8,659 establishments having more than 100 employees).

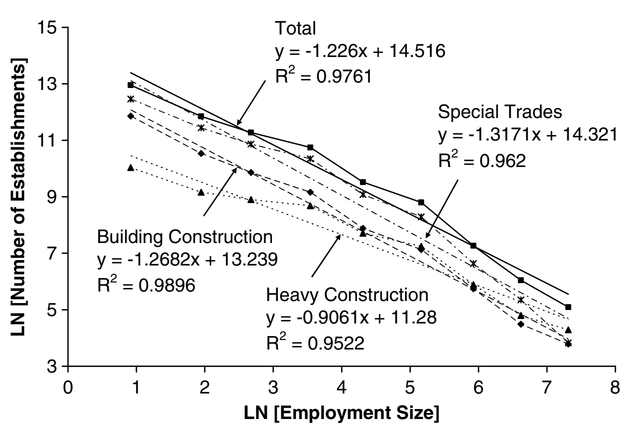

Fig. 2. Size distribution of establishments

Size Distribution of Firms in Other Industries

Different shapes for the size distribution can be found in other industries. For example, Fig. 3 shows the size distribution of establishments in the pulp and paper manufacturing industry using the Economic Census data. A significant curvature is found in this capital-intensive industry. In general, paper manufacturers utilize large automated machines that are expensive and require few staff to operate. Thus, in this industry, the power law is apparently not applicable because the number of establishments with small employment size is less than the power law would predict. Different size distributions in different industries are presumably attributed to unique characteristics of the industry. Similarly, the differences in slopes for different construction sectors in Fig. 2 are attributed to characteristics of each sector. The significant characteristics could include different levels of risk in jobs and competition, different overhead expenditures or capital needs, higher or lower entry barriers, level of equipment use, or others. Those issues are left for future investigation.

Risk Attitude and Firm Performance

Organizational Culture and Organizational Risk Attitude

Organizational culture is defined as "a complex set of values, beliefs, assumptions, and symbols that define the way which a firm conducts its business" (Barney 1986). As part of an organizational culture, risk attitude is defined as "a state of mind with regard to uncertainties that could have positive or negative effect on objectives … risk attitudes are usually adopted subconsciously" (Hillson and Murray-Webster 2005).

Organizational culture has the following four major characteristics (Schein 2004): (1) structural stability, in which culture becomes a stabilizing force within an organization when the organization develops its own sense of group identity, (2) depth, in which culture is the unconscious and deep part of a group. Outsiders have difficulty in understanding other organizational cultures, (3) breadth, in which culture is so pervasive that all aspects of organizational activities are influenced by it, and (4) integration and patterning, in which culture integrates organizational climate, values, and behaviors while developing patterns within an organization. On the basis of these characteristics, organizational culture plays a critical role in an organization. It unconsciously but deeply governs an organization through integration of the organization's behaviors and rationales while developing organizational stability so that it is not easy to change. Similarly, organizational risk attitude can be defined as a shared preference toward uncertainties, covering behavioral, emotional, and cognitive elements in an organization's business decisions. However, risk attitude is subconscious within an organization, making it more difficult to change.

Firm Performance and Risk Attitude

Heterogeneity in Risk Attitude

There have been studies about different risk attitudes among organizations, as well as among individuals (von Neumann and Morgenstern 1944; Walls and Dyer 1996; Pennings and Smidts 2003; Hillson and Murray-Webster 2005). Risk attitudes have been classified into three generic types: risk-averse, risk-neutral, and risk-seeking. While some studies of management assume that business managers are somewhat risk-averse, others question the assumption of global risk-aversion (Fiegenbaum and Thomas 1988). Many studies in organization theory and economics find the presence of heterogeneity in risk attitudes among organizations, even in homogeneous industries (Chatman and Jehn 1994). Walls and Dyer (1996) and Pennings and Smidts (2003) found the presence of heterogeneity in risk attitude using utility functions among petroleum firms and agricultural organizations, respectively. Many assume, even some in the construction industry, that construction contractors are risk-seekers because the jobs they take on are much riskier than other occupations. However, this assumption does not follow; just because the jobs are risky does not mean that contractors are risk-seekers. In fact, many contractors consider themselves risk-averters, not risk-seekers.

In a risky situation, individuals or organizations perceive the situation in their own ways, which are affected by their own risk attitudes. Therefore, depending on their own perceptions, individuals or organizations may make different responses to an identical situation. Consequently, questions have been raised about differences in the performance among firms that may have different risk attitudes, even though a firm's risk attitude is implicit in the corporate culture and not explicitly identified.

Empirical Studies

Many organization studies have been conducted to ascertain what organizational cultures are, why organizations have different cultures, how culture affects the behavior of an individual firm and its performance, and whether organizational culture can be a source of competitive advantage or a hindrance. Studying the effects of organizational culture is obviously very difficult because it requires comprehensive, long-term, longitudinal data on individual firms. Corporate cultures change slowly and data are limited to those available only retrospectively. Because of the difficulty in obtaining long-term data, questionnaire surveys have been favored. Calori and Sarnin (1991) found that the intensity and homogeneity of the firm's culture are positively correlated with the firm's growth. Chatman and Jehn (1994) found that industry type accounts for differences in the organizational culture of firms, but with high variance. Sørensen (2002) found that firms with strong cultures have less variable performance than other firms in stable business environments, whereas the benefit of a strong culture decreases as environmental volatility increases.

The question about risk-return association in management studies is how much firms earn on their investments at what levels of risk. The relevant studies tried to identify relationships between a firm's average returns and variance in the returns using a firm's historical data. Unfortunately, empirical results vary and are conflicting. Earlier studies before Bowman (1980) found positive correlations between average returns and variance (heteroskedasticity) in the returns, these findings presumably based on conventional wisdom in economics (Fiegenbaum and Thomas 1988). Bowman (1980) found a negative relationship— low performance firms take more risks to increase their chances of survival. This negative relationship is named Bowman's paradox or risk-return paradox, since risky tasks or jobs are supposed to be more profitable and thus more attractive to firms. Higher profits are expected to be associated with higher risks (greater variances). Conversely, Fiegenbaum and Thomas (1988) found the risk-return relationship to vary over time. They also found differences in the risk-return association in different industries, which suggests that risk attitudes are industry-specific.

Walls and Dyer (1996) pointed out a critical measurement problem in the empirical studies. Risk is usually measured as the variance of the outcomes (ex-post measure), which only becomes available after the outcomes of the events are realized. However, a decision must be made based on information available only before the outcomes are realized (ex-ante). It is difficult to determine in retrospect how the decision maker perceived a risky situation and made a decision at the time of decision making. Thus, empirical studies using ex-post measures have limitations and their results may be unreliable. To resolve this problem, Walls and Dyer (1996) reconstructed risky alternatives that firms might have considered at the time of investment decisions, using historical data from petroleum firms. As a result, the relationship between firm performance and risk attitude showed that moderate risk-taking firms in the field of petroleum exploration have better return on assets.

Methodologies

Evolutionary Approach

The current study uses the evolutionary approach that has been applied successfully in the areas of biology, ecology, economics, and others. This approach accounts for an individual's behavior, competition, and organizational changes arising from competition. Depending on a study's purpose, the focus may be on the underlying mechanism of evolution: an individual's organizational changes (birth, death, growth, and contraction), or aggregate patterns in a population. The approach takes multiple perspectives from the individual to the population level. The individuals can be members within a species or between species in biology, firms in market ecology, or individual decision makers in economics. Different explanations for organizational changes and industry evolution have been considered for many industries. They include organizational innovation (Nelson and Winter 1977; Kwaśnicki 1998), organizational learning, adaptation, or mutation (Levinthal 1991; Kandori et al. 1993), and others. However, there are still disagreements about the theoretical foundations: organisms influence their own environments and selection regimes, therefore, in such cases, boundaries between environmental development and organizational selection are not clear (Erwin and Krakauer 2004). Researchers recently started paying attention to evolutionary analysis of decision-making behavior in competitive environments (Sounderpandian 2007).

The current study investigates, using an evolutionary simulation model, the effects of a contractor's risk attitude, which governs risk-taking behavior in competition, on their organizational success at the individual level and market ecology in construction at the aggregate level. In the simulation model, a contractor's risk-taking behavior in competition is represented by go/no-go decisions in competitive bidding (explained subsequently). Simulation is one of the most advantageous methods to analyze competition in which individual behaviors need to be considered (Sounderpandian 2007).

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The advantage of the evolutionary approach is that it is not necessary to develop optimal decision rules for each entity. Different entities have different traits (fitness) and correspondingly different behaviors. Among the entities, some succeed and others fail as a result of the competition for resources (jobs). The model then simply correlates the successes and failures with these traits to determine which traits are more beneficial to the organizational entity.

Contractor's Go/No-Go Decision in Competitive Bidding

Mochtar and Arditi (2001) conducted a survey of the U.S. top 400 contractors regarding their current pricing practices and found most contractors use their intuition after subjective assessment of the competition. Much of the differences in the contractors' bids would be a result of their varying perceptions of the uncertainties, which are affected by their own risk attitudes. The current study simplifies each contractor's risk-taking behavior in a form of a go/no-go decision during the competitive bidding: does the firm take a risk on the job or not? The decision depends on each individual's risk perception and risk attitude. The current study uses utility theory and utility functions (von Neumann and Morgenstern 1944) to represent contractors' different risk attitudes. In the exponential form of the utility function, $U(x)$, which is most favored because of its simplicity: the exponential function requires only one parameter, the risk-aversion coefficient r, x represents the wealth of a firm, and r represents the firm's risk attitude. By definition, if r is zero, the utility function is linear and the firm is risk-neutral; it makes decisions on the basis of expected monetary value $E[x]$. If r is greater than zero, the firm is risk-averse, and if r is less than zero, the firm is risk-tolerant. By definition, the certainty equivalent (CE) of the amount x is the amount a risk-averse contractor would require to take on a risky project. By definition the risk premium (RP), RP $= E(x)$-CE, is the additional amount the risk-averse contractor would require to take on a risky project.

Consider a contractor that estimates the fixed price of a job. The actual cost of the job is subject to uncertainties and the true cost will be determined only at completion so that the contractor's price setting is a risky task. But, the contractor would have some knowledge about the possible range of actual costs and probabilities, i.e., a subjective probability distribution on actual cost. Assume all contractors have the same knowledge and let the expected cost of a job be $E(x)$. In a go/no-go decision for a job, a risk-neutral contractor would proceed to bid if its bid is equal to or greater than $E(x)$, which has a 50% chance of gain and a 50% chance of loss. The contractor's go/no-go decision simply depends on $E(x)$, which is based on expected monetary value theory. However, risk-averse or risk-seeking contractors would have different perceptions on the downside and upside uncertainties. The difference is represented by the risk premium. A risk-averse contractor would proceed to bid if its bid is greater than $E(x)+$ its risk premium. A risk-seeking contractor would proceed to bid unless its bid amount is smaller than $E(x)+$ its risk premium. The amount of risk premium varies depending on the degrees of risk-aversion or risk-seeking of the contractor. Then, contractors may have different budget thresholds in their bid decision, which can be represented by $E(x)+$ risk premium.

In the following description of the exponential utility function, for simplicity of comparison, it is assumed that all jobs are identical and bid decisions by contractors are independent and repetitive. Contractors' utility functions are normalized so that the possible values of utility lie between a minimum utility of zero and a maximum utility of one. Eq. (1) shows the normalized exponential utility function. The shape of utility functions varies depending on the value of r

$$\begin{aligned} &\text{if } r \neq 0, U(x) = \frac{1-\exp(-(x-a)r)}{1-\exp(-(b-a)r)} \\ &\text{if } r = 0, U(x) = \frac{(x-a)}{(b-a)} \end{aligned} \tag{1}$$

where r = risk-aversion coefficient to define risk attitude; x = contractor's bid and $x > 0$; a = minimum value of the contractor's bid; and b = maximum value of contractor's bid.

Calculation of Risk Premium and Contractors' Risk-taking Behaviors

This section provides a detailed procedure for estimating the risk premium for contractors having different risk attitudes and represents their risk-taking behaviors in competitive bidding. The estimating procedure is as follows:

1. Define the expected cost of the job, $E(x)$, from the assumed distribution of actual cost;
2. Define a contractor's utility function by choosing a random value for risk-aversion coefficient, r;
3. Calculate the utility of the expected cost, $U[E(x)]$, using the normalized utility function with the specified coefficient, r;
4. Calculate the expected value of the utility of x, $E[U(x)]$ using the normalized utility function with the coefficient $r = 0$ (risk-neutral);
5. Calculate the certainty equivalent [CE, in Eq. (2)] using the inverse function [in Eq. (3)] of the normalized utility function

$$\mathrm{CE}(x) = U^{-1}[E[U(x)]] \tag{2}$$

$$\begin{aligned} &\text{if } r = 0, x = y(b-a) + a \\ &\text{if } r \neq 0, x = a - \frac{1}{r}[\mathrm{LN}\{1 - U(x)(1-\exp(-(b-a)r)\}] \end{aligned} \tag{3}$$

6. Calculate risk premium: RP $= E(x)$-CE.

The value of the risk premium can be positive, negative, or zero, depending on each individual contractor's risk attitude.

7. Calculate the budget threshold: BT $= E(x) +$ RP.

A contractor's go/no-go decision is now based on the comparison of its bid amount with its own budget threshold as subsequently shown.

- Proceed to bid, if the bid ≥ BT: the contractor perceives the risk acceptable.
- Decline to bid, if the bid $<$ BT: the contractor perceives the risk unacceptable.

Fig. 4 shows a plot of budget threshold in which different contractors make go/no-go decisions depending on their risk attitude (their own perception of risk) using the above algorithm. The risk-aversion coefficient, r, is assumed to vary from -0.33 to 0.24. The expected cost, $E(x)$, is \$10 M and the contractors' minimum bid that attains the minimum utility (0.0) and the maximum bid that attains the maximum utility (1.0) are assumed to be \$6.0 M (value of a) and \$14.0 M (value of b), respectively. Individual contractors may have different estimates for an identical job even if they have the same estimating capability. A contractor's bid may take any value within the range [a, b]. As shown in Fig. 4, the more risk-averse a contractor is, the greater the contractor's budget threshold is, and vice versa. Risk-neutrality is found at $r = 0$.

Development of Hypotheses

The current study classifies different risk attitudes into four groups using relative terms: (1) more risk-tolerant, (2) moderately

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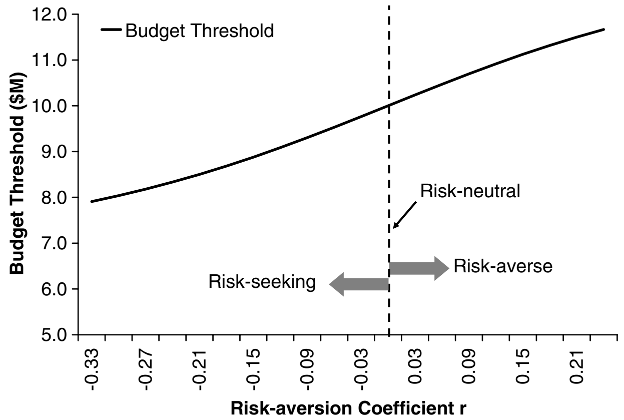

Fig. 4. Budget threshold for go/no-go decision

risk-tolerant, (3) moderately risk-averse, and (4) more risk-averse. This classification is better suited for the characteristics of go/no-go decisions; whether to take a risk or not.

There are always possibilities of profit/loss from a job in competitive bidding. If a contractor anticipates that its risk premium cannot cover the uncertainty, the contractor does not bid and waits for another job opportunity. Otherwise, the contractor makes a bid. Risk-averse contractors want to avoid the risks of large losses. They use large amounts of risk premium (have high-budget thresholds), but simultaneously may lose opportunities for large profits by turning down jobs. In contrast, risk-tolerant contractors have low-budget thresholds and accept large risks in order to potentially gain high profits. Assuming that contractors' cost estimates are randomly drawn from the same distribution (equal firm capability in all aspects), extensions of the previous idea follow:

- Risk-tolerant firms would bid more often than risk-averse firms because they are less selective in bidding. And, the bids from risk-tolerant firms would tend to be lower on average than those from risk-averse firms;
- Compared to risk-averse firms, risk-tolerant firms would obtain more jobs (higher market share) while having lower profits per job on the average. Sometimes they would suffer large losses;
- Compared to risk-tolerant firms, risk-averse firms would enjoy higher profits per job while obtaining a smaller number of jobs. Sometimes they would suffer losses due to their overhead burden (the cost of operating the firm with few jobs to pay the overhead); and
- Characteristics of more risk-tolerant or more risk-averse firms would be more apparent than those of moderately risk-tolerant or moderately risk-averse firms.

Different contractors may have different risk attitudes, which may result in different outcomes with respect to firms' profitability, survivability, or growth in the market place. Considering the characteristics of different risk attitudes, the following hypotheses are proposed and tested concerning the relationships between contractors' risk attitudes and their performance.

- Profitability versus risk attitude (risk attitude affects the firm's profitability);
- Survival versus risk attitude (risk attitude affects the firm's survival); and
- Growth versus risk attitude (risk attitude affects firm's growth).

Industry Evolutionary Model

The evolutionary model uses the well known Monte Carlo simulation technique. At the beginning of the simulation, the model generates an initial population of 500 construction firms in a market (from which the top 400 firms are selected to compare with the ENR data) by providing them with all identical initial conditions and characteristics except for their risk attitudes. The current study focuses on the effects of risk attitude. To avoid extraneous complications, the experimental (simulated) firms are identical in terms of their performances, wealth, and decision rules, which include initial firm size (small to allow them to grow), estimation capability, productivity, overhead rate, initial cash reserves, and rules about firm expansion, contraction, and death. A firm's risk attitude, represented by its risk-aversion coefficient r, is randomly determined from a uniform distribution at its founding as the firm's own genetic feature. Thus, all factors affecting the outcomes are eliminated (held constant) except for risk attitude.

Industry market demand is assumed constant with the same number of jobs in each simulation and the firms compete for jobs through competitive bidding over multiple periods. The market demand represents the average of total volume of gross revenues in the ENR data. All jobs are identical in every aspect, except for their actual costs to the contractors. For each job, a fixed number of firms are randomly selected based on their relative size (explained subsequently) and they estimate the cost of the job. The number of final bids for each job varies depending on the selected firms' go/no-go decisions. Their cost estimates are randomly drawn from the same normal distribution with a mean of μ_e and a standard deviation of σ_e, reflecting the incompleteness of construction cost estimates. Variable actual costs are also randomly drawn from the same normal distribution with a mean of μ_c and a standard deviation of σ_c, reflecting the uncertainties in project costs. Thus, contractors' profitability varies. At the end of each period, firms may expand, contract, or go out of business on the basis of each individual firm's performance and financial conditions (annual profit/loss and cash reserve). The initially identical firms become heterogeneous in size over multiple time periods in the competitive environment. The relative size of a firm is defined as the firm's capacity divided by the industry's total capacity. For each job, firms are randomly selected with weighting factors on the basis of this relative size, so that larger firms bid more often than smaller firms, everything else being equal.

Rules of the individuals' behavior in an evolutionary model should be plausible and simple (Metcalfe and Foster 2004). The basic rules of the individual firms' behavior in the model are:

- Go/no-go decision (explained above);
- Decision on expansion/contraction: a firm may expand when it has a profit or contract when it has a loss, but it is restricted by its random chances. Sometimes firms neither expand nor contract. The size of expansion/contraction depends on the amount of annual profit/loss; and
- Decision on exit: a firm goes out of business when its cash reserve is lower than a certain threshold, e.g., zero cash reserve.

All firms follow these simple rules. The simplicity of these rules eliminates unnecessary influential forces in the system and allows the current study to focus on the main issue, the effects of firms' risk attitude on competition over the long-term. All firm failures are compensated by new start-up firms to keep the total number of firms constant at 500. New firms are identical to the firms in the initial population. Their risk attitudes are also randomly determined in the same way. New firms compete with the existing firms through competitive bidding and they also may expand, contract, or go out of business. The simulation model tracks all individual firms' behavior, their competition and performances, as well as the aggregate effects at the market level over long periods.

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Results

The hypotheses have been tested using the model. The simulation is run until the system reaches a steady state. Stability occurs when organizational responses (the rates of organizational change) to the competitive selection force, if it exists, become stable so that industry patterns also become stabilized. Tests showed that the hypotheses were supported and the results were insensitive to the initial conditions given to the firms (Kim 2009). Contractors are classified by the risk-aversion coefficient r into the same groups as used in the section "Development of Hypotheses."

Profitability versus Risk Attitude: Risk Attitude Affects Firms' Profitability

For a contractor to be risk-tolerant or risk-averse, there are advantages as well as disadvantages: more jobs with lower profit per job versus higher profit per job with fewer jobs. Being moderately risk-averse between the two extremes can be beneficial in the trade-off between the profit per job and the amount of jobs won. Moderately risk-averse firms can have overall higher profits than risk-tolerant firms and more risk-averse firms. Fig. 5 shows the probability density function and the cumulative density function of annual profits (for the top 400 firms) by firms' risk attitude. Moderately risk-averse firms (Group 3, $r = [0.00, +0.120]$) show better performance than other groups. The mean profit of this group is higher than those of other groups and it has the longest tail on the right hand side, indicating greater likelihood of higher-than-average profits. More risk-averse firms (Group 4) have a more concentrated distribution (smaller variance) than other groups. However, this group has a short tail on the right hand side, indicating low likelihood of higher profits. At the low end of the plot, Group 4 firms have the least likelihood of losing money, as would be expected—more risk-averse firms avoid jobs with high risks of large losses but forego opportunities for high profits. Conversely, moderately risk-averse firms (Group 3) have a smaller probability of losses (negative profits) than risk-tolerant firms (Groups 1 and 2). More risk-tolerant firms (Group 1) show the worst performance.

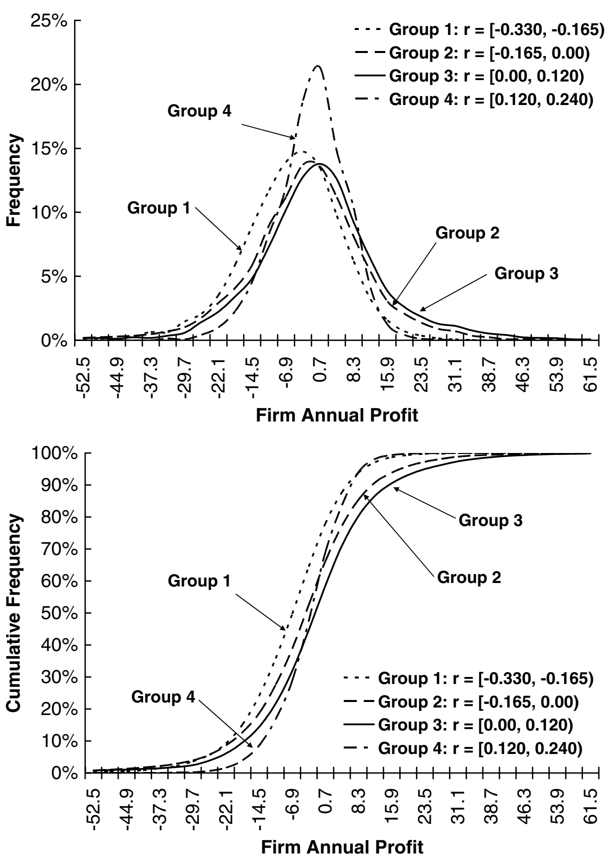

Fig. 5. Distribution of annual profit

Survival versus Risk Attitude: Risk Attitude Affects Firms' Survival

Moderately risk-averse firms can avoid the disadvantages of being risk-tolerant or more risk-averse: either a large amount of possible loss or a small number of jobs won (below the volume needed to cover overhead burden), which may result in financial problems. Therefore, moderately risk-averse firms can have more stable business operations that buffer against uncertainties in business and can survive longer. If a firm's net worth falls below its capitalization requirements, it fails (goes bankrupt) and disappears. Fig. 6 shows the evolution of the population distribution of the 400 model firms by their risk attitude. All firms' risk attitudes were randomly taken from a uniform distribution, as shown by the rectangular distribution of risk-aversion coefficients at period zero. Over many simulation periods, moderately risk-averse firms (Group 3) become dominant in the population, whereas risk-tolerant firms (Groups 1 and 2) and more risk-averse firms (Group 4) have reduced representation in the market. The peak is found at the right hand side of risk-neutrality, indicating that, for firm survival, being moderately risk-averse is better than being risk-neutral. At the steady state, moderately risk-averse firms are more highly represented in the 400 firm population than firms with other risk attitudes. Different prior distributions other than the uniform were tested, but the results always converge to the same results for the shape of the stable distribution. The results are absolute as well as relative: the peak in the surviving firms occurs to the right (the more risk-averse side) of the risk-neutral point, which is a fixed point.

Growth versus Risk Attitude: Risk Attitude Affects Firms' Growth

Risk-tolerant firms may have difficulty in financing growth due to the volatility in profitability, even though they can gain more market share. More risk-averse firms also have difficulty in growing because they do not bid often enough to obtain many jobs; they are too selective in bidding. Thanks to the stability in business, moderately risk-averse firms can accumulate financial resources, spend them for expansion, and continue stable operation.

Fig. 7(a) shows the distribution of the 400 model firms' gross revenues as a function of their risk attitude. Moderately risk-averse

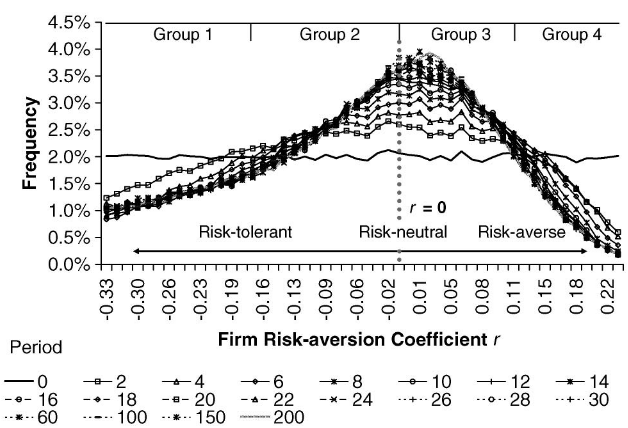

Fig. 6. Evolutionary change in the population

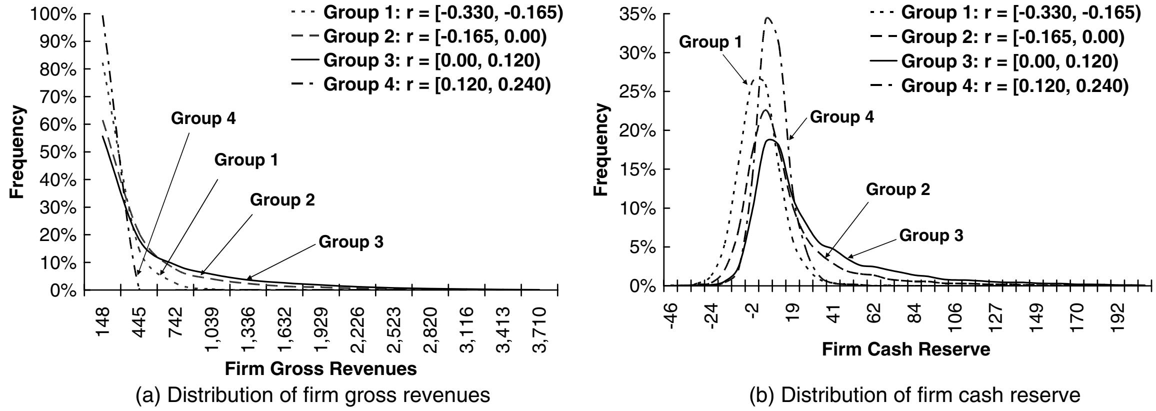

Fig. 7. Histograms of growth: (a) distribution of gross revenues; (b) distribution of cash reserve

firms (Group 3) have the most right skewed distribution, which indicates their ability to finance growth. More risk-averse firms (Group 4) have smaller variance in profit streams (see the concentrated profit distribution for this group in Fig. 5). However, they are not as successful in growth, as shown in Fig. 7. The distribution of firms' cash reserves in Fig. 7(b) shows moderately risk-averse firms' better financial performance which enables their growth.

Through the evolutionary process that differentiates the individual firms (by growth, contraction, birth, and death) the size distribution of the firms evolves into a steady state in the model. Fig. 8 provides a comparison between the size distributions of the ENR 400 contractors and the 400 model firms on a logarithmic scale. A power law, indicating the existence of the inverse proportionality (slope $\beta = -1.923$ with a high $R^2 = 0.94$) between population density and organization size, is found in the size distribution of the model firms. The slope and R^2 for the model firms are compared with the actual ENR 400 industry pattern, as developed in Fig. 1. The "No Risk-aversion" line in Fig. 8 shows the size distribution of the model firms obtained by using a different assumption of no risk-aversion: all firms never decline to bid regardless of the risk. This assumption results in no large firms (luck won't last long enough for the firms to grow). "All Risk-neutral" in the same figure shows the changed size distribution of model firms if they are assumed to be all risk-neutral. All firms behave just as expected value theory proposes. However, the assumption that all firms are risk-neutral produces a pattern quite different from the actual ENR 400 firms. The size distribution of actual firms is not consistent with an assumption that decisions are based on expected monetary value.

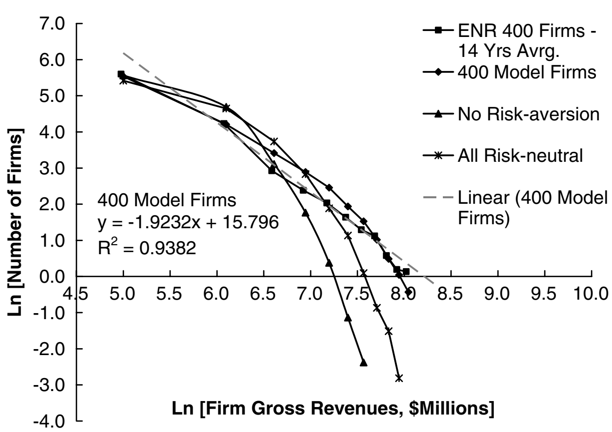

Fig. 8. Effect of different assumptions

On the basis of the tests, a contractor's risk attitude plays a critical role in competition. Moderately risk-averse contractors outperform other contractor groups. It is better for a contractor to be somewhat risk-averse than to be risk-neutral. Because of the risks inherent in the construction industry, without risk-aversion, contractors cannot survive and grow over the long term. There are also other competitive factors that could affect a contractor's performance, including expertise, experience, a good relationship with the owner, and others. These factors should be developed within an organization through continuous business, which requires the firm to survive and to grow in the industry. The current study shows that risk aversion is critical for a firm's survival.

Conclusions

This study identifies how an individual contractor's risk attitude affects competition and the contractor's competitive success in the construction market. Risk attitude is one of the most influential elements in competition and is critical to a contractor's survival and growth. Introducing organizational risk attitudes to competition among individual contractors develops the unique pattern (power law) in the size distribution of contractors that is observed in actual industry data. Moderate risk-aversion also outperforms risk-neutrality that is the fundamental basis of the evaluations using expected value theory. A contractor needs to be aware of its own attitude toward risk when it has to make a decision under uncertainty relying on expected value theory.

The current study makes several contributions: (1) application of an evolutionary approach to the study of competition in construction; (2) investigation of the missing link between risk taking and competition that has not been fully considered; (3) development of a method to represent a contractor's risk-taking behavior depending on different risk attitudes; and (4) determination of the aggregate pattern for the U.S. construction industry and identification of the hidden mechanism underlying this pattern.

The study results are all statistical, representing statistical association rather than causes and effects. For example, moderate risk aversion is associated with higher survival rates, higher profitability, and firm growth. In the model, firms cannot change their risk attitudes; they compete, expand, contract, and/or go out of business with the same risk attitude that they started with. For future research, a method for modifying a firm's risk attitude, if the modification is possible when the firm wants it, needs to be developed. Also, the effects of the modification need to be studied. Understanding and managing risk attitude would be possible through "emotional literacy" (Hillson and Murray-Webster 2005). The current

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study can be extended to investigate other aspects of competition and risk management, including a contractor's growth over different market sectors and owners' benefit from contractors' competition. More hidden links between risk management and competition in the construction business are waiting for further investigation.

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References

Barney, J. B. (1986). "Organizational culture: Can it be a source of sustained competitive advantage?" *Acad. Manage. Rev.*, 11(3), 656–665.
Besanko, D., Dranove, D., Shanley, M., and Schaefer, S. (1996). *Economics of strategy*, Wiley, New York.
Bowman, E. H. (1980). "A risk/return paradox for strategic management." *Sloan Manage. Rev. Bank Mark.*, 21(3), 17–31.
Cagno, E., Caron, F., and Perego, A. (2001). "Multi-criteria assessment of the probability of winning in the competitive bidding process." *Int. J. Proj. Manage.*, 19(6), 313–324.
Calori, R., and Sarnin, P. (1991). "Corporate culture and economic performance: A French study." *Organ. Stud.*, 12(1), 49–74.
Carbone, C., and Gittleman, J. L. (2002). "A common rule for the scaling of carnivore density." *Science*, 295(5563), 2273–2274.
Chatman, J. A., and Jehn, K. A. (1994). "Assessing the relationship between industry characteristics and organizational culture: How different can you be?." *Acad. Manage. J.*, 37(3), 522–553.
Chen, Y. K. (1991). "An analysis of decision strategy as applied to construction portfolios." Ph.D. dissertation, Stevens Institute of Technology, Hoboken, NJ.
Christodoulou, S. E. (1998). "Optimum bid markup calculation in competitive bidding environments using fuzzy artificial neutral networks." Ph.D. dissertation, Columbia Univ., New York.
Dozzi, S. P., AbouRizk, S. M., and Schroeder, S. L. (1996). "Utility-theory model for bid market decisions." *J. Constr. Eng. Manage.*, 122(2), 119–124.
Engineering News-Record (ENR). (1995). *The top 400 contractors*, 234(20), McGraw Hill Construction, New York, 46–61.
Engineering News-Record (ENR). (1996). *The top 400 contractors*, 236(20), McGraw Hill Construction, New York, 48–65.
Engineering News-Record (ENR). (1997). *The top 400 contractors*, 238(21), McGraw Hill Construction, New York, 64–81.
Engineering News-Record (ENR). (1998). *The top 400 contractors*, 240(21), McGraw Hill Construction, New York, 65–80.
Engineering News-Record (ENR). (1999). *The top 400 contractors*, 242(21), McGraw Hill Construction, New York, 79–96.
Engineering News-Record (ENR). (2000). *The top 400 contractors*, 244(20), McGraw Hill Construction, New York, 95–115.
Engineering News-Record (ENR). (2001). *The top 400 contractors*, 246(20), McGraw Hill Construction, New York, 73–89.
Engineering News-Record (ENR). (2002). *The top 400 contractors*, 248(19), McGraw Hill Construction, New York, 63–76.
Engineering News-Record (ENR). (2003). *The top 400 contractors*, 250(19), McGraw Hill Construction, New York, 85–101.
Engineering News-Record (ENR). (2004). *The top 400 contractors*, 252(20), McGraw Hill Construction, New York, 44–62.
Engineering News-Record (ENR). (2005). *The top 400 contractors*, 254(19), McGraw Hill Construction, New York, 34–48.
Engineering News-Record (ENR). (2006). *The top 400 contractors*, 256(20), McGraw Hill Construction, New York, 60–75.
Engineering News-Record (ENR). (2007). *The top 400 contractors*, 258(19), McGraw Hill Construction, New York, 58–73.
Engineering News-Record (ENR). (2008). *The top 400 contractors*, 260(17), McGraw Hill Construction, New York, 60–75.
Erwin, D. H., and Krakauer, D. C. (2004). "Insights into innovation." *Science*, 304(5674), 1117–1119.
Fiegenbaum, A., and Thomas, H. (1988). "Attitudes toward risk and the risk-return paradox: prospective theory explanations." *Acad. Manage. J.*, 31(1), 85–106.
Friedman, L. (1956). "A competitive-bidding strategy." *Oper. Res.*, 4(1), 104–112.
Hillson, D., and Murray-Webster, R. (2005). *Understanding and managing risk attitude*, Gower Publishing, Burlington, VT.
Jovanovic, B. (1982). "Selection and the evolution of industry." *Econometrica*, 50(3), 649–670.
Kandori, M., Mailath, G. J., and Rob, R. (1993). "Learning, mutation, and long run equilibria in games." *Econometrica*, 61(1), 29–56.
Kim, H. J. (2009). "The effects of risk attitude on competitive success in the construction industry." Ph.D. dissertation, Texas A&M University, College Station, TX.
Kim, H. J., and Reinschmidt, K. F. (2006). "A dynamic competition model for construction contractors." *Constr. Manage. Econ.*, 24(9), 955–965.
Kwaśnicki, W. (1998). "Skewed distribution of firm sizes—an evolutionary perspective." *Struct. Change Econ. Dyn.*, 9(1), 135–158.
Levinthal, D. A. (1991). "Organizational adaptation and environmental selection—interrelated processes of change." *Organ. Sci.*, 2(1), 140–145.
Marquet, P. A. (2002). "Of predators, prey, and power laws." *Science*, 295(5563), 2229–2230.
Marzouk, M., and Moselhi, O. (2003). "A decision support tool for construction bidding." *Constr. Innov.*, 3(2), 111–124.
Mayo, R. E. (1992). "Improved optimum bid markup estimation though workload related bid distribution functions." Ph.D. thesis, Stevens Institute of Technology, Hoboken, NJ.
Metcalfe, S., and Foster, J. (2004). *Evolution and economic complexity*, Edward Elgar Publishing, Northampton, MA.
Mochtar, K., and Arditi, D. (2001). "Pricing strategy in the U.S. construction industry." *Constr. Manage. Econ.*, 19(4), 405–415.
Moselhi, O., Hegazy, T., and Fazio, P. (1993). "DBID: Analogy-based DSS for bidding in construction." *J. Constr. Eng. Manage.*, 119(3), 466–479.
Nelson, R. R., and Winter, S. G. (1977). "Simulation of Schumpeterian competition." *Am. Econ. Rev.*, 67(1), 271–276.
Pennings, J. M. E., and Smidts, A. (2003). "The shape of utility functions and organizational behavior." *Manage. Sci.*, 49(9), 1251–1263.
Schein, E. H. (2004). *Organizational culture and leadership*, 3rd Ed., Jossey-Bass, Wiley, San Francisco.
Shash, A. A. (1995). "Competitive bidding system." *Cost Eng.*, 37(2), 19–20.
Simon, H. A., and Bonini, C. P. (1958). "The size distribution of business firms." *Am. Econ. Rev.*, 48(4), 607–617.
Singh, J. V. (1990). *Organizational evolution: New directions*, SAGE Publication, Newbury Park, CA.
Skitmore, M., and Pemberton, J. (1994). "A multivariate approach to construction contract bidding mark-up strategies." *J. Oper. Res. Soc.*, 45(11), 1263–1272.
Sørensen, J. B. (2002). "The strength of corporate culture and the reliability of firm performance." *Admin. Sci. Q.*, 47(1), 70–91.
Sounderpandian, J. (2007). "Evolutionary analysis of risk attitudes in competitive bidding environments using simulation." *Uncertainty and risk: Mental, formal, and experimental representations*, M. Abdellaoui, R. D. Luce, M. J. Machina, and B. Munier, eds., Springer, Berlin, 275–290.
U.S. Census Bureau. (2002). "2002 Economic Census." ⟨http://www.census.gov⟩ (Oct. 1, 2009).
Viner, J. (1932). "Cost curves and supply curves." *J. Econ. Bus.*, 3(1), 23–46.
von Neumann, J., and Morgenstern, O. (1944). *Theory of games and economic behavior*, Princeton University Press, Princeton, NJ.
Walls, M. R., and Dyer, J. (1996). "Risk propensity and firm performance: A study of the petroleum exploration industry." *Manage. Sci.*, 42(7), 1004–1021.
White, C. R., and Seymour, R. S. (2005). "Allometric scaling of mammalian metabolism." *J. Exp. Biol.*, 208(9), 1611–1619.