Title
Adoption of Voluntary Environmental Standards: The Role of Signaling and Intrinsic Benefits in the Diffusion of the LEED Green Building Standards.

Authors
Corbett, C.J.
Muthulingam, S.

Publication Date
2007-08-01

Adoption of Voluntary Environmental Standards: The Role of Signaling and Intrinsic Benefits in the Diffusion of the LEED Green Building Standards

August 17, 2007

Charles J. Corbett and Suresh Muthulingam

UCLA Anderson School of Management

charles.corbett _at_ anderson.ucla.edu

suresh.muthulingam.2010 _at_ anderson.ucla.edu

Abstract

We examine the role of signaling and of intrinsic benefits in the adoption of the individual elements of the voluntary LEED (Leadership in Energy and Environmental Design) standards for green buildings. We use goodness-of-fit tests on data for all 442 LEED certified buildings and find that neither signaling nor pursuit of intrinsic benefits can independently explain the observed adoption pattern, but that a combination of the two factors can. We also find tentative evidence that the adoption decision is made sequentially: organizations first choose a level of certification (consistent with signaling), and then choose how many LEED elements to adopt given their chosen level of certification (consistent with pursuing intrinsic benefits). We relate our findings to some open questions in the literature on diffusion of technology and draw implications for the design and the future development of similar voluntary standards and eco-labels.

Keywords: green building, LEED standards, diffusion, real estate, goodness-of-fit tests.

1. Introduction

Voluntary standards related to organizational practices are appearing in many areas including trade, environment and social governance (Kirton and Trebilock 2004). They are being adopted in a wide range of settings, including manufacturing, services, healthcare, education, governmental agencies, and elsewhere. In parallel, the management literature on adoption of voluntary standards has grown rapidly. Various perspectives have been bought to bear on the questions “Why do organizations adopt voluntary standards?” and “What is the societal value of such standards?”

The motivation for adoption of innovations, including voluntary standards, may be related to the quest for signaling, meaning that the organization wishes to communicate something about its practices to the outside world, including regulators, customers, the public, etc. Alternatively, adoption may be driven by the quest for intrinsic benefits, meaning that the organization expects actual economic and/or environmental benefits that are a direct result of the standard, regardless of perceptions in the outside world. The empirical challenge in distinguishing between these two types of motivation is illustrated by Venkatraman et al. (1994, p. 505), who write: “While our paper establishes the incidence of internal and external influences in the diffusion of joint venture and M-form structure respectively, our methodology was limitedly unable to distinguish between adoption due to “efficiency reasons” and adoption due to “legitimacy reasons”.” Here, the distinction between “efficiency reasons” and “legitimacy reasons” corresponds approximately to our “intrinsic benefits” and “signaling”; more on this terminology issue later. That this is recognized as a key unresolved issue in the broader context of the literature on diffusion of innovations is evident from this quote by Westphal et al. (1997, p. 367): “In attempting to explain evidence that network connectedness can facilitate the spread of discrete innovations, organizational scholars have invoked theories ranging from vicarious learning driven by efficiency imperatives [...] to mimetic isomorphism resulting from social cohesion and conformity pressure [...]. There has been little attempt in the diffusion literature to determine when each of these divergent theoretical perspectives is most applicable in explaining the spread of information about an innovation across organizations." In this paper, we formulate simple decision models underlying two of those different theoretical perspectives, that of adoption motivated by signaling and adoption motivated by intrinsic benefits, and test which decision model best fits the data on adoption of the LEED green building standards.

As Westphal et al. (1997) point out, to assess the effectiveness of an innovation (in our case the societal value of voluntary standards), it is essential to ascertain not just the breadth of adoption but also the depth of adoption. The depth of adoption is closely related to whether adoption occurred only for signaling reasons, in which case the depth will be the minimum required for the signal to be effective, or due to the intrinsic benefits of the standard, in which case adoption can (but need not) be deeper. Breadth of adoption (represented by the number of adopters) is often relatively easy to measure; depth of adoption, by contrast, is not easily observable. As a result, it has been difficult to test empirically, other than through surveys, whether signaling or the pursuit of intrinsic benefits drives the adoption of voluntary standards, because for the majority of voluntary standards (such as ISO 14000 or Responsible Care) adoption is a binary variable which only indicates whether a standard is achieved or not. King and Toffel's (2007) synthesis shows that the management literature on self-regulation focuses almost entirely on whether participation is driven by signaling or intrinsic benefits, with almost no measurement of *how* oganizations participate. Eco-labels, such as the US Department of Agriculture's "USDA organic" label,[1] the European Union eco-label,[2] and others (see for instance Basu et al. 2003 for a list) are also generally binary in nature, and provide little information on to what degree the product adheres to the underlying environmental standard.

In the highly successful LEED (Leadership in Energy and Environmental Design) standards for green building, adoption is not a binary variable, but has multiple levels of certification (certified, silver, gold,

---

[1] See http://www.ams.usda.gov/NOP/indexNet.htm, last accessed August 8, 2007.
[2] See http://ec.europa.eu/environment/ecolabel/index_en.htm, last accessed August 8, 2007.

or platinum), which in turn depend on the number of LEED elements a building adopts. This structure, including both certification levels and individual elements, allows us to examine the depth of adoption of green building practices. Specifically, for organizations that have adopted the LEED green building standard, we examine whether it is signaling or intrinsic benefits that determines how many LEED elements they adopt.

Buildings do have a significant impact on the environment. In the United States buildings account for 37% of the primary energy use, 40% of non-industrial solid waste, 12% of potable water use, 35% of carbon dioxide emissions, and 49% of sulphur dioxide emissions.[3] "Green building" evolved as a means to reduce this negative environmental impact throughout the complete building life cycle. In 1990 the British real estate industry asked the UK government to introduce a rating scheme for green buildings, which became BREEAM, the Building Research Establishment's Environmental Assessment Method (Lockwood 2006). The United States Green Building Council (USGBC) was founded in 1993 as a non-profit organization that seeks "to transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life."[4] In 1998 the USGBC launched the LEED Green Building Rating System, which facilitates design, construction, and operation of high performance green buildings. This rating system recognizes performance in five key areas: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. An example of the LEED-NC rating system, showing the full list of elements and the points that LaKretz Hall at UCLA earned towards LEED-NC silver certification, is provided in the Appendix. The LEED rating system for New Commercial Construction and Major Renovations (LEED-NC) was the first such standard in the US and is the most widely adopted amongst the various LEED standards to date. Other standards include LEED-EB for existing buildings, LEED-CI for commercial interiors, LEED-CS for core and shell, and a LEED

[3] "The Federal Commitment to Green Building: Experiences and Expectations," p. 9, available at http://www.ofee.gov/sb/fgb_report.pdf, last accessed on January 5, 2007.
[4] See http://www.usgbc.org/DisplayPage.aspx?CategoryID=1, last accessed on January 5, 2007

standard for homes is in the final stages of development. Under LEED-NC, a project is eligible for certification if it earns at least 26 points and meets certain additional prerequisites. A project will be LEED Certified if it earns 26 to 32 points, LEED Silver if it earns 33 to 38 points, LEED Gold if it earns 39 to 51 points and LEED Platinum if it earns 52 to 69 points.

The LEED standards have seen rapid acceptance in the past few years, as reflected in the increase in USGBC membership from 1137 in 2001 to 7200 in 2006.[5] The attendance at the annual Greenbuild Expo conference has risen to over 13,500 attendees in 2006.[6] The number of buildings that have registered their intent to seek LEED certification in 2006 is over 6000. The number of buildings that have achieved LEED-NC certification increased from one in 2000 to 442 certified projects as of September 20, 2006.[7]

This recent explosive growth of green building practices is reminiscent of the notion of punctuated equilibrium, as applied by Loch and Huberman (1999) to the context of technology adoption. In their model, network externalities can contribute to a new technology experiencing mass adoption even before its performance has caught up with the old technology. In the context of green building, this raises the question whether the recent rush to adopt LEED certification is based on the intrinsic benefits (or performance) of this new set of technologies or on the bandwagon effect (or network externality) created by the sudden visibility of the signal provided by LEED certification.

We analyze data on the adoption of specific LEED elements by all 442 buildings that, by September 20, 2006, had been certified to the LEED-NC 2.0 or 2.1 standard for new construction. We use this data to test whether signaling or the pursuit of intrinsic benefits dominates organizations' decisions to adopt the LEED standard. We find that neither factor independently can explain the observed pattern of adoption of

[5] See "*Building Design & Construction*s White Paper on Sustainability: A Report on the Green Building Movement," p. 7, available at http://www.usgbc.org/Docs/Resources/BDCWhitePaperR2.pdf, and http://www.usgbc.org/DisplayPage.aspx?CategoryID=1, last accessed January 5, 2007.
[6] See http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1553, last accessed January 5, 2007.
[7] See http://www.usgbc.org/LEED/Project/RegisteredProjectList.aspx, last accessed September 20, 2006.

LEED elements, however the two factors together can do so. To determine how the two factors can operate jointly, we consider two hybrid models. The first is a sequential model in which the organization first considers signaling by picking a target LEED certification level (certified, silver, gold, or platinum), and then uses economic and/or environmental analysis of the intrinsic benefits of the LEED elements to determine which ones to adopt, subject to the chosen certification level. The second is a simultaneous model, in which organizations simultaneously consider signaling and intrinsic benefits. (An alternative interpretation of the simultaneous model is that, within the population, some proportion of organizations is driven entirely by signaling, while the remainder is driven entirely by intrinsic benefits.) Only the model corresponding to the sequential decision-making mode fits the LEED adoption data.

This paper aims to make several contributions. It is the first study to examine diffusion of the LEED standards. The LEED standards are an interesting addition to the growing collection of voluntary standards, but they are particularly relevant due to the immense scale of the underlying industry: in the US alone, the construction and contracting industries accounted for approximately $1 trillion in sales in 2002.[8] Second, by using the specific structure of the LEED standards, we contribute to the literature on diffusion of innovation in general and that on diffusion of voluntary standards more specifically by improving our understanding of the interplay between motivations related to signaling and intrinsic benefits. Third, our findings have implications for industry associations and policy-makers about design of future voluntary standards and eco-labels.

The rest of this paper is structured as follows. In Section 2 we review relevant literature on diffusion of technology and adoption of voluntary standards, and that on environmental technology and green building. In Section 3 we formulate the hypotheses corresponding to the signaling, intrinsic benefit, and hybrid decision models. Section 4 describes the data, and Section 5 discusses the methodology and

---

[8] Data from US Census Bureau; the value of business done in 2002 in construction of buildings (NAICS code 236) was $522 billion, and that by specialty trade contractors (NAICS code 238) was $480 billion. See http://www.census.gov/econ/census02/data/industry/E23.HTM, last accessed July 24, 2007.

results. In Section 6 we discuss our results, including alternative explanations and limitations, and draw implications for design of voluntary standards and for future research.

2. Literature review

Our work is related to the literature on diffusion of technology and to that on adoption of voluntary standards. The classic work by Rogers (2003) distinguishes several drivers of adoption of innovations. One key driver of adoption of environmental practices is that they can frequently lead to operational improvements. Klassen and Whybark (1999) and King and Lenox (2002) find that firms that focus on pollution prevention experience superior performance; King and Lenox (2002) and Corbett and Klassen (2006) argue that this occurs because appropriate investments in environmental practices often lead to unexpected but significant process improvements. Specifically in the context of green building, similar synergies have been documented by Kats (2003), who finds that the direct (energy, emissions and water-related) and indirect (productivity and health-related) benefits of LEED certification outweigh the additional costs of green building. Other studies also find that the additional costs are lower than is often thought: Turner Construction (2005) found average cost premiums of 0.8% for LEED certified, 3.1% for silver, 4.5% for gold, and 11.5% for platinum buildings, while Davis Langdon (2004) found no statistically significant cost differential between comparable-quality LEED and non-LEED buildings. To summarize, environmental practices, including green building, can lead to intrinsic (economic and/or environmental) benefits, and may therefore be adopted for that reason.

A fundamentally different motivation for adoption of (environmental) practices lies in their external signaling value, in line with Spence's (1973) original model of signaling, where the action required for a decision-maker to be able to send a signal has no value other than that provided by the signal itself. Terlaak and King (2006) find that firms that adopt ISO 9000 grow faster after certification in ways that cannot be fully explained by the intrinsic benefits of ISO 9000, and conclude that signaling must therefore have played a role. Similarly, Russo and Harrison (2005) find preliminary evidence that electronics manufacturers with ISO 14000 certification have higher emissions than non-certified firms, and King and Lenox (2000) find that many of the chemical firms participating in the Responsible Care program improve their environmental performance more slowly than average. Both examples point to signaling rather than intrinsic benefits as primary motivations for adoption.

Another view holds that the process of adoption of an innovation itself creates institutional forces which can further accelerate diffusion, independently from the intrinsic benefits of the innovation (DiMaggio and Powell 1983). As an innovation is adopted by more organizations, it acquires increasing legitimacy; other organizations may then adopt the innovation based on its perceived legitimacy rather than on the intrinsic benefits of the innovation. In this literature, adoption decisions are sometimes viewed as driven either by "efficiency" or by "legitimacy", as the earlier quotes from Venkatraman et al. (1994) and Westphal et al. (1997) illustrate. Although closely related to our distinction between "intrinsic benefits" and "signaling", it is not identical. "Efficiency" has an economic connotation, while our "intrinsic benefits" intentionally allows for purely environmental (non-economic) benefits to play a role. Similarly, the signal associated with any given level of LEED certification may well confer social legitimacy on the adopting organization, but it is neither a necessary nor a sufficient condition for such legitimacy. For these reasons, we will use the terminology "intrinsic benefits and "signaling" in this paper.

King and Toffel (2007) provide a thoughtful overview of the various strands of management literature related to voluntary environmental standards. Anderson et al. (1999), Guler et al. (2002), Albuquerque et al. (2007) and many others examine which forces explain diffusion of the ISO 9000 and ISO 14000 quality and environmental management systems standards, but always treat adoption as a binary variable. Westphal et al. (1997, p. 367) argue that many innovations do allow considerable variation in the form of adoption, and that for such cases, "it may be more appropriate to explore how organizations define and implement an innovation, rather than simply to predict whether organizations adopt at all." They claim that without explicitly measuring such variation in adoption form it is impossible to truly separate signaling and intrinsic benefits as drivers for adoption.

King and Lenox (2000) measure membership in the Responsible Care program as a binary variable, but infer that not all firms adopt the principles to the same degree. Naveh and Marcus (2005) measure depth of implementation of ISO 9000 and find that firms that integrated it deeper into their daily practice obtained greater benefits from the standard. Conversely, Yeung et al. (2006) find that firms obtain operational benefits from TQM even if their implementation is not advanced. In a different context, Åstebro (2004) states (p. 382) that “depth of adoption is a relatively new construct [...]” and finds that depth of adoption of CAD and CNC technology depends more on plant-level factors than does the overall decision whether to adopt. Dieperinck et al. (2004) and Vermeulen and Hovens (2006) find that adoption of energy-efficient innovations in buildings depends on a range of innovation-specific and organization-specific factors, but they do not separate factors related to signaling and intrinsic benefits. Jin and Leslie (2003) study depth of adoption using the voluntary and mandatory restaurant hygiene grading cards in Los Angeles county; they find that the cards do improve hygiene, and that many restaurants earn precisely the minimum number of points needed to qualify for the letter grade received.

3. Model development

To understand the practical context of how organizations make decisions related to LEED certification, we organized a workshop at UCLA on March 10, 2006, in which we invited 4 panelists and 25 participants from the real estate and green building industries, including architects, designers, consultants, developers, and real estate professionals, from several independent firms as well as from the USGBC, Toyota, KB Home, The Olson Company, Swinerton, Turner Construction, Morgan Stanley Real Estate and Wells Fargo. Some participants explained that they had been involved in LEED certification as a result of client or government mandates, while others did it to save money. Two quotes illustrate the signaling and intrinsic benefit motivations. One participant remarked,

> "I'm concerned that people are making bad design decisions in order to get the LEED point,"

which would be consistent with a signaling-driven motivation behind certification. Another participant explained that

> "We do it to save money; making smarter development and design decisions gives us a competitive advantage over the long term, lower operating costs,"

which suggests an intrinsic-benefits perspective. Similarly, in the surveys by McGrawHill (2005) and Turner Construction (2005), respondents report motivations related to signaling and intrinsic benefits. The workshop, together with a review of the green building literature (Cryer et al. 2006), helped shape our hypotheses.

Motivations related to signaling vs. intrinsic benefits

Seeking LEED certification involves three main decisions: first, whether to seek certification; second, which level of certification to seek; and third, which specific elements to adopt. We focus on combinations of the latter two (as no data exist for non-certified green buildings). At one extreme, organizations may focus entirely on the level of certification, and consider the specific elements irrelevant as long as they yield the certification level desired. At the other extreme, organizations may adopt specific elements based on their intrinsic benefit, regardless of the level of certification that results. In between these extremes, organizations may consider both the signaling value of the certification level and the intrinsic benefits of each specific element adopted, and these factors may operate simultaneously or sequentially.

In Spence's (1973) signaling model, firms that are more environmentally proactive could invest in LEED certification, even if the process of certification provides no intrinsic benefit to the firm. If LEED certification would consume more effort from less green firms it could help outsiders distinguish between green and non-green firms, even if LEED had no intrinsic economic or environmental benefits. In this view, firms would adopt precisely as many LEED elements as necessary for outsiders to make that distinction; any LEED elements beyond that would be an unnecessary expense. Given that almost all public communications related to LEED certification refer only to the level of certification achieved, organizations wishing to send a signal would therefore focus only on which level of LEED certification to seek. For instance, the list of LEED certified projects on the USGBC website[9] shows the level of certification earned; only upon viewing the details for a specific project does one see the total number of LEED points achieved and the specific elements adopted. Similarly, company press releases and the plaques that adorn certified buildings often only mention the level of LEED certification achieved; see for instance Toyota's 2006 Annual Environmental Report[10] or the Goldman Sachs environmental policy framework.[11] In short, in our model of signaling, an organization wishing to make a public statement by adopting a green building will be more concerned with the level of certification achieved than with individual elements.

The contrasting view of green building holds that the corresponding environmental technologies do in fact provide intrinsic benefits, economic and/or environmental, as shown by Kats (2003) and other work discussed in the literature review. Moreover, some organizations positively value environmental benefits, and are willing to incur economic costs to achieve them, so they may be motivated primarily by the environmental rather than economic intrinsic benefits of LEED certification. In the intrinsic benefit model, organizations adopt LEED elements due to their intrinsic economic and/or environmental benefits,

---

[9] See http://www.usgbc.org/LEED/Project/CertifiedProjectList.aspx?CategoryID=19&CMSPageID=244, last accessed on January 5, 2007.

[10] See the Toyota North America Environmental Report 2006, http://a230.g.akamai.net/7/230/2320/v001/toyota.download.akamai.com/2320/toyota/media/about/ 2006envrep.pdf, last accessed on January 5, 2007.

[11] See the Goldman Sachs Evironmental Policy Framework document, http://www2.goldmansachs.com/our_firm/our_culture/corporate_citizenship/environmental_policy_framework/docs/EnvironmentalPolicyFramework.pdf, last accessed on January 5, 2007.

regardless of how the outside world responds to the adoption decision. Organizations would only consider the intrinsic (economic and/or environmental) costs and benefits of each individual element, and not the resulting level of LEED certification. In the purest form of this model, an organization would adopt a collection of LEED elements but would choose not to incur the documentation and auditing costs involved in certification, as the intrinsic benefits would accrue independently from the certification. No public information exists about such non-certified green buildings so our analysis of the intrinsic benefit model will have to implicitly acknowledge the existence of enough signaling motivation to explain why organizations pursue LEED certification. However, this is not a serious shortcoming as the cost of the certification process is minor relative to the cost of the building itself.

In their pure form, the signaling model and the intrinsic benefit model are two extreme forms of motivation to adopt LEED elements. We first characterize the distribution of the number of points one would expect LEED certified projects to earn under these two extremes. Because many organizations may be subject to both types of motivation, we also formulate two hybrid models, where signaling and intrinsic benefits are considered sequentially or simultaneously. For all cases, we specify characteristics that the probability distribution $f(k)$ of the total number of points k earned by each project needs to display to be consistent with the underlying decision model. The decision processes used in practice are undoubtedly more complex and more project-specific than any of the models we consider here, but until more detailed data about those processes is available the simplicity of our models seems appropriate.

Modeling signaling as main motivation for LEED certification

We argued above that if organizations are motivated by signaling alone, they will adopt precisely enough LEED elements to reach the desired certification level. The distribution of the number of points per project will then have positive values only at the minimum number of points required for each level of certification, i.e. for LEED-NC certification, at 26, 33, 39 or 52 points for the certified, silver, gold or platinum levels respectively. This assumes that there is no uncertainty about the outcome of the certification process. This assumption appears reasonable as it is common to have a LEED-accredited individual on the project team, and if project teams are unsure whether their proposed design will qualify for a particular LEED point they can ask the USGBC for an opinion during the design phase (using the Credit Interpretations and Rulings process) to prevent surprises during the certification process. Therefore, organizations do not appear to need to aim for higher point totals than desired. In the conclusions we do briefly discuss what effect any residual uncertainty in the certification process would have on our findings. The probability function $f_s(k)$, which describes the proportion of buildings that will adopt precisely k points under the signaling model, is then as follows:

$$f_s(k) = \begin{array}{cc} p_1 & k = 26 \text{ (certified)} \\ p_2 & k = 33 \text{ (silver)} \\ p_3 & k = 39 \text{ (gold)} \\ 1 - p_1 - p_2 - p_3 & k = 52 \text{ (platinum)} \\ 0 & k \in \{26, \ldots, 69\} \setminus \{26, 33, 39, 52\} \end{array} \qquad (1)$$

where p_i is the probability the organization will select LEED certification level *i*; for *i*=1 (certified), *i*=2 (silver), *i*=3 (gold), and *i*=4 (platinum).

Modeling intrinsic benefits as main motivation for LEED certification

If organizations are motivated by intrinsic benefits alone, the resulting distribution is less well-defined. However, under fairly general assumptions, one can show that the distribution is likely to be (approximately) unimodal. We do not claim that the following model is the only way of capturing the intrinsic benefits of LEED certification, but it provides a workable basis for our analysis.

Assume that the net intrinsic benefit to building *i* (per square foot, after subtracting costs) of adopting LEED element *j* is given by some v_{ij}, which we do not observe. These values can be determined by whatever assessment method the organization concerned chooses to use, based on economic and/or environmental objectives, and they can be positive or negative. In the intrinsic benefit model, LEED element *j* will then be adopted in building *i* if and only if $v_{ij} \geq 0$. (Using a strict inequality gives the same unimodality result.) Now define $q_j = \sum_{i=1}^{N} I(v_{ij} \geq 0) \Big/ N$, where *N* is the total number of buildings in our dataset, and the indicator function $I(v_{ij} \geq 0) = 1$ if the inequality holds and zero otherwise. In the intrinsic benefit model, q_j is precisely the proportion of all buildings that adopt element *j*. In order to formulate a probability distribution against which we can test our data, we model the probability that any given building will adopt element *j* as a Bernoulli distribution with probability of success q_j, and assume the trials are independent for each element. In expectation, each element *j* will then be adopted precisely equally frequently as we observe in practice, i.e. $Nq_i = \sum_{i=1}^{N} I(v_{ij} \geq 0)$ times. Let $k_i = \sum_{j=1}^{M} I(v_{ij} \geq 0)$, the number of points adopted by building *i*, where *M*=69 is the maximum number of points in the LEED-NC rating system. Under the above conditions, the distribution of k_i then follows a so-called Poisson's binomial distribution, first discussed in Hoeffding (1956). Wang (1993) shows that the density of k_i is unimodal; more precise characterizations are not known for this distribution. Only for the special and unrealistic case where $q_j = q$ for all *j*, i.e., the probability of being adopted is equal for all LEED elements, k_i would follow a binomial distribution with parameters *n* and *q*. In the more general case, if the Bernoulli trials for a given building are not independent, unimodality is no longer guaranteed. A few LEED elements are inherently interdependent and hence correlated: optimizing energy performance has five levels which earn 2 points each, and a few others are cumulative (e.g., 1 point for 5% renewable energy, an additional point for 10% renewable energy, etc.). However, the vast majority of LEED elements display little or no correlation, so our model of independent Bernoulli trials is not unreasonable. Hence, we hypothesize that, under the intrinsic benefits model, the resulting distribution of LEED points must be "approximately" unimodal. Although this characterization is imprecise, we will see later that the data are sufficiently multimodal to convincingly reject this hypothesis. Write $f_{ib}(k)$ for the proportion of buildings that will adopt precisely *k* LEED elements based on intrinsic benefits motivations alone.

Hybrid models of signaling and intrinsic benefit motivations

More plausible than either of the two extreme views considered so far is that organizations are motivated by both signaling and intrinsic benefits, either simultaneously or sequentially, leading to a hybrid model. In the sequential case, an organization would first choose which LEED certification level to achieve and then adopt any additional LEED elements, beyond the minimum required for the desired certification level, that still provide positive intrinsic benefits. The probability distribution $f_{seq}(k)$ that would describe this behavior is given by:

$$f_{seq}(k) = \begin{array}{ll} p_{seq,1} \times f_{seq-ib,1}(k) & k = 26,\ldots,32 \text{ (certified)} \\ p_{seq,2} \times f_{seq-ib,2}(k) & k = 33,\ldots,38 \text{ (silver)} \\ p_{seq,3} \times f_{seq-ib,3}(k) & k = 39,\ldots 51 \text{ (gold)} \\ \left(1 - p_{seq,1} - p_{seq,2} - p_{seq,3}\right) \times f_{seq-ib,4}(k) & k = 52,\ldots 69 \text{ (platinum)} \end{array} \tag{2}$$

where $p_{seq,i}$ is the probability that an organization chooses certification level *i* (defined as earlier in the signaling model), and $f_{seq-ib,i}(k)$ is the probability distribution of LEED points within certification level *i* that follows from intrinsic benefits. For simplicity, we assume that organizations do not exceed their chosen certification level, although it is possible that, for instance, an organization chooses silver but then adopts enough elements to actually achieve gold. In our tests we truncate the distributions accordingly; this has very little effect on the results.

Alternatively, signaling and intrinsic benefits can operate simultaneously. In this case, part of an organization's decision about which LEED elements to adopt is driven by signaling motivations, and part by intrinsic benefits motivations. The probability distribution that describes this behavior is given by:

$$f_{sim}(k) = \begin{cases} \alpha \times p_{sim,1} + (1-\alpha) f_{sim-ib}(k) & k = 26 \text{ (certified)} \\ \alpha \times p_{sim,2} + (1-\alpha) f_{sim-ib}(k) & k = 33 \text{ (silver)} \\ \alpha \times p_{sim,3} + (1-\alpha) f_{sim-ib}(k) & k = 39 \text{ (gold)} \\ \alpha \times \left(1 - p_{sim,1} - p_{sim,2} - p_{sim,3}\right) + (1-\alpha) f_{sim-ib}(k) & k = 52 \text{ (platinum)} \\ (1-\alpha) f_{sim-ib}(k) & k \in \{26,\ldots,69\} \setminus \{26,33,39,52\} \end{cases} \quad (3)$$

where $p_{sim,i}$ is the probability that an organization chooses certification level i (defined as in the signaling model), $f_{sim-ib}(k)$ is the probability distribution of LEED points that follows from intrinsic benefit motivations, and α the relative weight of signaling considerations in the firm's adoption decision.

5. Data

We use data on the adoption of specific LEED elements by all 442 buildings that, by September 20, 2006, had been certified to the LEED-NC 2.0 or 2.1 standards. These standards for new construction are the most widely used of the LEED standards. Of these 442 projects, 409 were located in the USA, 22 in Canada, 4 in China, 4 in India, and 1 each in Mexico, Spain and the UAE. 177 projects had attained the LEED Certified level, 139 projects had attained Silver, 112 had attained Gold and 14 had attained Platinum. 57 projects earned precisely 26 points, the lowest possible number, while the highest number of LEED points earned by any project was 60. The mean number of points was 33.92 with a standard deviation of 6.58. The histogram of LEED points earned is shown below.

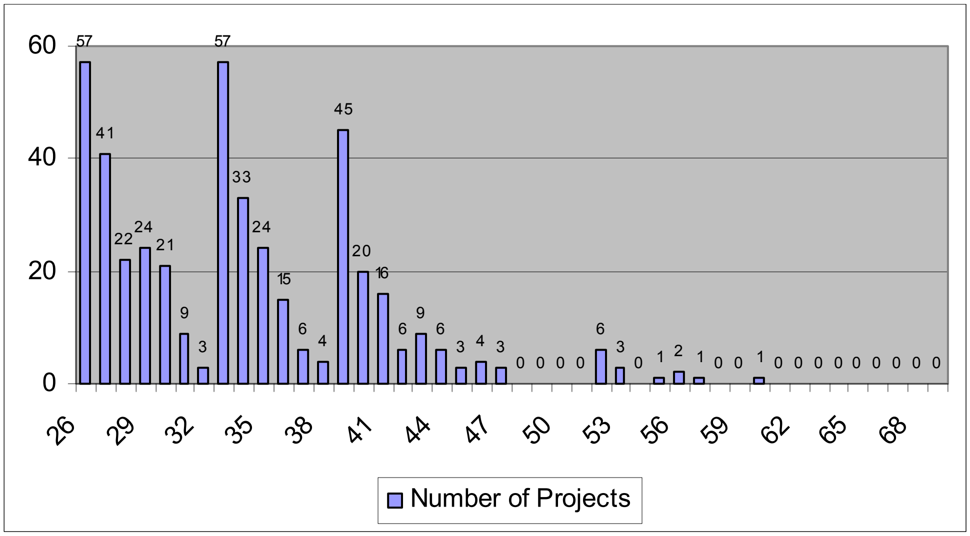

Figure 1: histogram of number of points earned by LEED-NC 2.0 or 2.1 certified projects as of September 20, 2006

6. Methodology and results

Our hypotheses are in the form of probability distributions, each derived from a different theoretical model. Therefore, our methodology consists of first determining, for each of the theoretical distributions, the parameters that best fit the observed adoption pattern, and then applying goodness-of-fit tests to determine which theoretical distribution is most consistent with the data. In all cases, we rely primarily on the chi-square test, but also report the Kolmogorov-Smirnov (K-S) test (see e.g. Massey, Jr., 1951) to assess goodness of fit. The procedure of estimating the parameters by minimizing the chi-square goodness-of-fit statistic can be traced back to Neyman and Pearson (1928), and is advocated by Berkson (1955), Berkson et al. (1980) and Harris and Kanji (1983).

The chi-square test is a function of the sum of squared errors between the empirical number of observations at each value of the probability function and the predicted number of observations. The chi-square test takes into account the number of parameters that are being estimated from the data (as it corrects for degrees of freedom). The chi-square test is not entirely unambiguous as some of the possible point totals have zero observations in our dataset. Although one can combine cells (point totals) to circumvent the resulting division by zero, there is no unique way to do this. For the signaling model, which predicts values of 0 for all point totals except for the certification level thresholds, the chi-square test cannot be meaningfully performed at all, as the observations would have to be grouped into bins that span an entire certification category, rendering the test meaningless. For the other models, the theoretical distribution contains various cells with predicted number of observations less than 5, which is often cited as the minimum for the chi-square test to perform well (Tate and Hye 1973). Despite these limitations, all alternative methods appear to have more severe shortcomings.

The K-S test statistic is a function of the maximum absolute deviation between the observed and predicted cumulative distributions. Although preferable in many other situations, the K-S test is not appropriate in our situation for two reasons. First, the reported critical values are only applicable when the parameters of the theoretical distribution are known, not when they have to be estimated from the data as is the case here. Using the critical values given in the standard tables for the K-S test will be conservative as the probability of a Type I error will be lower than would be the case with the "correct" critical values that take into account that the parameters were estimated from the data (Lilliefors 1967). To determine the correct significance levels, one would have to perform a Monte Carlo simulation starting with the family of theoretical distributions proposed, then randomly drawing empirical distribution functions, applying the K-S test, and tabulating the number of occurrences of Type I and Type II errors. Such analysis would not address the second shortcoming of the K-S test which is that it applies only to continuous distributions. The modification proposed by Pettitt and Stephens (1977) for discrete distributions (but with known parameters) has higher power than the chi-square test when the probabilities are increasing or decreasing, but it is not known how that test would perform with a multimodal distribution as is the case here. Refinements of the Kolmogorov-Smirnov test do exist to increase its power in the presence of multimodal distributions (Reschenhofer 1997), but still only for known parameters. We only report the K-

S test statistics and critical values for completeness as the K-S test is widely used. Other tests, such as the Anderson-Darling, are applicable when the parameters are unknown, but the test statistic depends on the precise family of distributions one is testing against; no test statistic is known for the specific probability distributions we use here. Finally, maximum likelihood is also not suitable for the signaling model as the likelihood function does not allow for observations other than at the four cutoff levels.

To ensure a fair comparison between the theoretical models, we determine the parameter estimates using a fit criterion that is derived from the test statistic used. When using the chi-square test, we select parameters that minimize the weighted sum of squared errors between the observed and predicted number of observations for each point total. When using the K-S test, we select parameters that minimize the maximum absolute deviation between the observed and predicted values of the cumulative distribution. Both methods give essentially similar results. First, we examine each of the four theoretical models separately, then we discuss how they compare. Due to the limitations of existing goodness-of-fit tests, we also use visual inspection when examining the pure signaling and pure intrinsic benefit models. Visual inspection does not allow a clear distinction between the two hybrid models; here, the traditional statistical tests are indispensable. All computations were performed in Matlab.

Results for signaling model

Recall that, if adoption of LEED certification is driven exclusively by signaling, we predict the distribution defined by (1), with spikes at k=26, 33, 39 and 52, and values of zero elsewhere. From Figure 1, it is immediately clear that there are indeed substantial "spikes" at the cutoff points for each of the four levels of certification. However, we also see a substantial number of observations with point totals in between the spikes. The test results for all models are shown in Table 1. The chi-square test is not well-defined for the signaling model, but visual inspection strongly suggests that we can reject the hypothesis that the data are generated by the signaling model alone. The K-S test, subject to the caveats above about its applicability, also confirms this conclusion.

Results for intrinsic benefit model

The second theoretical model assumes that LEED certification is driven by intrinsic benefits alone. For this model we predicted, under the conditions discussed earlier, a unimodal distribution of point totals. Unfortunately, testing for unimodality is difficult. Hartigan and Hartigan (1985) propose the dip test for unimodality and show that it performs better than earlier tests; however, it is only applicable for distinguishing unimodal from bimodal distributions, while our data clearly has four modes (the fourth, at the cutoff for platinum certification, being lower than the others). Hartigan and Hartigan (1985) also discuss various earlier tests, mostly based on assuming that the underlying distributions are normal, again clearly not the case with our data.

Therefore, to test the intrinsic benefits model, we proceed in two ways. First, visual inspection of the data strongly argues against unimodularity; it is difficult to imagine that any meaningful test would find our data to be unimodal. Second, we consider a wide range of specific unimodal distributions and test whether the data fit any of them. For instance, consider the geometric distribution, which is decreasing and hence unimodal, and therefore consistent with the discussion above. If our statistical analysis indicates that the distribution of LEED points could follow a geometric distribution, we would conclude that the distribution of LEED points is consistent with (but not necessarily caused by) the intrinsic benefit motivation for adoption. Conversely, if we were to test for every imaginable unimodal distribution, and find that none of them fit our data, we would be able to reject the hypothesis of intrinsic benefits driving adoption of LEED elements. Although we cannot test every possible unimodal distribution, we experimented with a variety of unimodal distributions (geometric, normal, exponential, weibull, etc,) and used the goodness-of-fit tests to test whether any of these unimodal distributions were consistent with the data. Unsurprisingly, given the observed distribution, we were not able to find any unimodal distribution that is even remotely consistent with our data. Of course, not being able to find a unimodal distribution that was consistent with our data is not in itself proof of multimodularity. However, based on our inability to find any unimodal distribution that fits our data, combined with a visual assessment of the empirical distribution, we believe that the data do allow us to reject the hypothesis that LEED certification is motivated by intrinsic benefits alone.

Results for sequential model

The results so far suggest that neither signaling nor intrinsic benefits alone can fully explain the adoption of LEED elements. To test whether hybrid models are more successful, we first consider the sequential model, given in (2). As with the pure intrinsic benefit model, the $f_{seq-ib,l}(k)$ are not uniquely specified, the model only hypothesizes that they be unimodal. As before, we consider a range of unimodal distributions. Pick any given family of unimodal distributions (for instance, geometric) and estimate the parameters of the corresponding full distribution $f_{seq}(k)$ given above. If the goodness-of-fit tests indicate that the data could be drawn from this full distribution, then we have constructed a model that is consistent with our hybrid model combining signaling and intrinsic benefit motivations, and that is also consistent with the data. After experimenting with a range of unimodal distributions, we found that a truncated geometric with $f_{seq-ib,l}(m) = w_l\, q_{seq-ib,l}\,(1-q_{seq-ib,l})^{m-L_l}$ provided the best fit. (Non-truncated distributions give similar results.) Here L_l is the minimum number of points required for certification level *l*, and $w_l = 1 \Big/ \sum_{m=L_l}^{L_{l+1}-1} q_{seq-ib,l}\,(1-q_{seq-ib,l})^{m-L_l}$ is a normalization factor to ensure that each of the four truncated geometric distributions has total probability equal to one.

Table 1 shows that the sequential hybrid model is consistent with the data under both the chi-square and K-S methods, suggesting that both signaling and intrinsic benefits contribute to explaining depth of LEED adoption. Figure 2 visually compares the observed and predicted distributions (using the chi-square criterion), also suggesting a close fit.

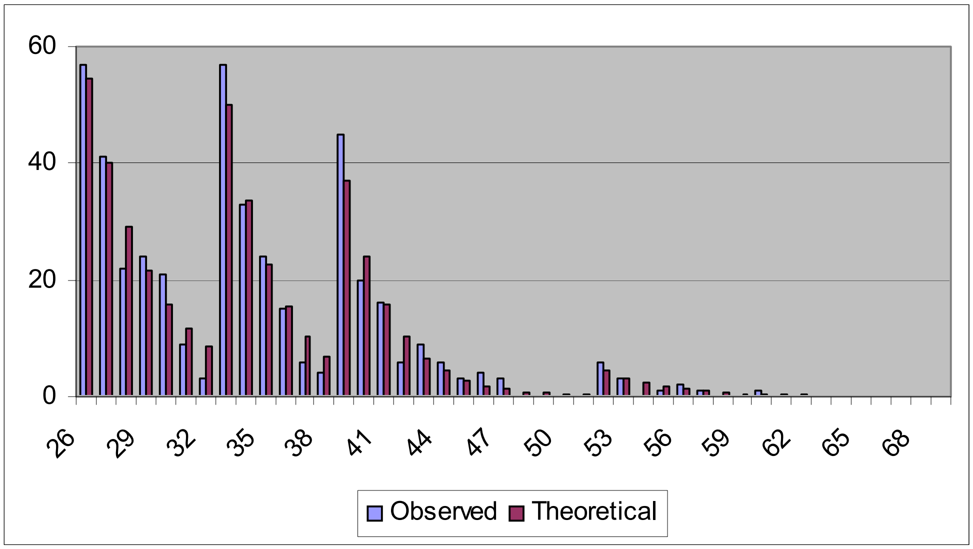

Figure 2: comparison of observed vs. predicted values for sequential hybrid model using the minimum-chi-square method

Results for simultaneous model

Finally, consider the simultaneous model in (3). We follow the same approach as above; using a geometric distribution for $f_{sim-ib}(k) = q(1-q)^{k-26}$ again provided the best fit. Correcting for the truncation at k=69 makes no noticeable difference.

Table 1 shows that the simultaneous model is also consistent with the data when using the K-S test but not under the more appropriate chi-square test. Both test statistics are higher than for the sequential model, which suggests that the sequential model fits better; moreover, the visual comparison between observed and predicted values in Figure 3 also suggests a less close fit for the simultaneous model than for the sequential model. In the simultaneous model, using the chi-square criterion, the mixing parameter α is 0.27, which would imply that 27% of each organization's decision about how many LEED points to adopt is driven by signaling motivations, while the remaining 73% is explained by intrinsic benefits, or alternatively, that 27% of all organizations are driven by signaling alone, and 73% of all organizations by intrinsic benefits alone. (For the sequential model, it is not possible to quantify the relative contribution of the two effects, as by construction they both contribute equally but in sequence.)

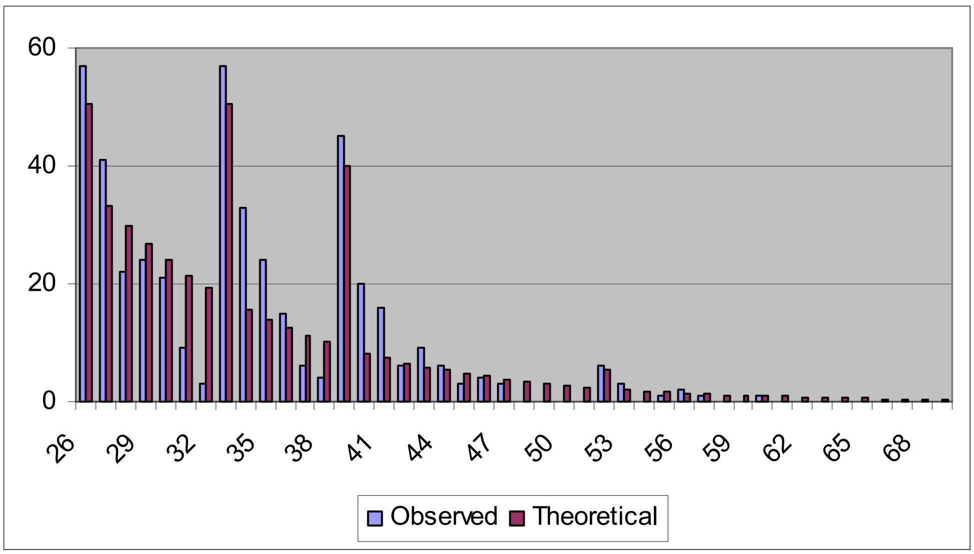

Figure 3: comparison of observed vs. predicted values under the simultaneous hybrid model, using the minimum-chi-square method

6. Discussion, alternative explanations, and limitations

In this paper, we constructed probability models that predict the distribution of the number of points earned by LEED-NC certified projects if the certification decisions were entirely motivated by signaling, entirely by intrinsic benefits, or by a combination of the two. We find that neither signaling nor intrinsic benefits alone can explain the pattern of adoption of LEED elements that we observe. The sequential model, in which organizations first choose a level of certification, then select individual elements based on their intrinsic benefits but subject to the constraint that the desired level of certification must be reached, does fit the data well. Below we review some implications of our findings, followed by a discussion of the limitations of this study.

If confirmed, our findings have significant implications for the LEED rating standards and for other voluntary standards and eco-labels. The presence of the spikes at the four cutoff values indicates that a significant part of LEED certification behavior is driven by signaling considerations, which in turn means that the earlier quote expressing fear about bad design decisions being made in order to get a LEED point may be valid. On the other hand, the substantial number of observations between the spikes also points to a significant contribution of the intrinsic benefit motivation. Additionally, given that the certification levels play a significant role, the cutoffs between certification levels have a major impact on the degree of green building practices that will be adopted. Given the inevitable arbitrariness of any chosen cutoff levels, the USGBC and other organizations administering similar schemes should seriously consider including separate prerequisites for each certification level. With LEED-NC, there is a set of prerequisites in order to qualify for certification, but there are no additional prerequisites to qualify for silver or higher levels of certification. Our study suggests that organizations are highly motivated by the levels of certification, so if there are green building practices that the USGBC would particularly like to encourage but that are too demanding to be a prerequisite for all certifications, including them as prerequisites for higher levels of certification may advance their spread. This implication may also carry over to other voluntary standards and eco-labels and enable the designers of such standards to promote select practices by appropriately manipulating certification levels and certification criteria. The challenge for industry associations and policy-makers involved in the design of such voluntary standards has parallels to those in green design, as highlighted by Chen (2001, p. 261): the need to “create a regulatory environment that is on the one hand benign to green product innovation and on the other hand strict enough to ensure the overall environmental quality.”

Due to the aggregate nature of the data we use, this study contains various limitations. First, because we do not directly observe the decision processes actually being used by organizations, all we can do here is formulate probability models derived from several modes of decision-making, but we cannot rule out alternative explanations for the adoption pattern we observe. Our findings do provide a starting-point aimed at directly observing the decision processes involved in LEED certification. Second, our formulation of the signaling model does not allow for the effect of uncertainty in certification. Although we believe such uncertainty to be minimal, based on interactions with practitioners, we cannot rule out that organizations aim for more points than needed for their chosen level of certification, and then adjust upwards or downwards as they learn more about the likely outcome of the certification. If that were the case, though, organizations would eliminate LEED elements as they learn they are overshooting the their target certification level; if they decide to maintain some elements regardless, they are in effect behaving more in line with our sequential hybrid model. If uncertainty were a major factor, one would either expect to find the four modes of the distribution several points higher than precisely at the certification level thresholds, or one would expect to find substantial numbers of projects scoring just below the threshold levels. So, while we cannot rule out the presence of uncertainty altogether, even a signaling model with uncertainty would still not be likely to fit the data. Third, other decision-making processes than the search for intrinsic benefits could also lead to a unimodal distribution, as in the following implausible example: if an organization were to rank all LEED elements in random order, and with probability q would adopt the element under consideration and proceed to the next element, and with probability $(1-q)$ would not adopt the element under consideration and stop the process, a geometric distribution for total number of points would result. We believe that the decision model we formulate here is plausible and consistent with the anecdotal evidence heard from practitioners, but we cannot rule out other decision models.

Although the sequential decision model, where the organization first chooses a category and then individual elements, displays the best fit with the observed data, we cannot rule out a more complex iterative process. An organization might start with an initial budget, then select a series of LEED-NC elements within that budget, determine which certification level results, then increase or decrease the budget based on the outcome, and iterate until a satisfactory combination of budget, LEED elements, and overall certification level results. Such a model would be considerably more complex than the simple sequential process we describe here, which already fits the data very well indeed. Using parsimony as a model selection criterion would favor the simple sequential process we propose, but studies based on direct observation would be needed to further deepen our understanding of the decision process involved.

An intriguing area for further research (in green building, and in studies of depth of adoption of new technology more generally) is to explain why, within the sequential model, it is the geometric distribution that fits our data so well. Although our study only focused on its unimodality, the geometric distribution does possess a very specific structure. It would be interesting to examine whether architectural and engineering decision-making processes do indeed follow some underlying logic that leads to this geometric outcome. Further analysis of how organizations decide the desired strength of the signal (which level of certification to aim for), and of how they assess the intrinsic benefits of individual elements, is also worthwhile.

Another area for future research involves comparing early adopters with later adopters. Following Corbett (2006), Delmas and Montes-Sancho (2007), and others, there are reasons to believe that early adopters of other voluntary standards are motivated by a different set of considerations than later adopters. Institutional theorists would predict that early adopters are motivated by intrinsic benefits, while later adopters would be motivated by the legitimacy conferred by a signal, as Westphal et al. (1997) found for the case of TQM. We have not yet found clear patterns of how LEED-NC certification behavior is changing over time, possibly due to the short history available. Our estimation framework easily allows such testing once more data are available. Our finding that signaling and intrinsic benefits are both already present in such an early stage of the development of the LEED standards does suggest that an innovation can acquire social legitimacy very rapidly indeed, which may partly explain why disentangling efficiency- and legitimacy-related reasons for adoption has often proved so elusive so far. Finally, by combining the LEED certification data with other data on environmental performance of organizations, one could also test whether firms with point totals that do not correspond to the cutoff levels in the LEED rating scheme are indeed more inherently environmental in other ways too.

Acknowledgements

The first author is grateful to the Technische Universiteit Eindhoven in the Netherlands, where he was on sabbatical during part of the writing of this paper. We are deeply indebted to Benjamin Cryer, Jeffrey Felder, Rebecca Matthews, Michael Pettigrew and Brian Okrent, the MBA students who helped with the data collection and literature study and who organized the workshop for real estate professionals on green building at UCLA, on March 10, 2006; we are also grateful to the workshop participants for their insightful comments, and to the UCLA Ziman Center for Real Estate for financial support. We are grateful for feedback from the participants at the 2nd Annual conference on The Institutional Foundations of Industry Self-Regulation at Harvard Business School, February 16-17, 2007.

References

Albuquerque, P., B.J. Bronnenberg and C.J. Corbett. 2007. A Spatio-Temporal Analysis of the Global Diffusion of ISO 9000 and ISO 14000 Certification. *Management Science* 53 (3) 451-468.

Anderson, S. W., J. D. Daly, M. F. Johnson. 1999. Why firms seek ISO 9000 certification: Regulatory compliance or competitive advantage? *Production Oper. Management* 8(1) 28–43.

Åstebro, T. 2004. Sunk Costs And The Depth And Probability Of Technology Adoption. *The Journal of Industrial Economics* LII (3) 381-399.

Basu, A.K., N.H. Chau and U. Grote. 2003. Eco-Labeling and Stages of Development. *Rev. of Development Economics* 7 (2) 228-247.

Berkson, J. 1955. Maximum Likelihood And Minimum X2 Estimates Of The Logistic Function. *Journal of the American Statistical Association* 50 (269) 130-162

Berkson, J., B. Efron, J.K. Ghosh, L. Lecam, J. Pfanzagl and C.R. Rao. 1980. Minimum Chi-Square, Not Maximum-Likelihood. *Annals Of Statistics* 8 (3): 457-487

Chen, C. 2001. Design for the Environment: A Quality-Based Model for Green Product Development. *Management Sci.* 47 (2) 250-263.

Corbett, C.J. 2006. Global Diffusion of ISO 9000 Certification Through Supply Chains. *Manufacturing & Service Oper. Management* 8(4) 330-350.

Corbett, C.J. and R.D. Klassen. 2006. Extending the Horizons: Environmental Excellence as Key to Improving Operations. *Manufacturing & Service Oper. Management* 8 (1) 5-22.

Cryer, B., J. Felder, R. Matthews, M. Pettigrew and B. Okrent. 2006. "Evaluating the Diffusion of Green Building Practices." Applied Management Research Project report, UCLA Anderson School of Management.

Delmas, M. and M.J. Montes-Sancho. 2007. Voluntary Agreements To Improve Environmental Quality: Are Late Joiners The Free Riders? Working paper.

Dieperink, C., I. Brand and W. Vermeulen. 2004. Diffusion of energy-saving innovations in industry and the built environment: Dutch studies as inputs for a more integrated analytical framework. *Energy Policy* 32 773–784.

DiMaggio, P.J. and W.W. Powell. 1983. The Iron Cage Revisited - Institutional Isomorphism And Collective Rationality In Organizational Fields. *American Sociological Rev.* 48 (2) 147-160.

Guler, I., M. F. Guillén, J. M. MacPherson. 2002. Global competition, institutions, and the diffusion of organizational practices: The international spread of ISO 9000 quality certificates. *Admin. Sci. Quart.* 47(2) 207–232.

Harris, R.R. and G.K. Kanji. 1983. On the Use of Minimum Chi-Square Estimation. *The Statistician* 32 (4) 379-394.

Hartigan, J.A. and P.M. Hartigan. 1985. The dip test of unimodality. *The Annals of Statistics* 13(1) 70-84.

Hoeffding, W. 1956. On the distribution of the number of successes in independent trials. *The Annals of Mathematical Statistics*. 27(3) 713-721.

Jin, G.Z. and P. Leslie. 2003. The Effect Of Information On Product Quality: Evidence From Restaurant Hygiene Grade Cards. *The Quarterly Journal of Economics* 409-451.

Kats, G. 2003. *The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force*. Available at: http://www.ciwmb.ca.gov/GreenBuilding/Design/CostBenefit/Report.pdf. Last accessed October 26, 2006.

Kirton, J.J., J.M. Trebilcock. 2004. *Hard Choices, Soft Law: Voluntary Standards in Global Trade, Environment, and Social Governance.*

King, A.A., M.J. Lenox. 2000. Industry self-regulation without sanctions: The chemical industry's responsible care program. *Acad. Management J.* 43(4) 698–716.

King, A.A., M.J. Lenox. 2002. Exploring the locus of profitable pollution reduction. *Management Sci.* 48(2) 289–299.

King, A.A. and M.W. Toffel. 2007. Self-regulatory Institutions for Solving Environmental Problems: Perspectives and Contributions from the Management Literature. In *Governing the Environment: Interdisciplinary Perspectives*, edited by Magali Delmas and Oran Young., forthcoming.

Klassen, R.D. and D.C. Whybark. 1999. The Impact of Environmental Technologies on Manufacturing Performance. *The Academy of Management Journal* 42 (6) 599-615.

Lilliefors, H.W. 1967. On the Kolmogorov-Smirnov Test for Normality with Mean and Variance Unknown. *J American Statistical Association* 62 (318) 399-402.

Loch, C.H. and B.A. Huberman. 1999. A punctuated-equilibrium model of technology diffusion. *Management Sci.* 45 (2) 160-177.

Lockwood, C. 2006. Building the green way. *Harvard Business Review.* June 129-137.

Massey, Jr., F.J. 1951. The Kolmogorov-Smirnov Test for Goodness of Fit. *J American Statistical Association* 46 (253) 68-78.

Naveh, E. and A. Marcus. 2005. Achieving competitive advantage through implementing a replicable management standard: Installing and using ISO 9000. *J Oper Management* 24 1–26.

Neyman, J. and E.S. Pearson. 1928. On the use and interpretation of certain test criteria for purposes of statistical inference. *Biometrika* 20 (175) 263.

Pettitt, A.N. and M. A. Stephens. 1977. The Kolmogorov-Smirnov Goodness-of-Fit Statistic with Discrete and Grouped Data. *Technometrics* 19 (2) 205-210.

Reschenhofer, E. 1997. Generalization of the Kolmogorov-Smirnov test. *Computational Statistics and Data Analysis* 24 433-441.

Rogers, E.M. 2003. *Diffusion of Innovations (5th edition)*, The Free Press, New York.

Scott, W.R. 1995. *Institutions and Organizations: Theories and Research.* Sage, London, UK.

Spence, M., 1973. Job market signaling. *Quarterly J Economics* 87, 355–374.

Tate, M.W. and L.A. Hye. 1973. Inaccuracy of the X2 Test of Goodness of Fit when Expected Frequenies are Small. *J American Statistical Association* 68 (344) 836-841.

Terlaak, A. and A.A. King. 2006. The effect of certification with the ISO 9000 Quality Management Standard: A signaling approach. *J Econ Behavior & Org* 60 579-602.

Venkatraman, N., L. Loh and J. Koh. 1994. The Adoption Of Corporate Governance Mechanisms - A Test Of Competing Diffusion-Models. *Management Sci.* 40 (4) 496-507.

Vermeulen, W.J.V. and J. Hovens. 2006. Competing explanations for adopting energy innovations for new office buildings. *Energy Policy* 34 2719–2735.

Wang, Y.H. 1993. On the number of successes in independent trials. *Statistica Sinica* 3, 295-312.

Westphal, J.D., R. Gulati and S.M. Shortell. 1997. Customization or Conformity? An Institutional and Network Perspective on the Content and Consequences of TQM Adoption. *Administrative Sci. Quarterly*, 42 (2) 366-394.

Yeung, A.C.L., T.C.E. Cheng and K.-H. Lai. 2006. An Operational and Institutional Perspective on Total Quality Management. *Production and Oper. Management* 15 (1) 156-170.

Appendix: sample LEED-NC certification checklist

LEED-NC

UCLA La Kretz Hall
LEED® Project # 677
LEED Version 2 Certification Level: SILVER
4/27/2006

34 Points Achieved — Possible Points: 69

Certified 26 to 32 points Silver 33 to 38 points Gold 39 to 51 points Platinum 52 or more points

6 Sustainable Sites — Possible Points: 14

Y			
Y	Prereq 1	**Erosion & Sedimentation Control**	
1	Credit 1	**Site Selection**	1
	Credit 2	**Urban Redevelopment**	1
	Credit 3	**Brownfield Redevelopment**	1
1	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
1	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
	Credit 4.3	**Alternative Transportation**, Alternative Fuel Refueling Stations	1
1	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
	Credit 6.2	**Stormwater Management**, Treatment	1
1	Credit 7.1	**Landscape & Exterior Design to Reduce Heat Islands**, Non-Roof	1
1	Credit 7.2	**Landscape & Exterior Design to Reduce Heat Islands**, Roof	1
	Credit 8	**Light Pollution Reduction**	1

2 Water Efficiency — Possible Points: 5

Y			
	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
	Credit 2	**Innovative Wastewater Technologies**	1
1	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

8 Energy & Atmosphere — Possible Points: 17

Y			
Y	Prereq 1	**Fundamental Building Systems Commissioning**	
Y	Prereq 2	**Minimum Energy Performance**	
Y	Prereq 3	**CFC Reduction in HVAC&R Equipment**	
2	Credit 1.1	**Optimize Energy Performance**, 20% New / 10% Existing	2
2	Credit 1.2	**Optimize Energy Performance**, 30% New / 20% Existing	2
2	Credit 1.3	**Optimize Energy Performance**, 40% New / 30% Existing	2
	Credit 1.4	**Optimize Energy Performance**, 50% New / 40% Existing	2
	Credit 1.5	**Optimize Energy Performance**, 60% New / 50% Existing	2
1	Credit 2.1	**Renewable Energy**, 5%	1
1	Credit 2.2	**Renewable Energy**, 10%	1
	Credit 2.3	**Renewable Energy**, 20%	1
	Credit 3	**Additional Commissioning**	1
	Credit 4	**Ozone Depletion**	1
	Credit 5	**Measurement & Verification**	1
	Credit 6	**Green Power**	1

4 Materials & Resources — Possible Points: 13

Y			
Y	Prereq 1	**Storage & Collection of Recyclables**	
	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
	Credit 1.2	**Building Reuse**, Maintain 100% of Existing Shell	1
	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
1	Credit 2.1	**Construction Waste Management**, Divert 50%	1
	Credit 2.2	**Construction Waste Management**, Divert 75%	1
	Credit 3.1	**Resource Reuse**, Specify 5%	1
	Credit 3.2	**Resource Reuse**, Specify 10%	1
1	Credit 4.1	**Recycled Content**	1
1	Credit 4.2	**Recycled Content**	1
1	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
	Credit 5.2	**Local/Regional Materials**, of 20% Above, 50% Harvested Locally	1
	Credit 6	**Rapidly Renewable Materials**	1
	Credit 7	**Certified Wood**	1

10 Indoor Environmental Quality — Possible Points: 15

Y			
Y	Prereq 1	**Minimum IAQ Performance**	
Y	Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	
1	Credit 1	**Carbon Dioxide (CO_2) Monitoring**	1
	Credit 2	**Increase Ventilation Effectiveness**	1
1	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
1	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
1	Credit 4.2	**Low-Emitting Materials**, Paints	1
1	Credit 4.3	**Low-Emitting Materials**, Carpet	1
1	Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
	Credit 6.1	**Controllability of Systems**, Perimeter	1
	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
1	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
1	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
1	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

4 Innovation & Design Process — Possible Points: 5

Y			
1	Credit 1.1	**Innovation in Design**	1
1	Credit 1.2	**Innovation in Design**	1
1	Credit 1.3	**Innovation in Design**	1
	Credit 1.4	**Innovation in Design**	1
1	Credit 2	**LEED® Accredited Professional**	1

The checklist above shows which elements of LEED-NC version 2 were incorporated in UCLA's LaKretz Hall, the home of the UCLA Institute of the Environment. This document was downloaded from the USGBC website's list of LEED certified projects: see http://www.usgbc.org/ShowFile.aspx?DocumentID=1576, last accessed January 25, 2007.

	Model							
	“signaling”		“intrinsic benefits”		hybrid, sequential		hybrid, simultaneous	
method used	chi-square	K-S	chi-square	K-S	chi-square	K-S	chi-square	K-S
p_1	n/a	0.26			0.40	0.41	0.17	0.12
p_2		0.37			0.31	0.31	0.41	0.35
p_3		0.27			0.26	0.24	0.38	0.49
$p_4 = 1 - p_1 - p_2 - p_3$		0.10			0.04	0.04	0.04	0.04
q , q_{sim}			0.10	0.09			0.10	0.11
$q_{seq,1}$					0.28	0.27		
$q_{seq,2}$					0.39	0.33		
$q_{seq,3}$					0.33	0.35		
$q_{seq,4}$					0.28	0.28		
α							0.18	0.27
test statistic (chi-square, K-S)		0.136	277.4	0.102	26.9	0.009	113.3	0.041
critical value (1%)		0.078	67.5	0.078	60.0	0.078	62.5	0.078
critical value (10%)		0.058	55.2	0.058	48.4	0.058	50.7	0.058
critical value (20%)		0.051	50.5	0.051	44.0	0.051	46.2	0.051

Table 1: parameter estimates and goodness-of-fit test statistics for all four models

Note: the critical values reported for the K-S test statistic are not correct, as these are calculated for the test when the parameters of the theoretical distribution are known. See the text for more on this issue.